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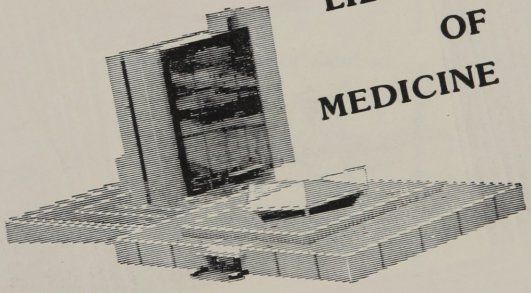

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PSYCHIATRY

A CLINICAL TREATISE ON

DISEASES OF THE FORE-BRAIN

BASED UPON

A STUDY OF ITS STRUCTURE, FUNCTIONS, AND NUTRITION

BY

THEODOR MEYNERT, M.D.
PROFESSOR OF NERVOUS DISEASES AND CHIEF OF THE PSYCHIATRIC CLINIC IN VIENNA

TRANSLATED (UNDER AUTHORITY OF THE AUTHOR) BY

B. SACHS, M.D.
INSTRUCTOR IN DISEASES OF THE MIND AND NERVOUS SYSTEM IN THE NEW YORK POLYCLINIC

PART I.

THE ANATOMY, PHYSIOLOGY, AND CHEMISTRY OF THE BRAIN

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TRANSLATOR'S PREFACE.

I HAVE no apologies to offer for presenting this American edition of Professor Meynert's "Psychiatry" to the English medical public. It is a scientific treatise on diseases of the mind by the one best fitted to write such a treatise. To most medical men Meynert is known as the great brain-anatomist. This book may serve incidentally as a text-book on the anatomy of the brain; but it is not merely that. I would direct particular attention to the subsequent chapters of this treatise, from which the students of psychiatry, of physiology, and of psychology may gather much information and much food for reflection.

For the shortcomings of my translation, I crave the indulgence of the reader. I am quite certain that those best acquainted with the original will not underrate the difficulties of the task, and will be most lenient in passing judgment upon my errors. That there are such, I do not doubt. It has been my aim to furnish a readable translation of this treatise, and to accomplish this, the attempt at a literal translation had to be abandoned. I trust, however, that I have in no instance departed from the sense of the original.

In regard to the encephalic nomenclature employed in the first section of this volume, I would say that I have coined but very few new terms; and that I have either used such terms as are familiar to all English students of cerebral anatomy, or have retained the Latin terms used by the author. The latter was done with the view of avoiding a conflict between the text and the author's plates.

In order to make this volume complete in itself, I have prepared a special index to the subject-matter therein discussed. A similar index will be added to Part II.

My special thanks are gladly given to my friend, Dr. M. Allen Starr, of this city, for his kind assistance in revising proof; and

to the publishers, Messrs. G. P. Putnam's Sons, for their generous efforts to make this translation worthy of the original.

If the work now given to the public will advance the cause of psychiatry in this country and in England, I shall feel that I have in some small measure acknowledged the debt of gratitude I owe to my former master, the author.

B. SACHS, M.D.

28 East Sixty-second Street,
NEW YORK, *October* 12, 1885.

AUTHOR'S PREFACE.

THE reader will find no other definition of "Psychiatry" in this book but the one given on the title-page: "Clinical Treatise on *Diseases of the Fore-Brain.*" The historical term psychiatry, *i. e.* "treatment of the soul," implies more than we can accomplish, and transcends the bounds of accurate scientific investigation.

Were I to give a functional designation to the morbid affections of the fore-brain, I would choose the term "Diseases of the *Mind.*" And on this term I would insist in order to avoid the common fallacy that it is permissible to regard the contents of cortical memories as paled sensory images, although we acknowledge the origin of these memories from external sensory stimuli. We shall show in this book that the fore-brain can neither give rise to hallucinatory phenomena, nor that its functional manifestations, the so-called "memories," are possessed of the slightest sensory qualities. It would be better, therefore, to speak of memory-symbols. In our memory of the most glaring sunlight, of the most intense roll of thunder, there is not as much as the billionth part of the light of a glow-worm, or of the sound produced by the falling of a hair upon water. But is there any other word in our language with which to designate phenomena devoid of all sensory qualities, but the word "psychical"?

This most conspicuous fact regarding the functional activity of the fore-brain accentuates the difference between the abstract and material character of our concepts. The latter is lacking altogether, and is purely a matter of external perception. But the centres for such perception are in the basal portions of the brain, and not in the *fore*-brain. The entire fore-brain I designate generally as *cortex*, for the conducting elements of the fore-brain —the axial fibres—are prolongations of the cortical cells, and, therefore, part of the cortex proper. Those divisions of the brain which effect sensory perceptions, without the aid of the *fore*-brain, and which are concerned particularly with the execution of

reflex movements (in the broadest sense of that term), are designated, by way of antithesis, as *subcortical centres.* This antithesis will be evident also in the different degrees of excitation (of these different centres), and will furnish us with the most important clue to the understanding of the activity of the cerebral mechanism under morbid conditions of the mind.

I have not, and never had, the slightest inclination for making books. To this effort I was impelled by the conviction that there was need of a *scientific* treatise on mental diseases in spite of the present large literature on the subject. The least doubt as to the correctness of any views expounded in this book induced me to stop, and to interrupt work until I had satisfied myself of the correctness of those views by scientific investigation and reflection. This will explain why so many years have elapsed from the time the book was begun (in 1877) to the date of its publication.

The title-page refers to the fundamental studies indispensable to an understanding of the clinical manifestations of mental diseases. My intention of elucidating diseases of the fore-brain in this way is based upon the conviction that our knowledge of them should be obtained, as all sound clinical knowledge is acquired, by a study of the structure, the function, and the nutrition of each organ. Hitherto the science of psychiatry has been too largely subjective. Many of its teachings, which are not based upon the studies just referred to, had better be forgotten. Naturally enough a knowledge of clinical phenomena precedes in time the knowledge of the fundamental facts underlying these phenomena. Morbid symptoms are not recognized by their scientific substratum, but in studying this substratum we are actuated by the desire to fathom the phenomena of disease. It follows, therefore, that the first half[1] of the present work is suggested by the second, clinical, half; and the subjects discussed in these fundamental chapters are chosen with a view to the thorough understanding of the clinical facts. These chapters constitute an integral part of this clinical treatise, and are not an adjunct to it. This, we take it, is a novel and legitimate feature of the book.

The number of clinical cases upon which my views rest is not only sufficient to base original conclusions upon, but by reason of their large numbers, these cases seem to me to be absolutely convincing. In 1875 I was fortunate enough to be able to change my clinic at the Vienna Provincial Insane Asylum, where there was but

[1] Part I. of the translation.

a slight change in the number and character of the inmates, for the Psychiatric Clinic of the Vienna General Hospital. My present "clinic" is the only State Insane Asylum of Austria, though its quarters are not in keeping with its importance. Fourteen to sixteen hundred patients are received annually into this clinic, and of these, only those who are inhabitants of Lower Austria are soon dismissed and assigned to other institutions. It was the study of such a vast number of cases which convinced me that many cases could not be properly classified according to the old rules and within the artificial types of mental diseases. The many variations from these types appeared not only to favor, but actually to compel, the establishment of a *natural* system of classification.

During the interval that elapsed between the inception and completion of my book, I have seen reason to depart in some respects from the account here given of the anatomy of the brain. I have not adopted any new method, but have elaborated with greater care the old cleavage (*Abfaserung*) method of my predecessors,—a laborious method, which has been unduly crowded out by the study of brain-sections. The former method supplies us not only with a key to the complexities of brain-sections, but enables us also to extend our knowledge of the minute anatomy of the brain beyond the information we can obtain from microscopical sections. From the notes to be appended to the end of this work,[1] the reader will gather wherein my views have been necessarily modified or supplemented by the investigations of other authors and my latest researches. The most important results which I have recently arrived at are in regard to the cortical and ganglionic fibres of origin of the *pes pedunculi* (crusta), and the connection of these fibres with the pyramids. My dissent from the adoption of a common system of cranial measurements, to which I agreed, at Ranke's suggestion, is explained by the fact that the chapter[1] on pathological craniology was written as early as 1880.

In view of the necessity of starting from anatomical facts, I have endeavored, in every case, not only to give due weight to the structure of the brain as the fundamental basis for the various forms of disease, but have endeavored, with the same end in view, to insist upon and to explain every visible symptom exhibited by the patient. This refers to the consideration of move-

[1] In Part II. of this edition.

ments of expression as well, which have not been properly utilized hitherto as aids to diagnosis. Thus in spite of the frequent smiles to be observed in stuporous patients during maniacal moods, stuporous insanity has been classified under melancholia.

Dissatisfied with the statistical method, which laid inordinate stress upon hereditary predisposition to disease, I have considered predisposition as a form of disease and not as a condition antecedent to it. I have above all referred to the anatomical peculiarities constituting predisposition. I was not content, as others have been, to accept the mystical conception of heredity, but have insisted on the anatomical peculiarities in patients which constitute predisposition. And these peculiarities were inferred not only from external appearances, but also from a due consideration of all abnormal proportions of the body. In an article, published as early as 1878, I showed that the nutrition and the excitability of the brain must be regarded as depending upon the reciprocal relation existing between the weights of the brain and of the heart. The important investigations of Benecke and Thoma on the size and weight of the different organs of the body appear to me to supply a firm anatomical foundation for the doctrine of predisposition to disease.

As regards the theory of predisposition, and more particularly the doctrine of heredity, which has been carried to the extreme of assuming the existence of innate ideas, and which, in clinical medicine, has led to the erroneous theory of moral insanity, I have deemed it necessary to criticise, in its proper connections, Darwin's theory of the inheritance of acquired faculties, as has been done before me by other German authors, among them DuBois Reymond and Weissman. It is taking altogether too simple a view of things, to regard morality as one of man's talents, and as a definite psychical property which is present in some persons and lacking in others. Indeed, there is great truth in Weissman's observation: "Talents do not depend upon the possession of any special portion of the brain; there is nothing simple about them, but they are combinations of many and widely different psychical faculties."

Just as the much-abused doctrine of hereditary predisposition to disease casts too great a suspicion upon the limits of mental health, so there is possibly the danger that this same suspicion might be increased by the consideration of those errors of organization which contitute the basis of predisposition. But thinking

physicians will avoid this danger, for they will distinguish between those who are possibly "called" to disease, and that fortunately smaller number of persons who are, in the saddest sense of the term, "chosen" for disease. Thus the limits of relative health, as they are generally conceived, will not be narrowed down by abstract theorizing to an intangible line. I trust that the dialectic efforts in this direction will bear fruit in the domain of forensic medicine, and it would be gratifying to me to know that I had contributed somewhat to this end.

THEODOR MEYNERT.

VIENNA, Easter, 1884.

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STRUCTURE AND ARCHITECTURE OF THE BRAIN.

SURFACES OF THE BRAIN.

UNTIL recently, it was commonly believed that no vestiges of the vertebrate brain were to be found in *amphioxus lanceolatus*. Its spinal cord, instead of dilating above into a rudimentary encephalon, was thought to terminate in conical fashion. Rohony, however, has demonstrated the existence of a primary cerebral vesicle in the amphioxus as well. The possession of a brain and spinal cord may, therefore, be said to be characteristic of all vertebrates. The prosencephalon (the fore-brain), the largest division of the *human* brain, diminishes so rapidly in volume as we descend in the animal series that even among the simpler *mammalian* forms it does not in every case exceed in mass the other parts of the brain. In the evolution of the brain from the medullary tubes, the prosencephalon is represented by secondary subordinate appendices of the primary cerebral vesicle. These vesicles of the hemispheres (so-called) are symmetrically disposed, and lie one at each side of the median axis of the primitive brain structure.

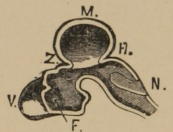

Fig. 1.

V. Prosencephalon (fore-brain; *Vorderhirn*). Z. Thalamencephalon ('Tween-brain; *Zwischenhirn*). F. Foramen between median and r. lateral ventricle. M. Mesencephalon (Mid-brain; *Mittelhirn*). H. Epencephalon. (Hind-brain; *Hinterhirn*.) N. Metencephalon. (After-brain; *Nachhirn*.) (Reichert.)

The arrow in Fig. 1 points to the aperture leading from the anterior cerebral vesicle to the laterally situated vesicle of the hemisphere—the fore-brain. The names given by Carl V. Baer to the various parts of the brain are most appropriate. We distinguish (Fig. 1) the transition from the spinal cord into the after-brain[1] (medulla oblongata); next the hind-brain (*H. cerebellum*), which the roof of the fourth ventricle joins to the posterior wall of the ventricle of the after-brain. The mid-brain (*M. corpora quad-*

[1] The terms After-, Hind-, Mid-, Inter-, and Fore-brain are respectively synonymous with Met-, Ep-, Mes-, Thalam-, and Pros-encephalon.—S.

rigemina) forms the summit of this structure. A part of the prosencephalic vesicle lies between the mid-brain and the vesicle of the hemisphere. This part is termed the inter-brain, and corresponds to the region of the optic thalamus (Z.). The vesicles of the hemispheres develop into the fore-brain (V.).

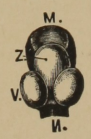

Fig. 2.

Frontal Aspect of a Fœtal Brain; *after Reichert.*

V. Prosencephalon. Z. Thalamencephalon. M. Mesencephalon. N. Metencephalon.

Fig. 2 is intended to show what an insignificant part of the original brain mass the prosencephalon is. (We descend from the mid- and inter-brain to the fore-brain as by a series of steps.) In consequence of a sharp bend of the cerebral axis on an ideal transverse diameter, the after-brain appears below as a posterior branch of this curved arc. A horizontal section of the brain (Fig. 3.)[1] shows the originally lens-shaped convex outer surface of the fore-brain (Fig. 3, V.), at a later stage of development. This originally convex surface of the fore-brain (which at this stage overlaps about half of the inter-brain) shows, midway between its anterior and posterior end, a trough-shaped depression. This depression is the first indication of the *fossa Sylvii* (S.).

It is to be noticed that the walls of the vesicles of the hemispheres have increased in thickness toward the median line at the expense of the lateral ventricles (*a. p.*); as a result of this growth we find the ganglionic region, which, later on, divides into the caudate and lenticular nuclei protruding between the anterior and posterior horns.

Corresponding to this thickening of substance toward the median line, the outer surface remains relatively undeveloped. On the other hand, the anterior and posterior portions of the rudimentary hemispheres do not form any ganglionic masses on their inner surface, but develop mainly into cortical and medullary substance, deposited upon their outer surfaces. The intervening portion (S.) sinks in, and thus forms the Sylvian fossa. The surface which presents in this fossa is the island of Reil.

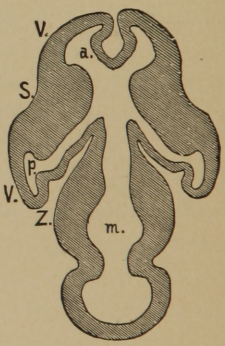

Fig. 3.

Horizontal Section of Fœtal Brain; *After His.*

VV. Fore-brain. a. Anterior horn. p. Posterior horn of the lateral ventricle. S. Fossa Sylvii, the outer surface of the ganglionic region of the fore-brain. Z. Inter-brain.

m. 3d Ventricle. Behind this, a part of the mid-brain, surrounding the Aq. Sylvii. The posterior boundary of the mid-brain is explained by reference to the parieta flexure (Fig. 4.)

[1] This figure must be inverted when compared with Fig. 5, p. 4.

At this level the student may note how in the fore-brain the anterior (a.) and posterior (p.) horns of the lateral ventricles open widely into the hollow of the primary cerebral vesicle. At this point the median wall of the prosencephalon encircles this opening. The outer wall of the prosencephalon has given rise mid-way to the *fossa Sylvii*. The inner wall closes in upon the cerebral ventricle. The fornix ascending from the *cornu ammonis* between S. and Z., regions corresponding to the *corpus striatum* and the *thalamus opticus*, constitutes the posterior portion of the median wall. The superior convex arch of the fornix is flattened down, but the descending portion of the fornix is enclosed within the front wall of the anterior cerebral vesicle.

The fornix bounds the hollow separating the fore- and inter-brain, which cavity is rendered cleft-shaped by the inward growth of the thalamus, and forever after remains broadest at its anterior end (foramen Monroi).

The upper wall of the thalamencephalon consists simply of the membranous roof of the third ventricle, which passes to the edge of an arch-shaped constriction arising from the upper and anterior wall of the thalamencephalon. This constriction represents the fimbria of the fornix. The middle choroid plexus of the upper wall is continued through the *foramen Monroi* into the plexus of the lateral ventricles. The fornix in reality limits the extent of the fore-brain. As soon as the *septum* and the *corpus callosum* are developed, the *gyrus fornicatus* appears to be a limiting formation, or at least a secondary free margin of the cerebral cortex. An examination of Fig. 3 shows that the outer cerebral wall growing from the fossa Sylvii toward the median line gives rise to the ganglia of the prosencephalon and encroaches upon the annular opening in the median wall, and thus fills in the once copious hollow of the ventricle.

The prosencephalon continues to extend in a posterior direction at later stages of development ; we find, therefore, on horizontal sections, that the corpus striatum and thalamus opticus are juxtaposed from the outside inwardly instead of lying one behind the other.

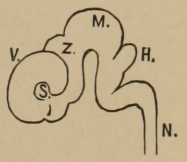

Fig. 4.

View of the Convex Surface of a fœtal Brain.

V. Prosenceph. S. Fossa Sylvii. Z. Thalamenceph. M. Mesenceph. H. Epenceph. N. Metenceph. Beneath the frontal portion of the prosencephalon lies the olfactory lobe.

(Lettering as in Fig. 1.)

The succession of the three cerebral vesicles is marked by several flexions on the axis of the original medullary tube (Fig. 4). The *cervical flexure* (convex posteriorly) marks the transition from the spinal cord to the metencephalon ; the *frontal flexure* (convex anteriorly), the transition from the metencephalon to the epencephalon ; and beneath the mesencephalon the *parietal flexure* is formed. The *chorda dorsalis* terminates in the sinus formed by the last-named flexure.

A.—THE PROSENCEPHALON (FORE-BRAIN).

CONVEX SURFACE.

The prosencephalon describes a curve about the Sylvian fossa which was formed by the insufficient increase in thickness of the

outer surface. The upper portion of this curve is the frontal end of the prosencephalon, the lower portion is its temporal end, while its summit represents the occipital region. On account of the insertion of the parietal region between the frontal and occipital portions of the brain, the upper arm of the arc is the longer one.

The island of Reil Fig. 4, S., is connected with a protuberance (the olfactory lobe) situated on the lower aspect of the frontal portion of the fore-brain. Behind the olfactory lobe, the thalamencephalon is visible in the shape of a basal protuberance which forms the region of the infundibulum on the anterior border of the parietal flexure.

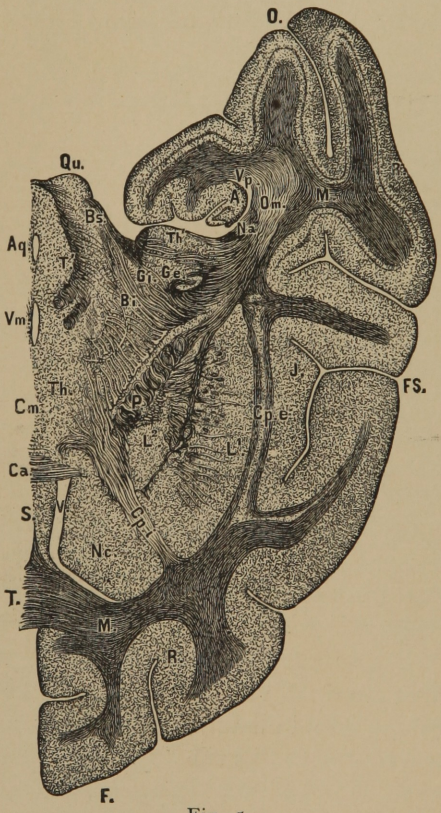

Fig. 5.

Horizontal Longitudinal Section from the Brain of *Cercocebus Griseoviridis.*

F. Frontal end. O. Occipital end, of fore-brain. A. Cornu ammonis. R. Cortex. M. Medullary substance. J. Island of Reil. FS. *Fissura Sylvii.* V. Anterior horn. Vp. Posterior horn of the lateral ventricle (prosencephalic cavity). T. Corp. callosum. S. Septum. Nc. Na. *Nucleus* caudatus and L.[1], L.[2] *Nucleus* lenticularis (the ganglia of the fore-brain). Cp.e. *Capsula externa. i. e.*, The medullary substance immediately adjoining the lenticular nucleus. To the outside of the capsule lies the claustrum, and next to this the thin medullary substance of the island. Ca.

Let us now proceed to examine with the aid of sections of the adult brain, the island of Reil—the floor of the Sylvian fossa. A horizontal longitudinal section (Fig. 5), as well as a vertical frontal cross-section (Fig. 6) of the brain will serve our purpose. A narrow passage, the Sylvian fissure (FS.), screens from view the sac-like dilatation of the fossa Sylvii in the furthest recess of which lies the island of Reil (J.). The outer walls of the Sylvian fossa, which are wanting in Fig. 4, are formed by the continued thickening of cerebral substance on the convex surface of the prosencephalic arch, until the edges of this arch approach

Commissura anterior. Th. *Thalamus opticus* (thalamencephalon). Th'. Pulvinar of the opt. thalamus. Cm. *Commissura media.* Qu. Mesencephalon—(Corp. quadrigemina). Bs. Brachium superius (of the upper corp. bigemina). Aq. *Aquæduct Sylvii.* Gi. *Corp. genic. internum.* Ge. Corp. genic. ext. T'. Tegmentum, lying in front of the gray substance surrounding the aq. Sylvii. Cp.i. Anterior portion of the inner capsule lying between the caudate and lenticular nuclei. P. Posterior portion of the inner capsule between optic thalamus and lenticular nucleus,—the origin of the fibres of the cruscerbri. Om. Projection system from occipital lobe to pulvinar corp. genic. int. and ext., the inf. corp. bigemina (Bi). and to the pedunculus.

so nearly to each other as to leave nothing but a narrow fissure (FS.), between them. The prosencephalic arch surrounding the fossa Sylvii developed its substance mainly in a lateral direction toward the cranial walls, whereas the region of the fossa S. itself increased in thickness by developing ganglia in a median direction toward the cerebral ventricle (Figs. 5 and 6).

The fissure of Sylvius is not a simple passage. It is bounded not only by two protruding lips, the operculum above and the upper temporal convolution below (Fig. 6 external to J.), which cover in Burdach's upper and lower fissures, but also by a front and rear wall lying on either side of the island and lapping over the front and rear fissures of Burdach, which are thus vertical branches of the upper fissure. These clefts are reached by the ascending anterior and posterior branches of the Sylvian fissure, *ramus adscendens anterior et posterior fissuræ Sylvii.* The anterior ascending limb lies behind the orbital surface of the frontal lobe, the posterior in front of the base of the first temporal convolution. The two ascending divisions of the Sylvian fissure bound the operculum. In man the island of Reil generally possesses six convolutions diverging superiorly in the shape of a fan. These convolutions are continuous above with

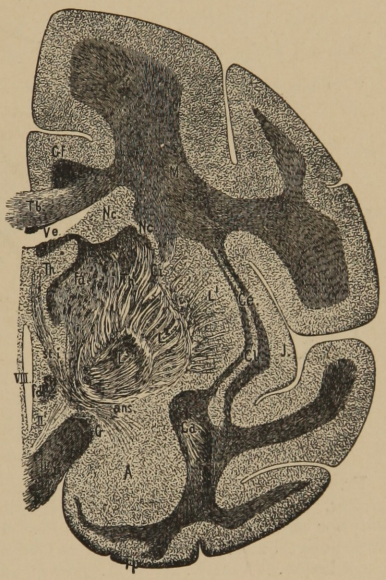

Fig. 6.

Frontal Cross-Section from the Brain of *Cercocebus Griseoviridis.*

J. Island of Reil, covered by the operculum and the first temporal convolution. Gf. Gyrus fornicatus. Tb. Corp. Callosum. Nc. Nucl. caud. Ve. Lateral ventricle. VIII. Median ventricle. Th. Thalam. opt. Fd. Descending, Fa. Ascending fornix. St.i. Lower pedicle of the thalamus from the ansa peduncularis. II. Chiasma. II.' A parallel bundle of fibres. A. Amygdala. Ca. Radiating fibres from temporal region to anterior commissure. $L.^1$, $L.^2$, $L.^3$ Nucl. lenticularis. ans. ansa of lenticular nucleus. Ce. Capsula external Cl. Claustrum. Tp. Temporal lobe.

the convolutions of the operculum, behind and below with the superior surface of the first temporal convolution (Huschke). Naturally enough these convolutions cannot be made out unless the entire brain-axis, together with the island of Reil, be dissected out from the surrounding mantle; the eye then rests upon the median surfaces of the hemispheres, and upon the inner surface of the convex hemispherical arch.

The ascending divisions of the Sylvian fissure are not as well marked on the convex surface of the human brain, and still less on that of the monkey, as they are in the brains of the carnivora (Fig. 7). Among the last named this peculiarity of configuration is most distinct (Fig. 7). In the brain of the bear we

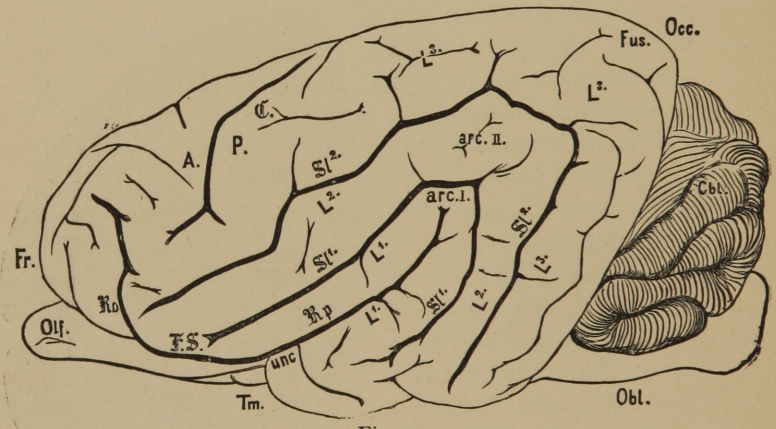

Fig. 7.

External Aspect of a Bear's Brain.

Fr. Occ. Tm. Frontal, occipital, and temporal end. Olf. Olfactory lobe. Unc. Uncus. Cbl. Cerebellum. Obl. Medulla oblongata. F.S., Ra. Rp. Sylvian fissure, anterior and posterior ascending limbs. C. Central fissure. Sl.¹ Parallel fissure. Sl.² Interparietal fissure. A. Region of the anterior, P. Region of the posterior, central convolution. Arc. I., Arc. II. Lower and upper parietal arches. L.¹, L.² Inferior parietal convolutions. L.³ Superior parietal lobe. L.¹, L.², L.³ Temporal convolutions. Fus. Gyrus fusiformis.

can easily distinguish: a blunt lower end of the operculum (near F.S.), a highly developed *anterior* ascending (Ra.), and a long *posterior* ascending, division (Rp.) of the Sylvian fissure. Similarly both the ascending branches are exquisitely distinct on the basal surface of the brain of Mustela (Fig. 10, right). The Sylvian fissure, which, in this instance screens from view an exceedingly rudimentary island, lies immediately adjoining to the *lobus olfactorius* (Ge.) throughout the entire length of the operculum, as was the case with the human brain represented in Fig. 4. In the rudimentary olfactory lobe of adult man, this external olfactory con-

volution (Fig. 15 Ge., Fig. 18) is replaced by the external white medullary strand of the *trigonum olfactorium.*

In addition to the *fossa* Sylvii which is present in all mammalian brains, and is often the only fossa present, we must now consider the typical fissures of more highly developed brains; these sulci mark out the various regions, or, at least, the convolutions of the convex surface of the fore-brain, and serve as our guides over this area. Apart from its morphological value, a thorough knowledge of these fissures and convolutions is absolutely indispensable to a proper appreciation of the physiological experiments performed on the animal brain.

If the "type" has been made out clearly enough to enable us to determine the identical regions of the mammalian and the human brain, then the important conclusions from physiological experiment and from pathological anatomy may safely be compared one with the other.

We find *typical* fissures in the human fœtal brain, from the sixth month of its development on.

I have not had the opportunity of making any detailed independent study of the human fœtal brain. My description is based upon a study of the monkey's brain. In some slight degree I am justified in taking such a course by the saying of v. Bischoff, that the monkey brain is not a miniature model of the human brain, but that the former represents arrested stages in the fœtal development of the latter. In the brain of the monkey there is a very distinct median, radiating furrow (ℭ.), sulcus centralis, or fissure of Rolando. The

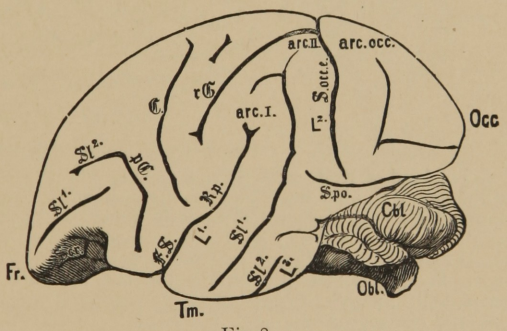

Fig 8.

Brain of Hamadryas.

Fr. Frontal end. Tm. Temporal end. Occ., Occipital end. Sl.[1] Inferior frontal fissure. Sl.[2] Rudimentary superior frontal fissure. pℭ. Anterior radial fissure (sulc. præcentralis). rℭ. Ecker's interparietal fissure (posterior radial fissure). F.S. Fissura Sylvii. Rp. Ramus ascendens posterior. Sl.[1] First temporal fiss. (sulcus parallel.) S. occ. e. External occipital fissure (primate ape fissure). arc. occ. Occipital lobe. (The vertical fissure might answer to the interoccipital fissure of man, and the horizontal fissure might mark Ecker's gyrus occipitalis. arc. II. Superior parietal arch. arc. I. Inf. pariet. arch. L.[1], L.[2], L.[3] First, second, and third temporal convolutions. Sp. o. Sulcus præoccipitalis. Cbl. Cerebellum. Obl. Med. oblongata.

radiating, primary fissures *diverge* toward the upper border of the hemispherical arch, and *converge* toward its lower border, *i. e.*, toward the *operculum.* In front of the sulcus Rolando, marking the posterior boundary of the frontal lobe, lies the anterior median furrow, the *sulcus præcentralis*, "transverse frontal fissure," (Fig. 8, ꝑ℄). This sulcus præcentralis combines with the straight inferior frontal fissure (𝕊l.¹) to form a cross-bow.

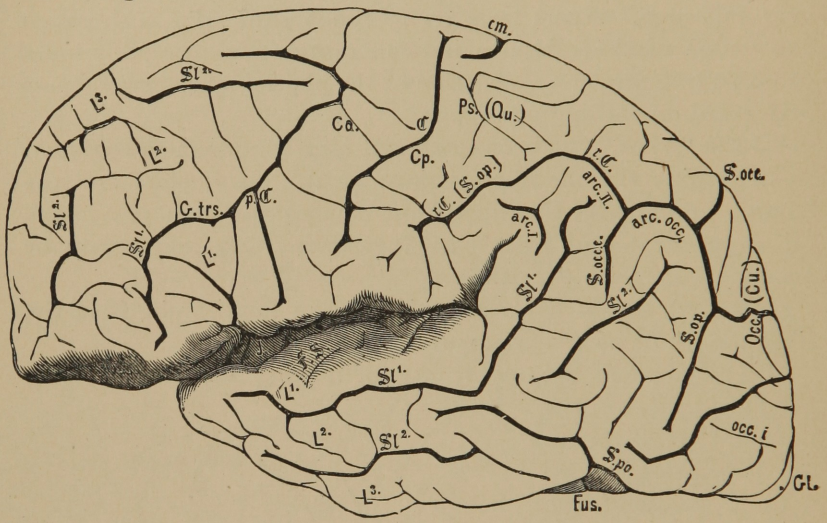

Fig. 9.

Convexity of the Human Brain.

J. Island of Reil. 𝔽.𝕊. Sylvian fissure. The letters are placed on the temporal lip of the fissure ; above the island lies the operculum, bounded by the anterior ascending limb, which passes upward toward the letters 𝕊l.¹ and the posterior ascending limb approaching the lettering arc I. ℄. central fissure. ꝑ℄. præcentral fissure (anterior radial fissure). r.℄. (𝕊.op.) post-radial fissure (sulcus occipito-parietalis). 𝕊.occ. Occipital fissure. 𝕊l.¹ 𝕊l.² Longitudinal fissures in frontal and temporal lobes. 𝕊l.¹ designates, below, parallel fissure. 𝕊.po. Præ-occipital fissure. Fus. Gyrus fusiformis. Ca. Anterior central convolutions. Cp. Posterior central convolutions. Ps. (Qu.) Superior parietal lobe (lobus quadratus.). Arc. I., arc II. Inferior and superior parietal convolutions. 𝕊. occ. e. External occipital fissure (ape fissure). Cu. Occ., Occ. i. The three occipital convolutions of Ecker, Cu. indicating the convex surface of the cuneus, and Occ. i. designating the convex surface of the gyrus lingualis. Gl. cm. Callosomarginal convolution. Arc. occ. Occipital arch. L.¹, L.², L.³, above 𝔽.𝕊. Frontal convolutions.[1]

The sulcus præcentralis represents the bow, the fissure 𝕊l.¹ the arrow. Behind the *sulcus* centralis lies the posterior radial fissure (r℄.) which diagonally divides the almost quadrilateral parietal lobe (lobus parietalis) into an inferior and superior parietal lobule. For this reason Ecker has proposed the name *Inter*parietal fissure. The lobus parietalis of the monkey is bounded in front by the

[1] The frontal convolutions are numbered from below upward. Meynert's first F. convolution is the same as Broca's Third F. conv.—S.

sulcus centralis, above by the border of the hemispherical arch, below by the *fissura Sylvii*, posteriorly by the external occipital fissure which is most highly developed in the lower apes. This "ape fissure "(Fig. 8 S. occ. e.) lies behind the radial furrows.

This fissure, which is less marked even in the higher forms of apes, is at times distinctly developed, at times scarcely recognizable, in the brain of man. But the most rudimentary form of it must be classed among the "typical" fissures. This fissure lies immediately adjoining to the posterior border of the second parietal arch. The anterior edge of the fissure protrudes, sword-like, beyond the posterior margin of the parietal lobe, only, however, in the lower orders of apes. This boundary line is also termed the *operculum lobi occipitalis*. In the higher apes these relations are more like those in man.

According to Reichert's opinion, which we accept, the parallel fissure (Fig. 8, Sl.[1]), lying between the first and the second temporal convolutions, must be added to the list of primary radial furrows. With Reichert, we may term this the *inferior radial* fissure. On separating the lips of this fissure, we notice that it winds around the fissura Sylvii toward the edge of the operculum, so that all four primary radial fissures converge toward the superior border of the Sylvian fissure.

Having given this (*true*) diagrammatic account of the surface of the monkey's brain, we will proceed to describe the various divisions of the fore-brain in man, the monkey, and in carnivora.

1. The *Frontal Lobe* reaches a high stage of development in man. After dissecting out the ganglion and the island, it constitutes 41–42 % of the remaining hemispherical substance, while in the monkey and bear but 35% and 30 % respectively can be put to the account of the frontal lobe. In the lower primates (Fig. 8), possessing a sulcus centralis, but no well-defined central convolution, the sulcus præcentralis may be taken as an indication of said convolution. On the other hand, the sulcus præcentralis (p. C.) clearly defines the boundaries of the anterior central convolution (Fig. 9, Ca.) of man. That part of the frontal lobe lying in front of the radial fissures is excessively developed. In front of the radial or

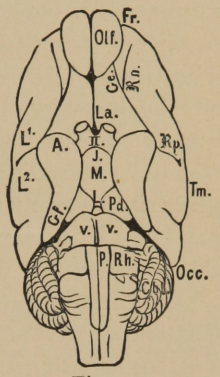

Fig. 10.
Brain of Mustela.

Fr., Tm,, Occ. Frontal, Temporal, Occipital end. Ra., Rp. The ascending branches of the Sylvian fissure, the middle part of which lies next to the olfactory convolution (Ge.). Ge. Lob. olf. La. Region of the anterior ethmoid plate. *II.* Chiasma opticum. J. M. Infundibulum and corp. mamillare. Pd. Pedunculus cerebri. V. Pons Varolii. P. Pyramid. Rh. Corp. rhomboideum. Cbl. Cerebellum. Gf. Gyrus fornicatus. A. Amygdala. L.[1], L.[2] Inferior convolution passing from the parietal lobe to the temporal lobe around the posterior ascending branch of the Sylvian fissure.

perpendicular fissures there are two more typical longitudinal fissures. The inferior longitudinal fissure (Sl.[1]) bounds an arch-shaped convolution (gyrus transitorius) which surrounds the ascending anterior division of the Sylvian fissure. The gyrus transitorius, emanating from the convex convolution in front of the operculum, passes on to the orbital surface of the frontal lobe (Fig. 9, forward of I.). The inferior border of this convolution is contiguous with that portion of the orbital surface lying to the outside of the olfactory lobe, and to which (in lower forms of mammals) Leuret applied the name *gyrus orbitalis.* Thus we find in the brain of a bear the anterior margin of the operculum bending over and passing into a convolution which, circumventing the ramus adsc. anter. fissuræ Sylvii, extends also to the orbital surface, and there lies to the outside of the lobus olfactorius (near Ra.). The frontal lobe of the bear is thus characterized by a gyrus transitorius homologous to the frontal lobe of man. The large frontal lobe of the human brain bears a second longitudinal sulcus (Sl.[2]), which, surrounding the inferior longitudinal fissure concentrically, gives rise to two superior longitudinal frontal convolutions (Fig. 9, L.[2], L.[3]). Like the gyrus transitorius, these convolutions pass from the convexity to the orbital surface of the brain.

On the basal surface of the brain of *Mustela*, it is also evident that the cortical substance of the operculum (between Ra. and Ge., Fig. 10), winding around the anterior ascending branch (Ra.), finally attains to the orbital surface, at the outside of the lobus olfactorius.

According to the above account, the frontal lobe of the human brain possesses four principal fissures: two perpendicular, *i. e.*, the central and præ-central fissures; two longitudinal fissures (an inferior and superior arch-shaped fissure); furthermore, four typical primary convolutions. These are: (1) The anterior central; (2) lower; (3) middle; (4) upper longitudinal, convolutions.

That the convolutions of the frontal lobe are not at all times and everywhere as distinctly defined on the surface of the brain as they are by the prominent lines on the accompanying cut (Fig. 9) is due, first, to the formation of anastomoses which connect parts originally separate, by bridging over primary ("typical") fissures; secondly, to the so-called secondary and tertiary fissures, which interrupt the primarily contiguous convolutions, and which, when surrounded by cortical substance, give rise to "insular" formations. The anastomoses, as well as the secondary fissures, are in the human brain an indication of the greater development of cortical substance. Thirdly, we find the primary convolution type obscured by serpentine intricacy of form, by the formation of *ansae.* Finally, all three extremes of cortical development

may exert their influences over proximate portions of the brain. Distinctness of *type* is by no means identical with paucity of convolutions. Wealth of convolutions is more characteristic of the human brain, as compared with the brain of monkeys and of carnivora, than when compared with the brains of herbivora and cetaceans. Consequently the superiority of the human cerebral surface must not be attributed exclusively to the wealth of convolutions.

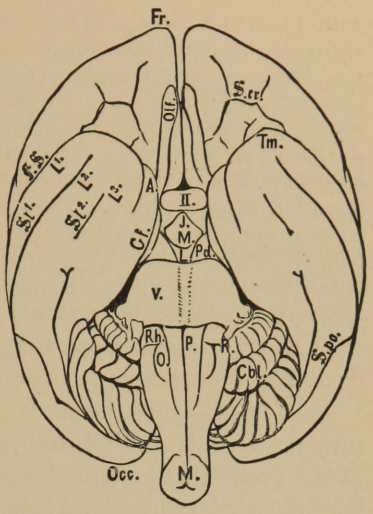

Fig. 11.
Brain of Hamadryas.

Fr., Tm., Occ. Frontal, temporal, occipital end. Olf. Olfactory lobe. S. cr. Sulcus cruciatus. F.S. Fissura Sylvii. Sl.[1], Sl.[2] First and second temporal fissures. L.[1], L.[2], L.[3] Temporal convolutions. Gf. Gyrus fornicatus. A. Amygdala. S. po. Præoccipital fissure. II. Optic chiasm. J. Infundibulum. M. Corpora mamillaria. L. Lamina perfor. post. Pd. Pedunculus cerebri. V. pons. P. Pyramid. Rh. Corpus rhomboideum. O. Inferior olivary body. R. Restiform body. Cbl. Cerebellum. M. Spinal cord.

The orbital surface of the frontal lobe of man's brain bears in its *typical* form close resemblance to that of the primates (Figs. 13 and 11). To be sure, we find in man the *sulcus* rectus, in which the olfactory bulb is imbedded (Figs. 11 and 18, Olf.), and which is wanting in the monkey's brain. But for the very reason that it is wanting in the monkey, in spite of a more highly developed olfactory lobe, the sulcus rectus can not be claimed to be destined to serve as a lodging-place for the *lobus olfactorius*.

The sulcus rectus brings about the division of the third frontal convolution into two parallel convolutions. This tendency toward a division of the terminal convolution is often, though less clearly, indicated in the formation of secondary fissures on the convex surface of the hemispheres (Fig. 9, L.[3]). Externally from the straight fissure lies the *sulcus cruciatus* which might be more appropriately termed the H-shaped fissure. This *typical* formation is well represented in the basal aspect of the primate brain (Fig. 11, S. cr.) and on the shaded surface of Fig. 13. The transverse fissure of the H causes an inflection of the middle frontal convolution. This transverse fissure may be absent in the primate brain. In that case four frontal convolutions lie next to one another.

The H-shaped fissure with its many variations presents the most instructive example of a great dissimilarity of forms, whose origin from the original *type* is yet

quite distinct. The transverse fissure of the H causes, as it were, an inflection of the middle longitudinal convolution. At times an anastomosis of the median third with the lateral first longitudinal convolution of the orbital surface crosses the transverse fissure in a median-exterior direction, thus uniting primarily (typically) separate convolutions. And then again the transverse fissure may be bridged over by an anastomosis uniting the portions of the middle convolution situated anteriorly and posteriorly, respectively, of the transverse fissure. In the last instance the H is resolved into three straight convolutions, which lie to the outside of the sulcus rectus parallel to the now created innermost fourth straight orbital convolution. Anastomoses have, therefore, in the above-mentioned instances, given rise to different divisions of the orbital surface. These two kinds of changes come entirely within the scope of the typical cortical complications mentioned above. Such changes result from the union of parts (originally) typically separate. Complications in the development of convolutions may turn the H-shaped into a star-shaped formation. Secondary fissures of the orbital surface are rarely wanting in man.

The third surface of the frontal lobe—the median—will be described together with the entire median surface (Fig. 13, p. 19).

2. The *Parietal Lobe.* The study of the parietal lobe of the primate brain (Fig. 8) is indispensable to a proper understanding of the convex surface of the parietal lobe in man. The anterior boundary of the parietal lobe is formed by the sulcus centralis; consequently the posterior central convolution is the frontmost convolution of this lobe. In man, also, there lies behind the sulcus centralis (Fig. 9) a posterior radial fissure—the sulcus interparietalis—which, extending quite up to the superior border of the hemisphere, diagonally divides the parietal region [Rc. (S.op.) Rc.]. The posterior radial fissure differs from the sulcus interparietalis of the monkey in this: that instead of terminating at the sulcus occipitalis it passes beyond it, in order, further on, to form the interoccipital fissure (Fig. 9, S.op.). Because of its transition into the occipital convolutions, the posterior limit of the superior parietal lobule is often indistinctly defined. The entire fissure (interparieto-occipitalis) bounds the arch-shaped parietal and occipital formations of the cortex.

The second "typical" line of demarcation of the parietal lobe is the posterior ascending limb of the Sylvian fissure; the third is the parietal portion of the parallel fissure.

The superior parietal lobe of man is frequently connected with the inferior lobe by means of a vertical anastomosis. There results a long vertical fissure behind the post central convolution (c.p.) which, if care be not taken to discriminate between them, may be mistaken for the fissure of Rolando.

The superior parietal convolutions form a triangular lobe whose base is situated superiorly. The superior parietal lobe [lobus parietalis superior. (Huschke)] is the external surface of the

lobus quadratus, the præcuneus of the median surface—from which it takes its name. Fig. 9, Ps., Qu.

The inferior parietal lobe (lobus parietalis inferior., lobulus tuberis, Huschke) starts often from the posterior central convolution as a simple gyrus; often, too, this mode of origin becomes complex. Below the interparietal fissure and in front of the posterior branch of the Sylvian fissure (Figs. 8 and 9), the inferior parietal convolution divides, as in primates, into two arch-shaped convolutions (v. Bischoff). The anterior (properly speaking) inferior parietal arch (Figs. 8 and 9, *arc.* I.) surrounds the posterior ascending limb of the Sylvian fissure and is contiguous with the superior temporal convolution. In addition to this, the inferior parietal lobe develops a second (posterior) superior parietal arch (*arc.* II.) surrounding the parallel fissure, which arch is continued into the second temporal convolution, back of that fissure.

The posterior boundary of the second parietal arch is formed by a fissure which is at times distinctly developed, and at other times interrupted (shortened) by anastomoses connecting the second parietal arch with the occipital lobe. This fissure is the external occipital fissure of man—the rudimentary ape fissure (Fig. 9, S. occ. e.).

Comparison with the brain of a primate impresses more firmly upon one's mind the "typical" lines of the parietal lobe in man. In both we find an anterior boundary defined by the sulcus centralis, a superior margin by the convex border of the hemispherical arch, extending from the sulcus centralis to the incision of the internal occipital fissure; an inferior border formed by the posterior half and the posterior ascending branch of the Sylvian fisssure and lastly, a posterior boundary, marked by the external occipital fissure, *i. e.*, by the fissure surrounding the second parietal arch (Fig. 8, S. occ. e.).

The double arch-shaped formations—the parietal arches—of the monkey's brain, connecting the lower parietal convolution with the two superior temporal convolutions, furnish the keynote to the understanding of the identical parts of the human brain. There is a certain diagrammatic simplicity about the manner in which the *arcus* I. of the monkey passes around the posterior ascending limb of the fiss. S. into the first temporal convolution; and in equally diagrammatic fashion the *arcus* II. passes around the vertex of the parallel fissure at the superior border of the second parietal convolution, in order to descend in the

direction of the parallel fissure as the second temporal convolution.

Not invariably, yet often enough, the first parietal convolution of man is bounded by a fissure (Fig. 9, *over* arc. I.). This fissure, though generally shallow, is certainly "typical," as is evident on the parietal convolutions of carnivora. There are undoubted exceptions to Pansch's rule, that the *typical* fissures of the brains are the deepest. Furthermore, as seen in Fig. 9. the superior border of the first parietal convolution not infrequently anastomoses with the inferior (concave) border of the second parietal convolution (vertical convolution between arc. I. and arc. II.). This is a *typical* convolution not of the monkey, but of the cat.

The cat possesses several vertical anastomosing convolutions. They seem to indicate the restriction of development of the convolutions in a longitudinal direction, due to the brachycephalic skull of the cat. The mechanical laws underlying the development of convolutions have been stated as perfectly as the present state of our knowledge would permit by Wundt, Henle, L. Meyer, and the author.

The convex surfaces of the parietal lobes of the monkey and of man exhibit four convolutions: 1. The posterior central convolution. 2. The lobus parietalis superior (lobus quadratus, præcuneus)—complicated in man, frequently connecting with the post. centr. convolution. 3. The inferior parietal arch. 4. The superior parietal arch, generally emanating from a single root of the inferior parietal convolution. The posterior central convolution and the anterior segment of the inferior parietal arch take part in the formation of the operculum.

3. The *Occipital Lobe.* The occipital lobe in the lower forms of primates may present an entirely smooth surface. Fig. 9 shows two fissures at right angles to one another. The vertical fissures may possibly be a rudimentary homologon of the sulcus interoccipitalis in man, and the horizontal fissure may represent those straight fissures which bound Ecker's occipital convolutions, of which mention will be made later on.

The sulcus interoccipitalis (S.op.), the continuation of the fissura interparietalis, divides the occipital lobe of man into an inferior (anterior) and a superior (posterior) cortical area. The anterior portion of the occipital lobe is arch-shaped in typical brains. The arcus occipitalis (Fig. 9, *arc. occ.*), the third arch (according to Bischoff), back of the central fissure, possesses a depression which I am disposed to regard as the occipital origin of the second temporal fissure (Fig. 9, Sl.²), reaching as high up as the origin of the first temporal fissure—the fissura parallelis.

This fissure, the lumen of the *arcus occipitalis*, wends its way toward the second longitudinal fissure of the temporal lobe, which is generally most distinct anteriorly between the

second and third temporal convolutions (L.^{2} L.^{3}), just as the parallel fissure can be best made out between the first and second temporal convolutions (L.^{1} L.^{2}). Just as the posterior branch of the first and second parietal arches passes into and connects with the first and second temporal convolutions, so the posterior portion of the *arcus occipitalis* passes into the third temporal convolution. But the continuity of this fissure, behind which the third temporal convolution arises from the occipital arch, is interrupted by anastomoses, which pass from the third temporal convolution, from the vertex of the occipital lobe, and finally from the *gyrus fusiformis*, to the second temporal convolution. As in the monkey, so in man, we may often be able to trace among the anastomoses of the second temporal convolution a deep fissure (sulcus præoccipitalis—Fig. 9, S.po.), the continuation of the inferior margin of the occipital vertex. These vertical anastomoses divide both the second temporal (Sl.^{2}) and the third temporal convolutions into a superior and an inferior portion. It is only in the anterior region of the temporal lobe that the two fissures and the three convolutions are distinctly developed.

Above the occipital arch the external marginal convolution continues the superior parietal lobule from the sulcus occipitalis internus downward. Ecker describes three occipital convolutions lying one above the other. The two lower convolutions pass in a horizontal direction from the occipital lobe to the front (*Occ.* and *Occ. i.*). The superior occipital convolution is the external surface of the cuneus, separated from the superior parietal convolution by the occipital fissure (superior occipital lobule of Huschke). The second and third occipital convolutions constitute the convex surface of the gyrus glossiformis, which, on the median aspect, is situated below the sulcus calcarinus. The third straight occipital convolution, in passing to the front, touches with its inferior margin upon the præoccipital fissure (Fig. 8, S. po.), of which v. Bischoff and Wernicke make mention.

The human occipital lobe is triangular in shape; anteriorly it is imperfect, bounded generally by the fissura occipitalis interna, the irregular opening of a convolution of the convexity. In Fig. 9, S. occ., the lower portion of such a loop is screened by the sulcus interoccipitalis. This ansa may descend a long distance, and yet will prevent the fusion of the external and internal occipital fissures. An ape-fissure, extending to the margin of the hemisphere, (W. Sander) will, therefore, be less frequent than appearances would

lead one to believe. The margin of the hemisphere forms the superior boundary of the occipital lobe; there is no natural inferior boundary, however, between the occipital and temporal lobes. An artificial boundary between the convex surfaces of the temporal lobe on the one side, and the parietal and occipital lobes on the other, might be denoted by a line passing from the lowest point, of the posterior ascending limb of the Sylvian fissure, to the lowest portion of the *sulcus præoccipitalis.*

The surface of the occipital lobe is marked by the following fissures: 1, the sulcus interoccipitalis; 2, the beginning of the second temporal fissure; 3, the fissure between the first and second convolutions of Ecker; 4, the fissure between the second and third convolutions of Ecker. The occipital lobe of man presents on its convexity four convolutions: 1, the *arcus occipitalis;* 2, 3, and 4, the three convolutions of Ecker.

4. The *Temporal Lobe.* Its superior surface borders upon the island of Reil; its superior margin touches the operculum. The inferior margin is continued, by means of a free, arched, anterior margin, into the superior. Posteriorly the temporal lobe is contiguous with the parietal and occipital lobes along the artificial boundary line mentioned above. The temporal lobe exhibits three typical furrows: 1, the superior longitudinal sulcus—*sulcus parallelis;* 2, the inferior longitudinal sulcus; 3, the sulcus præoccipitalis. The first of these sulci is rarely interrupted; the second, invariably so. The convolutions of the temporal lobe are: 1, the superior; 2, the middle; 3, the inferior longitudinal convolutions (L.[1] L.[2] L.[3]), 4 variable vertical convolutions anastomosing with the second longitudinal convolution.

For the understanding of the facts gleaned from experimental physiology we must needs rely upon our knowledge of comparative anatomy. We are prompted, therefore, to give in the following paragraphs an account of the homologous parts in the brains of man, the monkey, and the carnivora.

In the brain of the bear (Fig. 7) the fissure C. is, beyond a doubt, the boundary line between the frontal and parietal lobes. Characteristic of the frontal lobe are convolutions (in lower forms of carnivora this portion of the cortical surface is smooth) which, arising from the anterior margin of the operculum, make a curve about the anterior ascending branch of the Sylvian fissure (Transitional convolution of Huschke's). The human frontal lobe possesses two additional longitudinal convolutions concentrically surrounding the transitional convolution. The type of the frontal lobe in carnivora and man is fixed and modified by the simple or intricate development of those convolutions which form arches around the anterior limb of the Sylvian fissure, and pass on to the orbital surface. The frontal lobe of the bear contains still another deep sulcus, which separates two longitudinal convolutions, and lies close and parallel

to the superior free margin. In the figure this sulcus is denoted by a faint line, for the dark lines are to show at a glance the so-called *primary* fissures.

The sulcus centralis of the bear passes obliquely upwards and backwards as in man and the primates. In the majority of carnivora, however, the sulcus centralis assumes a different shape, extending backward quite to the occipital margin. In the latter cases the central fissure gives rise to the most external of the arched fissures which surround the post. ascend. limb of the Sylvian fissure. This *arch-shaped* central fissure is lodged within the superior parieto-occipital convolution. No animal possesses a *regio centralis* as much akin to the central region of man as is that of the bear, and this animal undoubtedly ranks highest in cerebral development. In Fig. 7 (L.[3]) the tendency to the formation of arched extensions of the sulcus centralis is expressed merely by insular, unconnected fissures. In the same figure the arrangement of parts is obscured by the insertion of a convolution (behind C.), which originates on the median aspect, but is not common to all bears. In front of the sulcus centralis (near A.) the bear shows a præcentral fissure much more marked than the thin line of the figure would lead one to suppose.

The arched fissures and arched convolutions, which lend a strange, non-human appearance to the brains of carnivora, pass around the posterior ascending branch of the *fissura Sylvii*. The first arched fissure (Fig. 7, Sl.[1]) which surrounds the arc. I. marks out a parieto-occipital convolution, whose opening the Sylvian fissure is ; this same arched fissure divides the first and second convolutions as the sulcus parallelis does in man. The former differs from the human parallel fissure in sending a long anterior branch into the lobus parietalis. The second *arched fissure* (Fig. 7, Sl.[2]) lies over the arc. II. of the bear's brain. This corresponds exactly to the position occupied in man by the posterior radial fissure, the sulcus interparietalis, which divides (in the parietal lobe) a superior parietal lobule from the two inferior parietal arches, which in turn connect with the two temporal convolutions (L.[1] L.[2]).

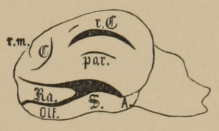

Fig. 12.

Fœtal Brain of a Dog (*after Wilder*).

r.m. Calloso-marginal convolution. Olf. Olfactory lobe. A. Amygdala. S. Sylvian fossa. Ra. Its anterior ascending limb. par. Parallel fissure. C. Central fissure. rC. Interparietal fissure.

The fissure in question lying behind the fissura centralis, and over the two parietal arches, undoubtedly represents the posterior central fissure. In contradistinction to man and the primates this fissure passes immediately into the second temporal fissure This simple type is modified in man and the monkey by the complicated structure of the occipital lobe.

The difference in the external aspect of the brains of man and the carnivora is due, first, to the slight development in the latter of the frontal and occipital brain (the occipital brain not overlapping the cerebellum) ; and, secondly to the enormous development of the parietal brain. An unusual development of the frontal, of the occipital, and of the parietal portions is characteristic respectively of the brain of man, the primates, and the carnivora. The most striking feature of the carnivora brain, as compared with the human brain, is undoubtedly the greater development of the parietal portions of the arched fissures and arched convolutions. The arched convolutions are very distinct owing to an equal development of both branches ; in man, methodical examination alone reveals them. The arched posterior extension of the middle radial fissure (central) adds to the number of arches in the carnivora. The primary position of the radial fissures of carnivora is well represented in the adjoining cut (Fig. 12), after Wilder, of a fœtal dog. In spite of its elongated shape, we can readily discern a frontal, a temporal, and an occipital region. The anterior ascending

limb of the open Sylvian fissure is beautifully developed, showing distinctly the course of the frontal end around this arch into the orbital surface of the frontal lobe, to the outer side of the olfactory lobe. This portion of the brain is bounded posteriorly by a central fissure which, as was the case in the bear, is surrounded on all sides by cortical substance, is insulated from the rest of the cortex. In the parietal region we discover a very delicate longitudinal fissure, which, in the adult dog, combines with the fissura centralis to form a superior arched fissure. Behind this sulcus centralis (an anterior radial fissure is not visible) lies a very marked fissure with two flat arches beneath it. These wind about the Sylvian fissure and have not yet extended to the temporal lobe. These must necessarily be taken to be the two parietal arches. The fissure separating both arches would, if continued backwards and downwards, bound a first temporal arch. This corresponds, therefore, to the sulcus parallelis, while the deeper fissure (before mentioned) which lies above both parietal arches answers to the posterior central fissure. Continued backwards, this fissure will, in later stages of development, form the boundary of the arc. temp. II. It separates, furthermore, the region of the superior parietal convolution from the inferior, which gives rise to the two parietal arches. We notice also in carnivora the rudiments of a posterior and an anterior arched fissure which represent in the same succession the radial fissures of man and the primates,

No reference need be made to the fissure c.m. I simply wish to remark that of the motor centres, of which we shall treat later on, Hitzig's centre for the innervations of the muscles of the neck is located in front of this sulcus. For this reason the motor centres are not limited morphologically to the sulcus centralis, about the position of which Hitzig is in error. The convolution of the dog's brain which he considers homologous with the anterior central convolution of the monkey, is not the anterior but the posterior central convolution.

THE MEDIAN SURFACE OF THE FORE-BRAIN, AND THE LOBUS OLFACTORIUS.

The cortical duplications of the median surface of the hemispheres are far simpler than those of the convexity of the brain; but special formations, such as the *lobus olfactorius and the cornu ammonis*, whose genetic bearings we must now study, complicate this otherwise simple surface.

In Fig. 1 we are supposed to look within the thin-walled cerebral vesicle, and from the cavity of the thalamencephalon into the small opening forming the communication between the prosencephalic vesicle and the third ventricle. This opening, whose anterior inferior portion is transformed later on into the foramen Monroi, must necessarily have annular boundaries. This ring, proportionately enlarged, is discernible in the adult brain in the shape of the fimbria, and the descending pillar of the fornix (Fig. 13, Fi. d.) The lateral wall of the thalamencephalon proliferates and forms the thalamus opticus within this constriction-ring, which it reduces to the arched cleft between the optic thalamus and the fornix. The separation of the vesicle of the hemisphere

starts from the upper wall of the anterior vesicle, or, in other words, from the superior and anterior walls of the thalamencephalon. This superior wall does not develop into nerve tissue, but into a membrane from which the *plexus chorioidei* are developed. The thinning out of this constriction-ring at the fimbria gives lasting evidence of the transition of this ring into the superior membranous wall of the thalamencephalon.

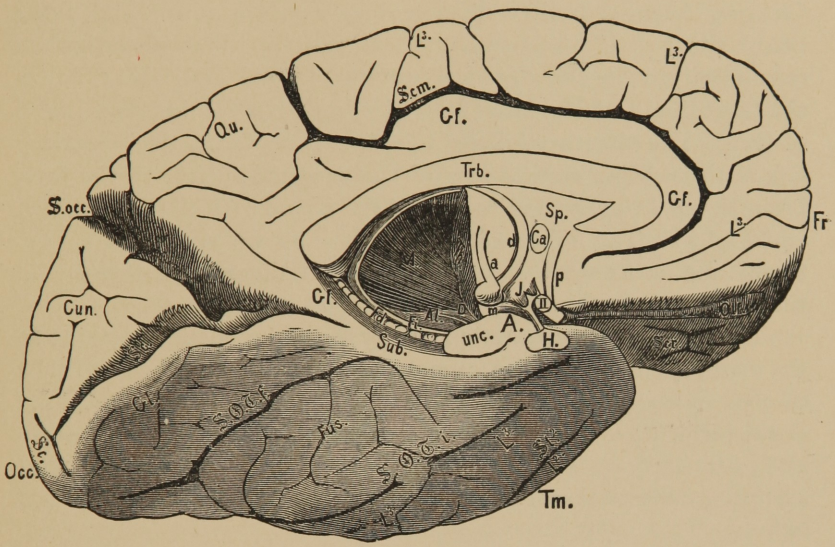

Fig. 13.

Median Aspect of the Human Brain.

Fr., Occ., Tm. Frontal, occipital, and temporal end of the hemisphere. Olf. Olfactory lobe. S.cr. Sulcus cruciatus. S.cm. Calloso-marginal sulcus. S.occ. Internal occipital fissure. Sc. Calcarine fissure. S. O. T. F. Superior occipito-temporal fissure. S. O. T. i. Inferior occipito-temporal fissure. Sl.² Second temporal longitudinal convolution. L.³ Median surface of the third frontal longitudinal convolution. Gf. Gyrus fornicatus. Qu. Lobus quadratus (præcuneus, superior parietal lobe). Cun. Cuneus, superior occipital lobe. Gl. Gyrus glossiformis convolution of Burdach's internal primary fasciculus. Fus. Gyrus fusiformis, convolution of Burdach's inferior longitudinal fasciculus. L.³ L.² Temporal longitudinal convolutions. Sub. Subiculum cornu ammonis. Unc. Uncus. A. Amygdala. Fd. Facia dentata Tarini. Al. Alveus. D. Digitations of the cornu ammonis. Th. Section of optic thalamus. M. Section of cerebral medullary substance. d., a. Descending and ascending fornix. Trb. Corpus callosum (trabs cerebri). M. Medullary substance. J. Infundibulum. Ca. Anterior commissure. Sp. Septum pellucidum. p. Its peduncle. II. Optic nerve. H. Hypophysis cerebri.

The cerebral fissure surrounding the optic thalamus is broadest behind the lowest portions of the descending crus of the fornix (Fig. 13, in front of a.), to permit the passage of the lateral choroidal plexus, and is here termed the *foramen Monroi*. The ascending crus of the fornix is also dissected out and rendered

visible in Fig. 13. The inferior wall of the inter-brain is continued into the infundibulum (J), and communicates on the median surface with the middle cerebral cavity. The fornix from the fimbria to the corpus candicans is the genetic and permanent constriction-margin of the fore-brain. It was remarked at the outset that the median surface of the fore-brain surrounds the entrance into the lateral ventricles in front of the ganglionic proliferation, and that the ring forms a hollow diverticulum at its anterior end, lying below the rest of the hemispherical vesicle. This diverticulum develops into the *lobus olfactorius* (Fig. 13, olf. and Fig. 4, below the frontal end of the arched fore-brain and adjoining the island of Reil). The olfactory lobe, at the same time, forms the boundary line of the median surface toward the external surface of the fore-brain, toward the Sylvian fossa and the island of Reil (Fig. 15, Ge. and Fig. 4). The lobus olfactorius has, as we shall see, an external and an internal convolution which diverge posteriorly in the *trigonum olfactorium* (Fig. 18, olf.).

The lumen of this genetic annular formation, which pertains to the median surface of the prosencephalic cortex, may apparently be traced on every section of the brain to the free margin of the gyrus fornicatus. The cortex presents its free margin anteriorly and posteriorly on straight horizontal (Fig. 5) as well as on sagittal sections; on frontal sections (Fig. 6) this margin is seen above and below.

The median aspect (Fig. 13) shows the corpus callosum to be surrounded, in front, above, and below, by the free margin of the cortex (Gf. Trb.); below the corpus callosum, it presents the fimbria of the fornix (Fi.). Sections of the brain prove that the cortex —the starting-point of all nerve fibres, encircles the brain like a pleated cap. *Gratiolet* described the cortex as a sac whose rim, the gyrus fornicatus, is drawn tightly together around the corpus callosum. This striking simile is not entirely correct, for a smaller sac, the olfactory lobe (Olf.) protrudes anteriorly from the mouth of the larger.

But in order to understand clearly the genesis of the fixed relation of these parts, it is well (when studying Fig. 13) to neglect altogether the corp. callosum and the anterior commissure, and to imagine a human brain *minus* the corp. callosum. Viewed in this way the *gyrus fornicatus* will be found continuous with the *septum pellucidum*. The primary margin of the median cortical surface skirts the fornix, as far as the vertex of

the uncus, in the disguise of the *septum and the fascia dentata Tarini.*

The *fornix*, however, taken together with the *fimbria*, does not form a ring, but an arch. The ascending crus of the fornix, coming from the corpus mammillare, does not enter into account at present. Similarly the free margin of the median cortical surface forms merely a ring-like arch about the fornix, which arch is interrupted between the *uncus* and the orbital surface. Beneath the orbital surface lies the olfactory lobe. The external and internal margin of the *trigonum*, the olfactory convolutions, isolate those convolutions of the cortical substance, which go to form the primary median surface and the margin of the cortex. The external olfactory convolution connects with the uncus, skirting the island of Reil and the orbital convolutions, while the internal olf. convolution is continued beyond the end of the internal orbital convolution, on to the frontal terminus of the median cortical arch. Lying in the *sulcus* rectus, and on the inferior aspect of those convolutions which are continued from the convexity of the brain, the olfactory lobe and its *trigonum* are bent at right angles in spite of their anatomical connections. To the basal position of the caudate nucleus this rectangular displacement must be attributed. And yet, the trigonum and its crura form but the basal margin of the prosencephalic cortex. Behind the cortical margin of the olfactory convolutions a ganglion of the fore-brain, the nucleus caudatus, presents its basal surface in the form of the lamina perforata anterior (Fig. 18, olf. La.). The lamina perforata verges upon the basal prolongation of the inter-brain—the *tractus opticus*. This marks the posterior boundary of the fore-brain.

The connection of the gyrus fornicatus with the olfactory convolution is evident from a peculiarity of structure common to both: The microscopically minute nerve fibres of the convolutions of the convexity are naked-eye appearances in these (olf.) convolutions. This part of the *cortex* presents medullary spots, both in the *substantia reticularis* of the uncinate convolution, and in the white streaks scattered through the trigonum olfactorium. The external medullary strand is intimately connected with the substantia reticularis, and so is the internal band, by means of the *nervus Lancisii*, which makes a detour about the anterior end of the corp. callosum.

The passage of the corpus callosum from one hemisphere

to the other causes that part of the cortical substance which immediately adjoins the fornix to separate from the gyrus fornicatus as *septum pellucidum*, the peduncle of which (p.) connects with the lamina perforata anterior—*i. e.*, with the basal mass of the caudate nucleus. This peduncle passes from cortical into ganglionic substance. It represents the projection-system of the septum's cortex. Between the pedunculus septi (p.) and the fornix, the anterior commissure (ca.) breaks through in a transverse direction. The breaking through of the corp. callos. shortens the cleft for the falciform process of the *dura mater* by the height of the *septum*, whose chambers correspond to the lower part of the longitudinal fissure between both hemispheres. In animals the camera are abolished because of the median adhesion of the septa.

The "peri-trabecular" substance of Huschke has a concentric shape, and is made up of the gyrus fornicatus of Arnold and the median surface of the marginal convolutions of the convexity. These two concentric formations are separated from one another by the sulcus calloso-marginalis. A fissure, which passes between the corpus callosum and the marginal convolution of the forebrain, extends (genetically) as far as the occipital (ape) fissure (Schmidt). Behind the posterior central convolution an ascending branch leaves the sulcus calloso-marginalis, forming the anterior border of the lobus quadratus—the præcuneus. Its prolongation to the occipital fissure may be either very shallow, or wanting altogether as in the brains of primates (Fig. 14, cm.). The *lobus quadratus* is the mesial representative of the region of the superior parietal lobule. The demarcation of the gyrus fornicatus is continued for some little distance in the temporal lobe by the extension of the sulcus calcarinus anteriorly. For the sake of completeness I propose at the close of this description to refer to a special complication of the gyrus fornicatus—to the uncinate convolution.

Caudad of the lobus quadratus we find the lobus triqueter (the cuneus), the median surface of the superior occipital convolution. The lobe is bounded by two >-shaped, deep fissures, which converge toward the gyrus fornicatus, of which the superior is called sulcus occipitalis internus; the inferior, sulcus calcarinus or sulcus hippocampi. The latter is one of the most constant fissures of the primate "type"; it can be discovered in the smoothest primate brains which have not yet developed either the exter-

nal occipital fissure or the sulcus centralis. It receives its name from the *calcar avis* (pes hippocampi minor); for, in consequence of the thinness of the mesial wall of the posterior horn, the calcar avis is formed by the convex protrusion of the reverse (Kehrseite) of this fissure upon the inner wall of the posterior cornu, just as the next following *eminentia collateralis Meckelii* is the converse of the next external fissure (S.O.T.F.). The sulcus calcarinus is in reality ⊢-shaped (Fig. 14, Sc.). In the human brain the longitudinal fissure of the ⊢ is frequently bent at an angle open posteriorly.

In addition to the occipital fissure of the sulcus calcarinus, the median surface presents two other fissures—Ecker's occipito-temporal fissures. But these fissures do not belong to that vertical portion of the median surface considered hitherto, which lies next to the falx cerebri; for we must remember that the median surface lies in two planes meeting at an obtuse angle. The longer vertical division, extending from the frontal end to the extremity of the occiput, rests upon the falx cerebri; the oblique horizontal division, extending merely from the vertex of the occiput to the temporal end, rests upon the tentorium cerebelli.

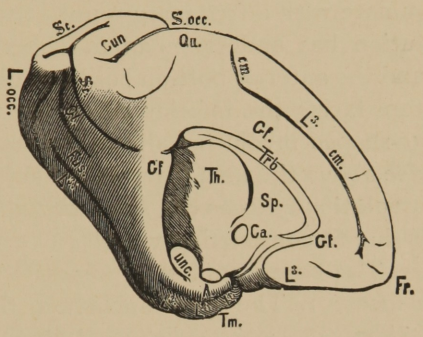

Fig. 14.
Median Surface of the Primate Brain.

Fr., Tm. Front., temp. end. L.occ. Occipital lobe. cm. Calloso-marginal convolution. S.occ. Internal occipital fissure. Sc. Sulcus calcarinus. L.[3] Third frontal convolution. Gf. Gyrus fornicatus. Qu. Lobus quadratus. Cun. Cuneus. Gl. Gyrus glossiformis. Fus. Gyr. fusiform. L.[3], L.[2], L.[1] Temporal convolutions. A. Amygdala. unc. Uncus. Trb. Corp. callosum (trabs). Sp. Septum pellucidum. Th. Optic thalamus. Ca. Anterior commissure.

The superior occipito-temporal fissures, together with the sulcus calcarinus, bound a convolution which, tapering anteriorly and uniting with the uncinate convolution, bears a strong resemblance to the tongue of a dog; whence the name, gyrus glossiformis. The superior and inferior occipito-temporal fissures enclose a convolution broadest at its middle part, the gyrus fusiformis. The latter is succeeded by the marginal convolution of the temporal lobe, which belongs to the convex surface as well (L.[3]).

At the anterior margin of the temporal lobe the three convolutions of the convex surface unite to form a transverse-arched

anastomosis, the cortical portion of which connects with the *uncus* (Fig. 14, Tm.).

A few words must here be added in reference to the cornu ammonis, a formation complicating the temporal end of the gyrus fornicatus. The cortical substance of the gyrus fornicatus, which terminates with a free margin over the corpus callosum, presents on cross-section, as does every convolution, an ∩ surrounding the medullary substance. Burdach applied the term *cingulum* to that portion of the gyrus fornicatus extending as far as beneath the *splenium corp. callosi.* At the temporal end of the gyrus fornicatus, in the *gyrus uncinatus*, the cortical substance does not terminate with a free margin until the middle portion of the convolution has undergone an ᔕ-shaped involution (*lamina convoluta*), and the anterior portion has been divided up wave-like ; the wave-tops facing the inferior cornu are the so-called *digitations.* The ᔕ-shaped involution allows the margin to become quite free, to rise above the medullary substance, and to appear from out of the involution-folds as the *fascia dentata*, the notched surface of which is due to constricting vessels.

The cornu ammonis possesses four adjacent longitudinal eminences: 1. The gyrus uncinatus, the core of the *cornu ammonis subiculum.* 2. The *Fascia Dentata Tarini* (Fig. 13). The *Fasciola Cinerea* (Arnold) is a continuation of the fascia dentata on the lower surface of the great commissure, commissural fibres having perforated part of the median cortical substance some distance behind the septum. The cornu ammonis, unusually large in carnivora, rodents, etc., lies adjacent to a considerable portion of the inferior surface of the corpus callosum, and extends far to the front. 3. The Fimbria (Sus.), the projection bundle of the cornu ammonis. Additions from other parts of the gyrus fornicatus transform this into the descending crus of the fornix (Fd.). 4. The *Alveus* (Fi.), whose white substance, spread over its own gray cortex, over the stratum convolutum, is continued into the cord-shaped fimbria. The alveus represents the ventricular surface of the cornu ammonis, which surface protrudes as though it were embossed from the inner wall of the inferior horn. The name, *alveus*, is quite appropriate, for the stratum convolutum is surrounded *trough*-like by this medullary layer, which is curved, with its convex surface toward the ventricle. The surface of the subiculum, together with the fascia dentata, forms a continuous cortical layer, which is folded ᔕ-shaped from right to left. The surface of the cortex is hid in

the depths of this scroll. The alveus corresponds to the white substance of the convolutions, and consequently faces the ventricles. The uncus also is a complex formation. Its apex or posterior portion alone contains the forward part of the free median cortical margin, which projects in a transverse direction above the subiculum cornu ammonis, and yet is a part of it. The appearance of a longitudinal anterior flexion of the uncus, distinct from the cornu ammonis, corresponds to the convexity of the amygdala; this irregular gray mass lies in front of the cornu ammonis, and covers over the fissure which otherwise would have been evident on the brain surface at its point of flexion.

B.—GANGLIA OF THE PROSENCEPHALON, THALAM-(DI-)ENCEPHALON, MESENCEPHALON, AND MET-ENCEPHALON.

The cerebral cortex and its white substance betray, as it were, their morphological independence by the constriction round about the ganglia (Fig. 4, g. Fig. 15), and by the ease with which both the island of Reil and its medullary substance can be dissected out from the external surface of the large ganglia. This anatomical independence is in accord with the physiological independence of the fore-brain from the rest of the brain-substance.

In order to demonstrate the entire natural surfaces of the cerebral ganglia and the brain-axis, it is necessary to remove, by a curved incision (passing around the island, on the floor of the Sylvian fossa), the hemispheric arch, which corresponds to the *cerebral mantle* of Burdach, in contradistinction to the *nucleus* of the brain (which includes the island, ganglia, and brain-axis).

The basilar aspect of the nucleus, or rather of the brain-axis (Fig. 15), presents a free surface in front of the *tractus opticus*, in the form of the lamina anterior perforata; the last-named structure is separated on each side from the island by the external olfactory convolution, before it joins the *gyrus uncinatus*. The convolutions of the island converge toward this external medullary strip of the trigonum olfactorium, and form generally a single convolution,—the peduncle of the island,—while they diverge above toward the operculum, dividing into five or seven convolutions. To the inside of the island, and the outside of the caudate nucleus, extends the plane of the incision which separated the trunk from the cerebral mantle, as though the former were the

nucleus of the latter. Just as the hemisphere describes an arc with a frontal, a temporal, and an occipital end, so we shall find that the collected fibres of the corona radiata describe a similar curve at their entrance into the cerebral trunk. A section like that repre-

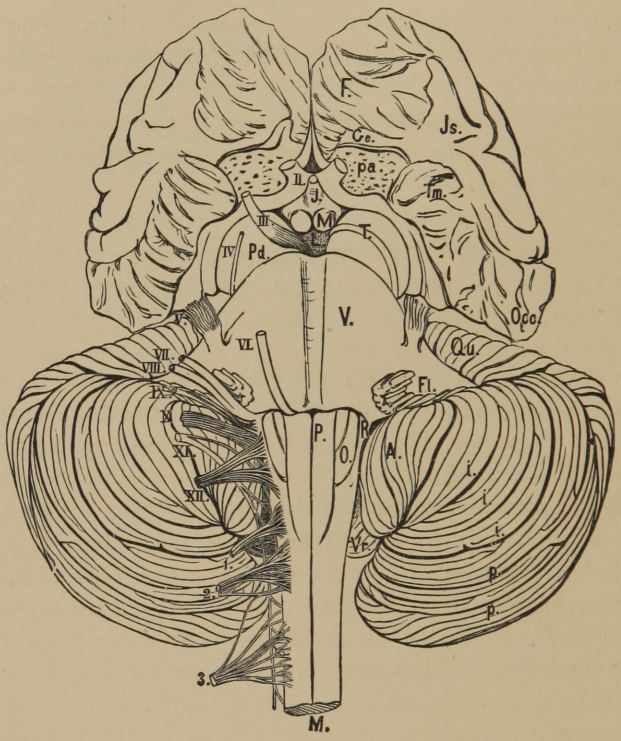

Fig. 15.

Basilar Surface of the Brain-Axis and the Cerebellum.

Fr., Tm., Occ. Section through the medullary substance, radiating from the frontal, temporal, and occipital portions of the cerebral mantle into the brain-nucleus. Js. Island of R. Ge. Med. substance upon the external olfactory convolution. pa. Lamina perforata anterior. II. Optic nerve ; the optic tract is divided posteriorly into an internal and external division. J. Infundibulum. M. Corp. mammillare. L. Lamina perforata posterior. Pd. Pedunculus (crus) cerebri. T. Tractus transversus pedunculi. V. Pons Varolii. P. Pyramis. O. Olive. R. Restiform body. M. Medulla spinalis. III. Oculomotor nerve. IV. N. trochlearis. V. Trigeminal nerve. VI. N. abducens. VII. Facial nerve. VIII. Auditory nerve. IX. N. glossopharyngeus. X. N. vagus. XI. N. recurrens Willissii (accessory nerve). XII. Hypoglossal nerve. Qu. Inferior surface of the lobus quadratus, superior lobe, of the cerebellar hemisphere. p.p. Lobus posterior inferior (semilunaris inferior). i.i.i. Lobus inferior (lobus gracilis et biventer). A. Amygdala. Fl. Floculus. Vr. Inferior vermiform process.

sented in Fig. 15 will present, therefore, a frontal and temporal end (F., Tm.), and between the two a parietal and occipital surface (Figs. 16, 17, P. Occ.). The marked convexity of the trunk,

causing it to protrude to the outside from under the insular convolutions at this section of the corona radiata, is due to the large size of the nucleus lenticularis, and furthermore, the temporal portion of this nucleus projects below the cerebral trunk, a fact not easily appreciated on the hardened specimen, owing to the slight contrast of colors. The caudate nucleus passes from the fore-brain to the basal surface, and there appears as the lamina perforata anterior. The inter- and mid-brain are continued to the base of the cerebrum through the tractus opticus, which, together with the optic chasm, constitutes the posterior boundary of the fore-brain.

The infundibulum represents a basal continuation of the cerebral gray substance surrounding the cavity of the thalamencephalon, and the corpus candicans must be regarded as medullary substance of the thalamencephalon, extending from the anterior tubercle of the thalamus to the basilar surface of the brain (Fig. 13, m. a.).

The *pedunculus* (Pd.) *cerebri*, which is bound from the fore-brain to the spinal cord, covers superficially and laterally the anterior circumference of the mesencephalon. The median lamina perforata posterior forms the median suture (raphe) of the two halves of the tegmentum, which connects the mes- and thalamencephalon with the spinal cord. The pedunculus cerebri is crossed in the median line by the third pair of nerves (III. oculomotorius). The left half of the *pedunculus cerebri* is crossed by a tract (the tractus transversus pedunculi—Gudden) which does not always lie as superficially as here indicated, and connects the anterior end of the peduncle with the superior corp. bigemina. The pons Varolii constitutes the basilar surface (Kehrseite) of the epencephalon. From the pons there emerge laterally the trigeminal nerves, and inferiorly the abducens, facial, and acoustic nerves. Below the pons Varolii and between the pyramids we come upon the anterior furrow of the cerebral axis, which is well developed even between the crura. The floor of the anterior cleft is analogous to the lamina perforata posterior lying between the paired peduncles, for its floor reveals the median surface of the raphe of the posterior division of the oblongata. And in the oblongata also the *raphe* divides the prolongations of the tegmentum. The oblongata can be divided into a superior and an inferior portion. The superior division extends to the inferior margin of the olivary bodies, the inferior half to the last decussating

bundle of the pyramids. A longitudinal fissure divides each olivary body toward the median line from the pyramids, and toward the outer side from the region of the *funiculus lateralis*. On closer examination the olivary bodies do not appear smooth, but striated, owing to the passage over them of oblique, slightly descending bundles (stratum zonale) which originate in the corpus restiforme. As a rule the stratum zonale covers all the longitudinal fibres coursing back of the pyramids. If there be a superficial longitudinal bundle of fibres to the inner side of the olivary body, this is termed fasciculus internus; if to the outside, fasciculus externus. These fasciculi may be nothing more than pyramid-fibres which the stratum zonale has separated from the main body of the pyramids. Behind the funiculus lateralis of the oblongata lies its most posterior longitudinal elevation, the corpus restiforme of the cerebellum (Fig. 15, R.).

The basal surface of the human isthmus presents many striking points of contrast with the brains of lower mammals, and even with the brains of primates. Entire structures seem to appear, or to disappear in man. On the whole, the *pedunculus cerebri* in animals is thin and possessed of so few nerve-tracts that the convexity of the tegmentum lying behind it causes it to bulge out. The pons appears low ; next to the pyramids rectangular formations are visible, which are made up of transverse fibres (corpus trapezoides). The olivary body, common to man, is wanting. I have shown that all these differences of structure depend upon a single factor, upon the greater or lesser development of the fore-brain. The smallness of the prosencephalon in mammals causes a diminution in the thickness of the peduncles, in the height of the *pons*, and in the size of the pyramids. Similarly the appearance of the trapezoid body and the disappearance of the olivary structures are due to the smallness of the fore-brain. If a mammal, whose basilar brain surface is as unlike that of man as is the brain of mustela (Fig. 10, p. 9), could develop mightier hemispheres, then its pes pedunculi would increase in size and in the number of its nerve-bundles, for the simple reason that the pes pedunculi to a great extent is the continuation of the medullary substance of the hemisphere. Furthermore, inasmuch as the pyramid, the prolongation of the *pes ped.* gets but a part of the latter's fibres, while a large part of peduncular fibres reach the cerebellum by way of the *brachium-pontis*, we shall find that the number of bundles in the pons is dependent in the first instance upon the number in the pes pedunculi, and in the second instance upon the greater development of the medullary substance of the hemispheres, and upon the cerebral cortex whence the white fibres emanate. The more highly developed these cerebral masses, the greater the extent of surface from which the pons-fibres can originate. In man the pons is so excessively developed longitudinally that the deeper transverse bundles are completely covered. In mammals the pons is so short that the course of the pyramid is usually prolonged anteriorly and remains uncovered. For this reason transverse bundles (corp. trapez.) come into view next to the pyramids ; in man these bundles are screened from view by the lower bundles of the pons. The *corpus trapezoides* is, therefore, not wanting in the human brain ; it is simply invisible on the basilar surface. Nor is the olivary body really missing in animals. It lies behind the pyramids ; from this position it has been dislodged by the thickness of the pyramids in man, pushed to the side, and made visible

on the basilar surface. We infer from such facts as these, and from a study of the ganglia, that the cerebral structure is governed by a law which establishes a harmonic dependence between the formation of the brain-axis and the development of the functionally highest organ—the fore-brain. (Details to be found in the "Mittheilungen der anthropologischen Gesellschaft," Vienna, 1870.)

The peculiarities of the human brain might not inappropriately be said to be "mentalized" (durchgeistigt). The lower forms of primates possess brains whose trunk shows evident transitional stages between the lower and higher forms; for instance, the visible co-existence of olivary and trapezoid bodies (Fig. 11, p. 11, Rh. O.). In the highest carnivora (bear) the brain presents the higher transitory stages of brain-structure. So early an observer as Stannius knew of the olivary bodies of water-mammals. The metencephalon, the oblongata, is apparently longer in animals owing to the shortness of the pons, and, with the exception of the pyramids, more highly developed than in man.

At the level of the entrance of the brachium pontis,[1] in front of the seventh and eighth pairs of nerves, the cerebellum presents the sulcus magnus horizontalis. From the basilar surface the lobus quadratus (Qu, Fig. 15) can be seen projecting above this furrow. This furrow divides deeply the convolutions of the posterior (subtentorial) surface of the cerebellum from those of the basilar surface. For our purpose it will be sufficient to give Henle's simplified account of the basilar lobes. From before backward we have the following hemispheric lobes: 1. The flocculus. 2. The amygdala. 3. The inferior lobes (i. i. i.). 4. The posterior inferior lobe (pp.). The median lobules: 1. The nodulus. 2. The uvula. 3. The pyramid. 4. The posterior vermis. These are not basilar formations, but are covered by the oblongata.

The pros- and thalam-encephalon possess surfaces which look from below into the cerebral ventricles, and consequently can be viewed from above (Fig. 16).

A bundle of fibres belonging to the corpus striatum corresponds to the stria cornea (stria terminalis), which appears to be the line of demarcation between the fore- and inter-brain. The fibres of this bundle from the temporal lobe pass into the nucleus *caudatus* along the entire length of the latter. The surface of the stria cornea is formed by a fold of the ependyma, underneath which a large vein collects the lateral branches from the surface of the nucleus caudatus, and conducts them to the vena magna Galeni, which is lodged in the membranous covering of the corp. quadrig. The cavity of the thalamencephalon (ventriculus III.) forms a circle around the commissura media. If the mem-

[1] Processus cerebelli ad pontem.

branous roof of the 3d ventricle were left intact, and the aquæductus Sylvii properly closed, a cast of the third ventricle could be taken. This cast of the third ventricle would resemble a ring whose opening would correspond to the median commissure. Inferiorly the ring would present a projection—the cast of the

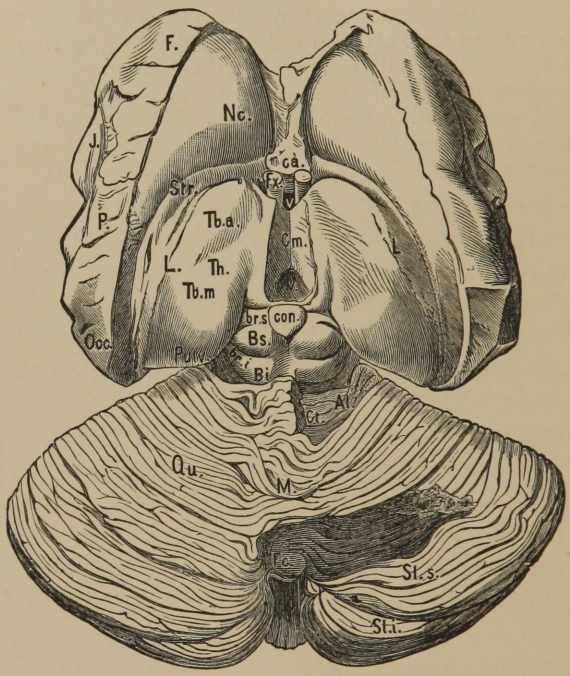

Fig. 16.

Superior and Posterior Aspect of Brain-Axis, and of the Cerebellum.

J. Island. F., P., Occ. Frontal, parietal, and occipital portions of the projection-system (radiating fibres from the cerebral mantle). Nc. Caudate nucleus. Str. Stria cornea. L. Linea aspera. Ca. Anterior commissure. Fx. Descending crus of the fornix. V. III. Ventricle. Cm. Median commissure. Th. Optic thalamus. Tb. a. Its anterior tubercle. Tb. m. Its median tubercle (elevation). Pulv. Pulvinar. con. Conarium, from the sides of which the plastic longitudinal prominences of the habenulæ originate. Bs. Superior bigeminal body. Bi. Inferior bigeminal body. brs. Superior arm. bri. Inferior arm of the corpus quadrigeminum. Cl. Central lobule of the superior vermiform process. M. Its mons. Fc. Folium cacuminis (the top layer of the superior vermiform process). Al. Alæ of the central lobule. Qu. Lobus quadratus (Burdach), superior lobe (Henle). Sl.s. Superior posterior lobe (lobus semilunaris superior). Sl.i. Lobus semilunaris inferior—(posterior lobe—Henle).

infundibulum. Behind the caudate nucleus and the stria, the anterior commissure and the descending crus of the fornix, we come upon the thalamus opticus. Its surface is on the whole wedge-shaped, with a blunt anterior edge, and a convex, broad-faceted ending at the pulvinar. Its median surface is composed of

gray substance (central cavity gray), for the united cavities of the primary medullary tube, from the primary anterior cerebral vesicle to the end of the spinal cord, are lined with gray substance. This narrow gray, cleft-shaped covering of the diencephalon passes in the mid-brain into the aquæductus Sylvii.

The surface of the optic thalamus presents several prominences. The best defined is the *habenula*—the pineal peduncle (between brs. and F. Fig. 17). The surface of the *habenula*, which is connected on both sides with the pineal region, receives white substance, as does the entire surface of the optic thalamus, from the *stratum zonale*. The stratum zonale of the habenula has the appearance of being torn off anteriorly after the removal of the adherent membranous covering of the ventricle from the ependyma. From this the false inference was made that there was a connection between the fornix and the habenula. The other three prominences are: 2. The anterior nucleus (Genu anterius Gratiolet) which tapers tail-like backwards and outwards *tuberculum anterius* (Burdach), (Fig. 16, Tb. a.). 3. The median protuberance (tuberculum medium) which arises simply from the demarcation of the *tuberculum anterius* and the flattening of the *thalamus* behind the habenula. 4. The pulvinar, which in the human subject presents the shape of a posterior free eminence.

In man the ganglia of the mesencephalon, the corpora quadrigemina, encroach considerably upon the thalamencephalon. The corpora quadrigemina comprise the superior and inferior corpora bigemina. If the pineal body (Fig. 17, con. cp.) be lifted from the back, we come upon a flat triangular space with its base above, situated in the middle of the superior corp. bigem., which receives the posterior surface of the pineal body, and bends over into the posterior commissure. We notice also a groove, open posteriorly, between the upper surface of the corp. quadrigemina and the lower surface of the conarium which latter rests upon the former. This is the reverse of the convexity of the posterior commissure (convex anteriorly). This commissure, with its convexity looking anteriorly, is, therefore, a transverse curved medullary lamina, and not a funicular formation, as it would seem to be from an inspection of the anterior surface. The superior corpus bigeminum is connected with an apparently columnar medullary border, which, concave posteriorly throughout its entire length, courses between the pulvinar and the corp. genic. *internum*. This is the brachium corporis bigemini superius (Fig. 17, brs.). The superior terminus

of the corpus geniculatum internum also tapers toward the corp. bigeminum superius, combining with the latter under the brachium corp. big. sup. mentioned above. The arm of the superior corp. quadrigem. forms the boundary between the mes- and thalam-encephalon. The superior half of the corp. bigeminum inferius is connected with a flat, white medullary structure appearing from under the internal *genu* (brachium corporis bigemini inferius,

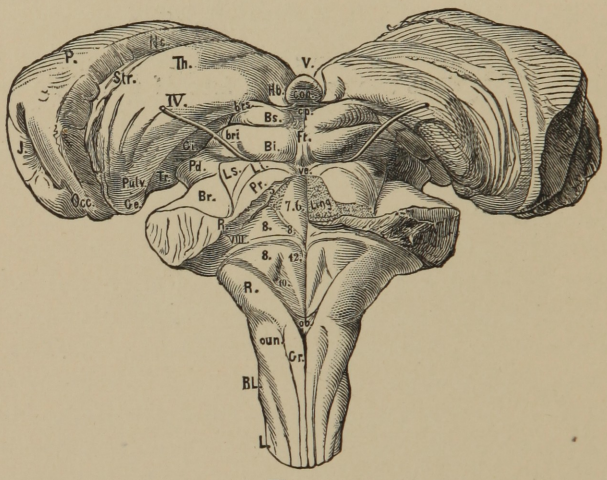

Fig. 17.

Superior and Posterior Surfaces of the Prosencephalon of the Lobus Candicis (Stammlappen), of the Thalam-, Mes-, and Met-encephalon.

J. Island. P., Occ. Parietal and occipital divisions of the projection systems from the cortex. Nc. Caudatus nucleus. St. Stria cornea. Th. Opticus thalamus. Pulv. Pulvinar. Ge. External geniculate body. Tr. Optic tract. Gi. Internal geniculate body. V. Third ventricle. Hb. Habenula conarii. con. Conarium. cp. Posterior surface of the posterior commissure. Fr. Frenulum. ve. Superior medullary velum. Bs., Bi. Corpus bigeminum superius et inferius. brs., bri. Brachium superius et inferius corporis quadrigemini. Ls., Li. Lemniscus superior et inferior (upper and lower fillet). 5. Locus cœruleus. 8 Auditory nucleus. 7. 6. Common nucleus of the 6th and 7th nerves. 8. Ascending root of the 8th nerve (Engel); auditory rod (Bergmann). Br. Brachium pontis. R. Restiform body. Pr. Processus cerebelli ad cerebrum. VIII. Striæ medullares nervi acustici transversæ (auditory striæ). 12. Region of the hypoglossal nucleus. 10. Ala cinerea, Arnold (nucleus of the vagus.—Stilling). ob. Obex: cun. Fasciculus, cuneatus Gr. Fasciculus gracilis. RL. Tuberculum cinercum, Rolando. L. Lateral column.

NOTE.—This drawing reproduces the exact position of the cerebral trunk within the cranial cavity, taking into account the parietal flexure.

Fig. 17 bri.). This brachium passes into the white surface of the inferior corp. bigem. The superior corp. bigem. presents a gray surface, more especially, however, in animals. Below the brachium corp. bigem. superius lie the spindle-shaped corpus geniculatum internum (Fig. 17, gi.), and the club-shaped corp. geniculatum externum, growing smaller as it nears the tractus opticus

(Figs. 15 and 17, ge.). The transition of the external corpus geniculatum into the optic tract is the only part that is visible. A distinct demarcating furrow lies at the boundary between the corp. genic. int. (gi.) and the inner ribbon-shaped stria of the tractus (Fig. 15). This band appears (at least below the surface) to pass into the thalamus in front of the corp. geniculatum internum. If the size of any brain-formation increases with an increase in the size of correlated parts, we may maintain that the corpora geniculata will increase with a large growth of the corp. quadrigemina ; and, on the other hand, that in these very animals disappearance of the pulvinar causes a diminution in the size of the optic thalamus. I was the first to observe, on longitudinal sections through the brain of a new-born cat, that the largely developed corp. genic. externum ascends beyond the optic thalamus. Forel has given a more detailed description of this. Accordingly, the development of the corpora geniculata is dependent upon the mesencephalon.

Between the posterior corp. bigemina a paired-conical column is formed, which, broadening below, passes as frenulum into the velum medullare superius (Fig. 17, ve.), and is continued through this into the medullary substance of the vermis superior. The velum m. superius is covered by the *lingula*, the foremost convolutions of the vermis superior. Stilling discovered the delicate bands of the lingula which lie immediately upon the processus cerebelli ad cerebrum (Fig. 17, to the right of *Ling*). The posterior surface of the after-brain would come into view below the mid-brain as a freed portion of the brain-axis, were it not covered by the cerebellum (hind-brain), (Fig. 16), which must be severed at its connecting arms, if a view of said posterior surface is to be obtained.

On the posterior subtentorial surface of the cerebellum the *mons* (Fig. 16, M.), the third and largest division of the superior vermiform process, covers the central lobe, and this in turn the *lingula* of the medullary velum. In a similar fashion the lateral divisions of the lingula (frenula lingulæ) are covered by the lateral portions of the central lobe—by the alæ, and these in turn are concealed on each side beneath the hemispheres of the mons, the lobis quadratus (lobulus superior of Henle), which projects anteriorly beyond the alæ (Fig. 15, 16, Qu.). The great horizontal fissure divides the posterior lobes of the upper and lower surfaces of the cerebellum, the inferior post. lobe projecting in an occipital

direction beyond the former (Fig. 16). In spite of the manifold numerical relations and the still more manifold modes of connection between the median and lateral cerebellar covolutions (which Malacarne counted and Stilling studied most thoroughly), an increase of lateral convolutions seems to correspond to an increase of median convolutions; and yet there is one exception to this superficial agreement. At the bottom of the great horizontal fissure all the convolutions of the upper semilunar lobe (superior posterior lobe) are united into a single layer of vermiform convolutions, in the folium cacuminis (Fig. 16, Sl.s. Fc.).

After dissecting away the cerebellum, we can examine the posterior surface of the brain-axis. The middle of the region between corp. quadrigemina and the entrance of the processus cerebelli into the cerebellum is taken up by the velum medullare (Fig. 17, to the right), developed from the frenulum. The velum medullare and the frenulum constitute the genuine processus cerebelli ad corpus quadrigeminum. At the superior margin of the valvula cerebri, the IV. nerve is seen to emerge (Fig. 17, IV.). The lateral margins of the velum verge upon two powerful flat bands, the *Bindearme;* these were falsely termed *processus cerebelli ad corpus quadrigeminum*, and correctly described by Stilling as the *processus cerebelli ad cerebrum.*[1] The processus ad cerebrum begin not quite at the corp. quadrig. and terminate at the frenulum lingulæ (Fig. 17, right), in the direction of the cerebellum. Superficial bundles of fibres emerging from the velum medullare and twining around these processus ad cerebrum, separate them from the corp. quadrig.; these bundles pass outward and over the processus cerebelli and disappear in the pons. Leveillé was the first to make a drawing of these bundles. I have designated these bundles as lemniscus inferior (Fig. 17, Li.), or the cerebellar bundles of the fillet. The superior fillet, the lemniscus Reilii (laqueus, Fig. 17, Ls.), covers the proces. ad cerebrum like a three-cornered cloth, lying external to the inferior fillet. The superior fillet extends from the corp. quadrigemina to the superior margin of the pons.

Toward the base of the brain, on the posterior surface of the trunk, the posterior aspects of the pes pedunculi and of the pons are visible. But the fillets, the *processus cerebelli ad cerebrum*, and the velum medullare inferius, constitute a series of structures which reach the surface behind the pes pedunculi,

[1] Superior peduncles of the cerebellum.—S.

as integral parts of the tegmentum. In the cerebellum the continuation of the *velum medullare* and of the *processus ad cerebrum* passes with a free medullary surface behind the rhomboid fossa and there forms its roof—the *tectum fossæ rhomboidalis.*

The central gray substance (Höhlengrau) of the mid-brain, surrounding the *aquæductus Sylvii,* dilates beneath the velum medullare into a semicircular canal with furrowed floor. The divergence (cordward) of the *processus cerebelli ad cerebrum* allows the central gray substance to expand most in breadth between the points of emergence of the two auditory nerves. At this level the corpora restiformia, which appear to be in direct connection with the funiculi graciles approach the central gray to form its lateral boundaries. These structures, converging symmetrically at the lower end of the central gray substance, cause the latter to deepen at the same time that it tapers to a point. Inferiorly the fossa is continued in funnel-shaped fashion into the central canal of the after-brain. This portion of the central gray substance has been termed fossa rhomboidea, from its being enclosed between the angles formed by the meeting of the *processus* ad cerebrum above, and the *pedunculi* cerebelli below. The fossa rhomboidea has important relations to the origin of cerebral nerves.

The same median furrow which was noticed on the ventral wall of the aquæductus Sylvii divides the fossa rhomboidea into symmetrical halves. The *eminentiæ teretes,* descending from the aquæd. Sylvii on each side of the median furrow, enlarge into an oval area just above the exit of the eighth nerve (Fig. 17, 6,7). To this area, which is intersected by the central fibres of the sixth and seventh pairs of nerves, various names have been given, viz.: abducens-facialis nucleus—Stilling and Clarke; abducens nucleus—Deiter; facial nucleus—Schröder.

To the outer side of the superior half of this prominence we find a long bluish groove, the *fossa cærulea.* The bluish color is due, according to the laws of refraction through cloudy media, to the black cells lying immediately below the transparent ependyma. I have shown that in this groove one of the roots of the fifth nerve takes its origin (Fig. 17, 5).

Below (caudad) the *fossa cærulea,* the *eminentia teres* is bounded laterally by a rhomboid elevation (region of the viii. nucleus), extending at its broadest part quite to the median line. Striæ medullares transversæ—the superficial posterior roots of the viii. nerve—may divide this rhomboid into a superior

and an inferior triangle (Fig. 17, viii., 8, 8). The acoustic nuclei and the joint nucleus of the sixth and seventh nerves are frequently separated from one another by several obliquely ascending striæ medullares (Engel, Bergmann, "Klangstab"); occasionally the eighth nucleus is covered by these *striæ* (Fig. 17, 8). The inner margin of this elevation bears on the lower part of the rhomboid fossa to the outer side. But this does not increase the breadth of the eminentia teres, for its outer margin converges below toward the median furrow, to bound a median triangular elevation, which represents the region of the hypoglossal nerve (Fig. 17, 12). There are two reasons for this narrowing (below) of the eminentia teres: First, the converging *fasciculi graciles* crowd in upon the *fossa rhomboidea* at its point of junction with the canalis centralis; and, secondly, the triangular nucleus of the tenth nerve, enlarging from above downward, edges its way in between the origin of the eighth nerve and the eminentia teres (12). This is the posterior nucleus of the vagus, which a grayish color (ala cinerea—Arnold) distinguishes from the whiter triangular area of the twelfth nerve, which area is covered by transverse fibres of the vagus.

A sling-shaped commissure, pointed below, often causes a columnar elevation of the ala cinerea. At the lower angle of the rhomboid fossa, the obex (Fig. 17, Ob.) effects a connection with the membranous roof of the metencephalon and the choroid plexus, similar to the passage of the fimbria into the membranous roof of the diencephalon.

This obex, a vestige of the fœtal posterior roof of the rhomboid fossa, remains attached to the latter when it is separated (by dissection) from its surrounding parts.

Let us pass now to the consideration of the nerve-tracts to be found on the posterior aspect of the after-brain. The corpus restiforme[1] emerges from the cerebellum at about the level at which the posterior surface of the processus cerebelli ad cerebrum disappears within that organ (Fig. 17, R). Above the decussation of the pyramids, which begins a short distance below the formation of the central canal, the corpus restiforme appears to divide into the funiculus cuneatus and f. gracilis (Fig. 17, cun., Gr.). And yet the latter are separated from the corpus restiforme by a shallow transverse furrow, which proves that they cannot arise from a division of the corp. restiforme of the same side. The origin of the funiculi graciles et cuneati is marked by gray substance within these plastic, conical protuberances.

[1] Pedunculus cerebelli ad medullam oblongatam.

Both these tracts of the oblongata are continued into the posterior columns of the spinal cord. In the cervical spinal cord the triangular column of Goll must be regarded as the prolongation of the *funiculus gracilis.*

These posterior columns of the oblongata do not abut, as is the case in the spinal cord, upon the lateral columns (Fig. 17, L.). The superior beginnings of a caput cornu posterioris, of the gelatinous substance of the gray spinal-cord nucleus, forces its way to the surface between the lateral and posterior fasciculi of the after-brain. This spindle-shaped mass—the tuberculum cinereum Rolando (Fig. 17, RL.)—is the nucleus of origin of the ascending root of the fifth nerve, which is equivalent to a posterior root of the spinal cord. The posterior roots of the spinal cord also possess ascending fibres. The root of the fifth nerve covers the substantia gelatinosa with a thin film of fibres, which do not altogether hide the gray nucleus (*tuberculum cinereum*) below.

On the anterior basilar surface of the trunk the inferior margin of the olivary body marks the boundary between the upper and lower halves of the *oblongata*, which are more unlike each other in structure than are the superior half of the oblongata and the inferior half of the pons. On the posterior surface of the isthmus, the boundary of the lower half of the after-brain is marked best by the superior margin of the tuberculum cinereum Rolando. The plastic prominences of the lower half of the oblongata are in due succession from the anterior to the posterior median furrow of the trunk, as follows: 1. The pyramids bounded by the roots of the hypoglossal nerve (Fig. 15, P.); 2. Funiculus anterior; 3. Funiculus lateralis (lateral column),—these are separated by the anterior roots of the uppermost cervical nerves (Fig. 15, 1, 2,); 4. Tuberculum cinereum Rolando (Fig. 17, RL.); 5. Fasciculus cuneatus (Fig, 17, cun.); 6. Funiculus gracilis (Gr.).

The final transition of the medulla oblongata into the spinal cord is effected at the level of the origin of the third cervical nerve.

REMARKS ON THE ARCHITECTURE OF THE BRAIN.

The structure of the cerebral cortex, like that of a crystal, can be studied best from its cleavage-surface. The cortical substance contains two distinct sets of fibres. First, we observe that the cleavage-surface of each convolution presents radiating fibres which are quite distinct from radiating blood-vessels; that this

system of cortical fibres passes into the medullary substance of the convolutions, and from there into that mass of internal white substance (in each hemisphere) which is known as the centrum semiovale of Vieussens. These radiating fibres extend apparently quite to the surface of the hemisphere; such at least we should judge to be the case from an inspection of the many torn sections of convolutions in figures 18, 20, 21. The cortex exhibits on the convexity of each convolution the shape of an inverted ∩, which is changed in the next adjoining fissure to an upright U (top and bottom of the cortical wave[1]). Cleavage of the cortex from the top of the inverted ∩ opens up the substance of the hemisphere in a direction parallel to the radial fibres. Secondly, in separating the cortical substance of any convolution from its adjoining white substance, we discover another set of medullary fibres taking a very different direction from those previously mentioned; these are the arciform fibres, or fibræ propriæ of the cortex. If we attempt to dissect away the gray substance alone from the bottom of a fissure, and to remove the U-shaped mass, we obtain a smooth surface which it would be quite impossible to get at the summit of a convolution, where the cortical substance is continuous with the radiating fibres. This might lead one to suppose that no radial fibres start inward from the bottom of a fissure; but in reality this appearance is due simply to the preponderance here of arciform fibres.

The depressed surface of a cortical wave can be easily dissected out as from a smooth medullary groove, which on closer inspection is seen to consist of U-shaped medullary fibres. These valleys and fissures of the outermost medullary substance of the cortex, which when devoid of the cortical gray are left wider than the fissures between the convolutions, resemble the half of a gun-barrel constructed of wire rings. The smooth enucleation of the cortex is possible in the longest fissures and in the shortest insular formation; and can be equally well effected at every depth, and whether the fissures be between primary, secondary, or tertiary convolutions. (Figs. 18–21 give a faithful representation of the convolution valleys and their vertical U-shaped cleavage sections. Some of them are marked As—association fibres.) These valleys and their U-shaped fibres are enclosed on both sides by radiating bundles, but this mode of dissection does not afford an insight

[1] The original reads: "Wellenberg und Wellenthal der Rinde."—S.

into the fine network of fibres by means of which radiating fibres pass also into the narrow cortex at the bottom of a fissure (which Henle incorrectly denies). On the other hand, there is every evidence here of the part the U-shaped fibres take in the formation of the summit of a convolution. The U-shaped bundles of the cortex do not necessarily extend simply from one convolution to the one next adjoining, but they may skip one, two, three, or an entire series of convolutions, and may thus join convolutions which are united among themselves to a convolution lying at some distance from these. The shortest *fibræ propriæ* lie nearest to the cortex; the longest at the greatest depth, and are separated from the cortex by other intervening fibræ propriæ, the length of which increases gradatim from the surface inward. The *fibræ propriæ* or arciform fibres, must therefore be divided into short and long ones; this division answering to a difference in shape, for the shortest fibres alone present the U-shape, which results from their close adaptation to the walls of a convolution depression. While the long bundles take entirely different directions, determined by the curvature of the surface of the fore-brain, and by the longer or shorter distance these fasciculi have to travel.

The fact of greatest importance concerning the fibræ propriæ is that they begin and end in the cortex. The direct opposite of these are those bundles of radiating fibres which take their origin in the cortex but end in some peripheral gray substance, nearer to the nuclei of the cerebral nerves, say, in one of the ganglionic masses at the base of the brain. These are not *fibræ propriæ* of the cortex; in their course they project the cortical surface upon every imaginary or artificial plane situated below the fore-brain; the higher the plane the more complete will this projection be.

I propose, therefore, to call these bundles of fibres which originate (but do not end) in the cortex, projection-fibres. This name is justifiable even if we were to consider the course of these fibres in a reverse direction. Let us disregard for the moment all but the complete nervous organization of man. The impressions of the body are conveyed to the brain by the ramifications of all the nerves and their terminal organs; *mutatis mutandis* we may argue that the cerebral cortex is the surface upon which the entire body is projected by means of these nerves.

It is a difficult matter to make an appropriate subdivision

of these *intra*-cortical fasciculi. The masses of fibræ propriæ, which take an arched course, are distinctly limited on their concave surface, but their convex surfaces are connected indirectly by means of graded tangential fibres from the convexity of shorter arches with the investitures of the convolution depressions. Keeping these restrictions in mind, we may distinguish and shall describe the following special formations: *a.* The medullary sub-

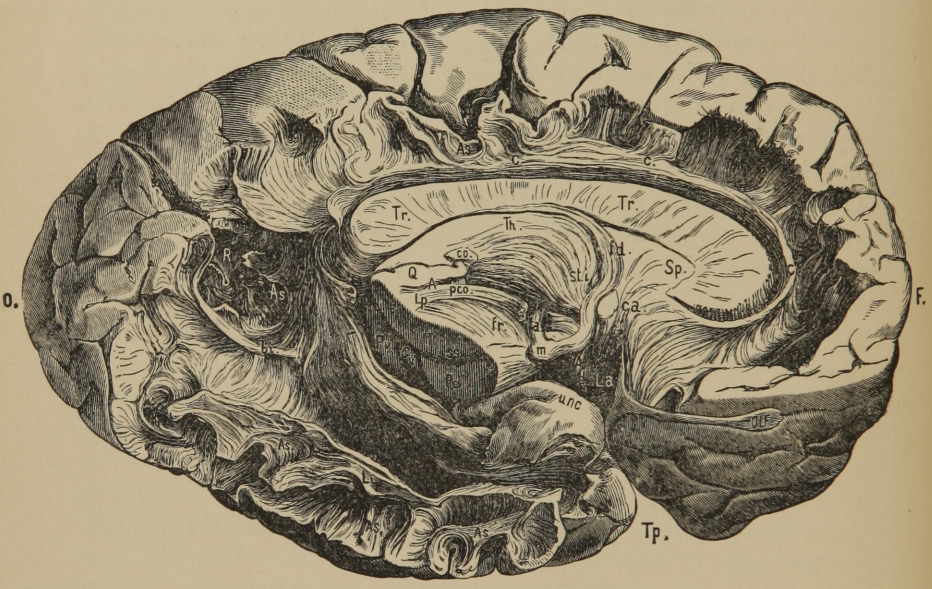

Fig. 18.

Dissection of the Cortex and the Medullary Substance of the Median Surface of the Brain.

Fr., Tp., Occ. Frontal, temp., and occip. region. Tr. Corp. callosum (trabs cerebri). c. c. Cingulum. As. Fibræ propriæ (association fibres). R. Cortex. bi. Fasciculus basalis internus (Burdach). Li. Fasciculus longitudinalis inferior. Olf. Olfactory lobe. La. Lamina perforata anterior. ca. Anterior commissure. unc. Uncus. Sp. Septum pellucidum. Th. Optic thalamus. fd. Descending fornix. m. Corpus mammillare. fa. Ascending fornix. Q. Corp. quadrigemina. A. Aquæductus Sylvii. Pv. Pulvinar thalami. Gi. Internal geniculate body. T. Tegmentum. Pd. Pes pedunculi cerebri. St.i. Stilus intern. thalami optici. Lp. Posterior longitudinal fasciculus. Above pco., descent of post. commissure. co. Conarium.

stance of the cingulum (Burdach); *b.* Fasciculus arcuatus (Burdach, Arnold); and *c.* Fasciculus uncinatus.

The cingulum (Fig. 18, c.) surrounds the corpus callosum. Above it lies a broad groove, due to the removal of the *callosomarginal* fissure. The medullary investment of this fissure is contiguous with the cingulum throughout its course, as an inspection of the frontal end clearly shows. The same is the case with

the fasciculi proprii of the gyrus fornicatus which cover the cingulum, and is true also of the superior frontal and parietal convolutions surrounding this gyrus.

Arnold recognizes a fusion of the gyrus uncinatus with the convolution of the cingulum; if we grant this we must also allow a similar continuity of tissue to exist with the superficial medullary bundles of the marginal convolution. The lowest fasciculus of the cingulum adjoining the corp. callos., the nerve of Lancisi, whose relation to the medullary substance of the cortex was alluded to on p. 21 connects the cornu ammonis with the olfactory lobe by a circuitous route.

The cingulum accompanies, as it were, the calloso-marginal depression; it is the means of uniting successively all the indirect (short) and direct (long) cortical connections; and after effecting this its fibres pass underneath the *splenium of the corp. callos.* and join (superiorly) the fasciculi proprii., on which the deep depression of the occipital fissure of the sulcus calcarinus with its medullary arches had rested. These medullary arches connect the cingulum with the gyrus glossiformis.

The posterior half of the upper occipito-temporal fissure exhibits after removal of the cortex a depression formed by arches which pass from the gyrus glossiformis into the gyrus fusiformis. In the anterior half of the same depression we find *fibræ propriæ* connecting the uncinate with the fusiform convolution. In this instance the upper branch of the U-shaped bundles, descending from above, attains to a considerable length, for their fibres originate in the medullary substance of the cingulum. The fasciculus basalis internus of Burdach, which a process of lateral exfoliation has reduced to a narrow medullary layer, lies in the axis of the gyrus glossiformis (Fig. 18, bi.), tends toward the gyrus uncinatus, and seems to consist of naught but arched bundles. The medullary band of the gyrus fusiformis, the lower longitudinal fasciculus, so-called because it can be separated into long-extended arched bundles, contains fasciculi which take either a longitudinal or transverse direction, and which, with the various-sized fellow-bundles of the third temporal convolution, form the floor of the depression in which the inferior occipito-temporal convolution is bedded. Later on we shall see, too, that the gyrus fusiformis receives distinct portions of the projection-system. Furthermore, Arnold knew long since that fibres from the cortex of the gyrus fornicatus pass into the fornix after

traversing the corpus callosum. These fibres also join the septum pellucidum. We may therefore conclude that not only the gyrus uncinatus but other convolutions despatch their projection-bundles through the fornix of the median surface.

Tearing asunder the convolutions of the convexity of the brain, we discover, beneath the ordinary fissures, depressions lined with arched bundles. Anteriorly the temporal and frontal ends of the hemisphere approach each other so closely, that the medullary fibres connecting these lobes describe as short an arc as those fibres do which combine any two ordinary convolutions. Because of this sharp curve, this bundle of fibres has been called *fasciculus uncinatus*. It is evident, however, that only the frontmost fibræ propriæ bordering upon the *fossa Sylvii* describe such a sharp curve. The further apart the regions are which are united by way of the fossa Sylvii, the flatter the connecting arches will be. Further back there are straight, long-stretched bundles connecting the frontal and temporal lobes, and some even describing an arc the opposite of that described by the gyrus uncinatus. These bundles, belonging to the medullary substance of the island (which contains to all appearances fibræ propriæ only) and crossing the claustrum, form a complete covering for the external capsule, which in turn is superimposed upon the smooth surface of the lenticular nucleus (Fig. 19, f.unc., n. l.). While the fasciculus uncinatus and the adjoining fibræ propriæ of the Sylvian fossa are contained within the region of the lenticular nucleus, the nucleus lent., together with the radiations of the corona radiata, are surrounded by the fasciculus arcuatus. This mass of fibres can be made to attain to any size, varying with the depth to which the parts have been separated. About the Sylvian fossa the fasciculus arcuatus is certainly well defined.

In the parietal region, underneath the operculum, the fasciculus arcuatus is most strongly developed. Anteriorly its superficial strata are continued into the convolutions of the operculum. In bending downward toward the temporal lobe, its superficial bundles can be seen entering the superior temporal convolution, the parallel fissure, and the second temporal convolution. The deeper bundles of the fasciculus arcuatus spread to the more distant convolutions of the entire convexity. From the general presence and the increase in length (as we proceed inward) of these arched fibres, we gain the conviction that all the convolutions of the median and convex surfaces of the fore-brain

form the closest and yet most varied connections one with the other.

The arciform bundles of each hemisphere constitute an anatomical connection between various convolutions, which are separated by fissures. These bundles are deservedly termed "association-bundles." They represent the union of the various divisions of the fore-brain, to which alone these fibres belong, just as the projection-fibres, which are to be found everywhere in the cortex, represent the various organs and surfaces of the body to which these fibres extend through their prolongations,—the peripheral nerve-tracts.

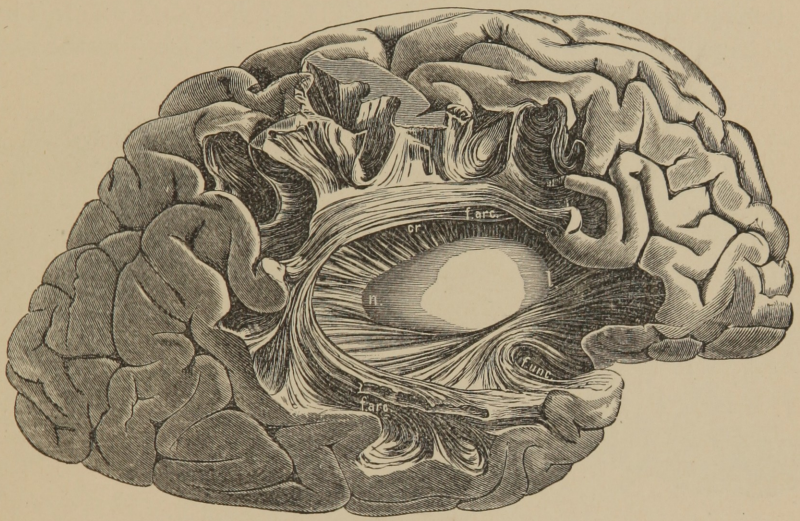

Fig. 19.

Dissection of Cortex and Medullary Substance of the Convexity of the Brain.

n. l. Lenticular nucleus. f.unc. Fasciculus uncinatus. f.arc. Fasciculus arcuatus. cr. Corona radiata, projection-system.

The corpus callosum, and, in man, the greater part of the anterior commissure, form a system of fibræ propriæ connecting both halves of the fore-brain. This transverse system of fibres is distinguished from the association-bundles by the fact that it unites identical parts of the two hemispheres, and not different parts of the same hemisphere. The fibres of this system interlace on their way to the cerebral convolutions with the projection-fibres, and through these with the intra-cortical fibres. The corpus callosum forms the anterior and superior wall of the fore-brain (Figs. 5 and 6), and its bundles there enter the medullary substance of the

frontal and parietal lobes. But the splenium corporis callosi is a double laminated structure, inasmuch as the posterior portion of its longitudinal axis turns downward to become the lower surface of the hindermost portion of the corpus callosum. The occipital bundles which leave this curved structure are not lost at once in the projection-system, but continue on their own course, quite separate and separable, toward the apex of the occiput. These occipital fibres of the corpus callosum take the same U-shaped course pursued by all commissural fibres from one hemisphere to the other. This ⊃ has been likened to a forceps, *forceps corporis callosi.* The two *laminæ* which make up the splenium diverge on their way to the temporal lobe ; they are separated by the ependyma, and while the one passes to the cavity of the pos-

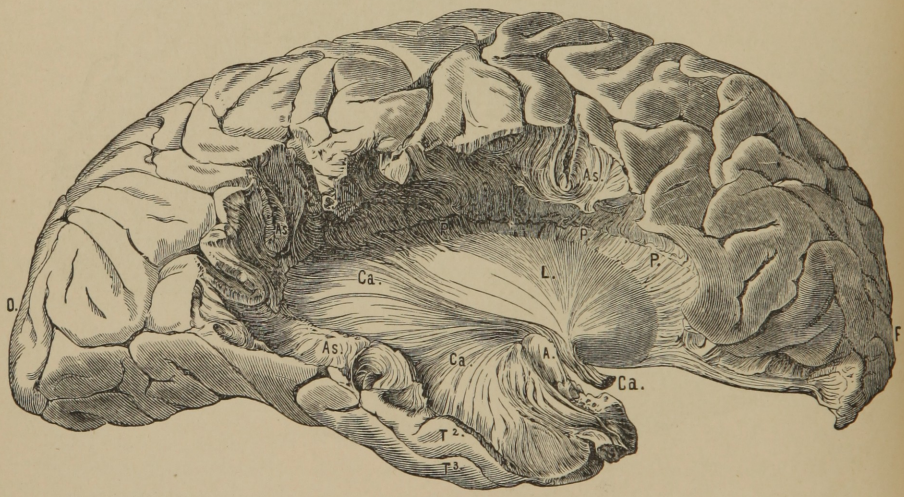

Fig. 20.

Preparation of the Cortex and Medullary Substance Starting from the Convex Cerebral Surface.

Fr., Tp., Occ. As before. As. Association-bundles. P. Projection-bundles. L. Nucleus lenticularis covered by a thin stratum of the capsula externa. A. Amygdala. Ca., Ca., Ca. Commissura anterior with its occipito-temporal radiating fibres. T.², T.³ Second and third temporal convolutions.

terior horn, the other extends to that of the inferior horn. They form at the same time the innermost medullary stratum of these horns, the inferior *lamina* of the splenium becoming the median wall, and the superior, the external wall of these horns. The external lamina of the corp. callosum, the *tapetum* Reilii, lies partly behind and partly around the thalamus, on the projection-bundles (Fig. 21). At the posterior cornu we meet the following parts

in due succession from below outward: 1. The cortex and the medullary substance between the cingulum and the gyrus fusiformis. 2. The fibres of the inferior lamina of the splenium. 3. Ependyma. 4. Ventricle. 5. Ependyma. 6. Tapetum. 7. Projection-bundles.

The lateral portions of the anterior commissure are lodged in a groove on the basilar surface of the lenticular nucleus, and are in no way connected with the external capsule. This nucleus is surrounded by the fibres of the projection-systems, and is covered on the outside by the capsula externa which emanates from

Fig. 21.

Dissection of the Cortex and Medullary Substance Starting from the Median Cerebral Surface.

Fr., Tp. As before. Occ. Occipital region, in front of it the fasciculi occipito-thalamici. ne. Remains of the *nucleus caudatus* which has been partly enucleated. Th. Thalamus opticus. P. Projection-bundle. fc. Fasciculi fronto-caudato-thalamici. Z. Stratum zonale thalami. c. Anterior commissure. ap. Ansa peduncularis. L. corp. quadrigem. S. Aquæd. Sylvii. Q. Fasciculus longitudinal. post. Tg. Tegmentum. f. Fasciculi temporo-thalamici. P. Pes pedunculi. r. Fibræ rectæ mediales pedunculi. A. Amygdala. o. Fasciculi frontales subependymiales.

the corona radiata, and whose medullary fibres converge toward the base of the brain. The fibres are continued into the *ansa peduncularis*, but this course cannot easily be made out until after the removal of the anterior commissure. Behind and below in the direction of the cortex the radiating fibres of the external capsule

are covered by the ramifications of the anterior commissure. The ramifications of the anterior commissure extend chiefly in the direction toward the occipital and toward the temporal lobe, and indeed along the entire breadth of the latter (Fig. 20, Ca.). The parietal and frontal lobes have no direct connections with the anterior commissure. But its connections with the olfactory lobe shall be referred to later on (p. 72). The middle portion of the anterior commissure, together with its relations to the external capsule, upon the outer surface of which it abuts, are distinctly shown on Fig. 22 (ca. caps. ext.). The sledge-shaped median portion was excavated from out of the mass of the corpus striatum above the lamina perforata anterior.

Continuing this demonstration of cerebral structure, by starting from the median surface and dissecting away as much as possible of the mass of the corp. callosum until the projection-systems are distinctly visible, we can observe the projection-fibres radiating from all the lobes of the hemisphere toward the lenticular nucleus as toward a common focus. Preparing a specimen in this way, by starting from the median surface of the hemispheres, we must also remove the gyrus fornicatus before removing the corpus callosum. After removing the gyrus uncinatus we leave the amygdala intact about two centimetres behind the apex of the temporal lobe. In spite of the part the *amygdala* takes in the apparent flexion of the gyrus uncinatus, it is in no wise connected with the cornu ammonis, but presents toward it, as its posterior surface, a free anterior wall of the inferior horn covered with an ependymal layer (Fig. 21, A).

The task of tracing the projection-bundles to their termini is rendered difficult chiefly by the remnants of fibræ propriæ near the cortex, but also by fissures, grooves, holes, and torn parts of bundles which result from the interlacing of the corpus callosum with the projection-system. The radiations of the projection-fibres from the cortex into the thalamus are quite manifold. To perceive this distinctly, we must remove the caudate nucleus and the stria cornea.

The tail of the caudate nucleus extends as far as the amygdala. The bundles of the stria cornea arise from the summit of the temporal lobe and traverse the amygdala before entering the nucleus caudatus, which is developed along the entire inner-margin of the amygdala.

Bundles of fibres from the cortex to the optic thalamus are mixed with lines of gray substance even after the enucleation of the nucleus caudatus, for coalescent fibres of the nucleus caudatus and the lenticular nucleus pass through the capsula interna which

separates the two ganglia just mentioned (Comp. Fig. 6 with Fig. 27). These anastomoses of gray substance between both ganglia give a comb-shaped appearance to the corona radiata (Reil).

Over the denuded surface of the *corpus striatum* projection-bundles pass into the stratum zonale (Fig. 21, Z.) of the optic thalamus. The frontmost radiations from the frontal lobe to the thalamus are covered at their point of entrance into the latter by that portion of the stratum zonale which emerges from the *ansa peduncularis*, passes in a transverse direction across the basilar surface of the crus cerebri, and is recruited chiefly from the temporal lobe, joining finally the anterior end of the thalamus (Fig. 21, ap.). The bundles from the frontal lobe, and more particularly the superficial groups, evidently do not take the shortest route to the *stratum zonale* of the thalamus, but take a more longitudinal course, and travel either through the corpus striatum (Fig. 21, ne.) or along its outer margin (Fig. 21, o.). The corpus striatum, being the lower wall of the anterior horn does not, as is the case in the primate brain (Fig. 6), abut upon the lower surface of the corpus callosum, which constitutes the upper wall of the anterior horn. To the outer side of the corpus striatum or its denuded surface (Fig. 21), we observe the stunted vertical outer wall of the anterior horn. After removing its ependyma this wall is seen to consist of longitudinal bundles which arise from the vertical surface of the frontal lobe, and passing to the outer side of the corp. striatum are merged in part behind the middle of the optic thalamus with its stratum zonale. We infer from this that projection-bundles connect the frontal lobe with posterior portions of the brain; the thalamus, for instance. Behind this formation radiating bundles of fibres connect with deep layers of the thalamus, and form a true corona radiata.

Vieussens applied to all these bundles surrounding the thalamus, the name "large radiating sun" (*grand soleil rayonnant*); but, as we have seen, the course of these fibres is, by no means, entirely radial. From the anterior portion of the *temporal* lobe radiating fibres start, which curve around the outer side of the amygdala to form a *stratum zonale* about the posterior surface of the optic thalamus (straight temporal bundles T.). Other bundles pass from the *occipital* lobe toward the optic thalamus; these bundles are finally lost in its deeper strata after taking a straight, upward course beneath the posterior stratum zonale just referred to. Below the parietal radial projections, and to the outside of

the corpus callosum these bundles form a medullary wall extending far below the thalamus, and presenting a basilar area parallel to the entire occipito-temporal surface. The breadth of these bundles seems to correspond to the region of the gyrus fusiformis. Those bundles which originate in this or in the third temporal convolution do not radiate toward the thalamus, but run parallel to the basilar cortical surface, whence they curve toward the vertex of the temporal lobe. Behind the amygdala, however, which the lowest bundles of this group almost touch, the entire group of fibres curves upward, forming parabolic arcades, directed forward, and finally joining the thalamus below the stratum zonale.

I have proved by careful investigations that these arcades cannot possibly be due to the interlacing of the *tapetum* with projection-bundles. Judging by appearances, we should say that at the summit of each arch-shaped projection-bundle, just before its entrance into the thalamus, temporal and occipital fasciculi merge into one another, the occipital fasciculi turning back in the direction of the temporal fasciculi.

Gratiolet has given a more summary account of this complicated medullary wall in the baboon, and has termed these bundles optic radiations.

He proceeded on the supposition that they emanated directly from the *tractus opticus*, but the latter's stock of fibres would be manifestly insufficient. Gratiolet also describes them as extending largely into the cortex of the parietal lobe.

From the anatomical point of view, this medullary stratum deserves the designation optic radiations, for radiating fibres pass from it into all the termini of the *optic tract* (corpora quadrigemina, corp. geniculatum—Fig. 5, Om.). The *stratum zonale* of the pulvinar, which is connected with the optic tract, takes its origin from the posterior superficial strata of the thalamus, in which strata the fasciculi temporo-thalamici (T.) disappear. Arnold was the first to entertain this view.

It suffices for our purposes to have demonstrated, by means of this one example, the manifold formations of the projection-system within the white substance of the hemispheres. We meet with the projection-system again in a dissection inward from the convex surface of the fore-brain; apparently the outermost distinct layer of the projection-system is made up of radiating fibres passing into the lenticular nucleus and its external capsule (Figs. 19 and 20).

Pushing this same method of dissection still further, we gain important information regarding the brain isthmus (Fig. 22).

Taking the methodically prepared (enucleated) brain-axis, the outer portion of which includes the formations of the fore-brain covered by the cortex of the island of Reil (lobus caudicis—Burdach), we intend to enumerate those strata which are developed from the basilar surface of the brain.

The right half of the adjoining drawing (Fig. 22) represents the superficial strata on the basilar surface of the lobus caudicis (Stammlappen), beginning with the external capsule of the lenticular nucleus, while the thalam- and mes-encephalon have been

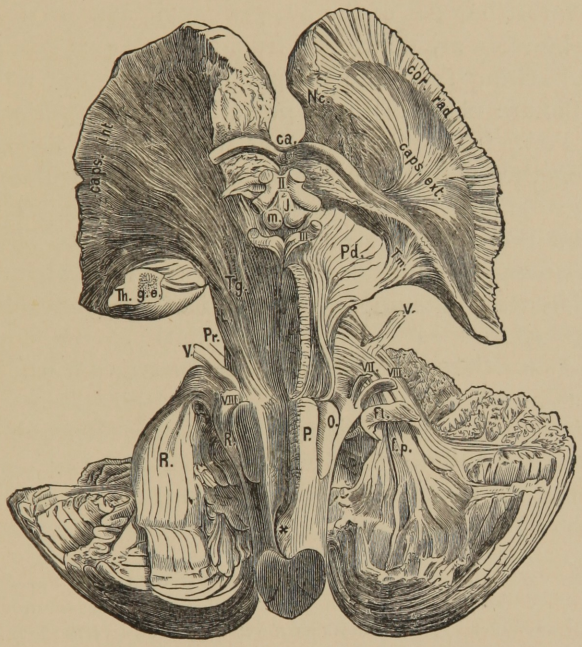

Fig. 22.

Dissection of the Brain-Axis and the Cerebellum Viewed from the Basilar Surface.

ca. Anterior commissure. Nc. Caudate Nucleus. cor. rad. Corona radiata. caps. ext. External capsule of the lenticular nucleus. II. Optic chiasm. J. Infundibulum. M. Corpus Mammilare. III. Oculomotor nerve. Pd. Pes. Pedunculi. Tm. Temporal radiating fibres of the former. P. Pyramid. O. Olive. Fl. Flocculus. Between O. and Fl. restiform body. V. VII. VIII. Trigeminal, facial, and acoustic nerves. x. Decussation of the pyramids. R. R. Left corpus restiforme and its foliæ in the cerebellum. caps. int. Internal capsule after enucleation of the lenticular nucleus. Th. Thalamus cut across above the optic tract. g.e. Corpus geniculatum externum. f.p. The pontine fibres of the cerebellum traceable to deep transverse fibres of pons. Tg. Tegmentum with intercalated cells of the substantia nigra. Pr. Processus cerebelli ad cerebrum (superior cerebellar peduncle). L. Lemniscus (fillet).

removed, or at least such portions of them as are included in the pulvinar, corpus geniculatum, and tractus opticus, which covered the

basilar (Fig. 15) and posterior (Fig. 17) surfaces of the crus cerebri. This figure enables us to continue with the enumeration of the occipital and temporal strata as given on p. 45.

The external capsule covers the lenticular nucleus with radiating fibres, whose focal point is screened by the anterior commissure. These fibres pass to the *ansa pedunclaris*.[1] Of this complicated structure (*vide* Figs. 6 and 21) we shall simply remark that its strata cross the pedunculus cerebri transversely. Its lowest stratum (Fig. 23, ans.[2]) forms a part of the pes pedunculi. The outermost bundles of the pes pedunculi, and particularly the posterior bundles, are developed from a fan-shaped group of bundles (Tm.) arising from the temporal and occipital lobes. The parietal flexure changes these posterior into superior bundles (Fig. 17, Pd.). The optic radiating fibres, which have been removed together with the pulvinar and corp. geniculata, lay immediately adjoining this fan-shaped group of fibres. The former constituted the seventh stratum of the temporo-occipital lobe. The above-named peduncular radiations from the eighth and the neighboring occipito-temporal radiations of the anterior commissure (Figs. 20 and 22, ca.) form the ninth of the enumerated strata. [As for the temporal lobe, a tenth stratum would join it from the temporal lobe.]

Removal of the superficial groups of transverse fibres of the pons reveals the anterior longitudinal bundles of the pons as the direct connections between the pedunculus cerebri and the pyramids of the oblongata.

Fig. 22 (between Pd. and O.) shows a common variation from the regular typical course which these fibres take in different brains. An anterior bundle of fibres of the pes pedunculi seems with its narrowed lower end to join the olivary body; this isolated anterior bundle probably rejoins the remaining pyramidal fibres.

The pyramidal tract can be subdivided into three distinct segments: (1) fibres of the crus; (2) the anterior longitudinal bundles of the pons, and (3) the pyramids of the medulla oblongata. The fibres of the pyramidal tract then decussate and cross to the opposite side of the spinal cord, or rather into the lateral column of the opposite side.

The pyramidal tract, which is strong by reason of a preponderance of deep-seated bundles, forfeits more than two-thirds of its sectional area while passing through the *pons*. The fibres thus

[1] Hirnschenkelschlinge.

[2] Linsenkernschlinge.

lost help to build up the pons by changing their direction and congregating into transverse bundles. This anatomical nicety cannot be demonstrated on gross anatomical preparations. The oval median section of the deep transverse fibres of the pons seems chiefly to be a commissure of those medullary layers which start from the cerebellar cortex, and unite in the brachium pontis (process. cerebelli ad pontem, Fig. 22, f.p.).

The fasciculi of the brachium pontis lie in the cerebellum in a strict order of succession, where we can observe distinctly their origin from the ramified ribs of the leaves of the *arbor vitæ* and also the sections of the delicately foliated fibræ propriæ of the cerebellar medullary substance (Stilling's wreaths).

Before removing the pes pedunculi we must detach the ansa lenticularis (Fig. 23, ans.), which takes its origin in the lenticular nucleus and joins the innermost bundles of the crus.

By detaching upward the remaining peduncular fibres of the crus, we loosen the lenticular nucleus and a considerable portion of the internal capsule, which in part descend from the cerebral cortex through the pes pedunculi. Behind this surface we discover still another cortical stratum of the internal capsule, consisting of radiating fibres intersected by fibres from other strata; the former do not extend over the entire breadth of the corona radiata (Fig. 22, *caps. int.* to Tg. These fibres do not extend as far to the outside as they are here represented).

At the point at which the bundles of the internal capsule course at the same level with the pes pedunculi of the opposite side, these bundles mix with the *substantia nigra* of Soemmering, and with this black substance are fused into a very compact layer of the crus behind the superficial strata (Fig. 22, Tg.). This *stratum intermedium pedunculi*, as I have named it, which covers the tegmentum of the crus, shows in that area a convex bulging due to the red nucleus lying behind it. Further on this *stratum intermedium pedunculi* presents a concave surface resting upon the deep transverse fibres of the pons, and in the *oblongata* this stratum appears to develop into the foremost fibres of the anterior column lying behind the pyramids and to the inside of the olivary body. In a median direction from the fifth nerve, a narrow bundle of fibres, broadening above, joins the peduncular stratum intermedium; this bundle lies to the outside and separate from it, wending its way as the fillet from the posterior surface of the brain-axis across the superior peduncles of the cerebellum to the anterior surface (Fig. 22, L., Pr.) The *lemniscus* originates in

the corp. quadrig. (Fig. 17); it undoubtedly gives off bundles which coalesce intimately with the olivary body (Burdach, Arnold). If the cerebellum (Fig. 22, left R.) be denuded of all pons fibres, we discover a cerebellar strand which tapers toward the oblongata and enters into the restiform body.

Fig. 23

Deeper Dissection of Brain Isthmus and Cerebellum Viewed from Basilar Surface.

Nc. Caudate nucleus. II. Optic chiasm. I. Infundibulum. m. Corpus mammillare. P. Posterior perforated lamina. ans. Ansa peduncularis, between the external capsule of the lenticular nucleus and the pes ped. (Pd.) caps. i. Occipital bundles of the pes ped. St. Medullary stratum, together with Soemmering's substance, covered by cross-section of the *pes*. N.R. Red nucleus of the tegmentum. x. Decussation of the superior cerebellar peduncles, horse-shoe shaped commissure of Wernekinck, extending on the right to the exposed internal capsule. L. Medullary layers. J. Tegmentum. Fr. Torn fibræ rectæ of the pons, lying between deeper layers of tegmental bundles or their prolongation in the pons. Gi. Internal geniculate body. e. External geniculate body. Th. Pulvinar of thalamus. Pr. Superior cerebellar peduncles. Nd. Dentate nucleus of cerebellum. R. Corpus restiforme. Cbl. Cerebellum. Fl. Flocculus. V. Trigeminal. VIII. Eighth nerve. O. Olive, connected on the right side with a deep fasciculus coming from the posterior division of the pons (tegmentum). fa. Anterior column (*funiculus anterior*). fl. Lateral column (*funiculus lateralis*).

Note.—Figs. 22 and 23 present in their several halves four different levels and four different strata: 1. Fig. 22 (right side) throughout its entire length shows the most basilar strata; 2. Fig. 23 exhibits on the left as far as St. the next more superficial strata of the fore-brain; 3. Fig. 22, left side, exhibits, with exception of the pulvinar, a deeper stratum than the right side of Fig. 22, and a more superficial stratum than the remainder of Fig. 23, left side, and Fig. 23, right side.

The brachia pontis [1] are regularly stratified masses; the corpus restiforme, on the other hand, is a distinctly foliated medullary structure covering a convex body the outlines of which can be readily discerned. This convex body is the *dentate nucleus* of the cerebellum (Figs. 22 and 23, left side, R, right side, Nd.).

The red nucleus is exposed to view by a transverse division of the fibres of the pes ped. and of all longitudinal fibres of the stratum intermedium, and of Sœmmering's substance, just above the corp. quadrigemina (Fig. 23, Pd., St.), sections of the latter resembling two concentric crescents. The nucleus ruber is the *ganglion* of the superior cerebellar peduncles (Fig. 23, N.R.). These deep-seated structures in both halves of the *tegmentum* seem to be connected by a transverse horse-shoe commissure (according to Wernekinck). Stilling proved this commissure to be the decussation of the *processus cerebelli ad cerebrum*,[2] which arise from the red nuclei. In consequence of the density of its foliated mass the surface of the nucleus ruber appears smooth (Fig. 23, left). Above and to the outer side, the red nucleus becomes considerably attenuated, and connects with that portion of the *corona radiata* which courses immediately beneath the optic thalamus (Fig. 23, right, caps. int.). Viewed as a ganglion, the nucleus ruber represents a shell-shaped plate, thickened on its lower inner surfaces. A group of bundles takes a spiral course over the basilar surface of the red nucleus and adheres closely to it. It is possible that these fibres upon the lower surface of the nucleus ruber represent an uncrossed transition from the internal capsule to the posterior surface of the superior cerebellar peduncles (Fig 23, right side).

Before reaching those fibres which radiate from the internal capsule and pass into the nucleus ruber, as represented in the figure, we come upon layers of the internal capsule which pass into a bulging ganglionic mass immediately above the substantia Soemmeringi. Forel has given the most accurate description of this *discus lentiformis*. The foliated structure of this ganglion is intersected by transverse medullary fibres in a direction vertical to the bundles of the capsule. This formation provides the nucleus ruber on its upper and outer side with a plastic prominence which is well seen after removing the substantia nigra. Stilling discovered the connection of this ganglion with the optic tract. This lentiform body is exhibited on longitudinal sections

[1] Processus cerebelli ad pontem ; medipedunculi (Wilder).—S.

[2] Præpedunculi (Wilder).—S.

in Figs. 33 and 36, and on cross-sections in Fig. 34—all being taken from the human brain.

Besides separating the lemniscus from the processus ad cerebrum and detaching the pons-fibres which cover the basilar surface of the latter, we must also remove the corpus restiforme in the cerebellum and the ependyma of the anterior cerebellar surface, if we wish to get a full view of this superior cerebellar peduncle. Arising from the opposite nucleus ruber (Fig. 23, N.R., left) it passes through the decussation-elevation (Fig. 23, x.), and on the other side dorsad of the trigeminal root (Fig. 23, right, V.) into the cerebellum, where it disappears in the nucleus dentatus cerebelli (Fig. 23, Nd.). Inasmuch as this dentate nucleus is connected by medullary fibres with the cerebellar cortex, we may regard the decussated fibres of the processus cerebelli ad cerebrum as extending from the *cerebral* cortex of one hemisphere to the *cerebellar* cortex of the opposite side.

The brain-axis reveals the following formations connecting the crus with the spinal cord: (1) The ansa nuclei lenticularis. (2) The pyramidal tract discussed above. (3) The stratum intermedium with Soemmering's substance. The fibres of the intermediate stratum abut dorsad upon the pes ped. as far as the pons. Its anterior portion consists of bundles which simply pass over Soemmering's substance but (and this is quite remarkable) are in no wise connected with the origin of the tegmentum. The stratum intermedium is developed from the fore-brain; all the bundles of the tegmentum, however, come from the inter- and mid-brain. The layer of bundles belonging to the substantia nigra joins the posterior tract of the isthmus within the pons, and takes no part in the decussation of the pyramids. Without recognizing its relation to Soemmering's substances, Stilling has spoken of a posterior layer of the *pes* passing into the posterior division of the pons. According to Burdach and Clarke an undecussated portion of the pyramidal tract joins the anterior columns of the medulla oblongata. This can not refer to any others but the bundles of Soemmering's substance, which lie immediately upon the pyramids, and hold the same relation they held higher up to the pes ped. The anterior columns lie behind the pyramids, and both contain non-decussating fibres; a dissection of the posterior pyramidal fibres will, therefore, lead into the anterior columns. The name given above to this nerve-tract applied only to that part of it in front of the mid-brain in the cerebral peduncle, and not to the entire tract; to that part of the

pyramidal tract which does not properly belong either to the anterior or posterior tracts of the brain-axis I would give the name *stratum intermedium caudicis.* It requires no further proof that if the median furrow is bounded by the anterior tract of the isthmus—by the pyramids,—the stratum intermedium, as Clarke describes it, must be situated behind the pyramids. Below the pyramids the anterior column apparently forms the median fissure. The anterior columns develop median surfaces simply by pushing their formerly anterior surfaces (strata intermedia) inward toward the median line, approaching it more closely as the decussating pyramids pass outward and leave a free space between them ; the anterior columns first approach each other at an angle which is open anteriorly, but finally they oppose their median surfaces to each other along the anterior median fissure. For purely anatomical reasons, therefore, we find that the stratum intermedium is continued to and on the inner surface of the anterior columns of the spinal cord. Türck and Flechsig have reached the same conclusion from pathological and genetic investigations. (4) After dissecting away the *stratum intermedium,* the tegmentum comes into view. Its most anterior layer of fibres belongs to the lemniscus, which, together with some fibres of the optic thalamus, covers the *processus cerebelli ad cerebrum,* behind which the deeper longitudinal bundles of the tegmentum descend on their way through the pons to the antero-lateral column of the *oblongata* and spinal cord. One of the bundles of the tegmentum (Fig. 23, right) would seem to be a true *funiculus olivaris.* The dissection of these bundles gives no artificial, but an incomplete, notion of the complicated structure of the posterior division of the cerebral axis.

THE MINUTE ANATOMY OF THE BRAIN.

THE CORTEX.

THE cortical tissue of the hemispheres varies in different regions as regards the shape, size, and distribution of its nervous elements, while the basis substance remains the same throughout. We are justified in applying to the non-nervous basis substance the very fit remark of Reichert, in regard to the body tissue in general, and in arguing that the brain consists of a mass of connective tissue, in which the parts characteristic of the brain, the nerve ganglia and their processes, as well as the nerve fibres, are imbedded. That the existence of basement substance in the cortex is entirely independent of nervous elements is proved by the fact that the mere presence of nerve cells with numerous processes does not give the appearance of gray substance. We find dense rows of ganglionic cells in various parts of the brain, in the medullary substance which borders upon the cortex, in the medullary substance of the island of Reil, in the external capsule of the lenticular nucleus, in the nucleus dentatus cerebelli (Stilling), and, according to Boll, throughout the white substance of the brain; and yet the characteristic features of the medullary substance are in no way effaced by these cells. In contrast to these formations, others which contain but few nerve cells, the superficial strata of the cortex (Rokitansky's ependymal formation, Virchow's neuroglia), for instance, present the appearance of gray substance. The volume of gray substance, furthermore, is not at all commensurate with the number of nerve cells and fibres in the brain; it is more abundant in the brains of animals than in that of man, and indeed the proportion of gray substance increases the more remote the brain type is from the human, and the greater the simplicity of the cerebral surface.

This argument is best sustained by measurements which have been taken of the superficial strata of the cortex, containing but very few nervous elements, as compared with other regions which have an abundance of these elements. These superficial strata

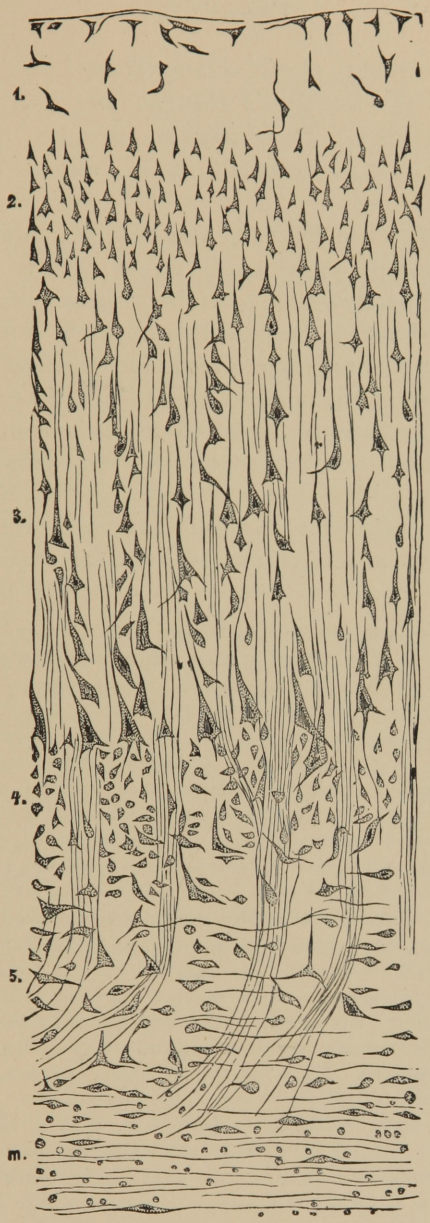

Fig. 24.

Section through the Third Longitudinal Convolution of the Frontal Lobe Adjoining a Fissure. (The Five-Layer Type of the Cerebral Cortex.)

1. Superficial layer of neuroglia. 2. Layer of small pyramids. 3. Layer of large pyramids ("formation of the cornu ammonis"). 4. The granular layer. 5. The layer of spindle-shaped cells ("claustral formation"). m. Medullary substance of the convolution.

constitute in man but $\frac{1}{10}-\frac{1}{8}$; in smaller apes, $\frac{1}{7}-\frac{1}{6}$; in the dog, $\frac{1}{6}$; in the cat, $\frac{1}{5}$; in the bat, $\frac{1}{4}$; in the calf and deer, $\frac{1}{3}$ of the entire breadth of cortex. Their absolute breadth of 0.25 mm. in man is exceeded by 0.4 in the calf, and 0.5 mm. of this substance in the deer.

This gray substance between the nervous elements appears under the microscope to be made up of densely crowded dark spots surrounded by tissue of a brighter color. It contains distinct connective-tissue elements, with a network of fibrils from the processes of these elements, and a second network of fibres derived from the processes of the nerve-cells. I learned as much as early as 1870 from preparations hardened in bichromate of potash, stained with carmine, dehydrated, and rendered transparent by oil of cloves (Stricker's "Handbook of Histology"). Further details were recorded by Jastrowitz[1] and Boll[2] as a result of their methodical researches, and it was shown to be a far more complicated structure.

The following minute description of cortical gray substance applies to all gray substance, wherever found, The cortical surface borders upon the *pia mater*. There is no epicortical lymphatic space, as was proved by careful injections[3] of the lymphatics of the pia mater. The gray substance has a sort of limiting membrane, consisting of connective-tissue cells with numerous processes, which are quite the same as the connective-tissue cells in the gray substance. Various influences conspire to affect the direction of these elements among the different tissue-structures, in consequence of which we find the processes from the outer cell-terminus spread flatly over the cortical surface, while the pointed processes starting from the other end of the cells, take a radiating course through the cortex. These processes, according to Löwe, are 0.125 mm. long and ramified, and are not unlike the cone-fibres of the retina. The outermost stratum of the cortex is, therefore, an epithelial arrangement of connective-tissue cells, whose individual form is best represented to the mind by the leaf of a palm-fan the stalk of which is at right angles to the leaf surface. Fleischl described as the outermost cortical layer a fenestrated cuticula, which is rendered visible by staining the cortical surface with silver; this cuticula Boll considered to be an albuminous membrane in the valleys between the very delicate prominences on the cortex caused by the flat connective-tissue cells. Boll's "fusiform"[4] cells are found, in lesser numbers and without the palm-fan shape, everywhere in the gray substance. These glia cells (neuro-glia), vary in shape (according to Jastrowitz), from spindle-shaped cells—resembling those of the tendons—to such as are surrounded by numerous fine (according to Boll) non-ramified processes. The size of the cells varies between 4-17 μ[5] (Jastrowitz). The body of the cell is at times considerably developed, and then again it disappears

[1] *Arch. für Psychiatrie und Nervenkrankheiten*, vol. II., p. 389; vol. III., p. 162, 1870–'71.

[2] The same, vol. IV., p. 1, 1874.

[3] Experiments of Boll and Golgi.

[4] "Pinselzellen," "pencil-cells" would be more literal.—S.

[5] $\mu = \frac{1}{1000}$ millimetre—S.

between the processes. From specimens obtained by teasing the preparations Boll described the protoplasm around the nucleus of the glia cells as a granular substance without well-defined boundaries, lying between the extremely delicate pencil-shaped fibres. The second form of non-nervous elements of the gray substance are the glia-nuclei, which are connected with the granular basement substance. They are more numerous in the newly-born and densest in the cortical layers. Their protoplasm cannot be separated from the granular basement substance. In the embryonic chick Boll could not observe that early stage in which distinct embryonic cells hold the ground occupied later on by the continuous basement substance, but he could notice that the granulated substance, consisting of a protoplasmic formation, uniformly studded with spherical dots, soon changes its appearance. This change is effected by a twig-like grouping of adherent granules, which is particularly distinct in the vicinity of the double-contoured nuclei, and converges slightly toward them. This resembles a formative activity of the cells. "On the strength of these investigations it would, perhaps, be fair to assume that in spite of the confluence of the cell-protoplasm, and the fusion of the cells proper, there exist virtually and physiologically separate cell units." The nuclei once densely crowded move far apart in consequence of the proliferation of the ground substance (increase of the granula—Boll). The granulated substance is absolutely independent of the nerve fibrils, or of connective-tissue fibrils, but simply remains attached to these fibrils after teasing them (Jastrowitz, Boll). The granulated basement substance is highly albuminous. Boll explains this by saying that the basement substance is developed out of primary embryonic connective-tissue cells, and that its quantity of albumen is similar to the granular albuminous material which is formed everywhere with the development of the connective tissue in and next to the nerve fibrils. This albuminous material is stored sparsely in some and liberally in other connective-tissue formations during the entire period of life. Jastrowitz ascribes to the granulated substance in the cortex the function of isolating nerve fibres, for in the cerebral medullary substance the axis-cylinders are separated from one another by the same white substance before the latter is transformed into the medullary sheath of the axis-cylinder. The views of Besser, Arndt, Rindfleisch, and Henle have been disproved by the investigations of Jastrowitz and Boll.

As I stated in 1867, the nervous elements of the gray substance, form regular concentric layers, the arrangement of these elements being modified according to the locality in which they occur.

The commonest type of cortical stratification is found in all the convolutions of the convexity. A transverse section of the cortex presents on the whole a uniformly gray appearance. In the middle of some of the broader convolutions we find a less grayish zone, due to loss of pigment. On transparent sections of these convolutions (magnified 100 diameters), we can distinguish five layers, the first being immediately beneath the pia mater.

The *first* layer is made up chiefly of the basis substance and its connective-tissue elements. The latter are most numerous near the surface of the cortex. A few irregular, angular cells are seen scattered throughout this layer. This is the neuroglia layer. The *second* layer is sharply defined on its outer margin, and consists of

densely crowded pyramidal-shaped bodies, which turn their apices toward the surface, and measure about 10 μ. in height. The internal boundary is also well marked, owing not so much to a change in the size of these nervous elements, as to the lesser density of distribution. This is the layer of small pyramids. In the succeeding *third* layer, a distinct columnar arrangement of the nerve-cells, which are quite separate from one another in a transverse direction, may be noted. This is due largely to the aggregation of nerve fibres from the basilar aspect of the small pyramids. These nerve fibres increase inwardly, and push their way in between groups of pyramids. The pyramids, while increasing in calibre, attain to a height of 40 μ. or even 60 μ. according to the width of the convolutions. In addition to the ramified apex-process, and from four to seven ramifying lateral base-processes, there is one median base-process (Fig. 24, lowest row of layer 3), which runs in a diametrically opposite direction, yet parallel to the apex-process, toward the medullary substance. The nuclei of the pyramids are miniature pyramids themselves, their angles often extending into the processes of the pyramids. This is the layer of large pyramids, or at least the layer which contains these.

A sudden jump as regards calibre is made from these layers to the *fourth*, composed of multiform elements, chiefly of a rounded-angular nature. This is called the "granule-like" or granular formation.

Between this layer and the medullary substance of the convolution, we find a *fifth* layer not definitely bounded, and consisting near its outer margin of rather large but short pyramids. The further we proceed toward the white substance, the more spindle-shaped nerve cells of about 30 *mm.* we find; these spindle-shaped cells, sending processes toward the granule-layer, present the appearance of vertically compressed pyramids. But they never show any thing in the least akin to a median base-process.

The medullary substance constitutes the *sixth* layer of these convolutions. This layer contains a fair number of spindle-shaped nerve cells, taking the same direction which those of the fifth layer do. The axis-cylinder, as well as the medullary sheath, varies very much in size, from the exceedingly delicate to the dimensions of spinal-cord fibres. The *central* fibres lack the membrane of Schwann and Ranvier's internodia (Boll), which are characteristic features of the medullary substance in peripheral nerves.

The white substance is studded with granules (cubic cells, Boll), which in their arrangement (though normally interrupted in the adult brain) imitate the course which nerve fibres take.

In the entire cortex there are but three forms of nerve corpuscles: (1) the pyramidal form, (2) the granule (mixed) form of small nerve cells, and (3) the spindle-shaped form. In the drawing (Fig. 24) the first formation is found in the second and third layers; the granules, in the fourth; the spindle-shaped cells, in the fifth layer. In Fig. 25 we find the pyramids in the second layer; the granular elements in the second, fifth, and seventh layers; the spindle-shaped bodies in the eighth layer. The pyramidal and spindle-shaped bodies differ from each other chiefly in regard to position. The longitudinal axis of the pyramidal bodies (parallel to each other) stands vertical to the cortical surface, while the longitudinal axis of the spindle-shaped cells lies parallel to the surface of the cortex. Throughout the central nervous organ a morphological law evidently operates, by reason of which the formative activity exercises an influence over the direction of the nerve cells, making the direction of their longitudinal axes parallel to that system of fibres which originates from them.

Let us recall the various directions which the different systems of cortical fibres take, and which were demonstrated by the preparations represented in Figs. 18 and 19.

Obviously enough the direction of the pyramids (vertical to the cortical surface) is parallel to the projection-system fibres, and, on the other hand, the fibræ propriæ (of the association-system), which do not conduct from or to the cortex, but from cortex to cortex, run parallel to the surface of the convolutions, just as in the above figures (24 and 25) the spindle-shaped cells lie parallel to that surface.

Although the spindle-shaped cells are by no means bi-polar cells, and have undoubted lateral processes as well, yet the latter run parallel to the surface, and, as they are turned away from the medullary substance of the convolution, can form no immediate connection with the projection-systems.

We can obtain double proof of the parallelism existing between the axes of spindle-shaped elements and the fibræ propriæ by comparing a section of the cortex taken from the summit of a convolution with one (represented in Figs. 24 and 25) taken from the margin of a fissure. The fibræ propriæ intersect at the margin of a sulcus with the projection-fibres (page 38), but at the apex of the convolution both systems of fibres run parallel to

one another; just so the spindle-shaped bodies of the fifth cortical layer, bordering upon a fissure, intersect with the pyramids of the second and third layer, but at the summit of a convolution the former lie vertical (radial) to the surface of the cortex and parallel to the axes of the pyramids.

Henle is wrong in stating that the pyramids are absent in the cortical substance bordering upon a fissure.

The cortical nervous elements can be distinctly made out in the chick from the third day of development on, and very shortly after this the direction of their axes is apparent (Boll). In the human embryo both these nerve-cells and their processes show not later than the fourth month. At this period there is very little basis substance separating them; as they are very dense at this early stage it is probable that they do not go on increasing in number. Their own growth and that of the basis substance seem to be part and parcel of the growth of the cortex.

Besser, Arndt, and Henle have expressed different views on this subject.

All cortical nerve corpuscles are composed of a sheathless protoplasmic substance, finely, but not always equally, granulated.[1] According to Reinisch and Max Schulze, the protoplasm of the nerve cells has a striated appearance, which Boll has proved, in specimens stained with hyperosmic acid, to be common also to the pyramids of the cortex. The striations of the ganglionic processes have been familiar to us for some time. These processes are equivalent to the axis-cylinders of nerve fibres. Because of these minute fibrils, the ganglionic process and the axis-cylinder are supposed to be not morphological elements, but aggregations (fasciculi) of minute fibrils; these fibrils alone are present in the invertebrata, and for that reason are considered the *elementary* nerve fibres. These processes and axis-cylinders emanate from the ganglion cells, in the protoplasm of which they appear to be scattered like the hairs of a brush; they pass from one process to the other, or tend toward the nucleus, which seems to be surrounded by such fibrils. These fibrils cross each other, interlace closely with one another, and thus lose their individuality. Max Schulze was, perhaps, the first to suggest that a ganglionic cell might possibly, from the arrangement of its fibrils, represent a plexus, and that the protoplasm was simply traversed by afferent and efferent fibrils.

[1] This granulation causes a pigmentation of the protoplasm, varying in degree and distribution.

Other authors have endeavored to prove that the nerve fibrils do in reality terminate in the granular basis substance, where, according to Rindfleisch,[1] the "fibrillary" and the "granular" structures are fused. Very soon afterward, Gerlach,[2] after politely saying that he would confirm this view, contradicts it, by showing (on potassium and gold chloride preparations) that the ganglionic processes, after ramifying minutely, send terminal fibrils into a general network. Prior to this, Jastrowitz stoutly maintained that whenever he detected fibrils covered by granular substance, the fibrillary elements extended beyond the granular. Boll declared that Rindfleisch's hyperosmic-acid method was the very one best adapted to prove the independence of the finest fibrils within the granular substance.

Those who attempt to divest the nerve cells of their importance as centres, and who trace the anatomical origin of nerves to a diffuse substance, such as the granular portion of the gray substance, render it impossible to establish a relation between the anatomical structure and physiological function of these parts. Strangely enough, the ganglion cell with its ramified processes would be in direct contrast to the spider in its web. The active agent would be, not in the spinning body but in the meshes of the web. Such a view of the anatomical structure of the nerve cell could undoubtedly be entertained, but it would then be impossible to conceive of any physiological agent discriminating between two such masses as the ganglion cell and the intercellular substance. Even if we were for the moment to lay aside all justifiable doubts as to the striated appearance of the ganglionic bodies, the striæ being deceptive, due perhaps to a mere folding, or to the changed tension of a body separated from its surroundings, to which its ramifications had attached it; discarding such doubts, I say, we can still find good anatomical reasons which force us to regard the nerve corpuscles of the cortex, the pyramids for example, as independent elements within the network of ganglion processes.

1. From the time of the existence of formative cells in the anterior cerebral vesicle, the nerve cells are independent of the formation of the basis substance, and, as we learn from comparative anatomy, the former is independent, throughout life, of the development of the latter; while, according to Boll, the fused protoplasm of the basis substance with its nuclei represents the remnants of other cells.

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[1] *Centralblatt für die medicinischen Wissenschaften*, 1872, page 77.

[2] *Idem*, 1872, page 273.

2. The processes start in the ganglionic cell, and are originally nothing but a prolongation of the cell protoplasm, granular and non-striated, but undergoing later on numerous ramifications (Boll, *l. c.*, "Entwicklung des Hühnchens"). The cell processes permanently retain their protoplasmic character, not only in continuity with the protoplasm of the ganglion, but also after the interruption of the granules at considerable distances from the ganglion, in the midst of the fibrillary striation (Max Schulze). From the very start the ganglion cell is an independent centre; the processes and their ramifications are portions of the ganglionic body. All their parts together form the protoplasmic individual. The striation would lie entirely within the latter, between one process and another.

3. The axis-cylinder develops out of special spindle-shaped cells in the medullary region (Boll), the protoplasm of which is continued into the gray substance of the cortex, and there splits up into very delicate fibrils; on the hypothesis of Gerlach and Boll these most minute fibrils connect with the finest ramifications of the ganglionic processes. There would then be a secondary connection merely between the processes of the latter and the largest aggregate of axis-cylinder fibrils. Ganglionic cells and axis-cylinders in their connections would be parts of two, not of one protoplasmic body. This independence of the ganglionic cell as an anatomical centre does not admit of a doubt as to its importance as a functional centre.

The composition of the axis-cylinder from the fibrillary elements of Schulze would not prove the isolation of these fibrils, for the axis-cylinder is not properly isolated until surrounded by a medullary sheath. Originally gray substance similar to the granulated basis substance of the cortex separates the axis-cylinders in the medullary layer from one another (Jastrowitz, Boll, Flechsig). From this Jastrowitz draws the correct inference that in default of a connection between this basis substance and the fibrillary elements (*cf.* above) we must look upon the granular substance as the true isolating mass between the fibrils. Isolation is therefore carried further in the cortical than in the medullary substance, and yet the isolating mass retains its embryonic character, for the granulated basis substance does not become medullated.

The anatomical structure of a functional centre demands that there should be no isolation in the centre itself. The striation of the ganglionic processes does no more prove the isolation of its

fibrils than it did in the case of the axis-cylinder. And then again the connection of the striated ganglionic processes with the protoplasm of the cortical pyramids effects the realization of the transition from the "fibrillar" to the "granular" where isolation ceases. Beyond this point the doctrine of cortical centres does not venture This is certainly not a novel point of view, but fortunately one that suffices for physiological purposes. We have no reason to grow sceptical on this point until we shall have succeeded in isolating Schulze's finest ganglionic fibrils from the surrounding protoplasm, as has been done in the granulated basis substance.

The development of the axis-cylinder from the cortical nerve-elements, and the relation[1] of the former to the pyramids are as follows:

The pyramids send median base processes (Meynert), which need not ramify (Koschewnikow), directly from their base into the medullary substance. Moreover, the pointed apex process extending from the third layer to the most external layers of cortical elements divides into a multitude of terminal ramifications, the finest spurs of which return loop-shaped toward the white substance (Boll) (?). These delicate filaments collect and form stouter filaments; these in turn give rise to the myeline, which is, therefore, in the first instance, a product of the pointed processes. Now this myeline is deposited next to those axis-cylinders which are formed by the median-base processes (Gerlach). The lateral processes could, in the same way, participate in the origin of the white substance. The gray substance, however, is traversed simply by nerve fibrils which enter into no combination with it.

In regard to the grouping of ganglion cells, it is very evident that the dimensions of the pyramidal cells are directly proportionate to the distance they are separated from the external cortical layers; that they are small externally, and steadily increase in size as far as the granular layer. The apex process splits up not only into a number of terminal ramifications, but gives off lateral branches nearer to the protoplasm, which (fibrils) take part in the formation of the so-called fibrillary network.

Even Gerlach's preparations, which I have been permitted to examine, do not enable one to detect any other internodia but the ganglionic cells, so that the minute fibrils seem to form a compact

[1]According to Gerlach's staining method: potass. and gold chloride 1:10,000 water.

mass rather than a net. The greater the cortical distance along which the apex process contributes branches to this network of fibres, the more fibrils this process will contain, and the stronger this process will necessarily be. Inasmuch as these ramified branches are continued in some way or other into the protoplasm of the pyramid, it naturally follows that stronger processes, or an increasing number of branches, will engender larger pyramids. I need scarcely add that the smaller pyramidal or other nerve cells, at a distance from the cortical surface ramify in the region immediately surrounding them—*i. e.*, at a greater distance from the cortical surface. Stout and short, or long and thin, pointed processes do not occur. The external layer of pyramids, whose pointed processes soon enter the fibrillary net, is composed naturally enough of smaller elements. These pyramids are not *wide* apart either, for their lateral processes have but a narrow area over which to distribute their ramifications. This refutes the opinions of those who hold that the small pyramids are sensory, and the large pyramids motor in function ; it also disproves the theory of Wundt, that the large pyramids are the old, and the small pyramids the young cells.

The pyramidal and spindle-shaped cells contain either oval, pyramidal, or spindle-shaped nuclei. The latter forms are found to be quite as numerous in brains that have never been hardened; for this reason Boll's view, that they are artificial products, seems untenable. These peculiar configurations of the nucleus seem to me to support the opinion of Beale, that the cell nucleus is surrounded by an optically denser protoplasm, which is differentiated from the external layers of protoplasm. The greater density of the nuclear portion of the protoplasm screens the oval nucleus, but it is penetrated by the glittering of the nucleolus. Owing to this dense protoplasmic layer the outlines of angular or pointed nerve corpuscles, together with their prolongations, seem crowded into the processes.

No morbid change and no physiological experiment give us any reason to hope that we shall be able to explain the difference in form of cortical elements in closely neighboring layers. Morphological interpretation is the only method which can come to our rescue. The nerve corpuscles of the gray anterior horns of the spinal cord, of the central nuclei of the *hypoglossal*, *facial*, and *abducens* nerves, and as far upwards as the *oculomotor* nerve, all show long, slender cell-forms with numerous processes. These processes seem to arise with a broad base from the body of the cell. The same peculiarities of configuration which we observe in those nerve cells which are connected with centrifugal nerve tracts, are found in the cortical pyramids, and there can be explained only by the similarity in the distribution of these bodies. Gerlach has

compared the median base process with those spinal cell processes which enter the anterior roots. The granules of the fourth cortical layer, which are distinguished from the free nuclei by their size and protoplasm, from spider- and spindle-shaped cells by the distinct boundary of the protoplasm, and by a lesser number of stout processes, may be likened to those branched ganglionic cells which occur in centres connected with centripetally conducting tracts, as in the substantia gelatinosa of the fifth nerve and in the posterior horns of the spinal cord ; these granules may be likened, also, to the internal granular layer of the retina, and to the smaller elements of the granular layers of the olfactory lobe.

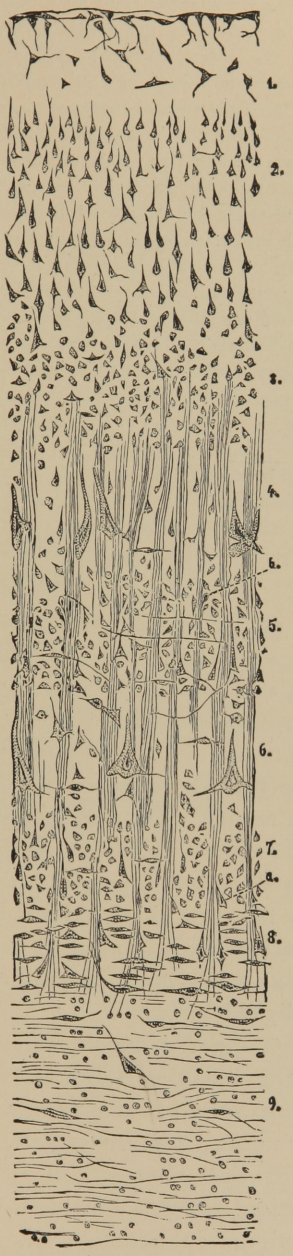
The axis-cylinders of the fibres of the convolutions and of the entire fore-brain are developed at a very early embryonic stage. In the chick they develop from spindle-shaped cells on the fourth to sixth day after impregnation (Boll). Simultaneously with these elongated formative cells, chains of round elements appear which change into spider-cells, granules, and ganglion cells, which Boll supposes (perhaps correctly) to be diffused over the entire medullary substance of the hemispheres. Jastrowitz thought them erratic. These chains of connective-tissue elements, separating as growth continues, lie between bundles of fifty to sixty fibrils. The axis-cylinders are separated by a gray, granular, albuminous basis substance, like that of the cortex. The fibres in the fore-brain do not develop medullary sheaths until later on, and for that reason are separated by gray substance only until long after birth (Jastrowitz), and in some parts up to the age of nine months (Flechsig). This gray substance may even appear darker than the cortex (Jastrowitz), though later on it becomes differentiated as the white substance. The transition of fundamental gray substance into medullary sheaths is preceded by a fatty infiltration of the latter, and by the appearance of granular cells possessed of amœboid movements (Boll); but later on their fat-granules disappear, and these cells are lodged between the medullary fibres as connective-tissue cells. Granular cells are present generally in the medullary substance from the fifth month of intra-uterine life to the fifth month *post partum.* A remnant of intrafibrillary gray substance is perpetuated. The star-shaped connective-tissue cells (Meynert), called also spider-cells (Jastrowitz) and fusiform-cells (Boll), form, after the complete development of white medullary substance, an interstitial fibrillary network of nerve fibres and bundles of the fore-brain, varying from fibres of minutest dimensions to fibres of respectable size. These cells seem to be fixed everywhere to the medullary substance, while the free nuclei, present

in varying numbers, might be classed as remnants of the gray medullary substance.

The cortex of the outermost part of the occipital extremity, and of the calcarine fissure (to which the vertical line gives a ⊢ shape, and the occipital extremity a distinct wall), can be divided *macroscopically* into three well-defined layers: (1) an external gray layer; (2) a median, distinctly-limited white layer; and (3) an inner gray layer. *Microscopically* we can discern eight layers. The eight-layer cortex is distinguished from the four-layer cortex: 1. By the reduction of the layer of pyramids to a narrow concentric layer (Fig. 25, 2), within which the size of the pyramids varies less than in the five-layer type. According to explanations given above, this is due to the lesser distance of the innermost pyramidal strata from the neuroglia layer. 2. By three granular layers, which constitute the third, fifth, and seventh layers. The granules are curiously intermingled with small pyramidal and small spindle-shaped cells. Owing to the narrowness of the medullary substance and the consequent greater parallelism of the *stratum proprium* of this portion of the cortex, its eighth layer, answering to the fifth layer of the first type, gives us valuable information regarding the spindle-cells, which are larger than those spindle-cells to be found interspersed in other layers. 3. By the less densely packed elements of the third, fourth, and sixth layers, comprising chiefly small pyramids and transverse spindle-cells. Both these layers are fitly called *intergranular* layers. These intergranular layers contain at considerable distances apart either single pyramids of astounding size, or groups of two and three such pyramids. These are the largest ganglion cells to be met with in any part of the cerebrum. The pyramidal cells appear upon the inside of the granular layer; their long pointed processes traverse the more external layers, and pass through the pyramids of the second intergranular layer—through two granular strata—through an intergranular layer and a portion of the pyramidal layer. The gigantic dimensions of these solitary pyramids can be explained on the principles before alluded to in regard to the progressive increase in the size of these pyramids. The presence of large numbers of small pyramids, especially in the second and third granular layers, as well as in the layer of spindle-cells, would lead us to believe that these pointed processes and their ramifications terminate in that part of the gray network of fibres which does not belong to

the most external layers of the cortex. The three granular and the intergranular layers consist really of mixed elementary forms, among which the granular ganglionic cells preponderate. The connection of the pyramids with the previously developed delicate radial medullary bundles of the cortex is easily recognized. The small fusiform (spindle) cells of these layers are contiguous beyond a doubt with transverse nerve fibres, which are by no means numerous enough, however, to constitute, as Kölliker would have it, the white substance of the intermediate strand in the cortex of the *sulcus calcarinus*.

To explain satisfactorily this white, intermediate strand, we must, because of its well-defined boundary, have recourse to the lack of pigment in the barren intergranular layers, for the nerve corpuscles evidently carry the pigment which is responsible for the deep tint of the gray substance. Besides, the effect of lack of pigment is intensified by radiating medullary bundles which are not prominent in other internal layers —in the seventh and eighth for instance,—where the impression gained from numerous pigment cells overshadows all else.



Transparent Section through the Cortex of the Calcarine Fissure.

1. Neuroglia layer. 2. Layer of pyramids. 3. External granular layer. 4. External barren intergranular layer with solitary cells. 5. Middle granular layer. 6. Inner barren intergranular layer with solitary cells. 7. Inner granular layer. 8. Layer of fusiform cells. 9. Medullary substance of the convolution.

Similar circumstances conspire to bring about a diffuse, paler tint of the middle portion of a section of the cortex taken from the central convolutions. Betz has stated that the anterior central convolution contained groups of particularly large pyramids, which he thought were the circumscript motor centres which Hitzig, on the strength of his physiological experiments, relegated exclusively to the anterior central convolution of the brain in dogs and monkeys. Apart from the mistake Hitzig made, and which we corrected above, in establishing the homologon in carnivora of the anterior central convolution, it has been proved that the size of the pyramids depends upon their distance from the cortical surface. The largest pyramids will, therefore, be found in the broadest cortical region ; but the broadest cortex is that of both central convolutions. The third layer, the equivalent of the third layer in Fig. 24, is very broad, and contains larger pyramids, which are naturally farther apart than their fellows in the dense groups of small pyramids. For this reason we observe an increasing lack of pigment near the surface of the cortex, due to a gradual diminution in the size of the pyramids. And on the other hand, these pyramids do not move asunder by reason of their size alone, but their regular distribution is interfered with by the steady increase inward in the circumferences of radiating bundles of fibres, which at the same time intensify the paler tint of the third layer. The largest pyramids appear, therefore, to be arranged in small groups at some distance from one another. It would be wrong to argue from this that these large pyramids have a different signification from the smaller ones. Luys is in a great measure responsible for this mistake. Betz appears to me not to have made a discovery, but to have failed to appreciate the general relations which obtain in the primary disposition of the cortical elements.

The *gyrus uncinatus* and the *cornu ammonis*, which represents a continuous involution of the former's cortex, are peculiarly constructed, and show but a meagre variety of cortical nerve-forms. The cornu ammonis contains principally cortical elements of the pyramid type. Essentially the same is true of the *lobi olfactorii*, joined to the *gyrus fornicatus* by frontal and temporal connections (olfactory convolutions). The cap of the olfactory lobe, the *bulbus olfactorius* (Fig. 10, Olf.) exhibits a special kind of cortical stratification. Nearest to the surface lies the origin of the olfactory nerve, which passes through the *lamina cribrosa* to the Schneiderian membrane. These nerves take their origin in glomeruli which contain capillary loops (*Schlingen*) and small nerve cells (Meynert).

The *glomeruli olfactorii* are transformed in mammals (Clarke), and in the lower vertebrates (Leydig), with the aid of gray substance, into round masses (stratum glomerulosum), between which granular nerve cells are collected and heaped up. 1. This distention of the *glomeruli* in animals is a single instance of the proliferation, independent of the number of nerve fibres and cells, of amorphous connective-tissue substance in animals, in contradistinction to its reduction in the gray substance of man (page 56). 2. Toward the inner side of the *stratum glomerulosum* the

olfactory lobe contains the gelatinous (connective-tissue) layer of Clarke, which, like the cerebral cortex, possesses on the outside small nerve cells, which are changed into larger, angular, elongated nerve cells as we proceed inward. 3. Closely packed granular layers succeed the innermost largest nerve cells as they do in the cerebral cortex; these granules are divided into strata by the medullated substance parallel to the surface of the olfactory lobe.

Animals whose olfactory lobe is hollowed out by a diverticulum from the lateral ventricle exhibit an ependymal layer with columnar, ciliated endothelium.

4. Through complications a fourth type of cortical substance is created, represented in the cortex surrounding the fossa Sylvii, where a gray lamina, the claustrum, runs parallel to the cortex of the island of Reil (Fig. 6, Cl.), of the operculum (Fig. 5, between J and L), of the first temporal lobe, and, continuing beyond the anterior fissure, parallel to the cortex of the orbital surface (Fig. 26, CL.). The claustrum is developed out of the formation

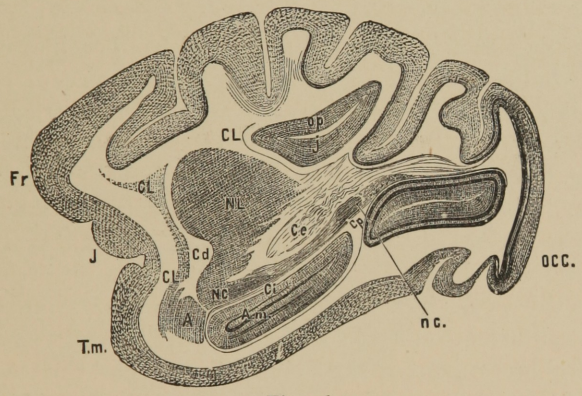


Fig. 26.

Sagittal Section through the Brain of *Hamadryas*, near the Island of Reil.

Fr. Tm. Occ. Frontal, temporal ends and occipital region of the fore-brain. I. Island (should have been placed over the entrance to the Sylvian fossa). op. Operculum. j. Upper margin of the island. CL. Claustrum. A. Amygdala. Cd. Anterior commissure. Am. Cornu ammonis. Ci. Inferior horn of the lateral ventricle. Cp. Posterior horn of the lateral ventricle. NL. Lenticular nucleus. NC. Temporal end of the caudate nucleus. nc. Hindermost portion of this nucleus. Between the two the stria cornea. Ce. Medullary capsule of the external geniculate body.

of spindle-shaped cells of the fifth cortical layer; the elements of this layer and of the claustrum resemble each other, not only in size and shape, but also in being parallel to the surface of the cortex. The claustrum, which lines the inner surface of the island, adapts itself to the fan-shaped form of the latter, the handle of the fan pointing downward (basis insulæ).

The margin of this trilateral fan is bent outward on all three sides. The claustrum is continued forward beyond the anterior fissure into the posterior margin of the orbital surface of the frontal lobe, upward into the operculum, and below, but to a lesser extent, into the first temporal convolution. This fan-shaped formation is furrowed or rather folded to correspond to the rise and fall of the island-convolutions. The pedicle (handle) of this fan-shaped formation, a ball-shaped body—the amygdala, —represents at the same time the most anterior portion of the uncus lying to the inner side of, and behind, the base of the island. The amygdala (Figs. 6, 26, 30, 32, A.) is composed of the same elements as the claustrum. Between these two bodies (claustrum and amygdala) there are small transitional heaps or strips of gray substance, which cannot be definitely classed as belonging either to the claustrum or to the amygdala, but together with these two formations constitute a continuous system of gray substance (Fig. 26, CL., A.).

Amygdala and claustrum are separated from each other by the anterior commissure in those frontal (transverse vertical) sections of the brain, on which the lateral portion of the anterior commissure, descending to the temporal lobe, is seen to pass between them (Fig. 6, Ca., Cl., A.). The claustrum is a formation of gray substance. The nerve cells of this formation are present also in the white substance of the island, as well as in the external capsule between nucleus lenticularis and claustrum, and in all these structures these cells have their axes turned in the same direction. I wish to call attention again to the connection existing between the claustral investment of the Sylvian fissure, and the association-bundles of that region. (Compare Fig. 19 with Fig. 26.)

The claustrum is not to be ranked among the ganglia, as it communicates with the fibræ propriæ of the cortex. The cerebral ganglia are connected with the cortical projection-bundles only.

Before passing to the study of sections of the cerebral ganglia and the projection-system I must stop to refer again to the medullary formation of the anterior commissure. Like the corpus callosum this commissure represents a system of fibræ propriæ connecting both hemispheres, and uniting with those commissural fibres which join both olfactory lobes, themselves parts of the hemispheres. According to the very general account given of it in Fig. 20, the anterior commissure consists apparently of a round (on section,

oblong) bundle of fibres, spreading out principally in the temporal and occipital lobes. But a more thorough examination of the anterior commissure (on sections) shows that a not inconsiderable number of its bundles originate in the olfactory lobe, and pass upward from the posterior margin of the trigonum olfac-

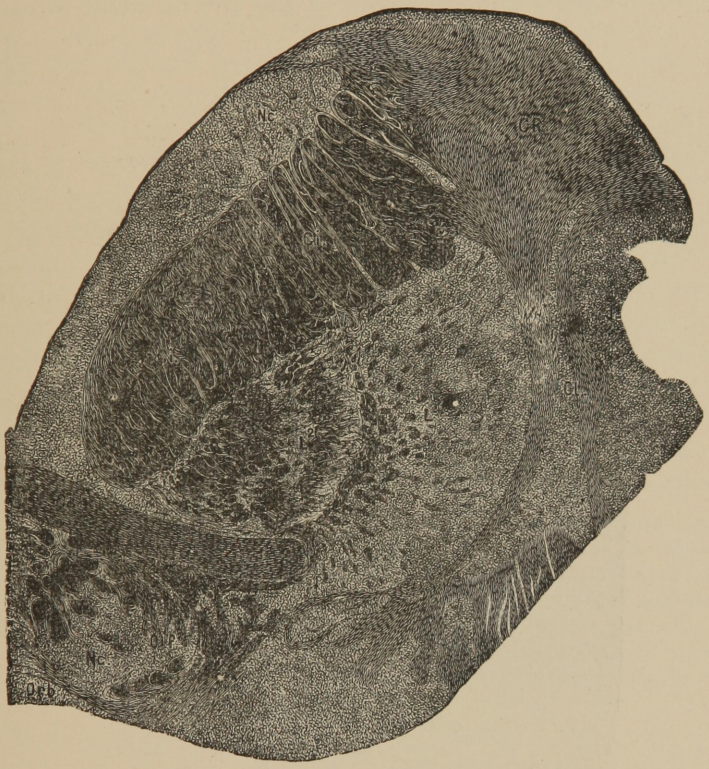


Fig. 27.

Transparent Frontal Section through the Cerebral Ganglia of Man. Anterior Commissure.

J. Island of Reil and its medullary substance. Cl. Claustrum. Ce. External capsule. L.[1], L.[2] First and second divisions of the lenticular nucleus. Nc., Nc. Ventricular and basilar portions of the caudate nucleus. Ca. Anterior commissure. Olf. Olfactory bundles passing to anterior commissure. Orb. Orbital surface.

torium through the substance of the *lamina perforata anterior*. And yet these bundles are not sufficient to account for the size of the anterior commissure (Fig. 27, Ca., Olf.). We must, therefore, infer that the anterior commissure contains bundles also which connect the occipital and temporal lobes, but stand in no sort of relation to the olfactory lobe. In man and animals this contribution to the

anterior commissure from the olfactory lobe comprises most of the medullary substance of these lobes. The relative position of the bundles entering the commissura anterior from the hemispheres and from the olfactory lobes is such, that the bundles coming from the latter join the commissure below, and those from the hemispheres form an acute angle in the frontal plane with the

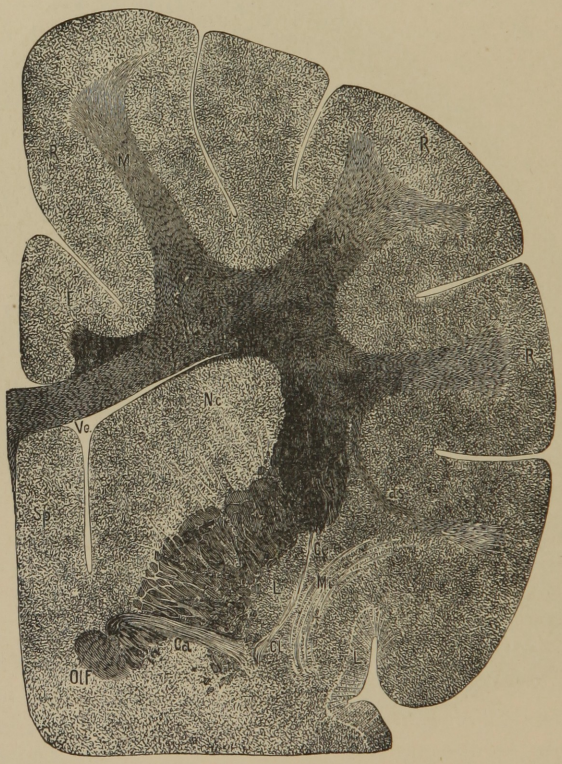


Fig. 28.

Frontal Transverse Section through the Brain of a Dog. Anterior Commissure.

R. Cerebral cortex. F. Gyrus fornicatus. M. Medullary substance of the fore-brain. Sp. Septum lucidum. Ve. Cerebral ventricle. Nc. Nucleus caudatus. L.[1] Cortex of the island of Reil. Mi. Medullary substance of the island of Reil. Ce. External capsule. L. Lenticular nucleus. Cl. Claustrum. Ca. Fibres from the hemispheres to the anterior commissure. Olf. Olfactory division of the anterior commissure.

upper portion of the commissure. Examined from this point of view, we observe that in the brain of a dog the superior—the hemispherical—portion of the anterior commissure (Fig. 28)

[1] The outer lower L on the figure should be J. (Engraver's mistake.)—S.

is smaller than the inferior portion coming from the olfactory lobe. Consequently, the hemispherical bundles of the anterior commissure, in animals having large olfactory lobes, would by no means cover in amount the wealth of commissural fibres. For that reason the bundles of the anterior commissure must serve to unite both olfactory lobes. Furthermore, it is apparent to the naked eye that fasciculi of the anterior commissure cross each other after the fashion of a twisted rope, and that these bundles are asymmetrically distributed in both halves of the anterior commissure. The latter undoubtedly possesses decussating bundles which connect each olfactory lobe with the temporal and occipital lobe of the opposite side. It is equally certain, however, and this we learn from longitudinal sections, that the entire medullary substance of the olfactory lobe does not pass into the anterior commissure, but that a part of this medullary substance forms into bundles which lie beneath the commissure and enter the basilar portion of the *nucleus caudatus*, *i. e.*, the mass between the *lamina perforata anterior* and the *commissura anterior*. The course of these olfactory bundles within and outside of the anterior commissure establishes a formation similar to the optic *chiasma* as interpreted by Joh. Müller.

As early as 1861 Clarke described the cerebral cortex, and more perticularly the eight-layer type of the occipital lobe. Clarke differed from us in enumerating but six layers; for he does not separate the pyramidal, granular, and spindle-shaped cells at their proper boundaries. Clarke found that the cortical structure varied very much as regards the width of the several layers, and described varieties of type which may be found in one and the same convolution. Careful study of the structure of *all* convolutions will not permit me to establish any other types but those I have described above.

GANGLIA OF THE FORE- AND INTER-BRAIN.

The ganglionic masses of the brain, which are traversed by a large proportion of the projection-system, must be regarded as brain-forms (*Organbilder*), the contours of which are determined in the brain by the course of the projection-fibres. This is exhibited very clearly on gold-preparations in which the gray matter is not stained.

THE GANGLIA OF THE FORE-BRAIN (PROSENCEPHALON).

the caudate and lenticular nuclei, really form but one mass, the continuity of which is interrupted here and there by the projection-system. The projection-fibres surround the lenticular nucleus in the form of the internal and external capsule.

In regard to the confluence of these masses we must note:

1. That in the frontal lobe the large ganglionic masses of the fore-brain are divided into layers by the medullary lamellæ from the internal capsule; the more anteriorly they are situated, the broader will be the bridges of gray substance in this fore-brain ganglion between the successive layers of white fibres. Thus Gratiolet distinguishes between the *corpus striatum intraventriculare* (nucl. caudatus) and *corpus striatum extraventriculare* (nucl. lenticularis). Forward of the inter-brain (*diencephalon*) the internal capsule lies solely between these two ganglia (Fig. 5, Cpi.; Fig. 27, Ci.).

The sections of the projection-bundles belonging to these masses contain not only fibres passing to the fore-brain ganglion, but also radiating fibres which travel from the frontal cortex to the anterior pedicle of the thalamus. (Compare Fig. 5 Cpi. with Fig. 21 f. Th.). In the diencephalon the *corona radiata* sends forth, in addition to the inner and external capsule, an oblique group of bundles lying one behind the other and collectively passing under the caudate nucleus to the stratum zonale of the optic thalamus. In the region of the inter-brain the caudate nucleus lies no longer to the inside of the internal capsule and next the lenticular nucleus, but on the former and above the latter (Figs. 6, 29—Nc., Th,, Ci.).

2. On longitudinal sections [Fig. 30, Pi. (n. c.)] the internal capsule exhibits a number of spindle-shaped masses of gray substance, which connect the caudate nucleus with the more exteriorly located portions of the lenticular nucleus.

3. On the upper wall of the inferior horn in the temporal lobe there is a complete fusion of the temporal extensions of both these ganglia (Fig. 26). In the direction of the occipital lobe the caudate and lenticular nuclei are separated by medullated bundles which pass from the white substance of the hemispheres to the capsule of the external geniculate body (Fig 26, NL., NC., Ce.).

The nucleus caudatus constitutes, in reality, the internal margin of the lenticular nucleus, or, better still, of its lateral gray division. The lenticular nucleus is a wedge-shaped body; its lateral division, but imperfectly separated from the nucleus caudatus by medullary substance, forms the base of this wedge, looking forward and outward (Figs. 5, 6, 19, 23, 26, 30, 32, 34, 36—Nl.). The *nucleus caudatus* bears a certain definite quantitative relation to the lenticular nucleus: anteriorly, where the surface of the lentic-

ular wedge is broadest, the nucleus caudatus develops its club-shaped head, while it diminishes posteriorly, and finally dwindles down into the *cauda*, just as the lateral division of the nucleus lenticularis is continued by means of a narrow, defective (notched) band to its equally meagre temporal continuation.

As the arch-shaped portion of the fore-brain ganglion, the caudate nucleus surrounds with its head the lenticular nucleus as far as the basilar surface, and does by no means originate in the cerebral ventricle. By curving spirally about that part of the internal capsule which contains the anterior pedicle of the optic thalamus, the nucleus caudatus makes its way from the base of

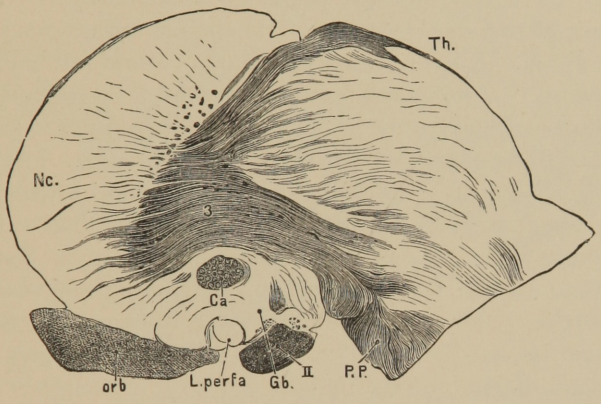


Fig. 29.

Sagittal Section through the Pros- and Thalam-encephalon of Man. (Stained with Carmine.)

orb. Medullary substance of orbital convolutions. Nc. Caudate nucleus. L. perf. a. Lamina perforata anterior. Ca. Anterior commissure. II. Optic tract. Gb. Basilar optic ganglion (the index line is erroneously extended beyond it). Th. Optic thalamus covered and invaded by fasciculi of the anterior capsule (stilus anterior thalami optici). 3. Fasciculi of the internal capsule running continuously from the caudate nucleus into the crus cerebri (P. P.).

the brain to the inner side of the septum lucidum, and as it proceeds upward it reaches the *stratum zonale* of the thalamus and lies upon it. On the base the caudate nucleus rests as ganglion over the lamina perforata anterior, and further front it lies upon the white substance of the orbital (cerebral) surface (Fig. 29, Nc., orb., L. perf. a.). While the *nucleus caudatus* presents itself beneath the orbital surface and on the base as *lamina perforata anterior*, it surrounds from within the anterior end of the *nucleus lenticularis* (Fig. 28, Nc. L.).

We have said that as far as minute structure and confluence

are concerned, these ganglionic masses must be regarded as one; and yet quantitatively these two ganglia, caudate and lenticular nuclei, are entirely independent of one another. Man possesses the largest lenticular nucleus, but his corpus striatum (caudate nucleus) is not proportionately larger than that of mammals. A similar difference is to be noted between the brains of the monkey and the dog.

Frontal sections exhibit the greater development of the lenticular nucleus in man and the monkey, whereas the ganglion in the dog is inferior (quantitatively) to the caudate nucleus with its head extending around the internal capsule (compare Figs. 6 and 27 with Fig. 28). The arciform shape of the nucleus caudatus is the inevitable result of the similar shape of the hemispherical arch around the fossa Sylvii. This arch sends out as its corona radiata an arch-shaped group of projection fibres, which, as they enter the fore-brain ganglion, separate the upper portion—the caudate nucleus—from the rest of the hemispheric ganglion (Fig. 21). The lenticular nucleus is clearly a wedge, the longest axis of which forms an acute angle, open anteriorly, with the longitudinal axis of the hemispheres. The base of this wedge-shaped body lies to the outside (and to the front), its sharp edge (*Schneide*) toward the median surface; for more bundles enter it from the cerebrum than leave its median portion to pass into the crus cerebri. The fasciculi of the corona radiata diminish in number as they pass through the lenticular nucleus, on their way to the crus. The wedge occupies an oblique position, and for that reason presents the same appearance on longitudinal as on transverse sections. The sharp edge is turned chiefly to the back, the base to the front. This wedge-shape, which has been accounted for above, is complicated by the creation of three or four concentric divisions.

In the inner divisions, the medullary bundles passing through this ganglion are more closely packed; first, because there is less gray substance, and secondly, because not only their own bundles, but bundles also from the outer divisions, pass through these segments. These internal members of the lenticular nucleus seem, therefore, paler and more medullated (*globi pallidi*) than the external division in which the gray substance preponderates. The vertical medullary partitions between the division of this ganglion are termed the *laminæ medullares nuclei lenticularis.* The greater development anteriorly of the gray substance in

the nucleus lenticularis and its satellite, the nucleus caudatus, provides a greater number of ganglionic cells to effect the connection with the superior member of the projection-system. For this reason the fibres of the corona radiata entering the posterior members must be far less in number; and the paucity of fibres will be more noticeable among those coming from the occipital than among those from the temporal lobes. The smooth anterior and external surface of the lenticular nucleus does not receive any fibres from the cortex, for but few bundles of the external capsule touch

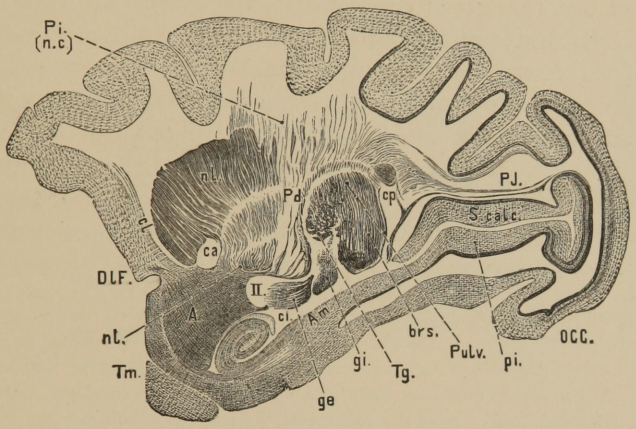


Fig. 30.

Sagittal Longitudinal Section through the Brain of *Hamadryas.*

Fr. Tm. Occ. As in previous sections. Cl. Claustrum. A. Amygdala. Am. Cornu ammonis. S. calc. Calcarine fissure. DlF. Fossa Sylvii. cp. Posterior horn of the ventricle; above it the caudate nucleus, behind it the greater commissure. ci. Inferior horn. ca. Anterior commissure. (n.c.) Caudate nucleus, as islands of gray substance in the corona radiata. nl. Lenticular nucleus. Pulv. Optic thalamus. gi. Internal geniculate body. ge. External geniculate body. II. Optic tract. Pi. PJ. Projection-bundles from the cortex. Pd. Pes pedunculi. Tg. Region of tegmentum (index line passes behind and above it). brs. Brachium of the superior bigeminal body. (In the wood-cut the semicircular bundles of the latter are not distinctly defined, nor is the index line properly placed.)

the lenticular nucleus superficially and cross it in a direction parallel to its outer surface. The finely ramifying radiating bundles of the first division, which collect into larger bundles, are distinguished from fibres of the corona radiata by the fact that the latter are invariably largest nearest to the cortex, and do not increase in the opposite direction toward the crus cerebri. It can be demonstrated from sections in any direction that the lenticular nucleus receives its cortical fibres—the upper division of the projection-system—on its upper surface facing the internal capsule. The cortical radiations of the capsula interna take in part a

radial (?) course, and in part they pass through the laminæ medullares, which are richly endowed with ganglionic cells.

That the radial fibres are fibres of the corona radiata can be stated positively only of the upper layers of the lenticular nucleus. The nearer we get to the basilar surface, the more probable it is that these radiating fibres issue from the ganglion itself. It is quite easy to see that the radiating fibres of the *globus pallidus* are connected with the cortex through the *laminæ medullares*, which pass vertically through the lenticular nucleus to the base, and that the radiations originate in the ganglionic cells of the cortex. The origin of the radial, branching bundles of the external layer of the lenticular nucleus is much more mysterious. I believe that these fibres also originate in the first (outermost) lamina medullaris, and run in an opposite direction toward the external capsule; that, moreover, after they have joined the gray substance of the lenticular nucleus near the external capsule, they turn about and are thus continued, together with other radiating white fibres of the *globus pallidus*, into the crus (Figs. 30, 32, 34, 36).

In regard to the *nucleus caudatus* we must take notice, apart from its connection with the temporal lobe through the stria cornea, of the return of cortical fibres of the internal capsule, after an interruption through the cells of the ganglion, into bundles of the crus. There are no radial cortical fasciculi of the nucleus caudatus, but we find branching medullary fibres near the surface of the nucleus caudatus similar to those that pass through the internal capsule into the outer gray member of the nucleus lenticularis.

The fibres of the second section of the projection-system, which originate centrally in the lenticular nucleus, and pass peripherally below the fore-brain into the crus cerebri, and indirectly into the anterior nerve-roots, and the equivalent cerebral nerve-roots, have a double origin in this ganglion. These fibres take (*a*) a vertical and (*b*) a transverse course.

(*a*) From the middle divisions of the lenticular nucleus, the uppermost layer, probably (?) the continuation of those radial fibres of the external capsule which pass through the lenticular nucleus without the intervention of the *laminæ medullares*, enters the pes pedunculi in front of those fibres of the crus cerebri which descend directly from the cortex (Fig. 33, 4). In the pes pedunculi, however, said fibres do not retain their anterior, superficial position, but cross those cortical bundles of the pes pedunculi which take a vertical course into the pons, in such a manner as to extend from the base backward into the stratum intermedium of

the crus cerebri. The stratum intermedium of the crus includes the substance of Soemmering. [Fig. 36 exhibits the continuation of the bundles of the lenticular nucleus, marked 4, Fig. 33. These bundles are those extending to JS below the chiasma (II.) and crossing the general run of fibres in the crus cerebri.]

(*b*) The transverse bundles of the crus cerebri issuing from the lenticular nucleus run, in part, parallel to the smooth basilar surface of that ganglion, and constitute the *ansa nuclei lenticularis* (Fig. 23, left side). The departure of this *ansa* from the medullated ganglionic meshes of the *laminæ medullares* is well shown on all frontal sections of the nucleus lenticularis; winding around the base of the internal capsule, the formation pushes its way from the inferior surface of the lenticular nucleus upward, forming on its course the innermost bundles of the crus. The base of the internal capsule (its anterior layers) passes into the base—the pes—of the crus cerebri. The fact that the bundles of the *ansa nuclei lenticularis* run upward, or more properly speaking backward, can be best and easily demonstrated by the cleavage method (*Abfaserung*). In this way we can discern laterally the exit of the ansa lent. from the gray substance of the lenticular nucleus; in a median direction the development of the ansa into the innermost fasciculi of the crus, which surround the bundles of the *pes*, and pass behind the *pes* into the stratum intermedium (Figs. 6, 23, 31—ans. lent., SS.). In addition to the superficial stratum of transverse peduncular fibres of the lenticular nucleus, we find also a deeper system of peduncular fibres which, coming in successive layers from the laminæ medullares, interlace as transverse laminæ with the vertical laminæ of the internal capsule (Fig. 36, above II.). The immediate cortical laminæ (*Rinden-*

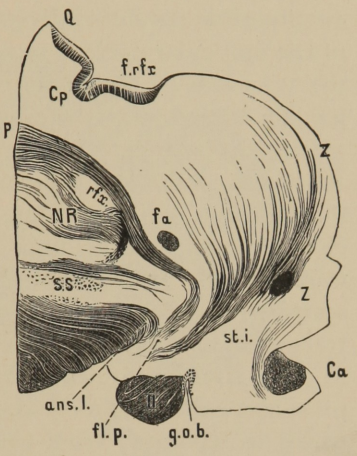


Fig. 31.
Sagittal Section through the Human Brain.

Q. Superior bigeminal body. Cp. Posterior commissure. f. rfx. Fasciculus retroflexus. rfx. The same, passing through the red nucleus (NR). fl. p. Posterior longitudinal bundles. SS. Stratum intermedium with Soemmering's substance. ans. l. Ansa lenticularis. II. Optic tract. g. o. b. Basilar optic ganglion. Z. Stratum zonale of optic thalamus (cut across obliquely at lower Z.). st. i. Stilus internus (internal pedicle) of optic thalamus. Ca. Anterior commissure.

blätter) of the pes pedunculi yield this area of interlacing fibres. The necessity of having these fibres interlaced is explained by the fact that the lenticular nucleus lies (in longitudinal sections) in front of, and the stratum intermedium of the cerebral peduncle behind, the cortical bundles of the internal capsule (Fig. 36).

The *tractus opticus* constitutes the ideal boundary between the internal capsule and the crus. The pes pedunculi is made up of vertical laminæ, which interlace at the nucleus lenticularis and continue throughout its length (Fig. 34). The medullary substance of the lenticular nucleus separates (probably not completely) from the crus cerebri above its entrance into the pons, dividing into laminæ and crossing the crus posteriorly in the direction of Soemmering's substance. In the stratum intermedium the medullary substance of the lenticular nucleus takes a downward course into the posterior division of the pons. The fasciculi of the peduncular stratum intermedium consequently increase on their downward course. In the upper half of the crus cerebri they are mere scattered bundles; in the lower half, however, they form compact transverse masses (Figs. 40 and 41).

The stratum intermedium of the crus cerebri with which the prosencephalic ganglion is connected, extends below the thalamus, which is separated from this stratum by the lower half of the *discus lentiformis* (Figs. 36 and 55). A marked increase in the thickness of the stratum intermedium does not take place until the mid-brain is reached. Consequently we may argue that the majority of the crus fibres from the lenticular nucleus enter the stratum intermedium below the discus lentiformis (Fig. 55, ss.). On this head consult pp. 51 and 53.

CAPSULA INTERNA.

Before giving a description of the diencephalic ganglion we must stop to glance at the capsula interna of the lenticular nucleus—that complicated collection of fibres from the different divisions of the projection-system which separate the ganglion of the fore-brain from the thalamus opticus—the ganglion of the inter-brain. Cephalad the internal capsule connects with a large portion of the corona radiata, caudad it is continuous with the crus cerebri. The extent of the internal capsule cephalad is that of the ganglia, caudad it is bounded by the optic tract. The minute structure of the internal capsule can be studied best from sections of a child's brain, which have been immersed in a solution of

palladium chloride 1 :1,000, before they are stained with potassium and gold chloride 1 : 10,000. Such preparations should present complete longitudinal sections of all the ganglia, and in addition they should be either sagittal or oblique toward the fore and outer part. The internal capsule is a conglomeration of medullated fibres from the hemisphere and the crura cerebri, and also of fibres from the cerebellum. We can discern five different orders of fibres in the internal capsule.

1. A portion of the internal capsule passes from the cortex to

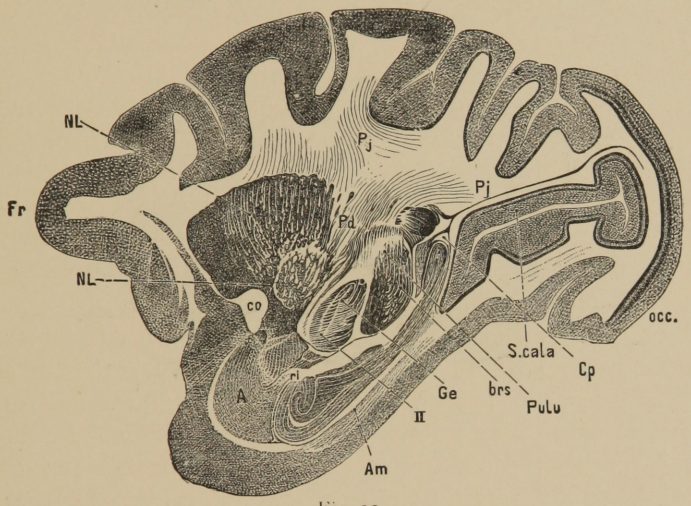


Fig 32.

Sagittal Longitudinal Section through Brain of *Hamadryas* Passing through a Plane between that of Fig. 26 and of Fig. 30.

Fr. Tm. Occ. As in previous sections. A. Amygdala, above it the claustrum. ri. Inferior horn of the ventricle. Cp. Posterior horn of the ventricle. NL. Lenticular nucleus ; under its temporal prolongation, the caudate nucleus ; below this, the optic tract. (The line from II is incorrectly drawn.) Ge. External geniculate body. Am. Cornu ammonis. (The index line is too short.) Pulv. Pulvinar. brs. Ought to point to the foremost semicircle of bundles in the optic thalamus (the brachium corp. bigem. superius). S. cal. Should point to the calcarine fissure. Pd. Bundles of the crus from the internal capsule. Pj. Projection bundles. co. Anterior commissure.

the lenticular nucleus (Fig. 5, 6, 30, 32). These fasciculi course along the superior surface of this nucleus, and on entering it, split up its superior margin. They do not enter the external segment of this nucleus in a body, but insinuate themselves in part (?) as *laminæ medullares* between the various divisions of the nucleus lenticularis (Fig. 34, 1).

2. Another set of fasciculi from the frontal cortex pass through the white substance of the hemisphere and finally

enter the optic thalamus, constituting a *seriatim* defoliated mass of white substance along the inferior surface of the thalamus. The medullated lines seen on longitudinal sections are the edges of the medullary laminæ succeeding one another from above downward, and alternating layer by layer with gray substance. This formation is the anterior pedicle of the thalamus, stilus *anterior thalami optici* (Figs. 5, 29, 33, 36, 55). From this group some fasciculi are contributed also to the stratum zonale.

3. Other fasciculi appear to connect the nucleus caudatus with the crus cerebri (Fig. 29). These bundles intersect with those of

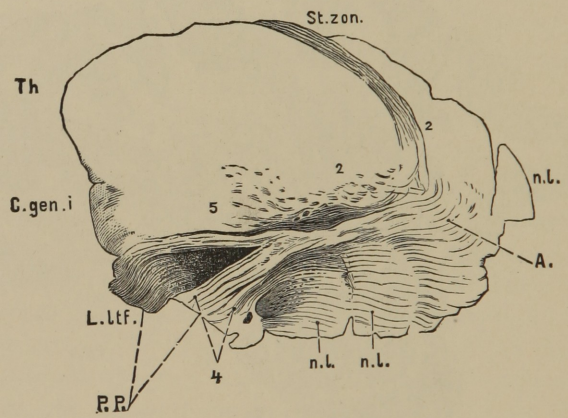


Fig. 33.
Sagittal Longitudinal Section through the Brain of a New-Born Infant.
(Preparation Stained with Potassium and Gold Chloride.)

Th. Optic thalamus. C. gen. i. Internal geniculate body. n. l. Caudate nucleus. n. L. Lenticular nucleus. A. Fasciculus Arnoldi. P. P. Pes pedunculi. 2. Bundles from the stilus anterior of the thalamus. 4. Cortical fasciculi and direct lenticular fasciculi. 5. Fasciculi from the internal capsule to the nucleus ruber. L. ltf. Should point to the black lenticular plate in the angle between 4 and 5.

the stilus anterior thal. opt., lying to the outside of the main mass of the latter formation, and covering the inner portion of the lenticular nucleus.

4. The pes pedunculi contains descending medullated fibres coming from two masses of gray substance. The anterior of these laminated medullary masses issues from the nucleus lenticularis; the posterior and stronger mass, from the medullary substance of the hemispheres—*i. e.*, from the cortex. The latter might fitly be termed the "anterior cortical laminæ" of the crus (*laminæ corticales anteriores pedunculi*). If we choose to speak of

a single bundle of fibres in this connection, it should receive the name *fasciculus of Arnold* (Fig. 33, 4).

The posterior cortical laminæ of the crus, the bundles of Türck, have been exhibited in Fig. 22 (Tm.), and Fig. 5 (Om., P.).

5. The fifth and most posterior medullary division (of the internal capsule), the basilar portion of which is covered by the laminæ of the fasciculus of Arnold and by the discus lentiformis, does not merge into the pes pedunculi, but passes over this on its way to the red nucleus of the tegmentum. This bundle of fibres, as seen in longitudinal sections (Figs. 33 and 36, 5), repre-

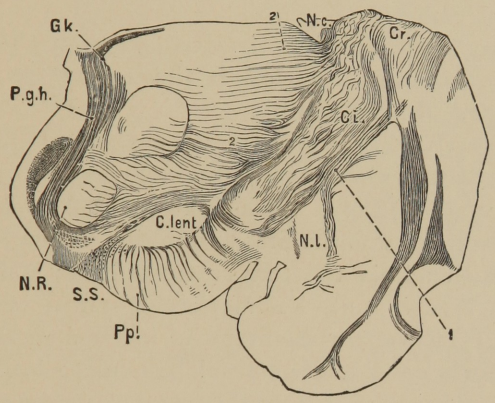


Fig 34.

Transparent Vertical Cross-Section through the Human Brain, Including the Optic Thalamus.

Gk. Stratum zonale adjoining the habenula conarii. P. g. h. Fasciculus retroflexus, or peduncle of the habenula. 2. Bundles from the corona radiata to the thalamus. Between 2 and P.g.h., the semicircular boundary of the thalamic cone, *lamina medullaris*. N.c. Caudate nucleus. Cr. Corona radiata. Ci. Internal capsule. 1. Radiating bundles entering the lenticular nucleus (N.l.) To the right of the lenticular nucleus bundles from the corona radiata pass into the external capsule. N.R. Red nucleus with lateral radiating fibres from internal capsule. C. lent. Lenticular body. S.S. Median portion of the substantia nigra. Pp. Pes pedunculi. In it ascending bundles are visible, which bend downward into the stratum intermedium.

sents the margin of a widely spread fan-shaped formation (Fig. 23). On cross-sections these fan-shaped bundles are also distinctly connected with the nucleus ruber (Fig. 34, to the outside of NR.). After leaving the cortex these fasciculi become entangled in the complexities of the *corona radiata.*

The *discus lentiformis* is connected with a radiating arch of cortical fasciculi, which are in turn interwoven with the rest of the internal capsule. These fasciculi assert their individuality

near their point of insertion, where they issue singly from this confusion of bundles. An innermost bundle of the internal capsule (Forel) is part of this radiating formation. Cordward, external fasciculi leave the discus lentiformis, and pass through the tegmentum into the *brachium corporis bigemini inferius.* In accordance with previous statements of mine, the *pes pedunculi* is traversed on the inner three quarters of its area by bundles destined only for the *substantia nigra* of Soemmering (Fig. 34). Its external quarter alone, into which the fasciculi of Türck are continued, contains bundles of fibres which pass from the upper surface of the discus lentiformis into the tractus opticus (*fasciculi nervi optici* of Stilling).

The discus lentiformis is an isolated ganglion which communicates neither with the red nucleus of the tegmentum, nor with the *substantia nigra* of Soemmering.

All the projection-bundles from the occipital lobe are part of the corona radiata, and not of the internal capsule. Among these bundles there are (1) those which lie to the outer side on the crus cerebri, and which I was the first to describe as bundles of Türck; (2) those which adjoin the former toward the inside, and pass through the brachium of the inferior bigeminal body into that body itself; (3) those which enter the internal geniculate body; (4) those which enter the external geniculate body; (5) those destined for the superior bigeminal body; (6, and lastly) those which enter the pulvinar of the thalamus (Fig. 5, *Om. p., br. s., ge. i., ge. a., br. i., pulv.*).

OPTIC THALAMUS.

The shape of the optic thalamus, and the medullary markings within it, are influenced (1) by the medullary substance of the hemispheres; (2) by fasciculi of the optic tract; (3) by the origin of the tegmentum of the crus cerebri in the substance of the optic thalamus.

Medullary layers make a well-defined ganglion of the optic thalamus. Its most distinct connection is with the tegmentum by means of direct medullary fibres, which thus make the optic thalamus one of the ganglia from which the spinal cord recruits its fibres. Its surface, facing the lateral ventricle, is covered by the stratum zonale, which extends from the stria cornea to the inner margin of the *habenula*—to the middle ventricle. Beneath the nucleus caudatus bundles enter the stratum zonale (1) from

the frontal lobe as superficial layers of the anterior pedicle (Figs. 5, 21, 29, 54, 55); (2) from the parietal lobe (Figs. 6, 34); (3) from the temporal and occipital lobes (Fig. 21); (4) from the retina, passing to the inside of the posterior temporal fasciculi through the tractus opticus; (5) from the ansa peduncularis along the anterior and inner edge of the stratum zonale (Figs. 21, 31); (6) from the ascending pillar of the fornix.

These fasciculi of varied origin, covering the thalamus superficially before entering its depths, intersect at various points. They contain ganglion cells (Boll) before they are merged with the substance of the ganglion proper. The outlying temporal fasciculi pass over the occipital and parietal fasciculi from behind, and cover them as far as the outer margin of the thalamus. Furthermore, those bundles which come from the ansa peduncularis intersect with bundles from the frontal lobes to the stratum zonale (Fig. 36). Bundles of fibres from the ascending pillar of the fornix pass obliquely from the base of the brain through the interior of the thalamus in order to reach the stratum zonale (Figs. 6, 31, 55).

The surface of the thalamus descends vertically from the inner margin of the stratum zonale to the third ventricle, and seems to consist of gray substance.

But this gray substance is not part of the thalamus; for it extends below the optic thalamus into the infundibulum. It is part of that gray investment of the primitive medullary tube which belongs to the primary anterior vesicle, which later on develops into the thalamencephalon; the upper wall of the thalamencephalon retains a membranous covering. This central gray substance, which surrounds inferiorly the basal ganglion of the tractus opticus (Fig. 31), touches externally upon the inner wall of the stratum zonale of the thalamus. The *stilus internus*, derived from the ansa peduncularis, forms the median surface proper of the thalamus, and the (median) most superficial fasciculi of the *stilus internus* take an arciform course backward before entering the posterior commissure. The thalamic stilus anterior of the *ansa peduncularis* takes its origin in the temporal lobe (Fig. 6), and in all probability also in the external capsule.

The optic thalamus has an outer boundary of medullary substance; for the internal capsule of the lenticular nucleus may at the same time be considered the external capsule of the thalamus (Figs. 5, 6): and as soon as traces of the lenticular nucleus in the parietal region are lost, a continuation of medullary substance behind the

internal capsule surrounds the thalamus on its outer side (Fig. 37). The stilus anterior encircles the thalamus on its lower side (Fig. 35). Like the stratum zonale, the stilus anterior is a layer of white substance superimposed directly upon the thalamus; in entering the thalamus it divides into laminæ, and may therefore be considered an integral part of that ganglion. In that part of the thalamus which belongs to the parietal region, a narrow layer of substance forms what might, roughly speaking, be termed a claustrum. (This is the "lattice-like layer" of Arnold.) This formation has a twofold origin: (1) This outer narrow vertical layer of the ganglion (Figs. 30, 32) is bounded by fasciculi from the temporal lobe which ascend with the gray substance of the thalamus to the inner side of the transverse laminæ of the parietal region, and in a direction parallel to the external surface of the ganglion; (2) radiating fibres uniting the hemispheres with the *corpus geniculatum externum*, and, taking a vertical course, intersect in the external gray substance of the thalamus with transverse medullary laminæ from the parietal region, which, on cross-section, present the appearance of transverse fibres.

Being surrounded by a superior and inferior and by an external and internal medullary wall, the thalamus appears wedge-shaped, both on frontal and on sagittal sections. On anterior frontal sections (Fig. 6) the wedge turns its back upward and its edge downward; in sagittal planes, it is low anteriorly and high posteriorly (Figs. 29, 36); and on transverse horizontal sections (Fig. 5), it is narrow anteriorly and broad posteriorly. The longitudinal axis of the thalamus is bent at its posterior end to the outer side, a consequence of the median intrusion of the mid-brain (Figs. 16 and 17); from among the structures of the mid-brain, the corpora quadrigemina press but little, while their appendages, the corpora geniculata, pressing from the inner and lower side, crowd in upon the optic thalamus (Figs. 5, 38, 30, 32).

The formations surrounding the optic thalamus have shed considerable light upon the superior division of its projection-system between cortex and ganglion. We must now study: I. The course of the *hemispheric* fasciculi in the interior of the thalamus. II. The origin of the tegmentum in the thalamus. III. The basilar structures which support the thalamus and which, together with the bundles of the tegmentum, present a special sectional area.

I. The hemispheric (white) substance in the interior of the

optic thalamus, the upper member of its projection-system, enters it from the surrounding white layer, and determines the arrangement of the gray substance by dividing up into laminæ, which can be distinguished on gross macroscopical preparations. The medullary systems referred to above furnish distinct boundaries for two gray nuclei of the thalamus.

a. The *crus adscendens fornicis* divides above, and, before it is lost in gray substance, forms the boundary of the anterior nucleus, *tuberculum anterius, nucleus caudatus thalami.* The stratum zonale, dividing as it were into an upper and lower lamina, participates in this boundary, through the mediation of a transverse layer of fibres from the medullary substance of the frontal lobe (Fig. 38, left a.).

b. That portion of the stratum zonale which is derived from the ansa peduncularis bounds, and passes through the ganglion of the *habenula conarii.* The small nerve-cells of this ganglion resemble in form and density of arrangement those of the conarium. Both are united to bundles of the posterior commissure.

c. Viewed on a cross-section the stilus internus (int. pedicle) of the optic thalamus (derived from the ansa peduncularis) is seen to spread, brush-like, at the outer side of the gray substance of the III. ventricle, over the entire width of the anterior half of the thalamus to the inside and outside of the crus fornicis (Fig 6, st. i. from Th. to Tp.). In the anterior third of the optic thalamus, and on frontal sections, we can discern a group of delicate bundles coursing upwards from the internal capsule over the lenticular nucleus into the deeper layers of the thalamus (Schnopfhagen). In the thalamus these bundles run parallel to those bundles of the ansa peduncularis which pass under the nucleus lenticularis. The former layer intersects from below with the radiating fibres arising from the stilus anterior of the thalamus.

d. The stilus anterior (anterior pedicle) of the thalamus enters this ganglion, in which it is successively denuded of the various laminæ of anterior medullary capsule (Figs. 5—Cp. i., 33, 36—2, 38—a, 55). These laminæ inflate themselves so as to present a surface parallel to the convexity of the thalamus, and close like onion leaves in upon the medullary capsule. Layer by layer the medullary substance alternates with the gray substance, the spindle-shaped nerve-cells of which invariably have their axes directed parallel to their medullary laminæ. The medullary substance of the stilus anterior crosses in the anterior third of the thalamus the radiations belong-

ing to the internal pedicle; further back it lies more to the outer side. An inner (median) portion of the thalamus enters the posterior commissure; the greater portion assumes a funnel shape, and passes directly into the tegmentum. The laminæ of the anterior pedicle have their convexities concentrically arranged, consequently they, and the intervening gray substance, appear truncated on longitudinal and sagittal sections, and present the appearance of arches convex anteriorly, and pushed one within the other (Fig. 55), as seen in cross-sections.

e. The radiating fibres from the parietal lobe give rise in the posterior half of the optic thalamus to transverse laminæ alternating layer by layer with gray substances (Fig. 34).

f. The relations of the occipital and temporal lobes to the thalamus were demonstrated in a previous section by means of preparations obtained by the cleavage method. (Fig. 21, p. 47.) Its relations to the optic radiations were commented upon above, (see p. 86; also pp. 93, 94.)

II. Other medullary fibres in the thalamus opticus indicate the origin of the tegmentum of the crus cerebri. 1. On cross-sections, passing immediately in front of the corpora quadrigemina through the widest part of the wedge-shaped formation of the ganglion habenulæ (Figs. 16 and 17), we see a considerable group of fibres derived from various parts of the stratum zonale, and possibly also from the posterior commissure. These fibres pass through the swelling of the fifth-order-fasciculi of the internal capsule, through the nucleus ruber of the tegmentun. Longitudinal sections through this group clearly exhibit the passage of these fibres into the tegmentum. As the anterior innermost bundle of tegmental fibres, they either curve around the outer side of the third nerve, or are inter-woven with the latter and are then continued into the fasciculus longitudinalis of the posterior division of the pons. Through the intervention of ganglion cells, these fibres are in all likelihood continued into the oblongata, ultimately into the spinal cord. To this group of fibres the name *pedunculus ganglii habenulæ*, or *fasciculus retroflexus*, has been given. Forel suggested "fasciculus of Meynert." (Figs. 31, 34, and 35.)

2. Above the nucleus ruber another nucleus is exhibited, which seems to unite toward the median line with the thalamus opticus, but is distinctly limited to the outer and lower side. Appearances would lead one to suppose that arciform

medullated fibres lying in the frontal plane had joined the cross-sections of those fasciculi which surround the nucleus ruber (Fig. 34). This medullated arch is surrounded on the outside by a few striated, irregular, concentric medullary lines, *striæ medullares thalami optici.* But these medullary fasciculi do by no means course within the frontal planes alone. Schnopfhagen discovered on gold preparations that these striæ consist of short fragments of fibres and of cross-sections of fibres. On longitudinal sections of gold preparations (Fig. 36) these striæ are seen to be made up of segments of fibres from various directions, some of which turn about to enter the *tegmentum* of the crus. On superficial examination the innermost lamina medullaris forms a medullary vesicle, which encloses a semicircular area of thalamic gray substance isolated from the remainder of the thalamus on all but the inner side. This enclosed gray substance does attain to the dignity of a centre in the optic thalamus, for it is not traversed by the same longitudinal fasciculi which contain radiating fibres of the anterior pedicle, and invades much larger areas of the thalamic substance than the small semicircular area bounded by the laminæ medullares after their interruption by ganglion cells of the thalamus.

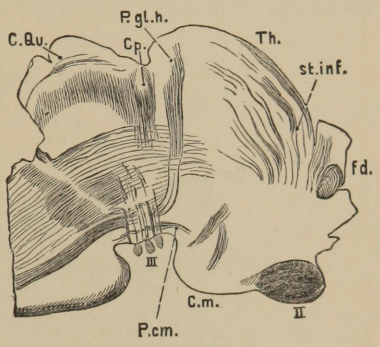


Fig. 35.

Sagittal Longitudinal Section through the Brain of *Lemur.*

C.Qu. Corp. quadrigemina. Cp. Posterior commissure passing into the tegmentum. P.gl.h. Fasciculus retroflexus of the tegmentum. III. Oculomotorius nerve in front of the pons and behind the corpus mamillare—C.m. P. cm. Its tegmental fasciculi. Th. Optic thalamus. st. inf. Stilus internus of thalamus. fd. Descending pillar of the fornix and anterior commissure. II. Optic chiasm.

These *striæ medullares* with ganglion-cells interspersed in between are simply slender continuations of the anterior pedicle. Cross-sections passed through the brain trunk at various levels present the same deceptive appearance of the innermost lamina medullaris taking a transverse arciform course to the tegmentum. This deception must be ascribed to a number of concentric arches diminishing in size in a downward direction, of which one would fit within the other. At the level of the posterior commissure, this arciform formation has disappeared and a cross-section

of bundles has usurped its place on the outer side of the nucleus ruber. From this we may infer that longitudinal fibres contribute to this origin of the tegmentum by uniting downward in funnel-shaped fashion.

The laminæ medullares of the optic thalamus are, therefore, composed not of transverse fasciculi, but of longitudinal bundles, which are juxtaposed in such a way as to give rise to an arciform formation on cross-sections. The laminæ medullares seem to form a dense medullary mass, and to be the extension of long-drawn fasciculi: but this is a deceptive appearance, due probably to the

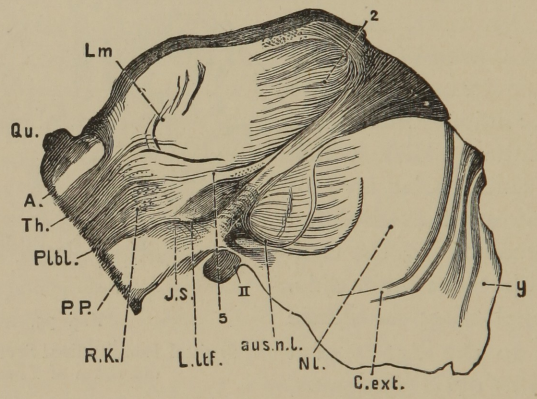


Fig. 36.

Sagittal Oblique section through an Infant Brain. (Stained with Potassium and Gold Chloride.)

This section through the thalamus and lenticular nucleus of the right side runs obliquely in an internal and posterior direction, and would cross the median line if continued below the corp. quadrigemina.

Qu. Corp. quadrigemina A. Aqueductus Sylvii. Th. Bundles of tegmentum from the thalamus. R.K. Lateral layers of the red nucleus. Lm. Laminæ medullares in optic thalamus. 2. Interlacing of bundles destined for the stratum zonale and for the thalamus in the internal capsule. Nl. Lenticular nucleus. C.ext. Its external capsule. Plbl. Superior peduncle of the cerebellum above the point of decussation. P.P. Pes pedunculi. J.S. Stratum intermedium. L.ltf. Lentiform disc. II. Optic tract. Ans.n.l. Ansa lenticularis, which on its way to the estratum intermedium is interwoven with the fasciculus of Arnold belonging to the internal capsule. y. Island. The layers as far as the internal capsule are incorrectly represented in the wood-cut.

N. B.—The apparent anterior end of the discus lentiformis represents the radiation of the posterior longitudinal fasciculus. The same is true of the dark crescent of the optic tract.

introduction of transverse radiating fibres from the parietal lobe. These radiating fibres are interwoven with the juxtaposed, tegmental fasciculi from the corona radiata and pass in the direction toward the third ventricle. By filling up the gaps left by the other

order of fibres, these two distinct groups (the lam. med. and the fasciculi from the parietal lobe) form a compact mass of medullary substance. Longitudinal oblique sections through the thalamus exhibit, in addition, concentric arched formations, which are convex anteriorly and open posteriorly, thus contrasting strongly with the appearance of the striæ medullares on longitudinal sections. But the former do not form compact medullary masses; they are the result of the defoliation of the stilus anterior in the optic thalamus, the resulting laminæ having a concentric arrangement, and presenting their convex surfaces toward the

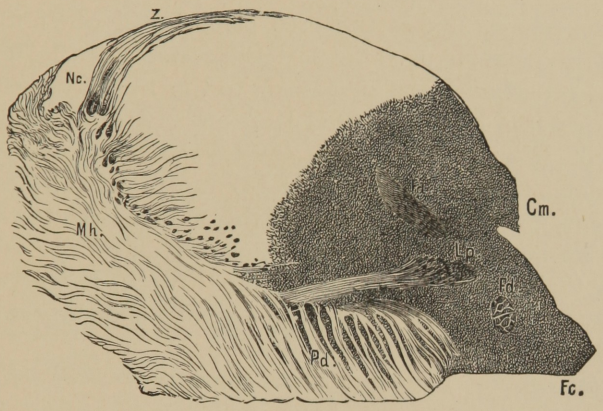


Fig. 37.
Frontal Transverse Section through the Human Thalamus.

Nc. Caudate nucleus. Mh. Medullary substance of the hemispheres. Pd. Pes pedunculi. Z. Stratum Zonale of thalamus. Cm. Median commissure. Fa. Ascending pillar of fornix. Fd. Descending pillar of fornix. Lp. Cross-section and radiation of the posterior longitudinal fasciculus. Fc. Tuber cinereum.

third ventricle. These laminæ belong to an anterior region of the thalamus, in which they and the connecting fasciculi change off with layers of gray substance, in which they end and originate anew (Fig. 33).

This entire system of nerve bundles, which enters the thalamus as its stilus anterior, and emerges from it as an outer division of the tegmental fasciculi, forms two stratified cones with adjoining bases, situated about midway between the ends of the thalamus. The anterior cone is by far the larger one of the two; the posterior cone is hollow, and exhibits a cleft-like opening toward the median line. The innermost median area of the

thalamus is occupied by the system of fibres composing the internal pedicle, which connects with the posterior commissure and runs back of the *fasciculus retroflexus*. This accounts for the formation of the median cleft of the tegmental cone in the thalamus.

At the same time the external concentric laminæ which surround the *laminæ medullares*, are too low to rise in concentric fashion above the upper segment of the latter. There are several reasons for the lowness of these parts : First, the height of the brain-trunk diminishes in the direction from the thalamus to the tegmentum; and, secondly, we find that the fasciculi of the tegmentum, originating in an antero-posterior direction, take, in keeping with the parietal flexure a course from above downward toward the pons.

To the tegmentum of the crus cerebri still other fibres are added, which emanate from the posterior commissure, lie below the fasciculus retroflexus, and in passing to the front run parallel to the "fasciculus of Meynert,"[1] but later on curve downward toward the medulla (Fig. 35, Cp.). The *commissura media*, between the optic thalami, resembles the posterior commissure in structure ; for by the cleavage method we can prove that bundles pass through this commissure also, which unite the stilus interior of one side with the optic thalamus of the opposite side (Fritsch, Holländer). In the thalamus these bundles seem to ascend a short distance in an oblique longitudinal direction.

A stout anterior bundle of fibres from the *tractus opticus* connects the retina with the thalamus. This bundle ascends between the corpus geniculatum externum and the pes pedunculi, in front of the pulvinar, and has its radiating fibres enter the thalamus on its inner aspect. These radiating fibres are situated at some distance from the fibres connecting the tractus opticus and the discus lentiformis, and ought not, therefore, to be confounded with the latter group of fibres.

III. The ganglia of the fore- and inter-brain are surrounded by medullary formations, which start from the base of the brain and take a course about parallel to that of the tractus opticus. These constitute the *substantia innominata* of Reil. This medullary layer lies in front of the tractus opticus, and in the depths of the brain structure it separates the optic tract from the pes pedunculi. After removing the optic tract (Fig. 23), we observe that this basal zone undermines the lamina perforata anterior, and passes through the nucleus caudatus as it

[1] Forel suggested this designation.

did through the anterior commissure, only in a more basilar direction.

There are morphological reasons for the formation of this girdle. Its bundles pass from the outermost region of the brain-axis (principally from the corona radiata of the temporal lobe, and from the external capsule), over the crus cerebri to the median points of decussation (median and posterior commissures. Schnopfhagen's decussation). As regards the origin of this medullary substance of the ansa peduncularis (Gratiolet), from the temporal lobe, the interweaving of bundles of the *ansa peduncularis* with the fibres radiating into the pulvinar, and with the outermost bundles of the pes pedunculi (Fig. 23, Tm.), presents the appearance as though the outer fibres of the crus travelled in girdle-like fashion below the posterior margin of the lamina perforata anterior to the inner surface of the crus (Fig. 23, in front of Pd.). This is easily explained, for the radiating fibres from the temporal lobe into the brain-trunk either turn backward to enter the thalamus and crus cerebri, or forward to enter the ansa peduncularis; but fibres running in both directions, from identical points of the sectional area of the temporal corona radiata, interweave with one another. This network of fibres, and the course of these bundles in opposite directions, can be well exhibited on cleavage preparations (Fritsch, Holländer).

The following formations go to make up the basilar girdles of the brain-trunk:

1. The *tractus opticus*, which not only sends decussating fibres through the chiasma into the optic nerve of the opposite side, but also transmits non-decussated posterior fibres into the optic nerve of the same side. Part of the tractus opticus adjoins the *tuber cinereum*, and here its upper surface is connected with Wagner's *ganglion opticum basale* (Fig. 31, g.o.b.). The chiasma is suspended as it were on this ganglion, for the latter stands out entirely free in a basilar direction. The ganglion transmits non-decussated fibres to the optic nerve.

2. In front of the *chiasma* we find the *pedunculus septi pellucidi* (as the superficial layer of the *lamina perforata anterior*) passing beneath the nucleus caudatus and to the outer side.

Between this superficial layer of fibres and parallel deeper layers in the caudate nucleus, which, as was noticed above, arise from the ansa peduncularis, we discern a special stratum of dense, transversely directed ganglion cells, which are parallel to said fibres, and can be traced as far as the external capsule. They constitute a flat, sharply

defined, special ganglionic formation, which equals in area the *lamina perforata anterior*. This *ganglion ansal peduncularis* has its cells run parallel to the ansa peduncularis and is intersected by bundles coming from the latter.

3. Immediately above the optic tract lies the *commissura inferior* (Fig. 6, II.), the median portion of which is lodged in the convexity of the tuber cinereum, while its recurrent lateral portions lying to the outer side of, and immediately adjoining, the crus cerebri, about which they form a belt, run deeper in ascending.

4. The *ansa peduncularis*. We can gain no insight into the general structure of the brain-trunk without keeping in mind preparations obtained by the cleavage method. From such preparations we can understand at a glance the stratification of the ansa peduncularis; and transparent transverse sections will corroborate in excellent manner the facts brought out by these preparations. The posterior surface of the ansa peduncularis projects gutter-like over the commissura optica (Fig. 22 to the right and next to the cut end of the optic tract). The ansa peduncularis is composed of three layers: the internal pedicle of the optic thalamus, the posterior medullary lamina of the tegmentum (so-called *fasciculus longitudinalis posterior*), and the *ansa lenticularis;* all three layers taking entirely different courses.

a. The *stilus internus* forms the most ventrad layer of this formation (ansa ped.). It was fully described on pp. 88 and 89. There is this, however, to be added, that part of its bundles cross the median line through the median commissure (Fritsch, Holländer).

b. The posterior longitudinal bundle (fasciculus longitudinalis posterior) lies, as viewed from the base, above the stilus internus, and under the ansa lenticularis. To the outer side the three layers of the ansa ped. are super-imposed upon and cover one another. In the median direction they are distinctly separable, for the stilus interior extends least, and the ansa lenticularis extends farthest, backward. Within the ansa the posterior longitudinal bundle is distinguished by a more grayish tint. This applies to gross preparations, from which we may learn also that this bundle is softer than the other two layers. On their course backward, parallel to the third ventricle, the stilus internus and the fasciculus longitudinalis posterior diverge to a distance equal to the height of the *aquæductus*, for the stilus internus passes behind the aquæduct into the posterior commissure, and the poste-

rior longitudinal fasciculus enters the gray substance in front of the aquæduct. These bundles, emanating from the ansa peduncularis, are joined by others from the tuber cinereum, which lie close to the inner surface of the third ventricle, or the infundibulum, respectively, while, on the other hand, the commissura inferior lies closer to the outer surface of the tuber cinereum. The bundles in question were demonstrated also by Schnopfhagen on frontal sections of preparations which had been stained with gold. Turning back, at least a portion of these bundles enter Schnopfhagen's commissure, which lies in the posterior wall of the third ventricle above the red nucleus and behind the corp. mammillaria. Below this commissure they course over the nucleus ruber (Fig. 31), and through the mid-brain (Figs. 40 and 41), probably as the innermost bundles of the cross-section. This portion of the posterior long. fasciculus, derived from the central gray substance, seems solely to cover the ascending crus of the fornix; in order to enable the latter to enter the thalamic ganglion, the posterior longitudinal bundle divides into two laminæ for a certain distance of its course.

The expression *fasciculus longitudinalis posterior* applies only to the lower portion of this medullary formation, with which every one has been made familiar through Stilling's investigations, and which has been described as lying in front of the aquæductus Sylvii in the mid-brain, and in front of the gray substance of the pons (Figs. 40, 41, 42, 43—L.). That portion of this system, which I described more than twelve years ago as a connecting link between the ansa peduncularis and the posterior longitudinal fasciculus (Figs. 31 from rfx to the basal fl.p.), is merely the inner margin of the powerful radiation of the posterior fasciculus, which covers the entire posterior surface of the peduncular system. The familiar leaf-shaped tapering (to the outside) form of the fasciculus longitudinalis posterior is nothing more than the lower, probably imperfect, extension of this medullary radiation.

The radiation of the posterior fasciculus represents a projection-system passing from the medullary substance of the hemispheres (from the cerebral cortex) into the central gray substance, which forms, as it were, at one and the same time, the floor of the ganglia and the roof of the crus cerebri.

All the radiating fibres converge from the central surface toward the inner, thicker margin of this radiating system, along which they take a sagittal course downward. Fibres taking such

a direction can be seen below the thalamus, on frontal sections also (Fig. 37, Lp; cut made in the year 1866). This fact was recognized later on by Forel.

The radiations of the posterior longitudinal fasciculus, from the frontal lobe of the cerebrum, pass through the internal capsule into the medullary substance above and in front of the *discus lentiformis*, which is part of the radiation of the posterior fasciculus (Fig. 33, the short, interwoven bundles of the fasciculus of Arnold).

The radiations from the temporal lobe bend from below upward with those of the external capsule in the ansa peduncularis, and take the same course as the other fibres under the *thalamus opticus* (Fig. 31). In the ansa peduncularis these radiating fibres do not form a mere strand, but a broad, stout lamina, the outermost bundles of which lie so far distant from the median bundles that they ascend to the outside far above the *tractus opticus* (comp. Fig. 31, fl.p. and Fig. 29, where the ascent to the inner capsule is not marked above II.). That portion arising above the optic tract surrounds the inner capsule with its concave surface turned outward, so that the internal capsule is seen to interrupt on sagittal sections the course of the anterior segment of radiating fibres into that segment which passes over the crus.

No part of the tegmentum of the crus extends as high up in the brain-trunk as does the *fasciculus posterior*. At the highest point the radiations lie in front of the pes pedunculi (Fig. 31 fl.p.), then in front of the stratum intermedium, the bundles of which connect at the outer side with the nucleus lenticularis; after that this system of fibres rises above the discus lentiformis,[1] and lower down the posterior fasciculus is pushed far off from the pes pedunculi by the nucleus ruber of the tegmentum. In order to cross the processus cerebelli ad cerebrum, the fasciculus longitudinalis ascends from the median side of the præpeduncular (Wilder) *radiations* to that process itself. Over the discus lentiformis, on the contrary, the *radiating* fibres of the posterior bundles were covered by the radiations of the processus ad cerebrum (Forel), the latter lying close under the thalamus as the fifth layer of the internal capsule (Fig. 33, 5). In this figure the discus lentiformis unites with the radiations of the fasciculus longitudinalis posterior. Figures 54 and 55 exhibit the radiations of the longitudinal bundles as dark cross-sections of medullary sub-

[1] In Fig. 31 it should fill out the space NR., fl.p. and of the bundles SS.

stance in front and above the discus lentiformis Lb. and L.lf. The nerve-bundles passing over these belong to the radiation of the processus cerebelli ad cerebrum.

(*c*) The ansa lenticularis has been described above, p. 81.

C.—THE MID-BRAIN (MESENCEPHALON).

Four symmetrically situated ganglia belong to each half of the mid-brain region, viz.: 1. One half of the upper, 2. one half of the lower, corpus bigeminum; 3. the external, and 4. the internal,

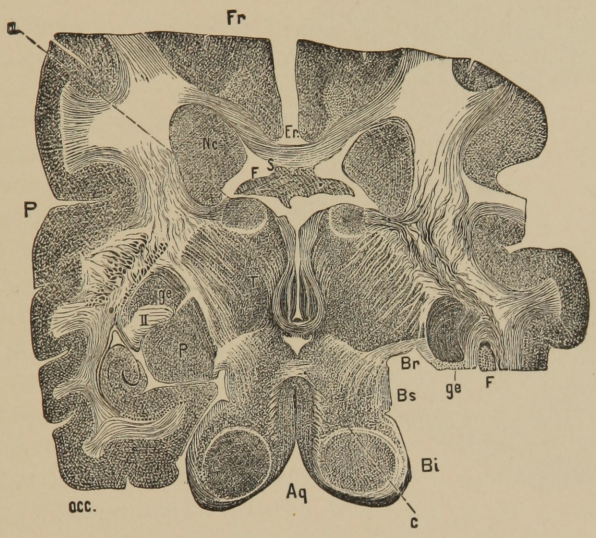


Fig. 38.

Horizontal Transverse Section through the Brain of a Dog—the Right Half nearer the Base than the Left.

Fr. Frontal lobe. P. Parietal lobe. occ. Occipital lobe. Fr. Corpus callosum. S. Septum pellucidum. F. Descending pillar of the fornix. a. Stilus anterior of the thalamus. Nc. Caudate nucleus. Th. Optic thalamus on its median surface; next to the gray substance of the third ventricle are bundles in the habenula and to the outside of it which enter the decussation of the posterior commissure in front of a fragment of the pineal gland, and are connected with the inner margin of the stratum zonale; the median choroid plexus has been torn off from the latter. ge. External geniculate body. II. Optic tract. Bs., Bi. Superior and inferior bigeminal body. Br. Brachium of the superior bigeminal pair. c. Transverse bundles in the roof of the aqueduct, adjoining the posterior commissure. Aq. Sylvian aqueduct.

corpus geniculatum. In mammals we must speak of upper and lower corpora geniculata (Forel). Both parts of the corpora quadrigemina unite at the one end with the hemispheres, and at the other end with the retina, which must be considered homologous to the *bulbus olfactorius*. There is this difference, however,

the bulbus olfactorius connects directly with the cortex; while the retina is united first to the corpus bigeminum. From the *retina* fibres of the optic tract enter internodal masses, which are joined to the cerebral cortex by portions of the so-called brachia of the corpora quadrigemina.

1. Connections with the *tractus opticus:* The connection of the tractus opticus with the corpus géniculatum externum (Figs. 26, 30, 32, 38) is very evident. This ganglion is not a homogeneous mass, but consists of gray laminæ alternating with white substance. Properly speaking, the corpus geniculatum externum is a folded gray membrane which does not, like the gray substance of the retina, unroll its entire surface, but remains enclosed in a medullary capsule. All the fibres of this capsule are not connected with cells of the corpora geniculata. The superior corpus bigeminum is joined to the corp. genic. extern. by bundles of fibres which in man constitute the posterior portion of the superior brachium, or its well-developed posterior margin, and are covered by the pulvinar. In mammals whose pulvinar is scantily developed, these very same fasciculi lie exposed on the surface; here, moreover, the corpus geniculatum externum lies upon the optic thalamus (Forel). The radiating fibres from the corp. genic. extern. into the corp. bigem. super. pass into the superficial layer of neuroglia; this layer of gray substance is more developed in the mammalian brain, on account of its greater (typical) wealth of con-

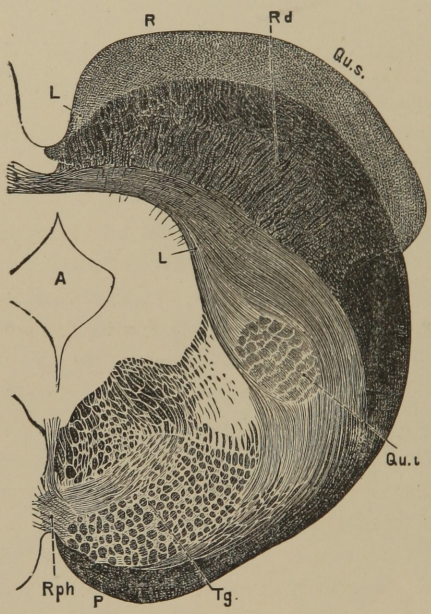


Fig. 39.

Oblique Section through the Brain of a Lion (Stained with Potassium and Gold Chloride).

Qu. s. Superior pair of bigeminal bodies. R. Gray substance of its surface. Qu.i. Oblique section of the inferior bigeminal body. Rd. Radiating bundles from the corp. quadrigemina to the gray substance surrounding the Sylvian aqueduct. L. Formation of the lemniscus (the line of the upper L should point to the decussation). A. Sylvian aqueduct. Rph. Raphe. P. Pes pedunculi. Tg. Tegmentum of the crus.—The presence of external (dark) lemniscal fibres, derived from higher levels of the superior bigeminal body, is due to the obliquity of the section.

nective tissue (Fig. 39, R., cortical layer, Forel). The *fasciculi bigemino-geniculares* of the upper bigeminal body surround on both sides its oblique oval ganglia, which are flattened anteriorly by lying upon the *stratum lemnisci.* For this reason these ganglia present on cross-section the appearance of plano-convex lenses. The axes of the superior bigeminal body intersect close behind this ganglion and diverge anteriorly, leaving the posterior commissure exposed between them (Fig. 17.) In comparison with the distinctly transverse direction of the lemniscal layer, the *fasciculi bigem.-geniculares*, which enter along the entire upper margin of the superior corpus bigeminum, might be considered to be longitudinal fasciculi of the latter (Fig. 39). This is particularly true of those bundles which are situated on the inner border of this ganglion.

The corpora quadrigemina are connected also with the *corpus geniculatum internum*, which is united distinctly (1) to the corpus bigeminum superius and (2) to the corpus bigeminum inferius, through bundles which reach it from the *brachium corporis quadrigemini inferius.*

Radiations from the tractus opticus into the corp. geniculat. internum travel by way of the *discus lentiformis*, with which the tractus is connected (Stilling). The discus is united toward the rear, by a medullated pedicle, to the *brachium corporis quadrigemini inferius*, situated on sagittal sections in front, and on frontal sections to the inner side, of the thalamus. At the same time it is unquestionably true that the internal geniculate body effects a connection between the inferior brachium of the quadrigeminal body and the superior bigeminal body; but its connections with the corpus bigeminum inferius are equally distinct, so that the optic tract may well appear to be connected by means of the discus lentiformis with the inferior bigeminal body. The transverse position of the bundles which surround the ganglion of the lower corpus bigeminum does not enable us to distinguish between the indirect radiations from the *retina* and the cortical fasciculi of the inferior brachium, as we can do with the longitudinal optic radiations in the upper bigeminal body.

A superficial inspection of these parts would lead us to suppose that the tractus opticus is connected directly with the corpus geniculatum internum; but this is not borne out by a more careful examination.

It will be well to divide the radiations from the *nervus* and *tractus opticus* into four component parts: *1.* The anterior radiation into the *ganglion basale.* Ascending fasciculi unite this ganglion

with other regions of the central gray substance. *2.* The upper radiation, entering the *discus lentiformis* which lies above the corpora geniculata. This discus lentiformis enters apparently into connection with the radiation of the posterior longitudinal fasciculus (?). *3.* The outer radiation, or radiation into the corpus geniculatum externum. *4.* The internal radiation into the thalamus, which contributes, on the inner side and to the front of the corpus geniculatum externum, to the formation of the latter's capsule; and which, after the fashion of the corona radiata, enters the thalamus from the outer side in front of the *pulvinar*. That these bundles, after having been interrupted in the thalamus, are continued toward the corpus quadrigeminum, has not been proved.

2. There is a twofold, powerful connection between the corpora quadrigemina and the cerebral cortex.

a. The corpora quadrigemina receive radiating fibres direct from the cortex (upper member of their projection-systems). In the superior bigeminal body, cortical radiations are found in the course of the arm of this upper corpus bigeminum, constituting its deeper anterior layers, which are covered by the connection between this said brachium and the corpus geniculatum externum (Fig. 38, left, between T. and P.).

The brachium of the superior bigeminal body covers the corpora geniculata, and a wedge-shaped mass of thalamic substance between them; on frontal sections this *cuneus thalami optici intergenicularis* appears triangular.

The bundles of its brachium connect the cerebral cortex with the inferior bigeminal body.

b. The superior and inferior corpora bigemina also receive indirect fibres from the cortex, inasmuch as their annexed ganglia, the corpora geniculata, are favored with special cortical radiations. The cortical fibres entering the corpus geniculatum internum may possibly also enter the corpus bigem. superius, for (as was stated above) there is a distinct medullary connection between these ganglia. The connections of the external corpus geniculatum with the cerebral cortex radiate from above as a stout medullary mass into this ganglion. While coursing along the outer surface of the thalamus, this radiation contributes to the formation of the lattice stratum of the thalamus (*vide* p. 88 and Fig. 32, above *Ge.*).

The *frenulum*, or, as it should be termed, the *processus cerebelli ad corpus quadrigeminum*, unites both bigeminal bodies to the cerebellum.

The peripheral connections of the corpora quadrigemina lead

(1) directly into the central gray substance surrounding the aquæductus Sylvii; from the fascicular substance of the upper corpus bigeminum, or from its gray substance, numerous fine, radiating bundles are developed, which, on gold preparations, seem to be the main constituents of that area of the corpora quadrigemina lying to the outer side of the lemniscal layer; these penetrate the strat. lemnisci, and can be traced still further into the gray wall of the aqueduct than is exhibited on Fig. 39 Rd. The terminal masses of the optic tract are connected in this way with the central gray substance, in which fine medullary fibres, belonging to the origin of the third nerve, circumscribe a nucleus confluent with the nucleus of the fourth nerve (Fig. 39, Rd.; Fig. 40, III.).

3. The corpora quadrigemina are connected indirectly with the central gray substance, for by giving rise to the lemniscus they constitute the central origin of a portion of the spinal cord. The bundles of the lemniscus enter the ganglia from deeper layers of the brachium corporis bigemini superius, and of the brachium inferius. The former portions, after broadening on their way downward into the median base of a triangle, attain the median line, which they cross, and then enter into a deeper stratum of the lemniscus of the opposite side. The latter division of the lemniscus forms a triangular group of bundles with an upper median base, which lie immediately below the brachium anterius, which in turn is spread most in a median direction. The bundles of the lemniscus arrange themselves in such a way on their downward course that those which lie uppermost at the decussation are pushed furthest toward the raphe.

The superior bigeminal body exhibits (if light is allowed to fall through) a concentric stratification corresponding (1) to its layer of neuroglia; (2) to a layer of vertical fasciculi from the corp. geniculatum externum; (3) to a radial layer interwoven with these fasciculi; (4) to the transverse layer of the lemniscus (Fig. 39).

The anterior surface of the lemniscus receives a number of fasciculi, the origin of which is a matter of conjecture; their participation in the decussation of the lemniscus behind the aqueduct is very improbable also, for they would have to cross back again in front of the aqueduct. These bundles surround the aquæductus Sylvii, and lie next and to the one side of the lemniscus, of which Forel thinks they form a part, and which he terms *fasciculi decussationis anticæ*. They form a convex swelling along the

anterior margin of the aqueduct (Fig. 40, Krz B.), due to their interweaving with longitudinal bundles in which I recognize the cross-section of the posterior commissure.

These bundles appear to me to spring from that cluster of cells which Jacubowitsch and Virchow likened to the cells of the sympathetic, and which, at the same time, furnish the central origin of the descending root of the fifth nerve (Fig. 41, 5). I have termed these capsular bundles of the aqueduct quintus-

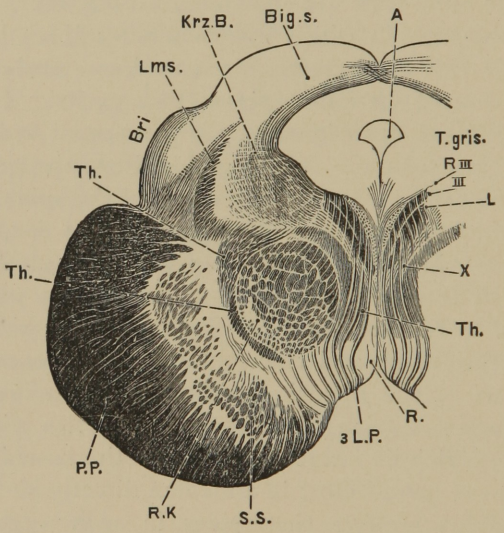


Fig. 40.

Transverse Section through the Region of the Superior Pair of Quadrigeminal Bodies in a Plane Vertical to the Longitudinal Axis of the Brain.

Big. s. Superior bigeminal body. A. Sylvian aqueduct. Lms. Lemniscus (fillet) arising from the decussation behind the aqueduct. Bri. Inner protuberance and fasciculi of its brachium. Krz. B. Anterior cross-bundles of the corpus quadrigeminum. x. Points to the region of decussation. Th. Bundles from the thalamus to the Tegmentum. L. Posterior longitudinal fasciculus. T. gris. Central cavity-gray. R. III, III. Nucleus and central roots of the oculo-motorius. 3 L.P. Root of the third nerve and lamina perforata posterior. R. Raphe. P.P. Pes pedunculi. S.S. Stratum intermedium and Sœmmering's substance. R.K. Red nucleus of the tegmentum.

columns; perhaps the term *fasciculi marginales aquæducti* would be better (unbefangener). On the cross-sections they are seen to rise from a narrow margin parallel to the aqueduct, to spread in rays in order to interweave with the bundles of the posterior commissure mentioned above, then to attain their point of decussation in the median line by forming a narrow band between the posterior longitudinal bundle and the nucleus ruber (Fig. 40, L. and R.K.). From the point of decussation they encircle the

nucleus ruber on the inner side, and are then lost to the front and to the outer side of this nucleus.

The corpus bigeminum inferius is simpler in structure than the superior bigeminal body. The fasciculi of the brachium corp. quadrigem. inferius, which run under and past the corpus geniculatum internum, give the former a white surface, traverse the ganglion, and bound it below giving it the shape of a biconvex lens. After decussating in the roof of the aquæductus, the bundles of the

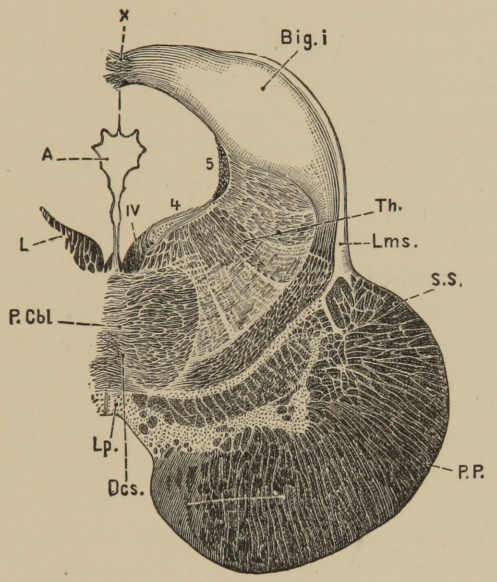


Fig. 41.

Cross-Section through the Inferior Pair of Bigeminal Bodies in Man.

Big. i. Inferior bigeminal body. x. Crossed transition of the inferior brachium of the corp. bigem. into the lemniscus. A. Aqueduct (the outlines of which have been unnecessarily indented and prolonged anteriorly). L. Posterior longitudinal fasciculus. IV. Nucleus of fourth nerve (the line should point further outward to the oval space containing small cells). 4. Root of fourth nerve. 5. Descending trigeminal root. P. Cbl. Dcs. Decussation of the superior peduncles of the cerebellum. Th. Thalamic fasciculi of the tegmentum. Lms. Lemniscus. Lp. Posterior perforated lamina. S.S. Stratum intermedium, and Soemmering's substance. P.P. Pes pedunculi.

above brachium enter the lower division of the quadrigeminal portion of the lemniscus (Fig. 41, Fig. 56, L. II.). The cross-section of the posterior decussation of the lemniscus extends on sagittal sections through the middle of the inferior corpus bigeminum only as far as the middle of its entire length, and stops short at the beginning of the frenulum.

The mid-brain (mesencephalon), like the posterior half of the

inter-brain (thalamencephalon), shows four distinct layers: 1. Posteriorly, the ganglion, Big. s., Big. i; 2. The cross-section of the tegmentum (Figs. 40 and 41, Th., Lms., L., R.K., P. Cbl.); 3. The stratum intermedium (S.S.; in Fig. 41 the arrow is too short). 4. The pes pedunculi (P.P.).

Above its point of decussation the superior peduncle (Bindearm) traverses the tegmentum in front of (ventrad) the *upper* bigeminal body; during decussation this cerebellar peduncle crosses the tegmentum in front of the *lower* bigeminal body. Ventrad of the lower bigeminal bodies the fasciculi of the tegmentum are crowded from the inner side outward, owing to the considerable space occupied by the decussation. The sections of the medullary portion of the stratum intermedium do not extend as far to the outside, but further toward the median line, than the sections of the medullary fibres of the lemniscal layer (Fig. 41).

The composition of the tegmentum remains quite unchanged in the upper cross-sections of the pons, ventrad of the entire corpus quadrigeminum; with this exception, however, that the fasciculi of the processus cerebelli ad cerebrum emerge again from the decussation, proceed to the outer side, and form that posterior portion of the system of the superior peduncle, which comes from the region of decussation and enters the cerebellum (Figs. 22, 42).

The superior peduncle, as it reaches the external surface, appears club-shaped on cross-section (Figs. 42–45). In the cross-sections of the pons, at levels below the corp. quadrigeminum, this peduncle is powerfully developed. On its outer surface lies the lemniscus, which consists of bundles that on their downward course appear dark, like cross-sections, and of other bundles, the course of which, both to the inner and outer side of the former group, happens to coincide with the plane of the section. The outermost of these flowing bundles might properly be considered as part of the origin of the lemniscus from the lower corpus bigeminum; the inner group of bundles is undoubtedly part of the inferior lemniscus, which ascends from the vermis superior of the cerebellum, through the valvula cerebri, to a position above the processus ad cerebrum, and is transformed in the medulla spinalis into a fasciculus of the lateral column, immediately in front of the posterior cornu (Figs. 23 and 54, LS). The cross-sections of the thalamic bundles seem to be surrounded by the

sup. peduncles, and deserve to be termed the *thalamic area* of the posterior division of the pons.

Before giving an account of our present knowledge of the course the fibres take from the brain-trunk to the spinal cord, we will take note of the relations of the gray substance to the nerve-nuclei, down to the point at which the eighth nerve emerges from the brain substance. On gold preparations from the infantile brain (Figs. 43–46) the gray substance seems to be a barren basement substance.

On sections through the brain-trunk at the level of the upper corpus bigeminum, the aquæductus Sylvii was seen to be surrounded by a gray substance; and the gray substance of its anterior wall could well be compared with the anterior horn of the spinal cord, into which this gray substance is ultimately prolonged.

The nuclei of the third nerve (Fig. 40, III.) are bounded by fibres which reach the central gray substance after passing from the crus cerebri of the opposite side through the raphe, and which in describing delicate, posteriorly convex arches, surround and penetrate an oblique-oval group of nerve-cells.

From this nucleus, which remains confluent with the rest of the gray substance in spite of its well-defined boundary lines, stout root-bundles of the third nerve emerge (Fig. 40, 3), which turn to the front and are slightly concave toward the raphe; these roots either surround the red nucleus of the tegmentum, or lie on its inner side. The innermost of those bundles which pass into the raphe approach close to the aquæductus, between the nuclei of the third nerves, and there divide into a number of diverging fibres. It is as difficult to trace these to their final termination, as it is to follow up those radiating bundles which seem to approach them from the corpus quadrigeminum. Cross-sections of descending root-fibres of the fifth nerve lie immediately next to those marginal bundles (p. 104) which enter the decussation in the tegmentum, in front of the aquæductus Sylvii. These descending roots spring from clusters of vesicular cells. The shape of these cells, which possess distinct sheaths, we said above could be compared to the shape of the sympathetic ganglion cells. They take no part in the gray reticulum of fibres surrounding the aquæductus, into which optic fibres, and the prolongations of third nerve-cells enter.

On cross-sections, through the plane of the lower bigeminal

body (Fig. 41, L., IV.), the area occupied by the nucleus of the third nerve seems imbedded in a posterior groove of the posterior longitudinal bundle (nucleus of the fourth nerve). From this nucleus bundles pass to the outside, and along the margin of the aquæductus Sylvii, which take an obliquely descending course from the anterior periphery of this nucleus to its posterior periphery. In a part of this course they necessarily on cross-section present the appearance of circular formations at the lateral margins

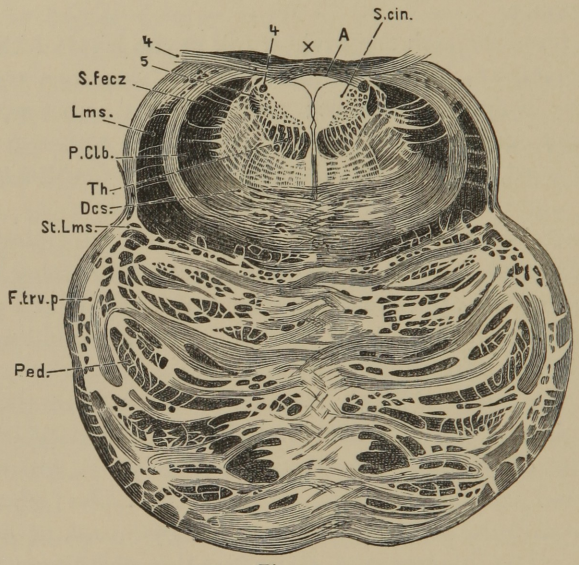


Fig. 42.

Cross-Section through the Pons, at the Level of the Exit of the Fourth Nerve.

x. Decussation of the fourth-nerve roots, in the velum medullare. 4, 4. Fourth-nerve roots. 5. Descending trigeminal nucleus bordering anteriorly on the posterior longitudinal fasciculus, Th. P.Clb. Superior peduncle of cerebellum. S.fecz. Its fasciculi lying one above the other. Dcs. Decussation of the peduncles. Lms. Lemniscus. St. Lms. Lemniscal layer, including the stratum intermedium. F.trv. p. Transverse bundles of pons. Ped. Peduncular fasciculi. S.cin. Gray floor of fourth ventricle (substantia cinerea).

of this central gray substance. These ring-like fasciculi are situated to the inside also of the trigeminal root in the gray substance surrounding the aqueduct. Finally they decussate and enter the valvula cerebri, immediately below the corp. quadrig., from which they emerge free (Fig. 42, 4, 4). New additional bundles from the round cells in the region of the lower bigeminal body render the crescent of the fifth nerve more distinct, which at the level of the emergence of the fourth nerve forms the outermost part of the anterior boundary of the aqueduct. The posterior longitu-

dinal bundles abut upon the median portion of the aqueduct. The velum medullare forms its posterior boundary. At this level a new formation of cells is discovered within the gray substance—*i. e.*, the *substantia ferruginosa* (Fig. 43, S. foa.). This is connected with bundles which run as far as the raphe in a transverse direction parallel to the gray substance. Near the raphe large nerve cells are liberally interspersed between, and inter-

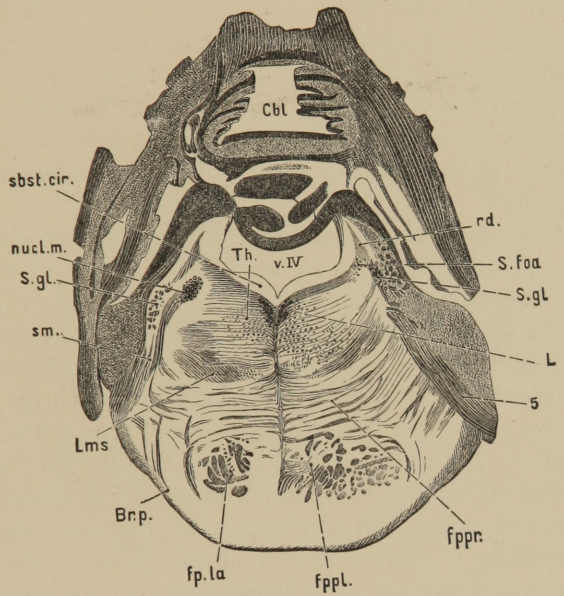


Fig. 43.

Potassium and Gold-Chloride Preparation from Brain of the New-Born.

Cross-Section through the Pons at the Level of the Emergence of the Small Trigeminal Root (the Right Half of the Section Representing a Higher Level than the Left).

Cbl. Cerebellum. v. IV. Fourth ventricle. sbst. cir. Gray floor of fourth ventricle. nucl. m. Nucleus of the small (inner) fifth-nerve root. S. gl. Gelatinous substance with (sm.) bundles of the large fifth-nerve root. Lms. Lemniscal layer and stratum intermedium. Br. p. Bundles from the brachium pontis. fp. la. Anterior longitudinal bundles of pons. fppl. Interwoven transverse bundles of pons. fppr. Deep transverse bundles of pons. 5. Large fifth-nerve root. Th. Thalamic area of posterior segment of pons. S. foa. Substantia ferruginosa. rd. Descending fifth-nerve root. (The dark, club-shaped section of the superior cerebellar penduncles are not lettered.)

woven with, the fibres of the posterior longitudinal bundle. A transverse commissure or decussation apparently establishes a connection between these cells. It is certain that the dark cells under the locus cœruleus on the floor of the fourth ventricle (Fig. 43) connect in this way with fibres of the raphe, which are derived from the anterior division of the pons and lend a medullary

appearance to its posterior division. These fibres may be looked upon as originating in the pyramidal tract.

The *substantia ferruginea* is a powerful mass extending from the lower corpus bigeminum nearly as far as the lower half of the pons (Stilling). At its periphery it is connected with the innermost bundles of the large root of the fifth nerve. The nucleus of origin of the small fifth-nerve root is situated posteriorly from, and to the inner side of, the large fifth-nerve root (Fig. 43, *nucl. m.*). From this smaller root arise the inner bundles of the entire fifth-nerve root (Fig. 43, sm.). The central nuclei of that massive portion of the large trigeminal root, which originates and emerges at the same level, presents a clustered arrangement of minute heaps of small-celled gray gelatinous substances (Fig. 43, S. gl.).

At the level at which the entire trigeminal nerve emerges (Figs. 43 and 44—5) we distinguish from within outwards: (1) an inner large-celled trigeminal nucleus, with the small root; (2) bundles passing from within outward, and between the cross-section of posterior longitudinal bundles, which bundles are derived from the subst. ferruginea of the opposite side, and belong to the descending roots; (3) the upper descending trigeminal root (the familiar small crescent—Figs. 43—*rd*, 44, r.dest.); (4) the bundles of the ascending trigeminal root, which evidently originate from a nucleus situated below the emergence of the fifth nerve—this nucleus extending to the lower end of the tuberculum cinereum Rolando in the oblongata. The trigeminal root encircles its gray nucleus with medullary substance, which becomes attenuated as it proceeds downwards, and is finally lost in the spinal *caput cornu posterioris* (Stilling). This root is of very considerable size; (5) *Cerebellar* fasciculi also join the large trigeminal root. These fasciculi lie either immediately upon the outer edge of the processus cerebelli ad cerebrum, or actually invade the latter; (6) the large trigeminal root is joined beyond a question by cerebellar bundles, which are closely moulded to the outside of the superior peduncle (Stilling), and possibly invade the latter.

Below and indeed within the planes at which the fifth nerve emerges, begins the central origin of the sixth and seventh nerves. At the highest level we notice decussating bundles leaving the raphe to enter the root of the facial nerve (Fig. 45, right side). Dorsad of the bundles from the raphe lies a circular spindle-shaped section, the *genu facialis*, the bundles of which arise from the

anterior facial nucleus, which is situated in an anterior inferior portion of the pons (Fig. 45 ncl. 7). The knee of the facial nerve is made up of root bundles, which curve around the common nucleus of the sixth and seventh nerves, and, in so doing, present a convex surface facing dorsad. For this reason, the knee seems separated from the emerging root (Fig. 45, left, g) on sections which are laid below this connecting arch, between the

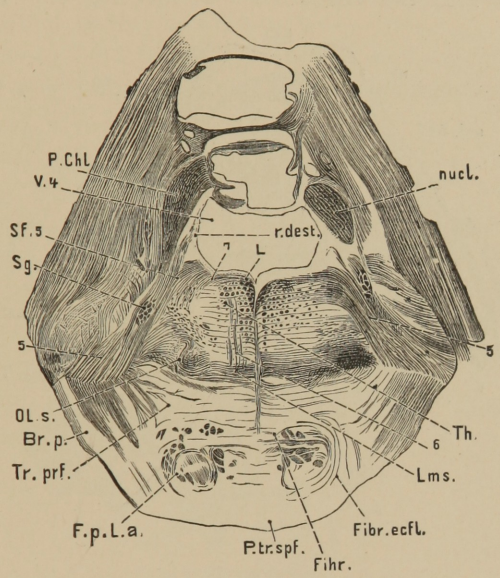


Fig. 44.

(From the same series as Fig. 43.)

Cross-Section through the Pons at the Level of the Exit of large V. roots.

P. Chl., nucl. Superior peduncles of cerebullum. V. 4. Fourth ventricle. r. dest. Descending root of V. nerve. Sf. 5. Trigeminal root from sutstantia ferruginosa. Sg. Substantia gelatinosa. 5, Large V. root. Ol. s. Superior olive. Br. p. Brachium pontis. Tr. prf. Deep transverse bundles of brachium pontis. F. p. l.a. Anterior longitudinal fasciculus. P.tr.spf. Superficial transverse bundles. Fibr. ecfl. Circumflex fibres of pons. Lms. Lemniscal layer and stratum intermedium. 6 VI. roots. Th. Thalamic area of posterior pons segment. L. Posterior longitudinal fasciculus. 7. Facial roots.

knee and the emerging portions of the root. The genu, descending vertically, appears cut on cross-sections. The common nucleus of the sixth and seventh nerves lies between the two portions of the root. The large and radiating cells of this nucleus are similar to those in the nuclei of the third, fourth, and in the outer nucleus of the fifth nerve. The roots of the sixth nerve bend outward, and undoubtedly connect with the cells of this common nucleus

(Deiters). It is equally certain that the root of the seventh nerve also connects with a lesser portion of this nucleus, the lateral portions being taken up entirely with the emerging fibres of the facial, which on their course from the nucleus forward constitute a much narrower bundle. Like all nerve-nuclei, this nucleus is in reality nothing more than the more compact portion of a formation of cells scattered all around it (Deiters). From this nucleus fibræ arcuatæ pass into the raphe, thus connecting this nucleus with

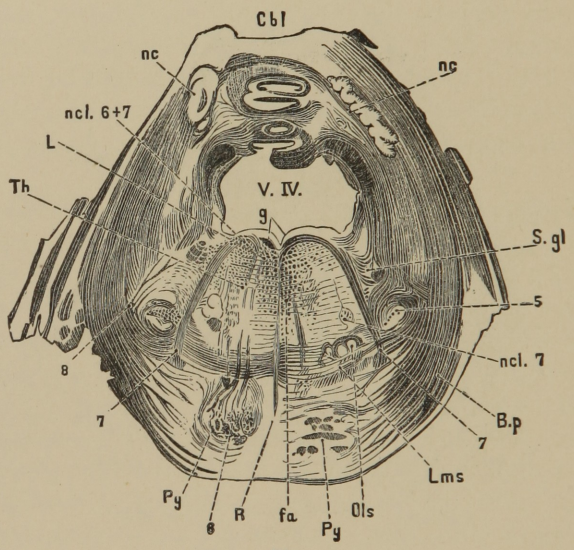


Fig. 45.

Stained with Potassium and Gold Chloride.

Cross-Section at the Level of Emergence of Seventh Nerve. (The Right Side Represents a Higher Level than the Left.)

Cbl. cerebellum. nc. Dentate nucleus of cerebellum. ncl. 6 + 7. Joint nucleus of sixth and seventh nerves. g. Central knee of facial nerve. L. Region of posterior longitudinal fasciculus. Th. Thalamic area of posterior pons segment. 8. Fibres of auditory nerves. 7. Root of facial nerve. 6. Root of sixth nerve. Py. Bundles of the pyramid. R. Raphe. fa. Anterior column. Ols. Superior olive. ncl. 7. Anterior facial nucleus. Lms. Lemniscal layer and stratum intermedium. B. p. Brachium pontis. 5. Ascending trigeminal root. S. gl. Gelatinous substance in the ascending trigeminal root. V. IV. Fourth ventricle.

topographically higher centres. There appear to be commissures also uniting both nuclei. The anterior facial nucleus is distinct in higher facial planes, increases in size as we proceed downward, and is traversed by the root-fibres coming from the *genu* (Fig. 45. ncl. 7; Fig. 46, ncl. 7, and on the right to the inner side of 7). This nucleus lies close to the trunk of the facial, which passes between it and the ascending trigeminal root. The

knee gathers from the anterior nucleus a number of fine parallel bundles, and at its upper level of origin does not yet present a compact mass to the front of the tubular gray (Fig. 46; compare right and left). The nerve fibres from the lower nucleus do not narrow down at once towards the genu, but the external fibres form a loose capsule around the ventral surface of the posterior nucleus. It is possible also that root-fibres pass directly and obliquely outward and forward from the lower nucleus to the emerging portion of the facial root.

Analogous to the descending, vertical, and ascending roots of the trigeminal nerve, we find that those facial bundles which issue

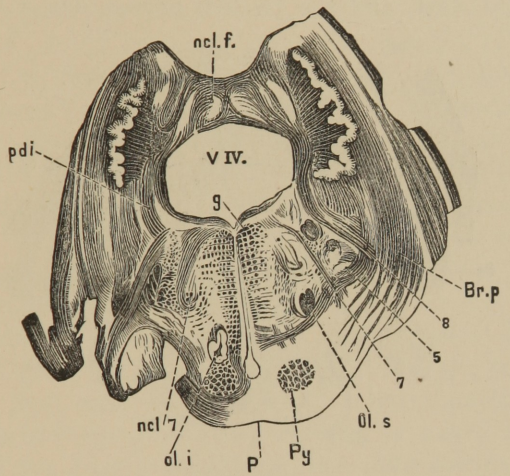


Fig. 46.

Stained with Potassium and Gold Chloride.

Cross-Section through the Highest Level at which the Auditory Nerve Emerges—The Right Half of Specimen Represents a Higher Level than the Left.

ncl. f. Nucleus tecti (Stilling). V IV. Fourth ventricle. g. Knee of facial nerve. pdi. Internal division of the cerebellar peduncle. ncl. 7. Lower nucleus of seventh nerve, which receives the bundles from the knee of the facial. ol. i. Inferior olive. P. Pons. Py. Pyramid. Ol. s. Superior olive. 7. Facial root. 5. Ascending root of trigeminus. 8. Auditory root not designated on left side. Br. p. Brachium pontis. (Medipedunculus.—Wilder).

from the raphe, are in reality descending fasciculi, arising possibly from the internal capsule, but certainly from the nucleus lenticularis. The planes of origin and emergence are identical in the case of these roots which enter the posterior nucleus; but the root derived from the inferior nucleus of the facial, the genu n. facialis, is an ascending root (as is evident from fig. 46). The bundles emerging from the lower nucleus pass toward the gray

substance, anteriorly from this, and move upward as the *genu n. facialis;* the knee is continued into the emerging root. The *genu* has the shape of a horse-shoe; its lower branch travels from the inferior nucleus to the gray substance, its upper branch from the middle of the gray substance forward. The knee of the facial nerve constitutes the middle piece and connecting link between these two branches of the horse-shoe formation, lying one over the other. This formation is placed diagonally in each half of the posterior division of the pons. The connecting arches converge in a median and posterior direction. The facial does not run parallel to the anterior roots of the spinal cord, as do the third, the sixth, and the twelfth nerves, which form the ex-

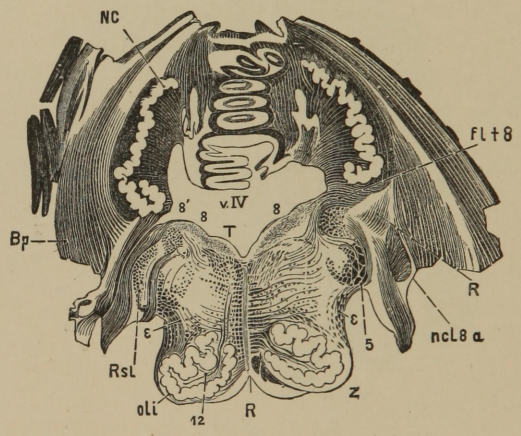


Fig. 47.

Preparation Stained with Potass. Gold Chloride. From the Newborn.

Cross-Section through the Lower Level of the Exit of the Auditory Nerve—The Right Half Represents a Higher Level than the Left.

NC. Dentate nucleus of cerebellum. Bp. Brachium pontis. R. Rst. Corpus restiforme. e. Fibræ arcuatæ from the corpus restiforme. 5. Ascending trigeminal root. oli. Inferior olivary body. R. Raphe beginning between the pyramids. Z. Stratum zonale. ncl8a. Anterior acoustic nucleus. v. IV. Fourth ventricle. 8'. External auditory nucleus. 8. Inner acoustic nucleus. T. Eminentia teres. fl+8. Bundles of the flocculus and the external acoustic root which are not separated from each other.

ternal boundary of the region of the anterior columns; it lies to the outside of the lateral columns, next to the formation analogous to the posterior horn—*i. e.*, the substantia gelatinosa of the asc. trigeminal root.

On sections through the level of the origin of the facial nerve the gray substance exhibits two prominences. The inner prominence, the eminentia teres, is due to the common

nucleus of the sixth and seventh nerves; the external prominence is to be placed to the account of the auditory nucleus (Fig. 45). The origin (?) of the eighth nerve, however, can only be studied in connection with the region surrounding it, including the cerebellum,

THE CEREBELLUM AND THE N. ACUSTICUS.

It is not my intention to give an exhaustive account of the minute anatomy of the cerebellum; for many gaps in our present knowledge of the subject will undoubtedly be filled up by the great monograph which Stilling is now preparing.[1] It would be a gratuitous and unnecessary task to attempt to anticipate the work of such a great master.

We have already described cerebellar bundles in the internal capsule in the form of radiations from the cerebrum into the nucleus ruber of the tegmentum. We have observed the *processus cerebelli ad cerebrum* emerging from the red nucleus of the opposite side; we noticed, furthermore, the unfolding of the *frenulum* into the *vermis superior*, after passing through the anterior velum medullare, and in the *vellum medullare* we found the cerebellar portion of the lemniscus.

The bundles of the *brachium pontis* (processus cerebelli ad pontem) consist (1) of a superficial layer, (2) of the interwoven layer which gives rise to secondary bundles in the pes pedunculi, and (3) of deep, transverse fasciculi. These bundles lie to the front of the stratum intermedium, which is joined by the inner bundles of the crus arising from the *ansa lenticularis*. Gray substance with its ganglion cells, which invade the entire anterior division of the pons, reduce the volume of the crus proper. Through the mediation of these cells, and a gradual reduction of its volume, the bundles of the crus are transformed into a cross-section of the pyramidal tracts, and then enter the brachium pontis. For this reason alone the bundles of the brachium pontis are not commissural fibres, but the continuations of recurrent fibres of the crus.

Their commissural nature is disproved furthermore by the fact that a large number of bundles of the brachium pontis pass on the outside around groups of peduncular fasciculi (Figs. 43, 44). Both ends of this circular formation turn toward the opposite brachium pontis, and belong to different levels of the pons, passing, as they do, either from the superficial layer to the interwoven layer, or

[1] This work was completed in 1878.—S.

from this layer into the layer of deep, transverse fibres. Each arch of the *fibræ circumflexæ pontis* exhibits two branches, one of which enters the crus after taking a superficial course from the brachium pontis of the opposite side ; while the other leaves the *pedunculns* again, mingling with gray substance and emerging through the opposite brachium pontis.

Its *processus ad pontem* forms a considerable mass on the outer side of the *meditullium* of the cerebellum. The cerebellum, like the cerebrum, is surrounded by a mantle of convoluted gray substance, the cerebellar cortex, which serves as the point of origin of its medullary substance. It is developed from the posterior wall of the posterior (fœtal) cerebral vesicle.

Between the ends of the large horizontal fissure lies the *hylus*, which permits the entrance of the four medullary processes into the gray mantle of the cerebellar cortex. Owing to the medullary substance of the *velum medullare* (Marksegel) and of the processus cerebelli ad cerebrum entering through the hylus, the vermis superior presents a white anterior surface (Fig. 55).

Up to the date of Stilling's great investigations of the cerebellum, the only gray cerebellar masses known were the cortex and the nucleus dentatus. We are indebted to him for our knowledge of the ganglia tecti, which unite in the median line, and of other nuclei, to which he refers in a preliminary notice published in the *Centralblatt für die Medicinischen Wissenschaften.*

The cortex of the cerebellum consists of three layers : an external gray layer proper and an inner grayish-red layer, which are distinguishable by the naked eye. On microscopical examination of the cortex, we discover between these two layers another layer containing cells of Purkinje. The basis substance of the cerebral cortex, of the ganglia, and of the cerebellar cortex remains the same throughout. According to Obersteiner the cerebellar cortex in the child is covered by a layer of formative cells, which are transformed into spindle-shaped fibrils, thus constituting an innermost stratum of the *pia mater.* The gray layer proper exhibits small nerve-cells, the destructible protoplasm of which often makes it difficult to distinguish between these and non-ganglionic elements. In addition to these generally triangular granules, there are, near the grayish-red granular layer, transverse, spindle-shaped bodies, which run parallel to the convolutions around the fissure between two convolutions, but, unlike the cerebral, spindle-shaped cells, lie to the outside instead of to the inside of the granular layer. I

agree with Stilling in regarding the cells of the granular layer as multipolar ganglion-cells ; but, instead of looking upon the widely separated groups of cells as the breeding-place of regenerating cells, I would prefer to assume a connection between them and the ramifications of the inner processes of the cells of Purkinje. In doing this, I must demur, however, to the view of Koschewnikoff, who believes that one solitary, non-ramifying process issues from the inner side of Purkinje's cells. The large cells of Purkinje, which occur at considerable distances apart, and form but a single row, are connected with the internal and external layers of the cerebellar cortex. The external powerful processes of these cells are formed by a gradual attenuation of the latter's protoplasm. They branch dichotomously at first around the sulcus between two convolutions, at an angle of nearly 180 degrees. From these main branches many others are sent off at right angles; these undergo secondary ramifications like the antlers of a deer, and are continued into, and give the appearance of parallel striation to the outer layers of the cortex. They seem to ramify in those planes of the cortex which belong to one of the delicate, separable laminæ of the medullary substance. According to Hadlich these processes take a recurrent course when near the cortical surface. The appearance of recurrrent processes may be due to the terminal ramifications turning back in order to unite with the triangular cells of the external layer. The inner halves of the cells of Purkinje are vesicular in shape. Purkinje compared these large cells to field-flasks—*ampullæ*,—from the neck

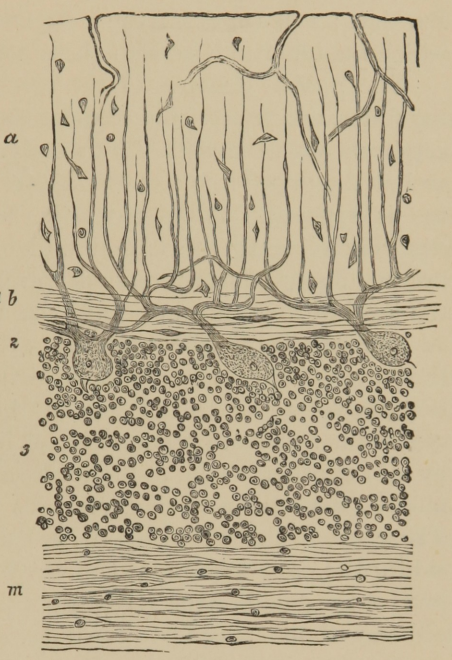


Fig. 48.

Transparent Section of the Cerebellar Cortex of Man.

1 *a* and 1 *b*. Gray layer proper; (1 *b* with spindle-cells and transverse fibres.) 2. Cells of Purkinje, 3. Granular layer. *m*. Medullary substance.

of which the strong process just described would issue. Those processes which issue from the bottom of the flask are much more delicate, and though they may give rise to more than one process (contrary to Purkinje's opinion) they ramify but little. They split up soon into a network of fibres connected with the granular layer. The medullary fibres of the cerebellum have, in all likelihood, a twofold origin in the cerebellar cortex: (1) from recurrent, ramified branches of the external process of the cells of Purkinje; and (2) from the network of the granular layer into which the inner processes of these cells of Purkinje enter.

The *nucleus dentatus* of the cerebellum is traversed by radiating fibres, which probably connect the bundles of the processus ad cerebrum with the cells of this body. At the level of the facial and at the upper levels of the auditory nerve, the nucleus dentatus is separated as yet from the processus ad cerebrum, and lies very close to the lateral wall of the *oblongata*, after it has become distinct from the trunk formations in the oblongata. At the level of the central origin of the auditory nerve, the processus ad cerebrum is crowded away from the lateral wall of the floor of the iv. ventricle: (1) by bundles which decussate in passing through the *ganglia tecti;* and (2) by another group of bundles which covers the nucleus dentatus (Fig. 46, left, to the outside of pdi.); (3) by still another, which at higher levels was situated between the nucleus dentatus and the processus ad cerebrum (Fig. 45, Cbl.). These groups, constituting the corpus restiforme lie to the outer side of the cross-sections of the ascending trigeminal root. At the level of the ganglion tecti (Fig. 46), the first group of bundles passes either, without crossing, to the outer side of this ganglion, or, after decussating through the ganglion tecti on the inner side, downward to the oblongata. These bundles appear truncated on the outer side of the auditory nucleus in the gray substance. They intersect with bundles of the auditory root which, entering in a reverse direction from the anterior surface of the trunk, turn inward on the outer side of the ascending trigeminal root, and after mingling with the former are cut across also. At the junction of these converging bundles from the cerebellum and from the auditory root, an angle is formed opening outward. This angle is completely filled by the corpus restiforme, which descends from the region of the nucleus dentatus cerebelli, and edges its way into this angle. These bundles, which have been first described as entering the gray auditory nucleus to the inner side of the corpus restiforme, occupy the area of Clarke's external auditory nucleus.

In his publications on the *lingula* and the *lobulus centralis*, Stilling has shown that the neighboring cerebellar convolutions are united to one another by wreath-shaped bundles, and that on sagittal sections of the *vermis* we perceive arciform fibres connecting various regions of the cortex; these arciform fibres varying in length and running in different directions. These arciform bundles lie nearer to the cortical surface than a certain system of fibres which Stilling has described as transverse and decussating fibres. The cortex of the cerebellum possesses single and general systems of association bundles, similar to those of the cerebral cortex.

The corpus restiforme must be divided into two parts: one part belonging to the pons, and the other to the oblongata. That portion of the posterior division of the pons which is not crowded out by arciform bundles emanating from the nerve-nuclei, and taking the place of the gray substance in the raphe, is occupied by transverse *fibræ arcuatæ* starting from the corpus restiforme. Above the auditory root they emerge distinctly from that portion of the corpus restiforme which is situated between the processus ad cerebrum and the nucleus dentatus, which passes through the trigeminal region at the level of the superior olivary body, and sends forth that superficial stratum of bundles which answers to the corpus trapezoides in animals (Fig. 45, Ols., Lms., 5). These bundles appear at first to course to the front of the superior olivary body, and after crossing each other at an acute angle, to enter the latter body. It is not as evident in man as it is in animals that pedunculated bundles issue from the superior olivary body on the inner side of the ascending trigeminal root; and that these bundles course backward between the nucleus and root of the eighth nerve. This relation bears a striking resemblance to that existing between the corpus restiforme and the lower olivary body. Longitudinal bundles from the region of the funiculus lateralis are also connected with the superior olivary body; as is exhibited on longitudinal sections of the brain-trunk, these longitudinal bundles lie behind the layer of the lemniscus in which the lower olivary body is lodged. The lower portion of the corpus restiforme—that part belonging to the oblongata—is separated in the cerebellum, by the *nucleus dentatus*, from the other portion belonging to the pons. This lower restiform body, which is a prominent feature on the surface of the medulla, together with its stratum zonale, we described above as it edges its way be-

tween the cerebellar and the auditory bundles into the section of the external auditory nucleus. The innermost cerebellar bundles, which pass down to the oblongata, descend far down in the company of the anterior roots of the auditory nerve, through the area of the external auditory nucleus. They are situated to the inner side of the corpus restiforme (Fig. 49, Rsl., 8′, R.). These bundles are evidently related to the auditory root.

Examination reveals that these cerebellar bundles in the auditory nucleus are part also of the auditory nerve-tract. On its course between its cerebellar origin and its central root, the auditory tract receives an addition in the form of the fibræ arcuatæ. The fibræ arcuatæ cross the median line, and undergo decussation between a large portion of auditory roots and the cerebellum. Auditory bundles may indeed be divided into such which decussate in the oblongata and such which do not decussate in that organ.

Crossed auditory bundles.

a. External auditory bundles, *striæ medullares.* They pass either directly to the point of decussation—the *raphe*,—in order to enter Clarke's nucleus (Fig. 49, 8′) through the intervention of fibræ arcuatæ, or they pass from the outer side into the cross-section of Clarke's nucleus (Figs. 50, 52, left), which, connecting with fibræ propriæ, conduct the former to Clarke's nucleus of the opposite side (Fig. 52, right). The external auditory bundles surround the inner limiting bundles of Clarke's nucleus, and then divide up into posterior bundles, travelling through a part or the whole of the inner auditory nucleus, and as far as the raphe, and into anterior fibræ arcuatæ which pass far front in the raphe (Fig. 49, right and left).

In the upper levels of the oblongata almost all fibræ arcuatæ constitute part of the auditory tract. These lend a medullary appearance to the whole of the raphe, through which they pass, and the stratum zonale even seems to be derived from bundles coming from Clarke's nucleus (Fig. 49, εε.).

b. The inner crossed auditory bundles form in conjunction with cerebellar bundles cross-sections in the area of Clarke's nucleus. They descend to within half the height of the hypoglossal triangle. Throughout this area these bundles are connected with fibræ arcuatæ, γ. The acoustic bundles, as well as the cerebellar bundles, after they have descended so far, may form either simple commissures with the ends of the fibræ

arcuatæ, or they may in passing through the raphe connect the cerebellar bundles of one side with the acoustic bundles of the opposite side. Of these two possibilities, the latter is the more plausible. The existence of commissural fibres in the raphe has not been proved at all. In descending, the inner crossed acoustic tract extends from the region of origin of the facial, through that of the tenth, to the central origin of the twelfth nerve. The raphe, as well as the area of the acoustic arched fibres γ, contains

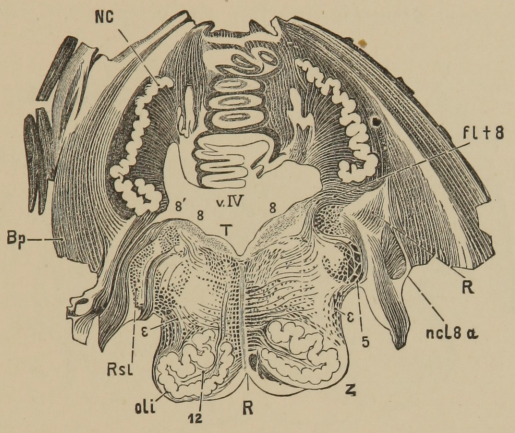


Fig. 49.

Stained with Potassium and Gold Chloride.

Section through the Level of Emergence of Auditory Nerve. Brain of a New-born Infant. (The Right Half Represents a Higher Level than the Left.)

Bp. Brachium pontis. NC. Dentate nucleus of cerebellum surrounding the superior peduncles of the cerebellum. To the inner side of the radiation of the superior cerebellar peduncles into this gray lamina there lies a dentate ganglion, which I have termed the accessory nucleus of the nucleus dentatus. v. IV. Fourth ventricle. 8. Inner auditory nucleus. 8[1] External auditory nucleus (Clarke's). fl+8. Medullary substance of the flocculus and an external auditory root. On the left side the pedunculus flocculi is distinctly separated from the external auditory root. Rsl. Left *corpus restiforme*, with the inner acoustic root resting upon the median margin. 5. Ascending trigeminal root. ncl8a. Anterior auditory nucleus (Stilling). oli. Inferior olivary body. 12. Hypoglossal root. R. Raphe. ε. Most anterior fibræ arcuatæ. T. Eminentiæ teres.

ganglion cells which are connected with the network of fibres issuing from the above-mentioned motor-nuclei, and which Deiters supposes to be scattered ganglion cells belonging to the nuclei of the nerve-roots.

The *uncrossed acoustic bundles are the following:*

The inner acoustic bundles[1] are connected with the cerebellum

[1] I prefer to speak of acoustic bundles rather than of acoustic nerve-roots, for their value as nerve-roots is, as Kölliker has shown, as questionable as in the case of the optic nerve and the so-called olfactory nerves.

directly by means of fibres which ascend toward the ganglion tecti, invading and covering the processus ad cerebrum (Fig. 46, right). There is a partial interruption of fibres through nerve cells on the external barren portion of Clarke's nucleus (Fig. 49 between 8′ and Rs.l., left). Acoustic bundles bend over also directly into the corpus restiforme, and particularly so, near the lower edge of this body.

Finally there is the anterior acoustic nucleus of Stilling lying between the inner acoustic bundles, the corpus restiforme and the

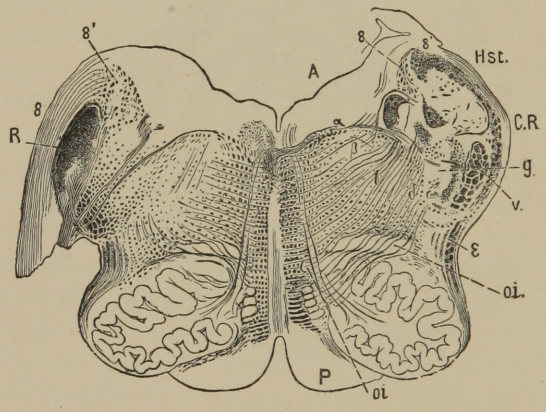


Fig. 50.

Stained with Potassium Gold Chloride.

Section through *Oblongata* of New-born. (Left Side Represents a Higher Level.)

A. Internal auditory nucleus. 8′ 8. External auditory nucleus ; external and internal auditory root on left side. R, C. R. Corpus restiforme. v. Ascending trigeminal root, to the outer side of the gelatinous substance. The trigeminal section is traversed by glosso-pharyngeal roots. oi., oi. Olive and accessory olivary body. Hypoglossal roots emanating from nuclei in the eminentia teres disappear in the olivary body. *α*. Fibræ arcuatæ from the nuclei of the tenth nerves. (These nuclei constitute the prominence between the eminentia teres (hypoglossal nucleus) and the inner auditory nucleus, and this prominence is very slight on the left.) *β*. Fibræ arcuatæ from the ascending vago-glosso-pharyngeal root. *γ*. Fibræ arcuatæ from the external auditory nuclei. *δ*. Fibræ arcuatæ from the post. column. Hst. Posterior column.

flocculus (or the medullary substance of the cerebellum, Fig. 49, ncl8a). This nucleus receives those parts of these bundles which take an outward course, and then again it is unquestionably connected with the medullary substance of the cerebellum.

EXIT OF THE 9, 10, 11, AND 12 PAIRS OF CEREBRAL NERVES.

With the disappearance of the fasciculi of the pons the pyramidal tracts lie immediately to the front of the anterior columns, from which they are not distinctly separable. The gray substance of this region exhibits three prominences: (1) the *eminentia teres ;*

(2) the posterior column of origin of the ninth, tenth, and eleventh cerebral nerves—the *ala cinerea*—pneumogastric nucleus; (3) the internal acoustic nucleus (Figs. 50 and 51).

The eminentia teres contains heaps of nuclei from which circular bundles emanate, which encircle their own cells of origin, and ultimately give rise to roots of the hypoglossal nerve (Figs. 50 and 51); but the superficial margin of the eminentia teres also contains smaller cells, through which definite portions of the root of

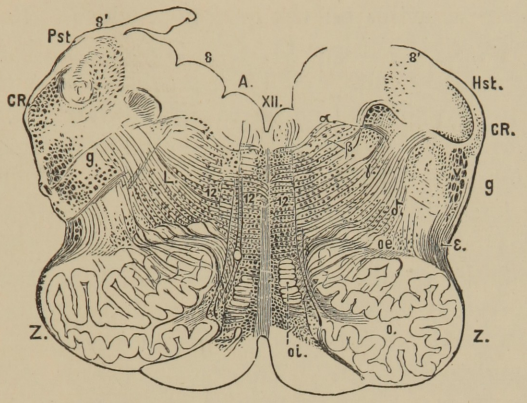


Fig. 51.

Stained with Potass. and Gold Chloride. New-born.

Transparent Section from the *Oblongata.* (Left Half Represents a Higher Level.)

XII. Hypoglossal nuclei. 12. Hypoglossal roots. The lateral 12 exhibits fibres from the nucleus XII., which are scattered in among the gray substance of the *funiculus lateralis* (L.). 8′ 8′. External auditory nuclei. Pst., Hst. Posterior columns. A. (ought to be further to the outside) *Ala cinerea* (nucleus of vagus). 8. (ought to be farther to the outside) Internal auditory nucleus. CR., CR. Corpora restiformia. g. Substantia gelatinosa surrounded by the ascending trigeminal root. On the left to the inner and outer side of g, the vagus roots. O., oi., oe. Olive, internal and external accessory olives. α. Fibræ arcuatæ from the nucleus of vagus. β. Fibræ arcuatæ from the ascending vago-glosso-pharyngeal roots. γ. From the external auditory nucleus. δ. From the posterior column. ε. From the corp. restiforme. Z. Stratum zonale.

the tenth nerve pass on their way to the raphe. These fibres pass around the hypoglossal cells in a circle presenting a posterior convexity. The joint nucleus of the ninth and tenth nerves, which disappears toward the inner side of the auditory nucleus in the plane of the rhomboid fossa, does not approach at all near the surface on sections at levels immediately below the striæ transversæ. On such sections it is merely a mass of gray substance, which takes a brighter carmine staining than the neighboring gray substance ("*eminentia teres* and auditory nucleus"), and gives rise, first of all, to roots of the glosso-pharyngeal nerve. At

lower levels (Fig. 50, left) a small nucleus of the tenth nerve is perceptible. A very large part of this nerve at its origin seems on carmine preparations to form a groove about a number of small cells (Fig. 50, glosso-pharyngeal nucleus on the left). This section of medullary fibres represents not only an ascending root of the glosso-pharyngeal nerve, but also of the tenth nerve, from which delicate fibrils are unrolled throughout its entire length; these delicate fibrils, as they are unrolled, mingling with small cells. This ascending root lies on the gray floor close to the trigeminal root (Fig. 50, right; Figs. 51, 52). The ascending trigeminal root has been justly compared to a posterior root of the spinal cord, and the hypoglossal nerve to an anterior spinal-cord root. The region of the vagus is accordingly situated between these two nerves, which are analogous to roots of the spinal cord. Inasmuch as it sends its fibres through the *funiculus lateralis*, it deserves to be termed the *lateral* system. In the funiculus lateralis we find a small cluster of cells, which, as it is analogous in position, should be considered the prolongation of the lower facial nucleus, and of the motor trigeminal nucleus; it contains also large multipolar cells. This is the motor nucleus of the tenth nerve, or, as it has been termed, the anterior column of origin of the lateral mixed system. The expression "lateral mixed system" was suggested by Deiters, and might be appropriately applied to the central nuclei of the 9th, 10th, and 11th nerves. In reality the anterior central nucleus of the vagus is a nucleus of the accessory nerve, which passes downward into the gray reticular lateral process of the anterior horn, from which the lowest roots of the accessory nerve emanate. Those bundles of this system which are analogous to the posterior roots of the spinal cord traverse the gelatinous substance of the trigeminal nerve, and are derived from the posterior column of origin of this system, from the *ala cinerea* (Fig. 51, 8). The ascending root arises on deeper levels, from fibræ arcuatæ issuing from the raphe (Figs. 52, left β).

Roots of the *vagus* from the raphe course behind the hypoglossal nucleus as bundles of the *eminentia teres*, while bundles from the *ala cinerea* pass in front of the hypoglossal nuclei, past the posterior columns of origin, and directly into the root of the tenth nerve (α). Bundles from the anterior column of origin curve knee-shaped into the vagus, and from this nucleus roots appear to arise, which pass directly to the front (radial fibres, Lenhossek). (Fig. 51, left, in front of the fifth nerve).

The region in which the motor nucleus of the tenth nerve and the hypoglossal nucleus are situated, though it appears to be a

centre of aggregated cells, has no distinct boundaries; and resembles the region of the facial nucleus (higher up) in having uniformly shaped cells scattered all around it. These cells, which contribute to the formation of a network of gray fibres, are traversed by arciform fibres, which can be traced into the bundles of the external auditory nucleus (Figs. 50, 51, 52—γ).

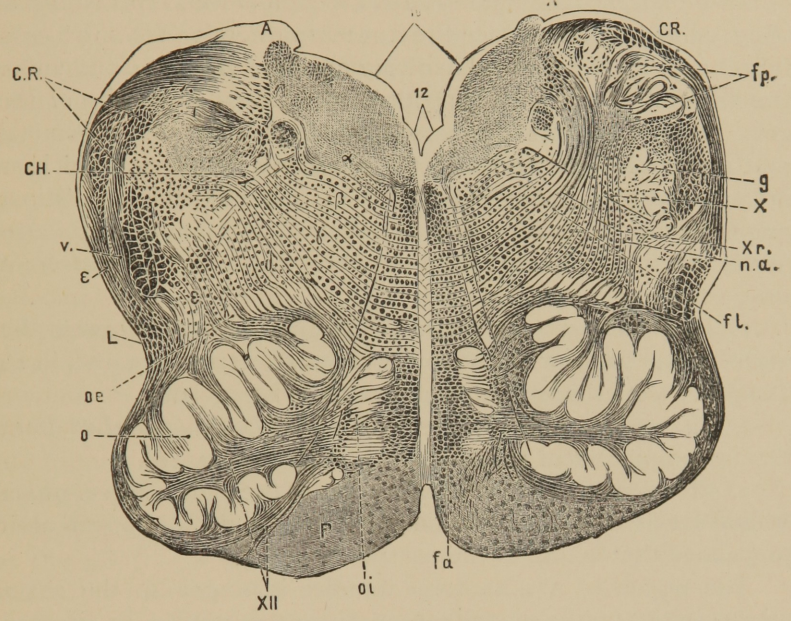


Fig. 52.

Stained with Potassium and Gold Chloride.

Transparent Section through the Medulla Oblongata of New-born Infant.

12. Hypoglossal nuclei. 10. Vagus nuclei. A., A. External auditory nuclei, with auditory roots. CR., CR. Restiform body. fp. Posterior column. v. Trigeminal root. g. Gelatinous substance. fl. Lateral columns. L. External bundles of lateral columns, on the inner side of which deep arciform fibres of the restiform body are situated. oe. External accessory olive. o. Olive. oi. Internal accessory olive. XII. Twelfth nerve. P. Pyramid. fa. Funiculus anterior. CH. (left). Roots of vagus. n.a. Region of the anterior nucleus of the vagus. Xr. Recurrent roots of vagus. X. Roots of tenth nerve: α fibræ arcuatæ from the vagus nuclei; β from the joint ascending root; γ from the acoustic nuclei; δ from the posterior column; and ε from the restiform body.

CROSS-SECTION OF THE OBLONGATA AND ITS TRANSITION INTO THE SPINAL CORD.

On the outer side of the median-anterior columns and the pyramidal area of the oblongata, the lateral columns extend as far as the cross-section of the trigeminal nerve. They are distinguished from the very dense and coarse fasciculi of the anterior

columns by the lesser density and the lesser thickness of their fibres. The lateral column fills out the segment of the cross-section of the oblongata between the roots of the hypoglossal and trigeminal nerves. The funiculus lateralis encloses the lower olive, and is joined to it by horizontal bundles (Fig. 57, o). Immediately behind the lateral column lies the trigeminal root, and behind this, to the outside, lies the scythe-shaped section of the corp. restiforme (Figs. 45 and 50, R., Cr.), and in a median direction from the restiform body lies the external auditory nucleus. This nucleus, under the name of Clarke's nucleus, forms the lateral boundary of the gray substance. The groove-shaped section of the trigeminal root surrounds a gray column, the substantia gelatinosa, which, as in the spinal cord, forms an indentation or wave visible on distinct preparations. This formation is traversed by tranverse arciform fibres, which issue in part from the nerve-nuclei and in part from the corpus restiforme.

1. The most posterior (dorsal) of the fibræ arcuatæ connect the nuclei of the vagus with the raphe (Figs. 50, 51, 52—α), and, in so doing, separate the hypoglossal root from its nucleus.

2. Then there follow fibres which have been unravelled from the ascending root of the ninth and tenth nerves (β).

3. Fibræ arcuatæ arise from bundles of the eighth nerve, which extend far down into the oblongata, and do not disappear until just above the closure of the central canal (γ).

The region of the arciform bundles issuing from the nerve origins is distinctly separate from the more anteriorly situated systems of fibræ arcuatæ; nor do the former traverse either the olives or inner olivary bodies.

The *corpus restiforme* soon forfeits a number of its bundles, which go to the surface of the oblongata, there forming the stratum zonale, covering and invading the olivary body. Inspection of the surface of the oblongata reveals the fact that the stratum zonale does not lie altogether in transverse planes, but that it descends obliquely. These bundles are situated on the outer side upon the trigeminal root. Deeper layers from the corpus restiforme send coarse bundles through the section of the fifth nerve, but invariably to the outside of the substantia gelatinosa. Superficial bundles of the restiform body, which lie upon the fifth nerve, often continue the *stratum zonale* far enough to cover the pyramids. If such bundles unite on the cross-section of the pyramids with islands of gray substance, then we consider

them bundles of the pons which cross the corpus restiforme. In the lowest strata of the pons, we find bundles taking such a course, into the corpus restiforme and not into the brachium pontis, the two types of bundles separating distinctly in the cerebellum. On the other hand, the *stratum zonale* allows an external layer of the funiculus lateralis to touch the surface, surrounding the latter on its inner aspect (Fig. 52, left L.). Such bundles protruding behind the olivary bodies give rise to an external limiting fasiculus and in the same way longitudinal bundles on the inner side of the olivary bodies may be exposed and form the inner limiting fasiculus; (Fig. 15), owing to a deeper course of the stratum zonale. As a rule the pyramids remain free. The superficial layer of the corpus restiforme, the stratum zonale, not only covers, but actually crosses the olivary body of the same side. The deep layers of the restiform body take the same course through the olives and inner accessory olives (Figs. 50, 51, 52—ε).

The bundles of the restiform body cross in a transverse direction through the raphe from one side to the other, emerging from the *hilus* of one olive and passing into the hilus of the other. These fibres cannot represent a true commissure of the olives, for the fibres have dissimilar (ungleichnamige) endings. From the opposite olivary body restiform bundles pass into a dense, columnar[1] mass of fibræ arcuatæ, which are found to the inner side of the gelatinous substance, and instead of entering the corpus restiforme pass into the posterior column.

On sections, which pass between the point of emergence of the ninth nerve and the region of the nucleus of the tenth nerve, a new formation is seen to edge in between the corpus restiforme and the region of the auditory root. This formation is the *funiculus posterior* of the oblongata, which passes into the posterior columns of the spinal column, through the *funiculi graciles* and *cuneati* (Figs. 50, 51, 52—*Hst.*, *Pst.*, *fp.*). The funiculus posterior has a net-like structure, the fibres of that net enclosing clusters of middle-sized ganglion cells. This formation stands in striking contrast to the external auditory nucleus, where distinct sections of bundles are imbedded in a floor of gray substance. In the one instance we find bundles imbedded in gray substance; in the other, gray substance in a network of bundles. These posterior columns gather fibres from that set of fibræ arcuatæ (Figs. 50, 51, 52—δ) which are situated between those derived from

[1] This refers to the appearance on cross-sections.

Clarke's auditory nucleus and those from the restiform body. The fibræ arcuatæ in question also pass through the olivary body, and, as is worth mentioning, through the external secondary olive also.

In the arciform course of those bundles which connect the posterior columns and the corpus restiforme, no cells are seen scattered in between these fibres, from which the posterior columns might be derived. It would be difficult, were it not for a single circumstance, to decipher the origin of the bundles which go to make up the posterior column ; this fact is, that in proportion as the corpus restiforme diminishes in volume by yielding up *fibræ arcuatæ* (Figs. 50, 51, 52—zone ε), so the posterior columns develop by the addition of the posterior *fibræ arcuatæ* (Figs. 50, 51, 52—zone δ). There can be but little doubt, therefore, that the corpora restiformia, after passing the olivary bodies, pass into the posterior columns of the opposite side. In the olivary bodies the restiform bodies end, and the posterior columns begin. It is known of the olive (Deiters), that very coarse fibres of the corpus restiforme pass through it, and that very delicate bundles are distributed within it. The coarse restiform bundles simply pass through the olivary body of the same side, but terminate in the olive of the opposite side. Proof of this may be found in the fact that if one half of the cerebellum and the restiform body atrophy, the olivary body of the opposite side will also degenerate.

The posterior columns once formed, the transition from the cross-section of the oblongata to that of the medulla spinalis is easily effected ; for the floor of the IV. ventricle changes into the gray substance surrounding the central canal. At such levels at which the corpus restiforme lies next to the beginnings of the posterior column, it is situated to the outer side of the latter. The posterior column forms on its inner side (Figs. 50–52), the substance of the restiform body diminishing on the outer side, and the posterior columns increasing on the inner side. In consequence of this mode of growth the region of the corpus restiforme and the funiculus posterior is pushed toward the median line, in the direction in which new growth takes place. The result of this is that in the adjoining halves of the gray floor upon which the posterior column encroaches after the disappearance of the acoustic nucleus, the nuclei of the tenth nerve occupy a more median position. The hypoglossal nucleus, the representative of the anterior spinal-cord nucleus, does not change its position, for the posterior column turns inward back of this nucleus. Cer-

tain roots of the tenth nerve intersect the gelatinous substance in the trigeminal nucleus, just as its continuation in the spinal cord is intersected by posterior roots. The nucleus and roots of the vagus are prototypes of the posterior horn of the spinal cord. The substantia gelatinosa represents the *caput* of the posterior horn; the vagus roots are its *cervix*, and the vagus nucleus, which is connected with the anterior horn (the hypoglossal nucleus) and turns toward the cervix the apex of a triangle, corresponds to the *trigonum cervicale* of Goll, the triangular section of the union of the

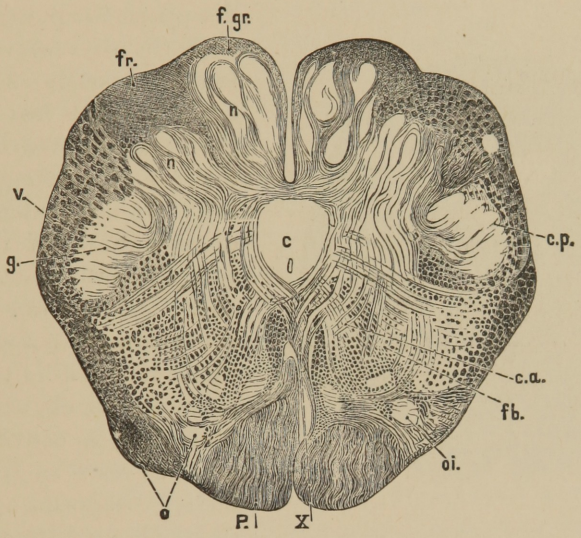


Fig. 53.

Stained with Potassium and Gold Chloride.

Cross-Section through the Oblongata of the New-born.

c. Central canal. P. Pyramids. X. Decussating bundles. o, oi. Region of olives. g. Gelatinous substance. v. Trigeminal bundles. c. p. Caput of posterior horn. f. b. Fibræ arcuatæ. c. a. Anterior horn. n. Nucleus of fasciculus cuneatus. fr. Fasciculus cuneatus. f. gr. Fasciculus gracilis.

N. B.—The commissure back of c. does not exist in reality.

posterior horn with the entire gray nucleus. This posterior horn of the oblongata lies, as it is, between the lateral and posterior columns, and there is a difference only in its being covered by trigeminal roots, and in the angle formed by the two posterior horns. The roots of the *vagus*, if prolonged, would intersect behind the oblongata, while the posterior roots of the spinal cord would intersect anteriorly. The former diverge anteriorly, and the latter posteriorly. The nucleus of the tenth nerve turns inward, approaches the median line, unites with its fellow of

the opposite side, and thus closes the *canalis centralis.* The fossa rhomboidea has disappeared. The posterior columns crowd toward the median line, behind the united nuclei of the tenth nerve, leaving naught but the posterior fissure between them. But the entire posterior horn has followed the inward twisting of the *vagus* nuclei, so that the posterior horns, from which the 1. and 2. cervical nerve-roots below the vagus arise, are no longer convergent posteriorly, but are juxtaposed at an angle of 180°; as soon as the fibræ arcuatæ disappear, the posterior horns with the nerve-nuclei in the funiculi graciles and cuneati are separated less and less until they approach one another and converge anteriorly. In consequence of the disappearance of the fibræ arcuatæ and of the inner olive, the anterior columns become more compact; and this is true also of the lateral columns, which, instead of presenting a convexity, exhibit, as soon as the olivary bodies disappear, a flattened surface behind the pyramidal tracts (Fig. 53). Behind the lateral column, the trigeminal fibres which are no longer covered by fibræ arcuatæ are replaced by the convex region of the *substantia* Rolandi (Fig. 54, V., SR.). Back of this the gray substance scattered in among the posterior columns, gives rise to two well-defined convex formations—the funiculus cuneatus, and funiculus gracilis (Fig. 53, fr., f. gr.), the latter lying immediately adjoining the posterior fissure. Before the total disappearance of the inner accessory olive, the lower boundary of which Stilling thought coincided with the lower limit of the hypoglossal roots, the posterior column receives additions from a decussation of fibres between the anterior columns; these fibres are

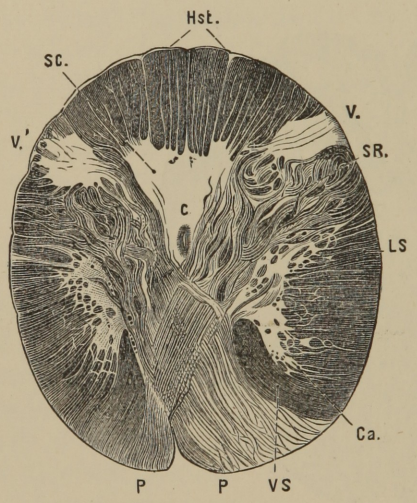


Fig. 54.

Carmine Preparation.

Decussation of the Pyramids in the Adult.

Hst. Funiculus posterior. C. Central Canal. V, V', SR. Caput cornu posterioris, substantia Rolandi, on the left side with vestiges of the ascending trigeminal root. LS. Lateral column. VS. Anterior column. P. P. Pyramids.

stouter than those of the fibræ arcuatæ which decussate higher up. Clarke and I thought they were derived from the external bundles of the pyramidal tracts. There is every reason to doubt the correctness of this view, for the inner accessory olive adjoins those bundles which take a transverse direction from the outside into the decussation. If they pass through this ganglion it would be natural to suppose that they were derived from the corpus restiforme. This view would not be contradicted by an inspection of gold preparations (53, *oi.*, X., f. gr.). Assuming this to be the case, they would be distinguished from the rest of the formation of the posterior column in this, that the decussation would not consist of restiform bundles decussating at the hither side of the enclosed olive, but that it would consist of fibres which enter the funiculus gracilis, decussating at the further side of the enclosed, inner secondary olive.

The entire pyramidal tracts are lost from the anterior fissure on through the great decussation of the pyramids; they crowd the anterior columns far from the raphe which they fill out and expand; they separate the anterior horns from the gray substance, but however much they may push the posterior horns backward, these pyramidal tracts still pass entirely and continuously into an area of the lateral column which lies next to the posterior horn, but does not extend to the external surface of the most posterior part of the lateral column. The position which the pyramidal bundles occupy after decussation as longitudinal fibres of the lateral columns, passing gradually into the anterior roots, they retain throughout the entire length of the spinal cord (Fig. 54, P. P.).

CROSS-SECTION OF THE SPINAL CORD.[1]

We remarked above that the cross-section of the brain-trunk, at the lowest division of the mesencephalon exhibits three distinct masses of fibres, bearing downwards, and superimposed one upon the other. These were the *tegmentum*, the *stratum intermedium*, and the *pes pedunculi*. The cross-section thus constituted re-

[1] Prof. Meynert's interpretation of the cerebral origin of the spinal-cord tracts differs widely from that given by other authors. The reader who is especially interested in this part of the subject is referred to the following publications: Flechsig: *Leitungsbahnen im Gehirn u. Rückenmarke;* Leipsic, 1876, p. 263, etc. Flechsig: *Plan des Menschlichen Gehirnes;* Leipsic, 1883. Alby: *Schema des Faserverlaufes im Menschlichen Gehirn und Rückenmark;* Bern, 1883. Roller: Die Schleife, *Arch. f. mikroskopische Anatomie;* Bd. xix., p. 240, 1881. Wernicke: *Lehrbuch der Gehirnkrankheiten;* Kassel, 1881. Starr: Sensory Tract, *Journal of Nervous and Mental Disease,* July, 1884, Spitzka: On the Lemniscus, etc., *New York Med. Record,* 1884. Edinger: *Zehn Vorlesungen über den Bau der nervösen Centralorgane;* Leipsic, 1885.—S.

ceived an increase in the oblongata, in the form of an addition from the cerebellum, which was joined to the other behind the continuation of the tegmentum. At this point there were four layers: *corpus restiforme*, or *funiculus posterior; tegmentum, stratum intermedium*, and *pyramidal tracts.*

The formation of the spinal cord is the result of the union of bundles coming from the different centres of the cerebrum and cerebellum. Whether their wealth of fibres increases or not, there

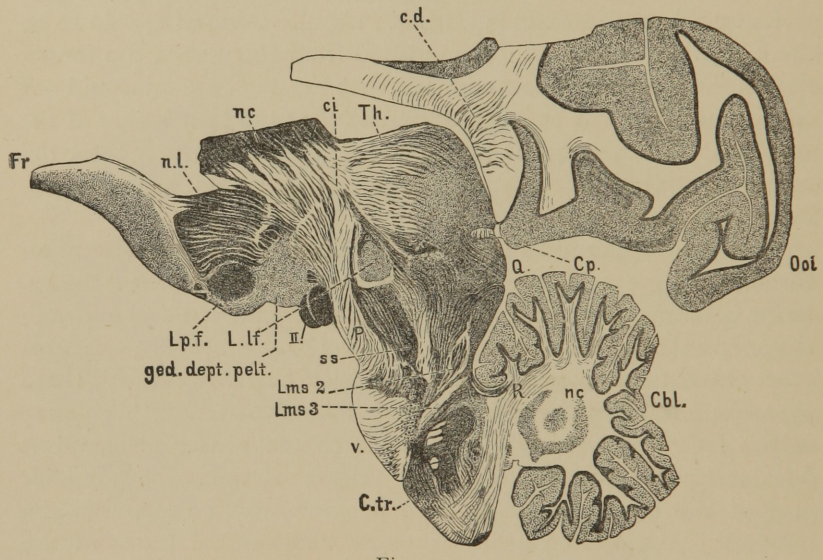


Fig. 55.

Transparent Sagittal Section through the Brain of the Monkey. (More Lateral than Figs. 56 and 57.)

Fr. Frontal end. Occ. Occipital extremity. c.d. Corpus callosum. n.l. Lenticular nucleus. nc. Caudate nucleus. Lp.f. (o) Lamina perforata anterior. ged.dept. pelt. Region of the pedunculus septi pellucidi. II. Optic tract., above it the optic commissure. ci. Internal capsule. Th. Optic thalamus. L.lf. Discus lentiformis. The dark (shaded) bundles, forming an < around its anterior end, constitute the radiation of the posterior longitudinal fasciculus. Between this formation and the thalamus is the radiation of the nucleus ruber. Cp. Posterior commissure. Q. Corpus quadrigeminum in which the brachium corp. big. superius (bearing downward and backward), and the fillets (Lms 2, Lms 3, bearing downward and forward) are seen. The lowest white bundle is the cerebellar lemniscus (Lms 3) from the valvula cerebri. Behind Lms 3, the trigeminal root. ss. Soemmering's substance with its medullary substance. P. Pes pedunculi. v. Pons Varolii. C.tr. Oblongata (corp. trapez.). R. Corp. restiforme. Cbl. Cerebellum. nd. Dentate nucleus of cerebellum.

is no reason to suppose that these bundles would occupy any other position relatively to each other than they hold in the crus cerebri and in the oblongata. Inasmuch as continuity of the bundles can be studied best on sagittal sections, Figs. 55–57 are added as supplementary to the previous descriptions of the brain.

The tegmentum is composed of four distinct sets of fasciculi of origin (Ursprungsbündeln).

1. The fasciculus longitudinalis posterior does not seem to end altogether at the lower margin of the pons and in the oblongata. It might be traced to those posterior bundles of the anterior columns (on the spinal-cord section) which are situated in part immediately in front of the gray spinal commissure—the prolongation of the gray floor of the brain,—and in part are crossed by the white bundles of the anterior commissure (Fig. 58). The radiation of the posterior longitudinal bundle from the cerebral cortex contributes a small number of fibres to the cross-section of the crus cerebri, and there is no doubt that in the brain-trunk its bundles are interrupted by masses of gray substance, each cerebral nerve-nucleus constituting an internodium. And yet the fasciculus longitudinalis posterior forms the most direct connection between the gray substance of the spinal cord and the cerebral cortex, for the gray internodia high up in the brain, such as the *ganglion opticum basale*, are equivalent to the central gray substance of the spinal cord (Figs. 18, 21, 31, 37, 40–44, 55, and 56. *Cf.* p. 96, etc.).

2. The bundles of the anterior pedicle of the thalamus, which, as *laminæ medullares*, emerge like the rays of a fan from the thalamus, and can be traced in the tegmentum to bundles situated to the outer side of the red nucleus (Figs. 29, 34–36, 38, 55. *Cf.* pp. 89, 91, etc.).

3. The *fasciculus retroflexus* might be considered the continuation of that portion of the stratum zonale which participates in the formation of the ansa peduncularis; it passes through the peduncle of the pineal gland into the posterior commissure.

An ependymal connection with the posterior surface of the fornix might lead one to believe that there is a connection of the pineal peduncle with the posterior surface of the fornix.

These bundles twist about in such a way that in the tegmentum they constitute the innermost anterior bundles, and in contrast to the posterior long. bundles participate in the formation of the anterior column of the tegmentum (Figs. 34, 35, 38, and a fragment in Fig. 56. *Cf.* p. 90).

4. The bundles from the posterior commissure, which enter the thalamus along its inner margin, after passing through the ansa peduncularis, and constitute its stilus anterior. These bundles and the fasciculus retroflexus represent the crossed thalamic origin of the spinal cord (Figs. 17, 18, 31, and 57). The

former bundles are well exhibited on Fig. 57, where they are seen entering the tegmentum ; according to Fig. 34 they lie behind the origin of the fasciculus retroflexus, and by comparison with the brains of carnivora seem to me to constitute an opaquely bounded column lying in front of the gray substance and to the outside of the posterior longitudinal bundle (in the mesencephalon). This column is intersected by the *fasciculi marginales aquæducti Sylvii.* On the supposition that it descends directly to the spinal cord we should have to look for this formation in the funiculus lateralis, next to the external margin of the anterior horn (Fig. 58, pp. 31, 89, 96, 103).

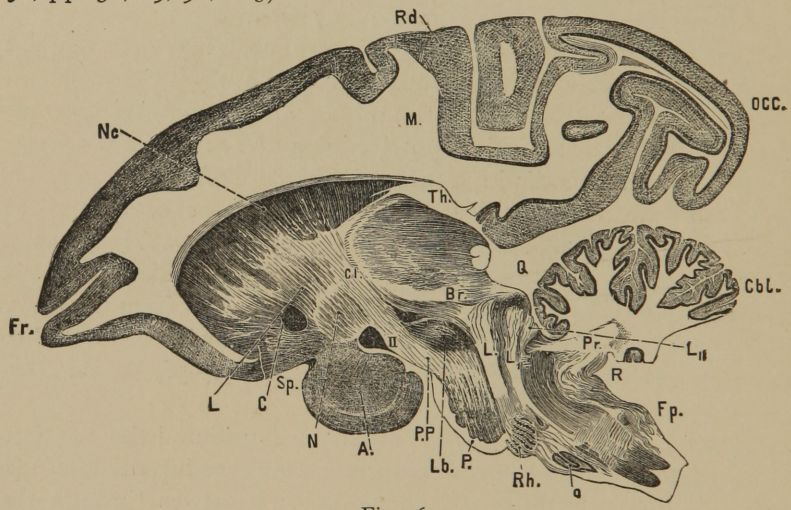


Fig. 56.

Transparent Longitudinal Section through the Brain of a Monkey.

Fr. Frontal end. OCC. Occipital end. Rd. Cortex cerebri. M. Medullary substance of the fore-brain. Nc. Caudate nucleus. L. Lenticular nucleus. C. Anterior commissura. N. Globus pallidus. A. Amygdala. II. Optic tract. CI. Internal capsule. Th. Thalamus. Br. Brachium corporis quadrigemini. Lb. Discus lentiformis (by mistake of the engraver united to the stratum intermedium. The dark-pointed triangular mass in front of it is the radiation of the posterior longitudinal fasciculus. Underneath Br. The radiation of the nucleus ruber). L, L_1, $L_{\frac{1}{11}}$. Lemniscus of the superior and inferior corpus bigeminum, and of the valvula cerebelli. P.P. Pes pedunculi. P. Pons Varolii. Rh. Corpus rhomboideum. O. Inferior olive. Cbl. Cerebellum. Pr. Processus cerebelli ad cerebrum. R. Corpus restiforme. Fp. Funiculus posterior.

5. The quadrigeminal origin of the spinal cord is embodied in the lemniscus, which can be pursued quite to the medulla spinalis on Figs. 55 and 56; particularly in the former. The divisions of the lemniscus constitute the most anterior layer of the funiculus lateralis, are crossed in or below the pons (according to the structure of the animal's brain) by the transverse bundles

of the *corpus rhomboideum*, and in the oblongata enclose the lower olive, in the cells of which possibly some of their bundles terminate, unless they should alter their position and pass to the back of the olivary bodies. In the spinal cord the layer of the lemniscus would correspond to the external stratum of the lateral column (Fig. 58), and possibly to the most anterior layer of the anterior columns. The analogue of the quadrigeminal layer of the lemniscus would, in the spinal cord, not extend as far as the caput of the posterior horn (Figs. 17, 22, 40–45, 55, and 56. *Cf.* pp. 34, 102, 103.

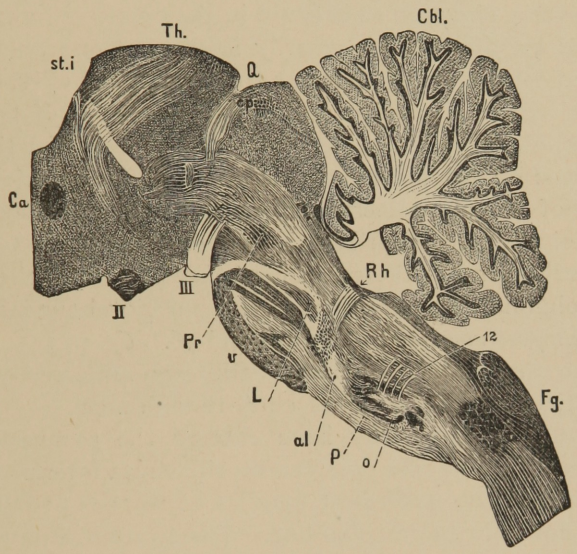


Fig. 57.

Sagittal Section through the Brain of a Monkey. The Most Median Section of Figs. 55, 56, or 57.

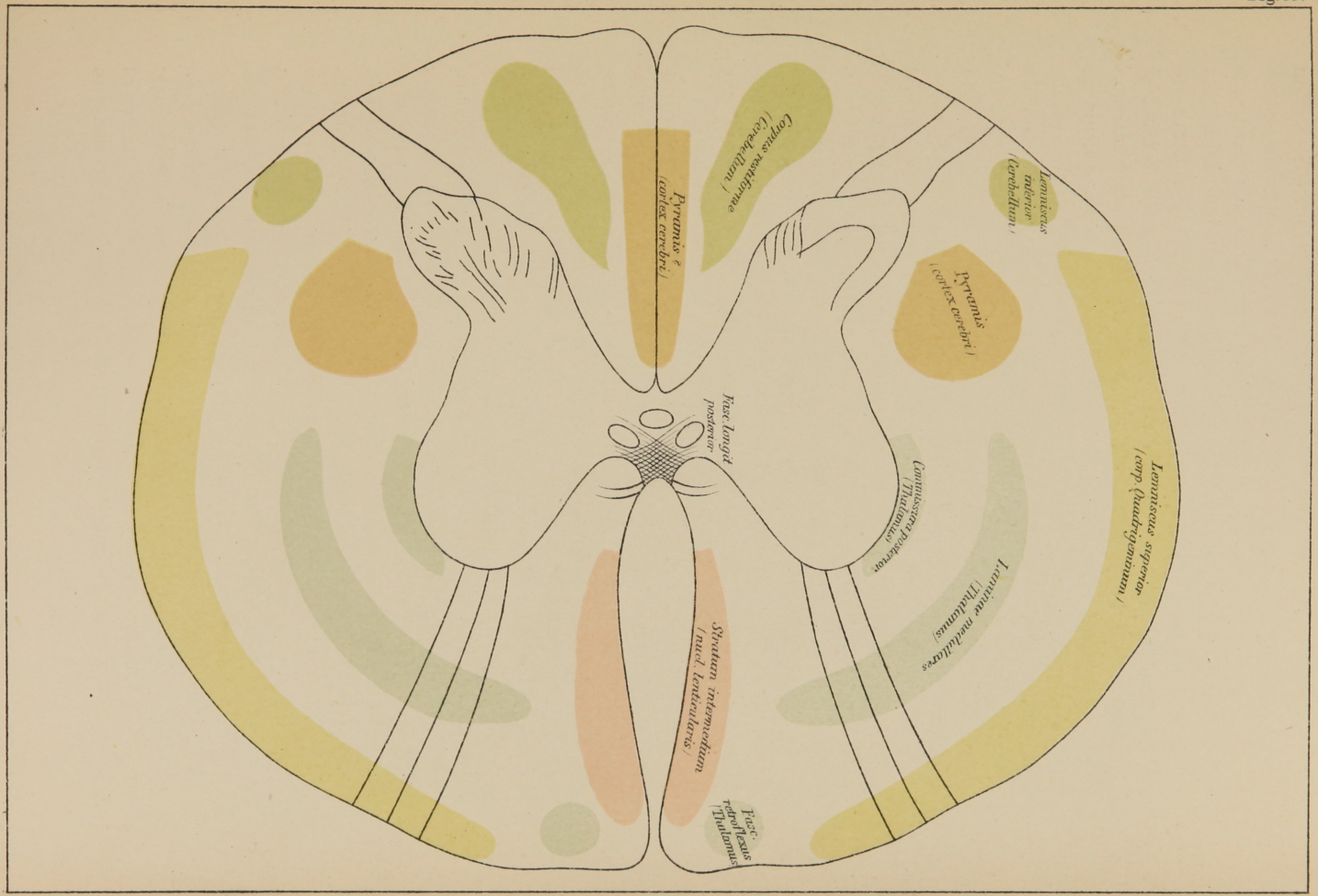
Ca. Anterior commissure. II. Optic tract. Th. Thalamus. st. i. Internal pedicle of thalamus covering the ascending crus fornicis (white). cp. Posterior commissure. III. Third nerve. Between cp. and III. the tegmentum, on the back of which lie the roots of the fourth nerve. Pr. Decussation of the superior cerebellar peduncles. Between pons and third nerve innermost bundles of the crus, which run from the pes pedunculi into the posterior division of the pons, and are cut off on their course toward the median line. L. Stratum lemnisci. Rh. Fossa rhomboidea, in front of it the roots of the sixth nerve. 12. Hypoglossal roots. v. Pons Varolii; behind the transverse basilar bundles, the pyramidal tract. al. Behind the pyramidal tract we find the lemniscus passing through the olivary body, for lower down the section inclines strongly to the outside; this lemniscal layer was traversed above by the roots of the sixth nerve and the transverse fibres of the corpus rhomboideum. Cbl. Cerebellum with the valvula ad. corp. quadrigemina. Fg. Funiculus gracilis.

The gap left in the spinal cord by the quadrigeminal lemniscal layer is filled in by the cerebellar or lower lemniscus, which is derived from the vermis superior of the cerebellum, passes through

the valvula cerebri, and joins the quadrigeminal lemniscus. From the manner in which the lemniscal layer advances, we can understand why this last addition should represent the most posterior (or, in the pons, the most external) bundles of the lemniscus; for in the cross-section of the lemniscus the quadrigeminal fibres are so arranged, that those originating highest are pushed farthest toward the median line, and the lower bundles join the lemniscus externally in the order of their descent. The lowest addition to the lemniscus would, therefore, form its most external bundle. But in the spinal cord the lemniscus cannot spread as readily in a transverse direction as it could in the crus cerebri and in the pons. Its bundles will necessarily lie behind one another, and the outermost bundle will become the hindermost (Fig. 58).

Genetically, this portion of the external layer of the lateral column would have a distinct anterior boundary, for the spinal-cord mantle develops around the anterior and posterior horn in the form of an antero-lateral and a postero-lateral column. The latter adjoins the posterior horn. The hindermost lemniscal layer undoubtedly forms in the spinal cord that portion of the postero-lateral column which constitutes the anterior boundary of the *caput cornu posterioris* (Figs. 17, 55, and 56. *Cf.* p. 34).

6. The *stratum intermedium* is the representative of the nucleus lenticularis in the spinal cord, though some of the crural bundles of the latter may have entered the pyramidal tracts. On sections through the crus cerebri the strata intermedia lay to the outside of the outermost bundles of the pes pedunculi, and were confluent in the median line. The stratum intermedium is composed of the ansa lenticularis, the innermost bundles of the pes pedunculi, and of other fibres of origin of the lenticular nucleus, which, after interweaving with the pes pedunculi, or the capsula interna, respectively, enter the lateral portions of Soemmering's substance. In the oblongata, this stratum lies in the same transverse position immediately behind the pyramids. Upon diminution in the size of the stratum intermedium, followed a diminution of the angle between the two continued halves of this stratum (originally amounting to 180°), for these two halves, forming the posterior boundary of diminished pyramidal tracts, had to approach each other more closely. As the decussation increases, the angle grows more acute, and as soon as the last traces of the pyramidal tracts have disappeared, the two halves of the stratum intermedium lie immediately adjoining the anterior



MEDULLARY TRACTS ON CROSS-SECTION OF SPINAL CORD.

Lith. Anst. v. Th. Fennwarth.

fissure of the spinal cord, there forming the innermost bundles of the anterior columns (Figs. 22, 23, 31, 34, 36, 37, and 58. *Cf.* pp. 45, 51, 54, 55, 80, 106, 107).

7. The *pes pedunculi* has a twofold origin: as the *fasciculus* of *Arnold* of the internal capsule from the cortex of the fronto-parietal lobe, and as the *fasciculus* of *Gratiolet*, from the occipital and temporal lobes. Its cross-section area in the mesencephalon is so constituted that its innermost bundles belong to the stratum intermedium (ansa lenticularis), that its outermost bundles are those described by Gratiolet and myself, and that the largest mass between the parts referred to contains the remaining pyramidal bundles, and the medipeduncular[1] bundles of the crus cerebri. In point of calibre, the lenticular portion is the smallest, the bundles of Gratiolet of far greater dimensions, while the last-named of the three divisions is the most powerful of all. In the spinal cord, the pyramidal bundles are lodged to the front of the posterior horn, but do not extend either to the outer surface of the lateral columns corresponding to the fillet, or to the anterior portions of the posterior horn (Stilling, Flechsig).

That portion of the spinal-cord section which immediately surrounds the gray substance from the anterior horn to the caput of the posterior horn, contains all the *thalamic* fibres of the spinal cord; though the origin of some of these bundles may still be hypothetical. (Figs. 15, 17, 22, 23, 30, 31, 33, 34, 36, 37, 40, 41; regarding bundles of Gratiolet, Fig. 33. *Cf.* pp. 27, 50, 81, 84, 85.)

8. The outermost area of the brain-trunk, the *corpus restiforme*, is added to the oblongata from the cerebellum; it is derived from the laminated medullary substance immediately surrounding the nucleus dentatus, and passes through the stratum zonale, and through the mediation of the two most anterior sets of *fibræ arcuatæ* into the posterior column. The term "*funiculus cuneatus* of Goll" may easily lead to confusion in spinal-cord terminology. This strand, which takes on a bright red color when stained with carmine, and in the fœtal spinal cord is distinctly separate from the lateral portions of the funiculi cuneati in the oblongata, is the spinal continuation of the funiculus gracilis and *not* of the funiculus cuneatus.

That the bundles of Gratiolet in the pyramidal tracts may participate in the formation of the posterior columns, or their inner portion at least, is not at all improbable (Figs. 15, 17, 22, 23, 45–47, 52, and 53. *Cf.* pp. 28, 36, 119, 126).

[1] In Wilder's sense.

ANATOMICAL COROLLARIES AND PHYSIOLOGY OF CEREBRAL ARCHITECTURE.

In the preceding section of this work we discussed the structure of the brain. We have now to consider a number of anatomical corollaries which will explain certain functions of this mechanism upon which physiological experiments have shed no light hitherto. Our understanding of those functions will be advanced, too, by close attention to the pathological anatomy of the organ under consideration.

A mechanism may operate before us without our recognizing the exact relation between its function and its architecture. But, on the other hand, if we are acquainted with the principles upon which this mechanism operates, we may infer its function from its structure, regarding the former as the natural outcome of the latter.

This method of reasoning would be applicable to the brain, even though the principles involved in its activity were entirely unknown. Moreover, matters are simplified very much in the case of the brain, for, without committing serious error, we may regard it as made up of a large number of entirely similar structural elements.

In order to establish anatomical corollaries, we need postulate but a single principle, abundantly proven by physiological experiments. This is Bell's law of the conduction of nerve-force in a *centripetal* direction through the *posterior*, and in a *centrifugal* direction through the *anterior*, spinal roots. We need not, however, accept Joh. Müller's opinion, that, at the very outset, different parts of the brain display different functional energies. A single functional energy only, though as inexplicable as all physiological forces, is inherent in the brain-cell, and that is *Sensitiveness*. Actual *sensation* is developed by the evolution of equally unknown external forces, which we must suppose differ very materially from one another.

These differences imply a difference in anatomical structures, not of the brain, but of the terminal organs of peripheral nerves.

This is well illustrated in the case of the anterior roots, which are motor in function, simply because the terminal organs of nerves derived from the anterior roots are connected with muscles. The latter alone are motor elements. Nerves and nerve-cells possess no motor power. Indeed, there is nothing more certain about the functions of the cerebral organism than that the centripetal sensory nerves are the keys which wind up the mechanism connected with the muscles, and excite the latter to action.

A varying functional energy of brain-cells, according to the special organ of sense with which they may be connected, is quite indemonstrable, since we are acquainted with the physiological conditions favorable to the action of external forces, and can prove easily enough that it devolves upon the terminal organs of the nerves to meet these conditions. Even if the auditory nerves possessed a specific *visual* energy, the media between the auditory nerve and the waves of light would be totally unfit to transmit visual rays.

Specific energies therefore depend altogether upon the peculiarities of the end-organs, and *sensitiveness is the only specific property of brain-cells.*

Within the *fore-brain* sensitiveness is converted into actual sensation.

The relation of the fore-brain to the other parts of the cerebral mechanism is easily understood. To this end we may recall the structure of the retina, which constitutes a hollow into which the visual rays from the external world are, as it were, entrapped. And, in the same way, we may look upon each half of the cortex of the fore-brain as a concave organ, duplicated in parts, enveloping all the nerve tracts, which conduct to it the impressions from the outer world. In this organ these impressions are converted into the phenomena of sensation. In assimilating totally unknown physical impulses, the cerebral cortex, a complicated protoplasmic structure, resembles the protoplasm of the primitive amœba, which can transform itself into a hollow mass, and can thus encircle any body which it wishes to assimilate. Just as the mollusca possess tentacles which they protrude toward the outer world, and claws by means of which they take possession of their booty, so this complicated protoplasmic organism, the prosencephalic cortex, possesses centripetally-conducting processes,—the sensory fibres of the nervous system—which we may consider its tentacles, and motor fibres, which are its claws. The

remainder of the body, with its sensitive surfaces, its muscles, and the skeleton to which these muscles are attached, serves to sustain these tentacles and claws, which enable the fore-brain to receive the images of the external world, and to react upon the latter. Comparing the disposition of the gray substance in the spinal cord with its arrangement in the cortex, we observe that the gray substance in the spinal cord is very much crowded by the aggregation of medullary strands on its periphery. Nerve-elements corresponding to tentacles and claws are thus closely united, and the functional result of this union is exhibited in the reflexes which the spinal cord necessarily develops, as soon as those higher cerebral structures which have an inhibiting influence upon its vital activities have been removed. In the fore-brain, on the other hand, the gray substance is not lodged in the white, but the white substance in the gray, and the former pushes the cortex asunder. Knowing the difficulties of nerve-conduction through the gray network of fibres, we may infer that this enlarged surface will be able to perform a number of totally independent functions; that a sensory perception, for instance, need not give rise immediately to a motor act. Every spinal-cord segment embraces the whole of the gray substance, whereas sections through the cortex contain but a small portion of the cortical gray. This distribution of gray substance will naturally prevent the entire cortex from acting to one single end, while it favors the isolated action of various cortical regions. Irradiation of functions is facilitated in the gray substance of the spinal cord, and rendered difficult in that of the cortex. We learned, furthermore, that the cortical structure was not the same throughout; that the arrangement of the cortical elements varied in different divisions of the cortex. Purely morphological data and a single pathological anatomical fact will enable us to determine which regions of the cortex, in the probable division of labor, take upon themselves centrifugal functions in the sense implied in Bell's law. The pathological fact referred to is the hemiplegia resulting from destruction of the prosencephalic ganglia, and particularly from destruction of the nucleus lenticularis. These ganglionic masses divide into a club-shaped body (*nucleus caudatus*), and a wedge-shaped body (*nucleus lenticularis*), both presenting their broadest surfaces anteriorly (cephalad). Upon the number of cortical cells, depends the number of radiating fibres which the ganglia receive; accordingly the anterior portions of the prosencephalic ganglion

must contain by far the largest number of cells for the reception of these radiating fibres. We may therefore establish this morphological corollary, that the cells of these ganglia will be able to receive more fibres from the anterior cortical regions than from the posterior ventral regions of the hemispheres, for these ganglionic masses, tapering as they do toward this latter region, will naturally have a lesser number of cells to put at the disposal of fibres coming from that direction. Besides, Gratiolet and I observed that the occipital and temporal cortex received fibres from those ganglia with which the optic tract is connected. And into these latter regions of the cortex those bundles of the internal capsule enter, which, when implicated in a lesion, give rise to hemianæsthesia (Türck). It was well known also that the anterior commissure, which was supposed to be an olfactory chiasm, was not connected with the cortex of the frontal lobe, but according to Arnold with those of the temporal lobe ; Burdach and myself insisting on a further connection with the cortex of the occipital lobe. This separation of sensory and motor areas in the cortex was later on substantiated by the results of physiological experiments.

Before discussing these physiological experiments, I wish to call attention to three anatomical facts which render a functional differentiation of the various cortical regions highly probable. The first of these facts is taken from comparative anatomy, and refers to the enormous difference in development of the olfactory lobe in different animals. Animals that are accustomed to run their noses close to the ground, and to obtain their food by following the scents they perceive, are characterized by a highly developed olfactory lobe, as is shown in Figs. 7 and 10. In man, whose erect posture has lessened such sense-impressions, as well as in the monkey and in all climbing animals, the olfactory lobe has deteriorated very much. Among water mammals, the sea-lion, which spends part of its life on land, has an olfactory lobe about equal in dimensions to that of man, while cetaceans have no olfactory lobe at all.

The second fact refers to the difference in the relation between the median and the convex surfaces of the cortex, in animals with strongly developed olfactory lobe, and in man. In the latter, the convolutions of the convex surface everywhere overtop the *gyrus fornicatus ;* whereas, in the former category of animals, this same gyrus, which is connected with the olfactory lobe, is enormously developed, forming, together with the external olfactory convolu-

tion, the gyrus uncinatus of the convexity which continues the formation of the *cornu ammonis* to the middle of the corpus callosum; while in man this formation but barely grazes the posterior surface of the corp. callosum.

Thirdly. Among the convoluted regions of the convexity of the human brain, the walls of the Sylvian fissure are most highly developed. This includes its floor, the island of Reil, as well as the operculum covering the island from above, and the first temporal convolution covering it from below, and also the transitional convolution, together with the posterior margin of the orbital surface closing in upon the anterior border of the island. In keeping with these peculiarities of structure, the human brain exhibits the most extensive claustrum. But I have shown that the disturbances of psychical speech, which are classed under aphasia and its allied conditions, depend upon lesions in the claustrum—in general terms, upon lesions in the walls of the Sylvian fossa. Man as far excels in the development of these psychical regions of speech, and in the number of convolutions belonging to these regions, as animals with highly developed olfactory lobes excel in regard to the size of these lobes. From this we may unquestionably infer that evolution of certain psychical functions will go hand in hand with a proportionate development of certain regions of the cortex.

We may as well add at once that there are quantitative differences in the brain-trunk, both in man and in animals, dependent upon quantitative variations in the different parts of the fore-brain. An inspection of the basilar surface of the cerebrum confirms this view. The ideas suggested by such considerations as these were referred to on page 82, where it was shown that, in keeping with the quantitative development of the fore-brain, those structures, which are connected with its centrifugal tracts, such as the crus cerebri (excluding the tegmentum), the pons, and the pyramidal tracts of the medulla oblongata, are the most powerful formations in the human brain; there seems, therefore, to be a harmonious dependence between the form of the brain-trunk-structures and the quantitative development of the fore-brain.

These well-ascertained, though general and incomplete anatomical facts, would justify us, from a purely morphological point of view, in affirming the localization of cerebral functions.

Having obtained this firm and safe anatomical foothold, it will

be especially interesting to examine those from among the many contradictory physiological experiments which confirm the view of a localization of functions in the cortex of the brain. This question has been studied in all its details by different physiologists and in different ways. The older brain-physiologists asserted that direct irritation of the cortex produced no effect; but Hitzig,[1] by means of electrical irritation, and Nothnagel,[2] by the use of mechanical irritants (principally pricking with needles), succeeded in proving that irritation of certain regions of the convexity produced movements in the opposite side of the body. Ferrier,[3] too, has furnished many details.

It would be a difficult task to give a critical review of all these experiments, which agree with each other in principle only, and not in the dimensions of the psycho-motor, functional areas governing special groups of muscles. Nothnagel operated on the rabbit, and could not make out as large a number of centres as Hitzig determined, though Nothnagel's centre for the anterior extremity occupies the same position as the centre to which Hitzig has ascribed similar functions. On the other hand, Nothnagel has described another possibly motor (leap) centre, which Hitzig cannot corroborate; and the difficulties of a critical review are increased still more by the fact that Hitzig, experimenting on monkeys, wishes to limit all centres to the gyrus *præ*centralis, in flat contradiction of his description of the motor areas in dogs, in which the facial centres, as well as those for the straight ocular muscles, are situated posteriorly to the fissura *centralis*.

No one will be disposed to agree with Hitzig's complicated interpretation of the gyrus præcentralis in the dog, and yet, in spite of the artificial expansion of the gyrus præcentralis over several other gyri, we may locate the centre for the muscles of the neck and trunk in front of the gyrus præcentralis, as Hitzig defines this convolution, and as was explained on page 18 of the previous section. No mention is made of this particular motor area in the brain of the monkey.

Ferrier's "centres" cover the largest area, extending from the middle frontal convolution over and beyond both central convolutions as far as the occipital fissure, and including the first temporal convolution. By way of anticipation, I will remark that Munk also looks upon a line drawn from the posterior end of the Sylvian fissure to the margin of the hemisphere as the posterior boundary of the motor area of the cortex. The radiating fibres which we observe entering the nucleus lenticularis and capsula interna, on longitudinal sections of the brain (Fig. 30), would seem to be radiations from that portion of the cortex which lies anterior to and including the region of the posterior central convolution, into these centrifugal conducting tracts. Hitzig's centres are located principally in the frontal lobe, although he has made an entirely gratuitous change, as was shown in the previous chapter, in making the *gyrus præcentralis* part of the parietal region.

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[1] Fritsch u. Hitzig: "Ueber die elektrische Erregbarkeit des Grosshirns, *DuBois-Reymond's Archiv*, 1870. Hitzig: Untersuchungen zur Physiologie des Gehirns, *ibid.*, 1873. "Untersuchungen des Gehirns," Berlin, 1874.

[2] *Virchow's Archiv*, vols. 57 and 58.

[3] "Experimental Researches in Cerebral Physiology," 1873; *cf.* also "Functions of the Brain," Am. Ed., 1876.

Hitzig has mapped out the centres in the præcentral convolution in the following order of succession from above downward: (1) Centre for the posterior extremity; (2) for the anterior extremity; (3) for the facial nerve; (4) for the movements of mastication. The disagreement among authors in regard to the topographical distribution of psycho-motor centres in the cortex makes it incumbent upon us to examine into the nature of those motor disturbances upon which all are agreed. In parenthesis be it said, that Ferrier's "centres" have met with opposition from *all* other authors.

Hitzig believes that the motor disturbance in the anterior extremities, consequent upon an excision of cortical substance, is to be explained on the ground that the animal has lost the muscular sense which informed it of the position of its extremities. An animal, thus operated, will allow its foot to be placed in the most uncomfortable position, with the dorsal surface to the ground, and so on, and yet is able to use the anterior extremity well enough in response to volitional impulses.

Nothnagel is inclined to the opinion that ataxic movements result from the lesion of the so-called psycho-motor areas of the cortex, agreeing with Leyden, who attributes ataxia (*i. e.*, the condition consequent upon the disease of the posterior gray columns of the spinal cord, which effects irregularities in lifting, and in the forward and lateral movements of the foot) to an interruption in the nerve-tracts issuing from the brain.

The present author believes he was the first one (in the pamphlet entitled "On the Twofold Cerebral Origin of the Spinal Cord," 1869) to insist that the processes of innervation from the hemispheres, which constitute what we term *volitional acts*, are nothing more than the *perception or memory of the sensations of innervation;* for such a sense of innervation accompanies each reflex act, and is registered in the cortex; there this same sense of innervation serves as a fundamental basis for similar secondary movements produced by excitation of the fore-brain.

By association, these memories (*Erinnerungsbilder*) acquire sufficient intensity to excite secondary movements starting from the fore-brain and passing along centrifugal nerve-tracts. I shall refer to this subject again later on.

Munk[1] has given a very lucid account, based upon experi-

[1] Ueber die Functionen der Grosshirnrinde. Berlin, 1881.

ments, of the relation of the cortex to the movements of the body. Munk subscribes to my views, believing that in order to explain conscious movements—*volition*, in psychological phraseology,—it is sufficient to postulate sensations of innervation. Munk distributes sensory areas over quite the whole of the cortical surface, and therefore terms the region from the occipital lobe to very near the frontal margin (in the monkey) the "sensory sphere" of the brain. The character of these sensations he described as tactile sensations, sensation of pressure (the knowledge of which is not enhanced by experiment), and as sensations of innervation. The tactile and pressure sensations are thought to be a means of regulating the excitation of sensations of innervation. Spiess and Lotze entertained the same opinion long ago, but were too one-sided in supposing that the "muscular sense" depended simply upon the perceptions of touch and pressure by any part of the skin and the joints.

Thus we see that an experimental investigator reaches the conclusion, that sensitiveness is the only specific energy common to ganglion cells; and we are led to infer a localization of sense-impressions only, which, in keeping with the above views, would be synonymous with the localization of so-called motor areas of the cortex.

In corroboration of the conclusions of Hitzig, who observed that blindness ensued upon the removal of a part of the *occipital* cortex, Munk finds that removing a piece (15 mm. broad and 2 mm. thick) of the same region gives rise to what he calls "psychical blindness." Removing another piece of about the same dimensions, from the *temporal* cortex, caused symptoms to which Munk gives the name of "pyschical deafness."

The dog which has undergone the former of the two operations, will show the following peculiarities, provided the healthy eye *on the side of the lesion* be properly bandaged. The dog, so conditioned, "no longer scents for his food as he used to do in the accustomed corners of the room, and if both the mess-pot and the pail of water be placed in his way he will go round about them again and again without taking notice of them. He takes no notice of his food until he smells it; neither a finger nor a flame brought close to his eye moves him; and the sight of the whip, which used to drive him into the corner, does not intimidate him in the least. He had been trained when the hand was passed by his eye to give his paw; now he does not respond to

that movement of the hand until he hears "paw"; and other like observations are to be made. But such a dog can again learn to see as in his earlier days, and to regulate his action according to his visual images; he is, therefore, mentally blind—not organically blind; he has lost the visual images registered in his cortex previous to the operation. This phenomenon, the revival of previously registered images, Munk explains by the fact that the visual area is larger than the part extirpated, and that up to the time of excision the entire visual area was not filled with visual images, but that after the removal of the part formerly entrusted with the care of the visual images, another part, connected also with the retina, assumes the duty of harboring new visual images. If the entire occipital cortex be removed, cortical blindness will ensue; the animal becomes totally blind, although the subcortical visual centres are intact. We are, therefore concerned with the loss of cortical functions only.

More recently Munk's "visual sphere" has been extended considerably, so as to include in the monkey the whole of the well-marked occipital lobe, including its median surface. Munk states, that after psychical blindness has disappeared, in the course of four to six weeks, the dog does not pounce directly upon meat which is placed before him, that he cannot snatch it until it has become distinctly visible by appropriate movements of the head. He draws the inference that after the extirpation of the cortical centre, a new blind spot is created on the *retina*, for a definite portion of the retinal elements is no longer connected with the cortical cells upon which retinal impressions were registered; and he contends, furthermore, that the arrangement of the cortical elements repeats the exact distribution of the retinal elements around the spot of clearest vision.

The psychical deafness resulting from the removal of a portion of the temporal lobe, brings about the following changes in the behavior of the dog:

"The dog has retained the power of hearing, every unusual noise exciting an equal pricking of both ears, but he cannot interpret what he hears. The meaning of 'pet,' 'come,' 'up,' 'there now,' 'paw,' and all calls to which he was accustomed to respond, he does not understand; so that he no longer performs movements which at one time had the value of reflex acts." Gradually the dog learns to hear again, and after four or five weeks behaves about as he did before the operation. In this

instance also Munk assumes the existence of a peripheral auditory area around the part extirpated; this peripheral area now receiving and storing up the newly acquired impressions. Removing this peripheral area and leaving the concentric inner sphere of the auditory area, produces no effect whatever; for no auditory images had as yet been stored in the former (peripheral) area, as was the case also with regard to the visual centre. This theory would explain not only the re-acquisition of facts which had once been familiar, but also every increase of knowledge effected by the mediation of cerebral cells which up to that time had not been functionally employed.

To this literal quotation of Munk's views, I wish to add that they give a plausible explanation of mental (psychical) *deafness* only. The introduction of projections of the *macula* lutea into an inner area of the "visual sphere" must necessarily lead to incalculable confusion. This re-acquisition of facts is simply the result of newly-registered images which are lodged in the environs of the parts removed. According to Munk's theory we should have to believe that these later impressions were indistinct, because they did not happen to be registered within the cortical (projection) area of the macula lutea. Munk thinks perception and memory are identical. We hope to prove later on that a cortical image has no material background (*sinnliche Klarheit*). Even darkness leaves its image upon the cortex. The term "psychical blindness" would suffice, and from this, *cortical* blindness would differ simply in being an incurable state.

There is no reason compelling us to assume that tactile and pressure-sensations, because of their relation to the muscular sense, are registered in the same parts of the cortex as are the sensations of innervation: first, because the external fasciculi (of Türck) of the crus cerebri, which carry tactile impresssions, are not united to one another throughout their entire course; and secondly, because association-fibres effect the co-operation of widely separated cortical districts.

Referring once more to that portion of the sensory sphere, (*Fühlsphäre*) which was called the psycho-motor centre until Munk called it the centre of sensations of innervation, we find that this author ascribed limits to this sphere in the brain of a dog, which, if followed in the brain of a bear (Fig. 7), would leave a functionally useless region occupying the convex surface between the two parietal convolutions, and a portion of the marginal convolution

above. The sensory sphere would be situated cephalad, the auditory and visual areas caudad, of this functionless area. Between this boundary and the olfactory lobe there lie, one above the other, the centres for the hind limb, for the fore limb, and for the head. In a later publication (December, 1878), Munk has added to the number of sensory areas in which the sensations of innervation are registered. These newly added areas are an eye-region on the summit of the second parietal arch of the dog, governing the protecting and motor apparatus of the eye ; and an ear-region on the summit of the first parietal arch, removal of which disturbs or annuls the movements and sensibility of the *concha auris*. The head-region, which he subdivides into centres for the tongue, facial nerve, etc., Munk distributes over the whole operculum as far as the anterior branch of the parietal arch. The centres for the fore- and hind-limbs lie in front of the sulcus centralis, and together do not occupy an area larger than the " head-region." The centre for the hind-limb lies nearer to the margin of the hemisphere. The extremities being represented in the frontal lobe, Munk locates the neck-region still farther to the front, as Hitzig did also, in that part of the frontal lobe lying in front of Leuret's transverse fissure; while he relegates the trunk-centre to the most anterior portion of the frontal lobe, resting upon the lobus olfactorius. With the exception of the gyrus fornicatus and the olfactory lobe, a corresponding portion of the median surface, which begins in man in front of the occipital fissure, is appropriated to the domain of the sensory sphere, including the various muscular areas. (" Verhandlungen der physiologischen Gesellschaft," Berlin, 1878.)

In the monkey (Fig. 8) the occipital lobe constitutes the visual sphere ; the temporal lobe presides over auditory functions, as has been repeated often enough. Within the sensory sphere we have the eye-centre on the posterior (superior) parietal arch, and the ear-centre on the anterior (inferior) parietal arch. The head-region extends from the margin of the operculum upward as far as beyond the lower portion of the sulcus centralis, and anteriorly it extends as far as the sulcus præcentralis, in the concavity of which the neck-region is lodged. Above it and partly behind it lies the centre for the hind-limb, along the posterior margin as far as the sulcus occ. ext. The sensory sphere of the trunk is situated in the frontal lobe, in front of the sulcus præcentralis and in the posterior portion of the orbital surface.

In keeping with his visual and auditory areas Munk establishes consistently enough a psychical paralysis after the removal of the so-called motor centres. This psychical paralysis, which is curable, is the result of the destruction of a small amount of cortical motor substance; but if the peripheral as well as central area of a motor centre be entirely destroyed, then permanent cortical [1] paralysis will be established.

Munk's sensory centres do not respect definite, prescribed boundaries, such as the convolutions would present; but there is this in favor of his views, that he makes the entire frontal lobe do serviec as a sensory sphere. Other authors, and among them Hitzig, who has misinterpreted the results of his own experiments, have pronounced the frontal region to be the exclusive seat of intelligence.

On this head Munk justly observes: "Intelligence is located everywhere in the cerebral cortex and nowhere in particular." I wish to add in corroboration of this view, that no author of the present day would be likely to insist on one special seat of memory, for memory is the common property of all cortical cells and fibres which are able to receive and conduct external stimuli of all sorts.

Consciousness and intelligence also, which is evolved in the fore-brain, depend upon a mechanism, the minute details of which enable us to understand the restriction of intelligence to the fore-brain. This discussion, which we now take up, shall be guided by the fundamental experiments of physiologists, and by certain morphological views which I published years ago (Leidesdorf, "Lehrbuch der Psychiatrie," p. 45, *et seq.*—1865).

There may be a difference of opinion among physiologists regarding the localization of definite impressions and functions in the cortex of the fore-brain, and their distribution among the medullary fibres of the brain; but there can be no question about this, that the intelligence of an animal is seriously impaired (obliterated) by the extirpation of its fore-brain. Those who removed the fore-brain with the knife, who destroyed it by freezing, or who, like Goltz, trephined the skull and washed out the fore-brain with a stream of water, all are agreed on this one point. Goltz (Ueber die Verrichtungen des Grosshirns, in *Pfluger's Archiv*, vol. xiii. and xiv.) presents the largest number of striking and critical observations, although he removed less of the fore-brain than

[1] The German text has *Rindenlähmung*. I have translated it *cortical* paralysis. The term is misleading, however; for the "psychical" paralysis is also based upon changes in the cortex. It would be better to speak in the one instance of "psychical" paralysis, and in the other of "absolute" or "complete" paralysis.—S.

others, for he could wash out[1] only about as much of the *cortical substance* as is visible after removing the roof of the skull. But on this very account Goltz has supplied facts which support the view of the localization of sensory areas on the cerebral surface. He observed a diminution of cutaneous sensibility, of the sensations of innervation due to ataxia and impairment of sight; but having left intact the base, and the median surface containing the olfactory area, and the basilar portions of the temporal lobe containing Munk's and Ferrier's auditory areas, the senses of smell and hearing were in no way affected. The mere loss of a few grammes of cerebral substance suffices, according to Goltz, an extraordinarily keen observer, to produce a degree of idiocy which he recognizes from the appearance and gaze of the mutilated dog. Idiocy develops in these dogs to such an extent, that they stumble into their meat-pots, bite their own legs, and, not remembering this experience, repeat the very same thing from day to day. Not knowing their whereabouts in space, they wander about the whole room in answer to their master's call; nor are they able to find with their snouts any portion of their skin which has been teased by *serres fines*, but simply run about restlessly and helplessly in consequence of the pain; they are not bright enough to discover or to lift up their whining pups, though they be very near them.

Apart from the difference in the arrangement of its nervous cortical elements (*vid.* p. 56, *et seq.*), the white substance of the hemispheres has everywhere the same structure; and we have shown that each hemisphere consists: (1) of projection-systems, which, with the aid of gray internodia interspersed among the medullary fibres, connect the cortex with sensitive surfaces and motor organs; (2) it (the white substance) consists of association-systems—*i. e.*, of arciform nerve-bundles. The wealth of such fibres, and their variation in length, connecting as they do near and remote parts of the cortex, will suffice, without formulating an anatomical hypothesis, to unite any one part of the cortex to any other. The phenomenon of mental blindness is exhibited in the case of the animal that no longer associates the sight of the whip with the idea of punishment, or in that other animal (of Goltz), from which the right hemisphere had been removed, and which, when its right, healthy eye was covered, took no notice of a servant wearing a mask and decorated with red rags; but as soon as its

[1] Goltz has long since abandoned this method of removing cortical substance. (For his present method see *Pflüger's Archiv*, Sept. 17, 1881.) S.

healthy eye (connected with the left hemisphere) was uncovered, pounced upon this fantastic figure, as every normal dog would do. If an animal has become psychically blind, it will recognize the sound of the whip but not the visual image.

We may note, therefore, that there is a localization of certain intellectual activities dependent upon, and coinciding with the localization of definite sensory areas. Longet was among the first to contend that a dog which had forfeited its hemispheres could be made to swallow colocynth, show displeasure, and perform all the retching movements which a disagreeable or bitter taste naturally excites; we must therefore assume the existence of sensory perception entirely independent of the fore-brain.

Schiff, who has given further details regarding these experiments of painting the tongue with colocynth, calls attention to the fact that he can again and again open the mouth of the animal, show it the instrument of torture (the brush), without eliciting the slightest repulsive movement; whereas young kittens give indubitable facial expression of the disagreeable gustatory impression they have received. Sensory impressions are therefore not wanting; but the recollection of previous pain, the recognition of movements preparatory to the infliction of pain, so-called volitional impulses which would induce the animal to escape, all these are wanting.

In order not to be dealing with intelligence in the abstract, let us determine by the simplest scientific analysis the contents of or, at least, a demonstrable factor of intelligence; and with this let us compare the brain-mechanism. We shall thus be able to conclude whether the cerebral mechanism can, or can not, account for the manifestations of intelligence which existed prior to the impairment of the mechanism.

First of all, animals deprived of certain cortical areas (Munk) or of the entire fore-brain, show no recognition of former impressions; the dog does not recognize the call of his master, nor the cat the preparations which are being made to insult her gustatory nerves. This non-recognition constitutes loss of memory, and loss of that special memory which is based upon the juxtaposition of successively received impressions. This is memory of the fore-brain, and must be regarded as a cortical function.

It is not part of our present purpose to dilate upon other phases of memory, such, for instance, as affect the entire organism, and are independent of the functions of the fore-brain,

though related to other parts of the nervous system. Among these would be classed those phases of memory which are manifested by the spinal cord in repulsive movements, the exact nature of which is varied, knowingly as it were, according to the character of a painful, exciting stimulus.

Lotze regards this phenomenon as an after-effect of oft-repeated innervations of motor spinal nerves, responding to definite stimuli reaching the hemispheres. Later on we shall refer in detail to this view, to whick Brücke also subcribes. The spinal cord of the new-born infant would not exhibit such phenomena. As long ago as 1867 I endeavored, in an essay entitled "Ueber den Bau der Rinde und seiner örtlichen Verschiedenheiten," to demonstrate the fitness of the cerebral cortex to be the seat of memory, by showing that it contained more than a milliard nerve-cells which could serve as the functional posts of successively received impressions; while in the retina, in which after-images occur as the result of protracted normal stimuli, these images are not permanently lodged; for every succeeding series of images occupies the retina in its totality, and finally annuls the after-effects of former images. Munk's experiments have verified this assumption in regard to the nature of cortical memory. They have demonstrated that animals possess a functionally unoccupied region in the vicinity of the visual and auditory spheres, the removal of which (region) produces no effect in regard to psychical blindness and psychical deafness; but if the central functional portions of these spheres be destroyed, these peripheral areas will be the recipients of new visual and auditory impressions.

From this it follows that in the normal (physiological) course of events, more and more of the cortex is called into requisition to receive new impressions, and that upon the increase in the number of registered images will depend the enlargement of the child's mental sphere. It is very probable that the number of cortical cells fixes the limits of memory—the foundation of all intellectual activity.

The recollection of former experiences, of which the animal that has forfeited its fore-brain is incapable, implies the association of one phenomenon with some other. The dog, for instance, would associate the sound of the whip with the bodily pains it inflicted. In examining the structure of the hemispheres, and remembering that different, distinctly limited and functionally separated portions of the cortex receive impressions from the various senses,

we may naturally infer that the association-bundles, the *fibræ propriæ* of the cortex, which form anatomical connections between the different cortical regions, effect the physiological associations of the images which are stored in these various parts; these images implying excitation of the cells of these parts. Since these medullary bundles are beyond a doubt conducting nerve-tracts, this interpretation is not a mere hypothesis.

But recollection constitutes a process of induction (Schluss-process).

Wundt was justified in calling an induction the fundamental logical function (*vide* his lectures "Ueber Menschen und Thierseele"). I was the first one to demonstrate the association and induction mechanism of the fore-brain, in my pamphlet on the "Anatomie der Hirnrinde als Träger des Vorstellungslebens und deren Verbindungsbahnen, 1865," which was reprinted verbatim in Leidesdorf's "Manual." Both ends of the association-fibres are connected centrally with cortical cells; the projection-bundles (*vide* pp. 42, 43), consisting chiefly of fibres of the corona radiata, spreading into the medullary substance of the fore-brain, conduct to the cortex the excitations from the external world, and distribute them over its different sensory spheres. All objects which, as soon as perceived, engage two different sensory spheres, may well serve to prove the existence of an induction mechanism, present everywhere in the brain, and anatomically dependent upon the association-, and projection-systems. John Stuart Mill, who certainly possessed no anatomical knowledge of this sort, furnishes a simple instance of this process of induction. A person who would happen to find a watch on an uninhabited island would infer not only that this island possessed a fauna and a flora, but that man must have been on this island; for the idea of a clock or watch is inseparable from the idea of a human being. To this I will add the example I employed in Leidesdorf's "Manual." Let us imagine the cortex to be a *tabula rasa*, and let us present to it a phenomenon which, perceived by two different sensory surfaces, would, through the mediation of the *corona radiata*, stimulate two distinct areas of the cerebral cortex. Let the phenomenon in question be a lamb, and let us suppose that it emits a bleating sound. The sight of the lamb will stimulate cells of the visual area, and the bleating sound will arouse cells in the auditory sphere. The lamb disappears and the two kinds of images which it caused to be registered will grow fainter.

If, in the course of time, one of these registered images be revived, through the bleating, say, of the lamb hidden in a stable, then not only the auditory, but the visual image also of the lamb will be reproduced. In the cortex an inference is made from the sound to the body that gave forth the sound. We can readily understand this process of induction, if we will but assume that the original excitation of both sensory areas included the excitation of those arciform bundles which united the cells of the visual and auditory areas of the cortex, which areas had in turn received stimulating impulses through the projection-bundles. In this way both registered images are associated, and whenever the one of them is re-excited, the excitation will extend along the association-fibres to the other cells, which on a previous occasion had been taken out of a condition of repose simultaneously with the cells harboring the former image. The association-bundles may be compared to a connecting thread, which enables one image to lift the other, as it were, over the threshold of consciousness.

Inferring one attribute of a phenomenon from the presentation of another attribute, constitutes an induction; it is a recognition in the direction of causality, for the bleating sound is taken to be the result of the presence of the lamb. And here it will be well to add that, though the seats of these registered images are connected with many other cortical regions, there is no need of supposing that *all* these association-bundles will be simultaneously excited. In the first hypothetical case we supposed that the perception, the recognition of these images, or the induction regarding them, were effected by a brain in which no other images had as yet been registered in any part of its cortex. In that event, of course, but one association could be established.

A second, not nearly so hypothetical a case, will show us that not all the existing association-bundles connecting certain groups of cells with other cortical regions need be called into activity when any one member of the associated groups receives an external stimulus. In spite of the existence of numerous functionally perfect connections between such cortical groups and others, recollection is due to the excitation of accessory impressions (simultaneous sensations), which were registered simultaneously with the impression just reproduced, and which were established with especial reference to the revivified image. In the example

cited above, the visual image of the lamb was inferred from the sound ; this can be explained by assuming that the visual image was an accessory impression, a sensation, received simultaneously with the perception of the bleat. Hence we argue that in real cases of numerous and complicated associations in various cortical regions, recognition depends upon the re-presentation of accessory sensations which had entered into a union with certain registered images. Among its numerous associations *each registered image may be considered to be a special group of simultaneously perceived sensations.* We shall see that this is analogous to the recognition of single retinal areas through accessory sensations, through local signs, the contents of which comprise sensations of innervation, by means of which the perception of space is effected in the cortex.

A person who met with some stirring experience on a large, monotonous meadow, will recall, in passing over this meadow, the very spot at which this occurred ; but all other parts of the meadow he will not be able to identify in this way, With this one spot impressions and secondary presentations have been associated, which will serve as local signs for recognition of this one spot in the midst of this uneventful barren meadow. It is safe to suppose in regard to all inductive processes, that certain obstacles which impede the excitation of cells in full repose are very much lessened after a single, and particularly after repeated, identical excitations of association-bundles uniting the cells of two distinct areas of the cortex ; while the transmission of such stimuli to association-tracts, which have been called upon to unite other, previously established, groups of associations, becomes wellnigh impossible. We may add that Wundt,[1] in his great psychological work, has adopted the term, " association-bundles."

Another characteristic of animals which have been deprived of the cortex is the lack of so-called spontaneous movements ; movements not of a reflex nature, but resulting from cortical impulses which seem to bear the stamp of volition (freedom), and are not caused by undoubted momentary impulses. They are the result of innumerable registered images, the residual-effects of past motor stimuli.

We are told also, on the authority of Goltz, that animals which have had the medullary substance of their hemispheres removed (by a stream of water) were able to walk ; in these cases subcortical motor apparatuses must have remained functionally intact.

[1] " Grundzüge der physiologischen Psychologie," 1873.

Longet, Schiff, and Goltz report that animals without hemispheres were able to fly and swim, and Goltz found that the frog could move forward well enough, as long as the mesencephalon and cerebellum were undisturbed. Plainly then co-ordinated movements may be initiated by subcortical centres; and these movements responding to momentary stimuli, among which we must class the retinal image, will come under the heading of *the primary mode of movement.*

It was stated above that all excitations of the fore-brain are secondary. By reason of the anatomical connections, at whatever level, between the cortex and subcortical centres, memories of innervation are deposited in the former, which record the active processes of the latter. Every registered image, in fact, depends upon impressions received primarily in the subcortical centres.

Let us illustrate this by analyzing the act of conscious closure of the eyelids. Let a sharp instrument touch the conjunctiva of the eye (O., Fig. 59); the impression of this will be conveyed by the tract Va. 5 to the trigeminal centre in the pons. A subcortical centre of the seventh nerve (7) is connected with the former, which will transmit this stimulus to a facial branch in the tract VIIa., in fact to the facial branch ending in the *sphincter palpebrarum* (Sph.). Three impressions will also be recorded in the cortex.

1. The image of the sharp instrument conveyed by the tract II. *aa* EII.

2. The sensation conveyed by the trigeminal branch of the conjunctiva and carried by the route a5 EV.

3. Sensations of innervation, transmitted by the closure of the lids to the cortex through the tract 7 a J7.

All of these simultaneously excited cortical centres will at once be united by association-bundles, and in the following order: The visual centre which received the image of the sharp needle will be joined to the trigeminal centre of the stimulated conjunctival branch; then, again, the visual image of the needle will be joined to the innervation-centre of the facial branch supplying the *sphincter palpebrarum;* and, lastly, the above-mentioned trigeminal centre will be united to the said centre of facial innervation (J7).

In this illustration we have proceeded on the supposition that this is the first impression of conjunctival irritation which the child received, and that those images, which were conveyed by the tracts described above, were aroused and associated with one another in the cortex.

If hereafter a needle should happen to be brought close to, without injuring, the conjunctiva of the child, the image of the needle will revive the sensation of pain in the conjunctiva, and with the image of the needle there will be associated also the sensation of innervation of the facial branch ; thus the mere sight of the needle will suffice to excite the act of innervation within the fore-brain. The association-bundle EII. J7. conveys the optic stimuli to the centre of innervation, and this may be re-inforced by stimuli conveyed along the tract connecting the trigeminal centre with J7. The recognition of the needle, and an inference

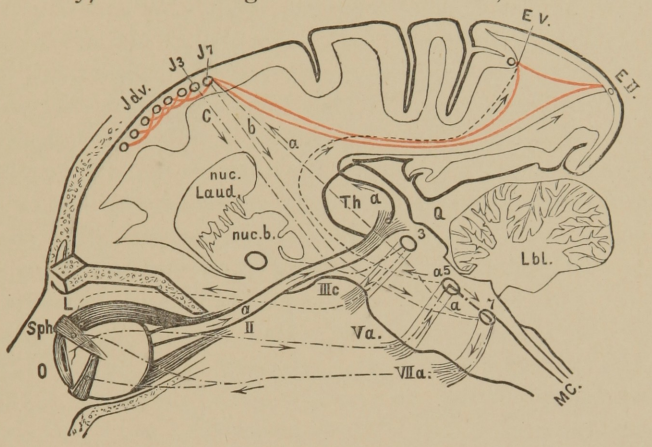

Fig. 59.

Diagram Explaining the Mechanism of Conscious Closure of the Eyelids.

O. Eye. Sph. Sphincter palpebrarum. L. Levator palpebræ superioris. nuc. Laud. Nucleus caudatus. nuc. b. Nucleus lenticularis. Th. Thalamus. Q. Corpus quadrigeminum. Lbl. Cerebellum. MC. Medulla spinalis. 3, 5, 7. Central nuclei of the III., V., and VII. nerves. II. Optic nerve. III. Third nerve (n. oculomotorius). V. Trigeminal. VII. Facial. Jdv. Individuality. J3, J7. Cortical centre of innervation for III. and VII. nerves. EV. Cortical centre of *Trigeminus*. EII. Cortical centre of the optic nerve. Lines marked *a* denote centripetally conducting projection-fibres ; b., c. centrifugally conducting proj.-fibres. Red lines denote association-fibres (systems).

as to the pain it inflicts, will, without any further injury, produce a closure of the eyelids through the centrifugal tract, J7. b7., by means of a volitional impulse starting from the cortex.

The cortex and subcortical centres may, therefore, be said to possess a mechanism which, intelligently unites two motor acts occurring at different times. Without such a mechanism conscious movement would remain inexplicable. The cells of the cortex are endowed merely with the power of perceiving the origin of sensations of innervation ; but the cortex could not

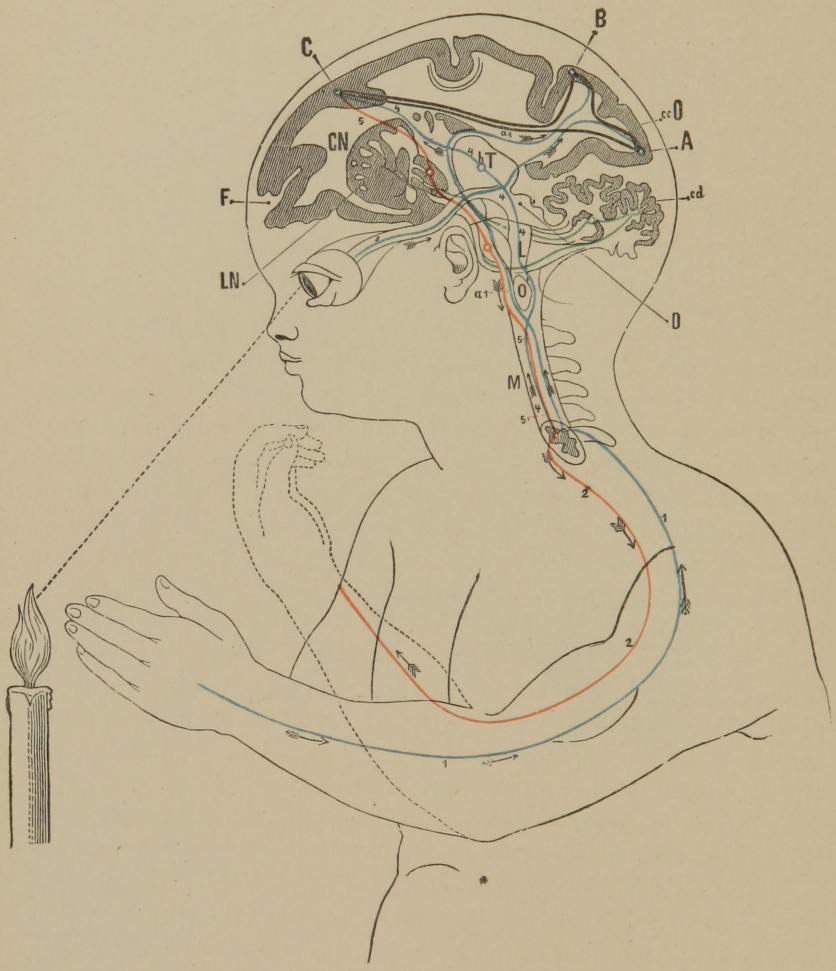

Fig. 60.

Diagram Explaining the Mechanism of a Conscious Movement of the Arm.

F. Frontal cortex. ccO. Occipital cortex. CN. Nucl. caud. LN. Nucl. lenticularis. hT. Thalamus opticus. D. Mesencephalon. L. Pons Varolii. O. Med. oblongata, characterized by the olivary body. M. Medulla spinalis, terminating with a cross-section of the cervical spinal cord. cd. Cerebellum. Blue lines indicate centripetal; red lines, centrifugal tracts; the red and blue circles in the spinal cord and fore-brain denote the central gray nuclei; black lines mark the association-fibres. 1 a1. Sensory tract of the arm. B. Part of the cortical centre for cutaneous sensation. 2. Tract for effecting the movement of the arm. 3A. Conducting tract of the optic nerve. A. Part of the visual centre. 4C. Tract conducting sensation of innervation, interrupted in the thalamus. C. A centre in the cortex for sensations of innervation. 5. Centrifugally-conducting tract, originating in the cortical area C.

originate movements, if the innervation-sensation of definite forms of movement were not conveyed to it from subcortical centres by the *primary* form of movements. In consequence of its connections with subcortical centres, and as a result of the sensations of innervation deposited in its substance, the cortex becomes a spectator of the reflex acts evolved in the subcortical centres. And thus we find that, in the normal brain, no reflex actions can be performed without exciting to action the second portion of this mechanism—namely, *secondary* volitional movement which no longer requires the stimulating influences of a reflex action.

The influence of innervation-sensations on centrifugal nerve-tracts is explained by assuming the former to be images registered in the cortex ; and that the assumption is a correct one is rendered probable by the fact that intense volitional efforts may be directed to paralyzed muscles, without producing the slightest contractions in these muscles, thus proving that the innervation-sensations in question do not arise from a perception of muscular contractions, but from sensations which the reflex centres, in their capacity as *subcortical* sensory centres for motor-sensations, transmit to the cortex of the brain.

The sensation of innervation which reaches the cortex, and from the cortex innervates centrifugal nerve-routes, does not present the fundamental motor-images; for the registered images, and the sense-perceptions are altogether incommensurable. Furthermore, if for the term "registered images" we should substitute the expression "*presentation*," we would find that in these instances of secondary stimulation of the fore-brain, the presentation of sensory impressions, be they ever so intense, does not in the least reproduce the image of the original (primary) sense-perception. This is true also of the sensory images of the innervation-sensations, which are distributed over various cortical regions as motor presentations (*Bewegungs vorstellungen*).

We must look for the indirect causation of even the remotest effects of cortical movements in the centripetally-conducting sensory nerves. Using a former simile, and comparing the ganglionic cells of the central nervous system to living organisms, we may say that stimuli acting upon their tentacles invariably produce excitation of the claws, and movements of their muscular apparatus. The light of the sun produces contracture of a muscle of the iris, the constrictor pupillæ ; and if it be excessive, it will bring about closure of the eyelids. Sensory fibres of the optic nerve convey

this stimulus through nerve cells and motor fibres connected with these muscles, the optic stimulus thus extending beyond optic-nerve cells. The optic nerves supplied the primary motor impulses, and gave rise in the first instance to the cortical sensations of innervation. Conscious closure of the eyelids is, therefore, an after-effect of the intense sunlight which stimulated the optic nerve. Whence it follows that the motor effects of our consciousness reacting upon the outer world are not the result of forces innate in the brain. The brain, like a fixed star, does not radiate its own heat; it obtains the energy underlying all cerebral phenomena from the world beyond it.

The secondary order of movements, hitherto described, comprised mere repetitions of movements which were primarily part of reflex actions. The reflexes had been transplanted to the fore-brain, and naught but the *means of exciting* such movements from the fore-brain had been changed. The initiatory impulse was conveyed by the association-bundles. But in the fore-brain any order of movements can form an indefinite number of associations, and so the associations engendered by reflex movements become part of the whole mechanism of association. The result is, that movements which were originally reflex in character can be set in action by any one of a larger number of associated impulses.

In order properly to understand the relation between primary and secondary movements, it will be wise to give another illustration; for in the former illustration we failed to explain the anatomical substratum of the functional activity of subcortical centres with regard to the sensations of innervation and the motor impulses.

Let us suppose a flame to have injured the hand of a child, and that the latter withdrew the hand from the flame. This movement (the withdrawal of the hand) will be effected, without the intervention of conscious impulses, by an impulse conveyed from the injured part by the centripetal tract 1 (Fig. 60), and transmitted through a spinal-cord centre along the path 2, which withdraws the hand from the flame. This movement and the altered position of the arm are indicated by dotted lines. The following records of this act will be transmitted to the cortex through the agency of the projection-systems: First, the visual image of the flame from the eye along the tract 3A.; secondly, a painful sensation from the injured part along the tract 4B. This nerve-tract passes uninterruptedly through the cerebral ganglia

and the capsula interna to the occipital lobe, as is evident from a study of the course of the outermost and posterior bundles of the internal capsule (p. 4, Fig. 5, POM.; p. 85; Fig. 22, Tm.).

Thirdly, the sensation of innervation resulting from the reflex movement. The interruption of this tract in the thalamus is in accord with the physiological fact, that the movements of the upper extremities are influenced by this ganglion, but that destruction of the thalamus is not (necessarily) followed by an interruption of the tract conveying cortical impulses to the muscles of the arm.

The innervation-sensation C. acts through the centrifugally-conducting tract 5 upon the central origin of those anterior roots which, through reflex excitation, protected the arm against the flame. This central origin of the anterior roots is controlled first by primary motor impulses carried to it by the posterior spinal roots, and secondly by secondary motor impulses emanating from the cerebral cortex. Since the centre C. is connected with the association-bundles CB., CA., and the latter with one another by the bundle BA., the child need not actually burn its hand again before guarding against the flame; but the *memory* of the flame and of its effect (through association with the centre in which the painful sensation has been stored), will suffice, through the one or the other of these associations, to initiate a movement which will put the arm beyond the reach of the flame.

We have taken our illustration from the movements of the upper extremity, because in so doing we can refer to a ganglion which we know positively to be connected with this extremity, and to be intercalated in the path of its sensations of innervation. This ganglion is the thalamus opticus.

The optic thalamus is not a ganglion of the fore-brain. All pathologico-anatomical lesions prove that the lenticular nucleus is the ganglion of the fore-brain, which conducts cortical impulses from the one hemisphere to the anterior roots of the opposite side of the body. Nothnagel has given the most accurate proof of this by observing the condition of rabbits after he had destroyed their lenticular nuclei by means of chromic-acid injections. He reports that the animals acted as though their hemispheres had been removed. They exhibited not a sign of spontaneous movements, and yet irritation of the skin caused them to leap forward. Nothnagel proved also that complete destruction of the thalamus did not in the least impair the movements of the animal, and that consequently centrifugal nerve-tracts between the

cortex and the anterior roots did not pass through the thalamus. In a case of right hemiplegia I found symmetrically situated cysts (of the size of a hazel-nut) in each thalamus. These symmetrical lesions of the thalami could not account for the *hemiplegia*, but

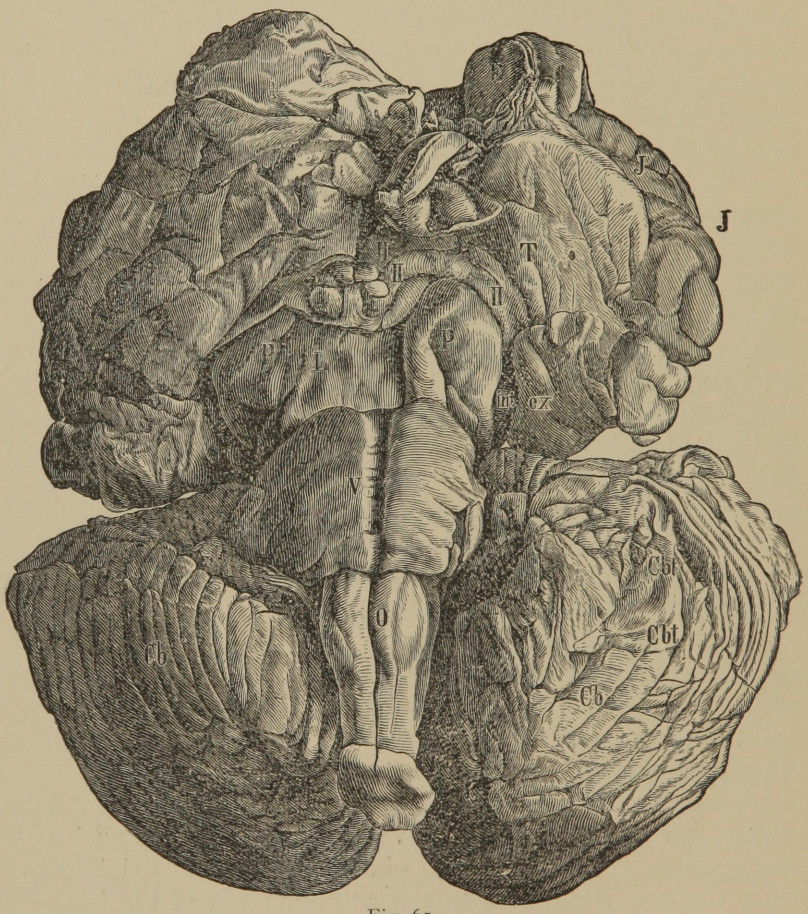

Fig. 61.

Basal Surface of a Brain-Axis with Tubercular Tumor of Right Side.

I. Island. T. The cut temporal end of the corona radiata. F. The cut frontal end of same. II. Optic nerve and tract. P. Pedunculus cerebri, broader on right side, and passing without a definite boundary line into the region of the lamina perforata posterior; crowding at the same time the right half of the pons backward. V. Pons Varolii. O. Oblongata. Cb. and Cbt. Cerebellum. The left half of the cerebellum is larger in volume in consequence of a tumor enclosed within.

I found in addition to these a unilateral lesion in the left nucleus lenticularis. This observation shows of what little moment the thalamic lesions were, and what great importance was to be

attached to the unilateral destruction of the nucleus lenticularis. Yet, on the other hand, Nothnagel was able to infer from his experiments that extirpation of the thalami, like the removal of the innervation-centres of the cortex, seemed to produce a condition in which the animals remained ignorant of the position of their extremities, from which it follows that the optic thalami

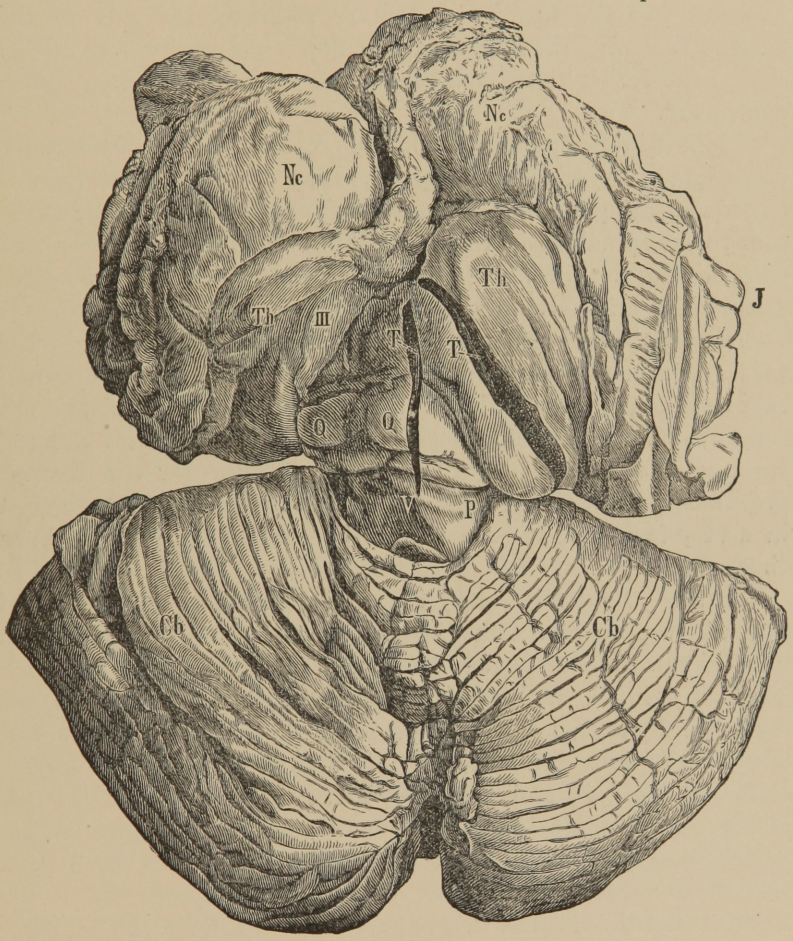

Fig. 62.

Dorsal Aspect of Same Brain-Axis (*vid.* Fig. 61).

I. Island. Nc. Nucleus caudat. Th. thalmus. III. Third ventricle. Q. Corp. quadrig. V. Valvula cerebri. P. Region of lemniscus and processus cerebelli ad cerebrum. The right corp. quadrig. is flattened ; the left is crowded away from the median line ; furthermore the broadened thalamus was pushed to the left. The third ventricle is not mesial. Two incisions, one into the corp. quadrig., the other into the optic mass, enabled us to inspect the convex surface of the tumor, which had attained to the dimensions of a pigeon's egg.

are a signal-station (Wundt) for sensations of innervation, akin to those contained in certain cortical centres.

According to the experiments of Longet, Schiff, and Nothnagel, incomplete and unilateral lesions of the thalamus influence the position of the head and the upper extremities. The muscles of the spinal column turn these in such a manner that the head looks toward the healthy thalamus; while on the side of the healthy thalamus the flexors of the upper extremity, and on the side of the lesion the extensors of the upper extremity, appear contracted.

From the description given in the previous section of the thalamic origin of the tegmentum (p. 90, *et seq.* and p. 132), we learned that decussating and non-decussating fibres passed from the thalamus to the spinal cord; the decussating fibres through the posterior commissure, the non-decussating through the *laminæ medullares*, which originate, in radiating fashion, from the thalamus.

As this twofold thalamic origin of the spinal cord holds good for its relation to the upper extremities, we can readily understand that both upper extremities should be represented in one and the same thalamus. The deviation of the upper extremities and the turning of the head toward one side account for the *manège*-movements of operated animals. This circular movement is lost in a very few days, and after that the animals which have been thus operated upon show no sort of paralysis.

In the year 1872, I had occasion to observe a five-year-old boy, who was affected with a large tuberculous tumor (figs. 61 and 62)—of the mesencephalon and the thalamus. The diagnosis was easily made, for the boy showed marked paralysis of the right third nerve, and slight paralysis of the left facial nerve, and of the left extremities. The architecture of the mesencephalon (fig. 41), and particularly the origin of the third pair of nerves, lead us to infer the dependence of such a grouping of crossed paralyses upon lesions affecting the right crus cerebri and the third nerve. In addition to the above symptoms, it was noticed that the head of this boy was turned toward the left side; and that, while at rest, there was flexion of the left upper extremity, and extension of the right upper extremity; a relatively great resistance was required to counteract this flexion or extension. From this circumstance it was fair to suppose that the tumor involved the right thalamus opticus. Figs. 61 and 62 represent the post-mortem appearances.

Whenever this boy was otherwise occupied, this compulsory position of the head and upper extremities disappeared; and, in spite of the paresis of the left facial nerve and of the extremities, he played quite naturally with the objects which engaged his attention for the time being.

A lesion of the thalamus does not produce paralysis, and for this reason we cannot agree with Schiff, who supposes that rotation of the head to the right results from paralysis of the left rotatory muscles of the spinal column, and that the flexion of the right arm was due to a paralysis of the extensor muscles of the same arm; and extension of the left extremity, to a paralysis of the left flexor muscles. But this typical pathological position following upon a thalamic lesion will admit of a different explanation. We may suppose that the boy, lacking the innervation-sensations of the left rotatory muscles of the spinal column, was induced to excite the missing sensation of innervation by a volitional rotation, to produce the lacking sensation of innervation of the left-arm flexors, by forcing a flexion of this arm, and under similar circumstances to compensate for the disturbed sensation of innervation of the right extensor muscles by exciting a forcible extension of the right arm.

The lack of innervation-sensations created delusions with regard to the position of his extremities, which in turn gave rise to volitional movements, in consequence of which he assumed the typical pathological position, the so-called forced position. If he had been a quadruped this position would have been followed by circus movements. Making use of our knowledge of the twofold, asymetrical origin of the spinal-cord bundles in the thalamus, we conclude that the rotatory muscles of the spinal column and the flexors of the upper extremity are represented by bundles which decussate below the thalamus, whereas the extensor-muscles of the upper extremity are represented by direct bundles from the spinal cord to the thalamus. In my pamphlet published in 1869, "On the Twofold Origin of the Spinal Cord in the Brain," I showed that the origins of the tegmentum and the ganglia of the di- and mes-encephalon were not connected with the centrifugal nerve-tracts of the fore-brain, but that they served to initiate the *primary* forms of movements, as we conceived of them above; that on the other hand the nucleus lenticularis was connected with no centripetal tracts which could possibly convey reflex stimuli to it, but that in accordance with all pathological data as

well, it carried the motor impulses from the cortex; and increasing with the dimensions of the hemispheres, attained the greatest magnitude in man. As a corroboration of this view, I have found the area of the tegmentum which contains the spinal-cord origins from the di- and mes-encephalon, relatively and absolutely more developed in animals than in man. The *secondary* movements which receive their innervation from the fore-brain are effected, therefore, by nerve-tracts, which pass through the nucleus lenticularis (*Vide Wiener med. Jahrbücher*, 1872).

Soltmann[1] has discovered a physiological fact which postulates the necessity of finding the origin of conscious movements. He has found that those regions of the cortex which if stimulated in the adult brain produce muscular movements, are in the new-born animals unexcitable and "not yet motor" in function. But as the reflex movements are perfect in these very young animals from the time of birth, we are doubly justified in believing that the reflex movements constitute the *primary* form of movements, and that centres for the innervation of the *secondary* forms are established later, and are derived from the sensations of innervation connected with the former class of movements. That centripetal tracts connecting the cortex with the subcortical centres for sensations of innervation, such as the thalamus, constitute the anatomical link in the chain producing secondary movements, is my own well-established conclusion, and one that is supported by Soltmann's discovery.

In its relation to the upper extremity the thalamus was shown to be a motor mechanism, through the agency of which decussating and non-decussating representatives of certain muscles effected certain definite forms of motion. This was demonstrated by the nerve-tracts of the case pictured in Fig. 60. The nucleus lenticularis, which, with its second division of the projection-system (p. 27), winds around the inner side of the pes pedunculi as the *ansa peduncularis* (constituting the innermost and most posterior of its bundles), and in part traverses this same pedunculus, in order to reach the *stratum intermedium* and the *substantia Soemmeringi* behind the pes pedunculi; this nucleus lenticularis, so connected, effects movements only on the opposite side of the body. The point at which this impulse crosses to the opposite side is not to be looked for in the decussation of the pyramids,

[1] Jahrbuch f. Kinderkrankheiten, N. F., IX. Experimentelle Studien über die Functionen des Grosshirnes des Neugebornen.

but since I proved anatomically (p. 136), in unison with Türck's processes of degeneration after destruction of the lenticular nucleus, that the stratum intermedium is transformed in the spinal cord into the innermost bundles of the anterior columns, it must be looked for in the anterior commissure lying next to these.

There is still a third grade or order of innervation from movements of the body which must engage our attention. The movements of this order, like those of the second order, are initiated through the mediation of the association-mechanism from the cortical centres of innervation. They are distinguished from movements of the second order by the fact that the form of movement is not a mere repetition of reflex movements, and that amid circumstances, and after stimuli, which would produce a definite form of reflex movements, or which would excite secondary cortical movements, copying the form of movement prescribed by the reflex,—under such circumstances entirely different forms of movement would be initiated in the cortex. Thus a cool and collected person, who submits to an operation on his eye, will, instead of allowing the *sphincter palpebrarum* to act as soon as the knife approaches the eye, be able to keep the eye wide open by innervating the *levator palpebræ superioris*. Mucius Scævola, of legendary fame, was able to retain his arm in the sacred flame, instead of withdrawing it in obedience to the ordinary reflex excitation.

The first of these two instances is explained in Fig. 59. From the cortical centre for the innervation of the (musculus) *levator palpebræ superioris* (J3), the roots of the third nerve may be innervated through the tract J3 C3 in response to irritation of the conjunctiva; whereas irritation of the conjunctiva ordinarily produces a reflex movement of the *sphincter palpebrarum;* this primary form of movement is followed by conscious closure of the eyelids—the secondary form. Consequently we may say that the innervation centre of the third nerve is controlled also by stimulating tracts, giving rise to movements which have no prototype in the reflex mechanism. The innervation centre for the third nerve is anatomically connected with a number of mutually associated centres arbitrarily drawn in Fig. 59 which should be represented as distributed over the entire cortical area. These centres, connected with one another by every variety and length of association-bundles, are nothing special, their "memories" are defined by the peculiarities of localization referred to above. The sum of these "centres" constitutes the "individuality," the

"ego" of abstract-psychologists. I attach some importance to the word "individuality," because it is founded upon the anatomical structure of the cortex, and the simple physiological process which enters into our present discussion. Individuality implies the sum of firmest associations, which under ordinary circumstances are wellnigh inseparable; the aggregate of "memories" forming a solid phalanx, the relation of which to conscious movements can be defined apparently with mathematical precision. This unequal activity of the fore-brain, constituting individuality, varies as regards contents and degree with each person; it is designated also as the *character* of the individual. It has been justly observed, if the character (individuality) of a person were entirely known we would be able to predict the thoughts and deeds of such an individual, however complicated they might be.

The observation of Munk quoted above, and the conclusions of experimental physiology, strengthen the opinion that intelligence is not limited to definite cortical areas, but that, being based upon perceptions including the sensations of innervation, it results from the activity of the entire fore-brain. Anatomically speaking, the exercise of intellectual activity by every part of the cortex depends upon the uniform structure of all parts of the fore-brain, which makes of each part a centre for inductive processes, and supplies to each part nerve-elements capable of perceiving and retaining "images." This is true also of individuality, the motives of which are to be sought in the most frequently repeated impressions of every sort. These impressions hold a causal relation to one another, and by means of nerve-arches establish a connection of causality between residual images[1] as motives for movements, and certain definite motor-acts. In order to be clearly understood, I will begin by explaning the simplest relations.

Kussmaul has shrewdly remarked that certian perceptions and movements are common to the fœtus in utero; that the fœtus feeds itself, as it were, by swallowing amniotic fluid, and that there may be special motives, such as the more-stimulating taste of the fluid after the occasional depletion into it of the allantois, which induce swallowing. Here, then, there are two alternatives, the fœtus swallows or does not swallow. We are already presupposing fœtal consciousness, which would exist, however, under circumstances which give but little opportunity for perception.

[1] The reader will by this time have noticed that I have given several translations for the German "*Erinnerungsbild*"; no one English term appears to me to be entirely satisfactory.—S.

The new-born infant at once discovers signs by which it distinguishes between one set of perceptions and another. One set of perceptions helps it to define the circumference of its own body, another set belongs to the world beyond it.

However obtuse this perception may be, and though the child may at first not even be able to discriminate between the various impressions of space, it is certain that the perception of its own body-circumference is established very early in childhood. Among other signs by which it learns to distinguish between impressions received from its body and from the outer world are these: Contact of a strange finger with its own skin excites but *one* tactile sensation; contact between two parts of its own body excites two tactile sensations—one from the touching, and the other from the touched part (Wundt). Furthermore, a number of strange auditory sensations strikes the ears of a child, but only the sound of its own voice is accompanied by muscular sensations; and so the attendant muscular sensations help the child to discriminate between movements of its own body and any other form of movement which it may have occasion to see. The number of such examples could be increased with ease. And, besides, it is important to remember, that the continued presence of impressions which its body yields—as, for example, the sight of its own hand, and the ever-increasing number of muscular sensations, due to movements of the hand, will soon become fixed in its consciousness, and that, by repetition, the intensity of such perceptions will soon outweigh the interrupted occasional impressions received from the outer world.

In the work of registering images in the cortex, the memories conveyed by those nerve fibres, which enter into definitely associated groups, and constitute tracts along which a motor impulse is most easily conducted, lend a helping hand; it is fair, therefore, to expect that frequent and simultaneous sensations, which emanate from the body itself, will enter into firm connections, which they will never again be able to dissolve, and which will thus form the first primary conception of the *ego*, based upon the perceptions of the body's circumference.

And here it will be proper to remark, that there is no order of movements which, under the cover of *instinct*, can be pushed in between conscious and reflex movements. The first instinct of a child would be its instinct for food; but the origin of that has been alluded to. There is absolutely nothing in the sensation of

hunger which would acquaint the child with the means of remedying this pain, of initiating movements suited to this end. It obtains naught but the concept of pain. In the general restlessness it displays, and in the convulsions ultimately resulting from anæmia, there is nothing which could be likened to an instinct for food. If the child is not left to depend upon its own resources, but has a nipple put into its mouth, then the sensation thus excited starts the reflex mechanism of sucking.

The child has thus acquired the concept that the sensation of satiation is connected with the act of sucking, and these two sensory memories are associated with the sensations of innervation aroused by the sucking-act, probably, also, with the scent of its mother's breast.

That the child should suck at every finger, we may attribute to a reflex mechanism; but that the child should suck in its dreams, proves that the act of sucking has produced images which have been registered in the cortex. If a child looks for the nipple by turning its head on its mother's breast, it is not moved by a reflex mechanism, and there is no logical reason to suppose that this is not a conscious movement, which is based upon the association of painful sensations and sensations of innervation, both implanted upon the fore-brain by the reflex mechanism, which gave relief to the pain. This would be analogous to the conscious closure of the lids and the movements of the arms, instanced above. There is no gap between conscious and reflex movements to be filled in by instinct.

The factors of this primary, abstract *ego* are not definitely defined. No child is likely to lack the sensation of hunger; but memories collected from certain sensory spheres may be wanting in consequence of deafness, blindness, or some other defective perception; and, in proportion to the lack of perceptive powers, there will be a corresponding defect in the sensory faculties of the *ego;* and yet through the more intense application (education) of the other senses (as has been shown in the case of deaf mutes who were blind also), an extraordinary wealth of images may be amassed, which can lead to an excellent knowledge of the external world. Munk's views may help us to understand the refinement and amazing development of any one sense which may do service, possibly, for other defective senses. Just as single sensory spheres do not occupy the entire cortical area connected with their special sensory nerves, but have a peripheral

zone which is left open for later occupation, so we can imagine, as long as the cortical surface is practically one, through the mediation of the gray network of fibres, that a greater area is left at the disposal and for the development of any one sense; for a larger area, generally occupied by other sense-perceptions, is left functionally vacant by the occlusion of its sources of perception, and through association-fibres this area may be joined to the only sensory spheres in active operation.

Thus we are told by the blind, that from slight changes of atmospheric pressure, the reflexes excited from the skin of the head and extremities by currents of air give rise to innumerable impressions and inferences sufficient for them to perceive from these sensations the presence of a large quiescent body in their vicinity, and still better the presence of moving objects. The first case only is to the point; no doubt moving objects produce auditory sensations as well.

A similarly exalted degree of sensory perceptions, which play a subordinate rôle in the life of normal man, is revealed by the bat. In *Autenrieth's Archives* experiments are recorded which have been performed on bats; their eyes were destroyed, their nostrils stopped up with molten sealing-wax, and their ears were also effectually occluded. But though blind, deaf, and minus the sense of smell, these bats contrived to fly through a regularly-constructed thread network without touching any of the threads. In accordance with the opinions then prevalent, it was thought necessary in order to explain this phenomenon to call up a sixth sense, akin to that sense which formed the basis of somnambulistic (?) perception. If we remember, however, that the bat possesses large wings, and very delicate, sensitive webs, which present an enormous cutaneous surface, we need not be surprised to find that, as in the blind, this large sensitive surface enables the bat to perceive changes in atmospheric pressure and atmospheric waves, created by bodies moving about in a direction opposed to the current of air. From such changes the bat infers the extent and direction of its movements.

The nature of the *ego* does not depend upon any definite order of memories; it is determined simply by the most firmly fixed memories. As soon as we apply the test of more complicated relations to the formation of the *ego*, we must bear in mind that the *ego* can be influenced only by images of permanent intensity, which are associated at the same time with other and

as firmly fixed images. The idea of *individuality* is an artificial one, though valuable from a practical point of view, for the degree of intensity by which these images and their connections adhere to this conception will not admit of accurate measurement; and it is plainly impossible to say that at a certain intensity a presentation becomes a factor of the *ego*, and not yet at another. There is but one safe stand to take on this question, and that is to attribute to the ill-defined conception of individuality only those presentations which, as soon as the "character" of an individual is known, will enable us to predict his deeds; whence it follows that the deeds of the individual obey certain laws. On the other hand, these same conscious deeds, as they are not mere copies of acts suggested by reflex movements, remain incomprehensible as long as the character of the individual is unknown. This very mystery attending the deeds of others is another and highest expression for the freedom of the will.

There can be little doubt but that the primary order of movements is effected by the diencephalon, the mesencephalon, and other centres lying still farther from the hemispheres; the first-named ganglion contributing largely to the formation of the spinal-cord columns, through the continuation of their bundles through the tegmentum of the crus. But now the question arises, whether there are distinctly separated cortical centres, or nerve-tracts, which mediate in the execution of secondary movements—copies of reflex movements—and of tertiary movements, which bear the stamp of individuality; both kinds of movements being distinctly cortical in origin. Charcot contended that paralyses, resulting from (lesser) lesions of the lenticular nucleus, were distinguished by their shorter duration from those resulting from lesions of the crus, or of such parts that spring directly from the hemispheres through the internal capsule; and that (complete) destruction of the crus entails permanent paralysis. But from the study of the anatomical structure of these parts, we learned that a considerable portion of the internal capsule and of the pes pedunculi is interwoven with peduncular portions of the lenticular nucleus, with the *stratum intermedium*. It is evident, therefore, that destruction of the pes pedunculi will also destroy tracts from the lenticular nucleus. It was absolutely necessary for the lenticular fasciculi, lying in front of the crus, to interweave with the peduncular fibres, in order to reach the substance of Soemmering, lying behind the *crus cerebri*.

Charcot's statement becomes intelligible only by supposing that the gray substance of the spinal cord conducts motor impulses after the interruption of the connection between the white anterior columns, inasmuch as all white bundles pass into the gray substance, and establish conducting tracts in the gray network of fibres, though the speed at which impulses are conducted is very much reduced. This might possibly hold good for a moderate-sized lesion affecting the gray substance of the lenticular nucleus, and amends might thus be made for imperfect conduction; but lack of gray substance precludes the possibility of such patch-work in that part of the crus in which lenticular and cortical bundles of the crus are interwoven. Lesion of the crus is, therefore, necessarily followed by impairment (annihilation) of lenticular conduction. There is one difference, to be sure, between the course of the stratum intermedium and the pyramidal tracts, and that is that the cortical bundles of the latter develop into the anterior longitudinal fasciculi of the pons, and as such, connect with the cerebellum. The possibility of a similar connection between the cerebellum and the stratum intermedium cannot be absolutely denied, for the latter, instead of being crossed by the brachium pontis, might possibly interlace with the superior division of the corpus restiforme. And yet the intimate union between peduncular and cerebellar fibres is the only one that can be regarded as established beyond controversy. The difference in regard to the function of the pedunculus and the bundles of the stratum intermedium might become intelligible by assuming that the peduncular fibres co-operate with the brachia pontis in effecting complicated (more co-ordinated) movements, while the lenticular nucleus constitutes a co-ordinating centre *per se*. Accordingly the co-ordinations of movements conducted by the stratum intermedium would be effected in the gray masses of the fore-brain. But I am not willing as yet to draw any positive conclusions as to the importance of one or the other of these tracts engaged in the transmission of motor-messages from the cortex.

The occurrence of sling-shaped bundles in the pons can be utilized to illustrate the manner in which the brachium pontis endows the cerebellum with a co-ordinating influence over conscious motor-innervations (p. 115, *et seq.;* Figs. 43 and 44).

These circular (sling-shaped) bundles, which unite in the pons with fibres from the crus, enter and terminate in the brachium pontis of the same side. I can conceive that the one arc of this sling

constitutes a tract along which cortical motor impulses, passing through the pes pedunculi, reach the cerebellum, and by which the cerebellum is notified of the cortical sensations of innervation, the work of association; that, on the other hand, the other arc, taking a recurrent course through the gray substance of the pons, conducts to the pedunculus cerebri the influence of the cerebellum. On page 28 it was demonstrated that the dimension of the pes pedunculi, the nerve-tract along which cortical motor impulses travel, varied with the dimensions of the fore-brain in general, and that for this reason all structures directly connected with the pes pedunculi, such as the pons and the pyramids, were particularly well developed in man. We showed also that the alternating visibleness of the olivary and trapezoid bodies in man and animals was determined by the fundamental factor in brain-trunk architecture—the relative development of the fore-brain. Were any animal able to increase the size of its fore-brain, the basilar aspect of its trunk-structures would approach more closely to the human "type."

The *stratum intermedium* forms an integral part of the section of the anterior tract of the brain-trunk, which far exceeds, in dimensions, the cross-section of the tegmentum. But the *stratum intermedium* is derived from the lenticular nucleus, which attains its greatest development in man, and from the pes pedunculi, with which it interlaces. Consequently the development of this *stratum* will keep step with the development of the fore-brain, at least as far as conducting nerve-tracts are concerned. If appearances deceive, it is due to the presence in animals of larger quantities of scattered gray connective tissue possessing no functional value.

The exact function of the radiation of the posterior longitudinal fasciculus is still a matter of conjecture: its connections with the nuclei of cerebral nerves, exhibited above with regard to the third nucleus, give undoubted evidence that it is partly motor in function; but, on the other hand, it is connected also with sensory tracts, those of the fifth and eighth nerve; and possibly also with the retina through the mediation of the basal ganglion of the optic tract.

Lesion of the lenticular nucleus produces hemiplegia; and yet there is no connection between the fibres of the anterior columns (descended from this ganglion) and the coördinating centre in the cerebellum save low down in the central gray substance, where the bundles just mentioned unite with the pyramidal tracts. There is no conscious stimulus starting single complicated acts of cerebellar coördination. And then, too, mere ataxia resulting from loss of cerebellar influence does not affect the conscious in-

nervation of uncomplicated movements ; while clinical observation goes to show that there need be but slight consciousness and hampered memory attending the distinctly coördinated movements in the hypnotic state and in cases of *chorea magna*. We may argue, therefore, that during normal cerebral activity coördinated and conscious movements are tolerably distinct phenomena. Since coördinated movements are no criterion for the activity of the lenticular nucleus, and since the initiation, direction, and inhibition of a movement, which constitute its conscious features, remain intact as long as the lenticular nucleus is preserved, and in spite of the presence of ataxia resulting from injury to the cerebellum, we must infer the only condition necessarily preceding a consciously excited movement to be this, that the lenticular nucleus be stimulate simultaneously with the cerebral cortex. Moreover this very ganglion, forming together with the nucleus caudatus, part of the gray substance of the fore-brain, stands in closer genetic relation to the cortical substance than do the other (strictly speaking) sub-cortical ganglia.

I return now to the discussion of the phenomena of the *ego* evolved by the cortex cerebri and its medullary mass; but I do not intend to treat this exhaustively at present, for we shall have occasion to study this subject more fully in the clinical portion of this work. Let us suppose, in order to give a concrete meaning to the term, that there be a primary *ego*, a nucleus of the individuality, defined by the limits of the infant's body. And, as a rule, the image of the primary *ego* will coincide with the mental concept of the body; there will be, as it were, a nucleus of the individuality. But the most frequently repeated perceptions of the outer world, as well as the most frequently revived memories, and particularly those joined to the emotions, will enter into firm associations, and will constitute the nuclei of a secondary individuality. Such memories will be more readily reproduced, and will exert a greater psycho-motor influence than transient impressions and less intense perceptions will do. And yet the substance of this secondary individuality lies beyond the circumference of the body itself. The entire individuality becomes decentralized and is made to include much of the external world.

The primary *ego* expands through permanent and intense secondary perceptions joined to it by association; so that intimately related persons, property, skill obtained by constant practice in any art, science, a fondly cherished aim in life, convictions, patriotism, and honor become part of the *ego*. That from among these component factors of the *ego*, the primary *ego* should be consciously endangered by surrendering one's own body, can be explained by assuming that component factors of the secondary *ego* have attained such a psycho-motor intensity in the play of association, as to become more effectual motives

than the original powerful motive of self-preservation. In fact, the very person who sacrifices his life believes, in so doing, that he preserves his own individuality, which now includes so much that lies beyond his physical self. Whatever explanation one may choose to give of this phenomenon, the simplest will be this: In all the actions of man, be they ever so complicated, problematic, or incomprehensible, the avoidance of greater pain is the determining motive.

The satiation of hunger is a powerful presentation in the infant's mind. But if we should attempt to put any thing which had been steeped in acetic acid into the mouth of a starving child, the perception of a momentary still greater pain would be joined to the sensation of hunger, and a reflex mechanism would be set in action which would prevent the swallowing or retention of this noxious substance. Whenever, later on, a substance that merely smells of acetic acid is brought near it, the infant's mind, having already learned to utilize its registered images and their associations, as well as to start simple processes of thought which determine the initiation of this or the other movement, the child will spit out, retch, cry, kick; it will consciously repeat *repulsive* movements which were originally reflex in character. These movements of *repulsion* are the direct opposite of those *aggressive* movements exemplified in the act of sucking, and in clinging to the mother's breast. The child may associate the pleasure of satiation with the swallowing of food, and yet this so-called pleasurable sensation will not be the determining motive for the child's action; but as long as it is exposed to two painful sensations, that of hunger and of the pain produced by a caustic substance—the choice of the lesser pain will be the determining motive.

This discussion of the individuality has led us far astray from the consideration of such facts in regard to the architecture of the fore-brain as are supplied by a study of its anatomy, and such as are supplied by physiological experiments.

A more definite observation of experimental physiologists, though clad in vague language, is this: They maintain that *loss of fore-brain entails loss of intelligence* in animals. In order to give tangible shape to this term "intelligence," I would say that under the guidance of this symbolic faculty, only those associations prevail (from among the anatomically possible associations of registered images and concepts) which represent the ordinary regular connections of things. All parts of this organ

of intelligence are joined to each other by an evident anatomical and functionally perfect association-tract. The anatomy of the cerebral structure, and the proof of the presence everywhere in the brain of an induction apparatus, render it highly probable that all perceptions received simultaneously or in continuous succession become correlated with one another. Such connections explain the relations of successively and separately received impressions to one another. Our methods of thought and of speech have designated this relation as one of causality; but this is a purely cerebral function, for there need be no bond in the outer world corresponding to these cerebral relations of causality; nor does this relation constitute intelligence. The so-called logical sequence in the evolution of association, which yields the factors of intelligence is effected in various ways and to a varying degree of perfection in different brains.

First the intensity of established associations, dependent upon their conscious and frequent re-excitation, is of greatest importance. An accidental succession of impressions is seldom repeated, and relations thus established vanish quickly in the brain. But, as soon as the subjective bond of causality represents an actual union of things, the re-occurrence of external stimuli will establish a permanent association within the brain. Thus by the renewal of perception, such associations are turned into the elements of inductive logical thought. *Deduction* we need not consider now for it is the simple outcome of *Induction*.

Secondly, a number of approved associations are transmitted through the medium of language, through conversation and instruction from one individual to another. According to the degree of culture, the intentions in transmission, and the logic of those who communicate them, the mass of such transmissible associations will be more or less remote from intelligence. The imprinting of prevalent associations by mere repetition upon the brain is demonstrated also in the negative phase of cerebral activity, in the dissolution[1] of conscious associations. It is characteristic of senile loss of memory, that the earliest memories are preserved best, for these had been revived innumerable times in the processes of thought during more than half a century, while the recent associations, acquired shortly before the death of the aged, can have been recalled but seldom to memory. The loss of foreign languages, following upon pathological processes in the brain, does

[1] Used in Jackson's sense.—S.

not entail ignorance of the sounds common to the foreign and the mother tongue, but includes only recently acquired knowledge of languages. The conclusion is forced upon us, that the individuality also, apart from its relation to emotions—which include the most frequently repeated associations,—is influenced largely as regards the union of its component factors, and the difficulty of disassociation by the more powerful bonds established between the earliest factors of the individuality.

If intelligence and individuality be not evolved from personal associations of ideas, and if the motives for the direction of thought, and actions connected therewith, be simple copies of psychical associations started in another's mind, then the growth of intelligence, as well as the expansion and composition of the individuality, will be seriously impeded.

As correlated sensations of sensory perceptions, motor images play a very important rôle even in the simplest processes of the fore-brain; in ordinary perceptions, such as those of space, for instance. The perception of space is by no means dependent upon the visual sense alone, for a blind person has as full a knowledge of the surface of his body as one with normal vision has. Such knowledge is enhanced by sensations accompanying tactile impressions received from different parts of the skin. Thus Lotze has shown how markedly the tactile sensation, dispatched from the skin over the sternum, differs from that forwarded from the skin of the thigh; and going still further into details, he mentions the different tactile impressions received from the finger joints, and from the more elastic and poorly supported skin between the fingers; from the movability of the skin over the tendons, and its compressibility between the tendons on the dorsum of the hand. Lotze insists, furthermore, on the great difference between the sensations accompanying compression of the volar surface of a finger against the nail—a perception influenced by the form of resistance presented at both ends of the nail margin—and the touch of the nail itself. He refers also to Spiess' remark, that the local signs of correlated sensations undergo further change through motion of the parts, through the varying pressure acting upon joint surfaces, the tension and relaxation of skin during flexion and extension, and through the contact between different skin areas.

Correlated sensations play a very important rôle, in the endeavor to establish, through the sense of touch alone, a skilful

and rapid recognition of all surface impressions from the body itself. To this category of sensations belong the sensations of innervation in varying intensity, produced by contact of near and distant parts of the body's surface, and the sensations dependent upon the difference of the muscles thus set in action. A correlated sensation of this sort has evidently the value of a secondary (allied) presentation, for if any part of the body be touched by a foreign body, we can, without putting our own hand to the part touched, be sure of the location of this point, simply from the local signs which we know from former experience to be associated with certain sensations of innervation. Projection and association are the two fore-brain principles at the bottom of such concerted action, which constitutes an induction. Funke ("Physiology," ii., p. 177) has given a lucid exposition of our judgments regarding the origin of sounds and noises in space. Animals form a conclusion as to the origin of a sound by utilizing the sensations due to the reflex movements of the concha, and other sensations produced by the reflection of sound-waves from the convex or concave surface of the concha.

Helmholtz and his pupil, Wundt, have given an explanation of the retinal space-image, by showing the genetic development of space-perceptions, instead of adhering to the nativistic standpoint of other authors; with the latter we are not concerned just now. The manner in which the retina evolves a space-image, which is apperceived by the cortex, seems, at first, easy enough to explain; as a matter of fact, this process is quite incomprehensible. It requires but little reflection to discover that a uniform surface, which we are looking at, very soon evolves itself into a mosaic of smaller areas, or, at all events, appears divisible into smaller spaces; and if, on the other hand, the most variegated areas of any surface be presented to our eyes, we should nevertheless conclude that they were parts of a continuous surface. Granted that every retinal fibre be endowed with a special perceptive power for definite colors, and even for definite shades of such colors, this would not suffice to produce a space-image, for one would be compelled to suppose that these distinct local peculiarities of perception are so distributed that the disposition of variegated or uncolored portions of any surface would correspond to the exact juxtaposition of nerve-fibres of varying and special sensibility—a view which no one will consider plausible.

Supposing the various points of a visible surface to be pro-

jected upon different retinal cells, it would be possible to account for the division of this surface into smaller areas, but it would be difficult to form a concept of these smaller areas as a continuous surface. If, on the other hand, we assume the various parts of the retina to be connected with one another, and that their respective cells join in common action, we can understand then how conception of a continuous surface is engendered, but will be puzzled to explain the correlated concept of its divisibility into smaller areas. We may, however, conclude that each single spot of the retina receives its local signs in a different way, and we are justified in assuming that the development of a retinal space-perception depends upon the association of innervation-sensations of the ocular muscles and retinal impressions, just as in the development of space-perception through the sense of touch sensations of muscular innervation acted in unison with tactile sensations. I wish here to dwell upon Lotze's conception of the nature of local signs, and I do this not with the intention of combating the views of others, but because by reason of their very simplicity, Lotze's views commend themselves to our purpose.

It goes without saying that the remarks previously made regarding the inadequateness of the retina to develop a space-perception, apply equally to the inadequateness of the cerebral cortex, if the latter, in taking cognizance of space-perceptions, is to confine itself solely to the adoption of projected retinal images.

The retina is composed of two zones: a smaller zone of distinct vision—the macula lutea; and a larger one of indistinct division —the horopter circle. Distinct vision is accompanied by movements of the *bulbus*, by means of which definite points on the horizon are conveyed to the region of distinct vision. Thus the visual act is attended by sensations of innervation, which are projected upon the cortex, and result from the play of the ocular muscles. The projection-areas of the retina, and of the sensations of innervation, are united in the *cortex cerebri* by association-systems. In the annexed drawing, the projection of the retina extends from the *bulbus* through the optic nerve to a segment of cortical surface, corresponding to the region marked 1, 2, 3, on the outside of the skull (Fig. 63).

Three bright points, 1, 2, 3, lying in front of the bulbus, fall upon different spots of the retina, lying one above the other (1, 2, 3. The points are erroneously numbered, but this need not interfere with our understanding of the diagram). If these spots

should lie above the macula lutea, it would be necessary, in order to produce distinct vision, to move the macula lutea so far upward that the ray of light from each bright point would, in due rotation, fall upon the macula. As an effect of the varying intensity of its contractions, the *inferior rectus* muscle (J) will be able to bring the macula lutea into the line of incidence of each one of these bright points. A slight contraction of the inferior rectus will cause the macula lutea to change position with that

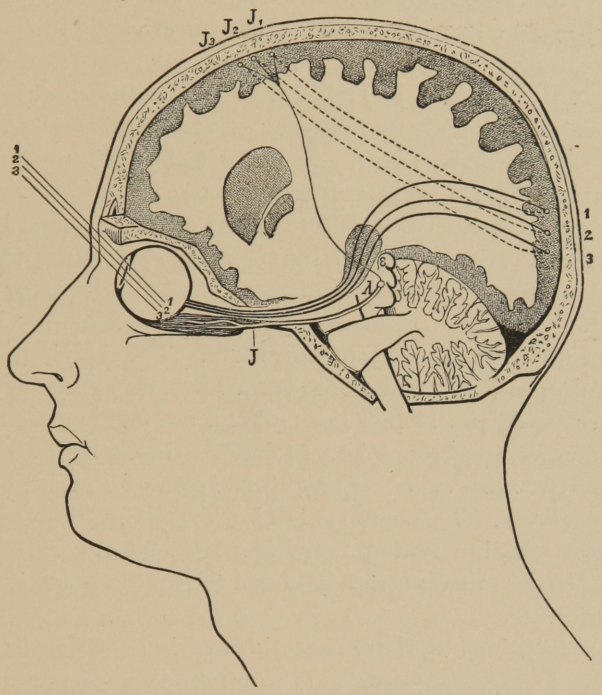

Fig. 63.
Space-Vision.

part which has been irritated by the bright point 3; after a stronger contraction, the retinal point 2 and the macula will have exchanged places, and a still more powerful contraction will advance the macula lutea to the portion of the retinal area, upon which the point 1 had been projected. Through certain fibres of the tractus opticus, the points 1, 2, 3 are represented somewhere in the cortex, and in another cortical region there is a representation of that branch of the third nerve which innervates the *inferior rectus* muscle. In the diagram one fibre is connected

with three cells, J_1 J_2 J_3, and these three cells are joined to one another in the net of gray fibres. The contents of the sense-perceptions stored in 3, 2, 1, in the cortex, are visual impressions; of those lodged in J_1 J_2 J_3, are sensations of muscular innervation. There are certain resistances opposed to the conduction of nerve-force in this gray network of fibres, which in the case of the nerve-tract leading to the cells J_1 J_2 J_3, as long as the intensity of innervation is very slight, will excite but the one cell J_1; if the intensity be increased, there will be sufficient irradiation to involve the cell J_2; and if the intensity of innervation be increased still more, the irradiation will extend to all three cells—from which we may infer that the signs J_1 J_2 J_3 correspond to different intensities of innervation. The least intensity of variation results from the effort to advance the macula lutea to the position occupied by the retinal spot 3; a greater, from its attainment of the point 2; and the greatest intensity will result when the macula lutea has usurped the position occupied by 1. In a succeeding portion of this book we shall have occasion to refer to the fact, that the intensity of innervation attending emotions (*Affecte*), for instance, is revived with the memory of this state. The varying distances between retinal areas and the macula lutea on every meridian or parallel circle of the retinal hemisphere, are designated by these local signs of graded sensations of innervation, which are derived from different muscles, according to the change in the position of the macula lutea. The sensation of innervation, which is joined to the light-impression falling upon any spot on the retina, varies according to the muscles employed and the innumerable gradations of intensity.

The perceptions of these sensations of innervation and of the optic areas become associated in the cerebral cortex; and by an inference as to the retinal spot, from the nature of the correlated sensation inseparably connected with it, every retinal area has its proper place in the perception of space. In this way, the topographical relation of retinal areas is registered in the corresponding cortical region; and from this relation we complete the image of space. If I suppose the three bright points of the preceding figure to be stars, it may be said that the retina perceives space between the three stars. But we cannot suppose the dark ether to be a retinal irritant; as far as perception is concerned, it is *nil*. That this *nil* between the stars is filled in by space, proves that there is no direct perception of space, but that the

latter constitutes a subjective inference. It is not the vacant ether which is actually measured, but the inference made, aiding in generating the idea of space, is based upon a measurement of the distances between the three spots (stars) on the retina. To the extent that the visual concept of space is utilized by the sense of touch, we shall find sensations of innervation derived from the ocular muscles associated with similar sensations of varying intensity from the upper extremity. The movement of stretching out the hand to seize objects lying at the side of us is accompanied by sensations of innervation from the sixth nerve, which directs the eye outward. If *paresis* of this nerve provokes a stronger sensation of innervation, then by association more forcible movements of the hand will result, so that the hand is extended beyond the object it had intended to seize upon.

This subjective power of the brain to evolve the idea of space from nothing, expands under pathological conditions to the power of filling out space with images which are the creations of the brain—the outcome of cerebral irritation.

To this account of the widespread activity of the fore-brain, not only as the recipient, but also as the creator, of sensations, I wish to add that it is the boldest hypothesis, shared alike by the ordinary mind and by scientific realism, to assume that the world is such as it appears to the brain to be ; that the latter can be likened to a mirror which simply reflects the forms of the outer world ; that the world as it appears to the brain exists independently of the presence or absence of mind. Indeed, it seems to me to be a crucial test of an individual's power of thought, to determine whether he can conceive or not of the unreality of the world clad in forms which our minds have bestowed upon it. It should be reiterated that the idealistic conception of the world is supported by physiological facts, and still more positively by the facts of cerebral architecture before alluded to.

Residual images would not furnish adequate motives for our movements and deeds if the phenomena of feeling were not inherent in them. To the reflex of sucking we applied the term reflex of aggression ; to that of vomiting, reflex of rejection, of repulsion. The conscious movements based on these reflexes were termed respectively movements of aggression and repulsion. These resulted from association with the ideas of satiation and injury. Such concepts were not mere passive reproductions of former images ; but their reproduction was attended by a degree of

intensity which we term emotion. In both cases the emotion varied, producing pleasure in the one case and pain in the other. A pleasurable emotion gives rise to movements of aggression, a painful emotion to movements of repulsion. Possibly we may be better able to fathom the different degrees of emotion or feelings by following a more complicated though physiological train of thought and omitting psychological definitions altogether. Our understanding may be furthered by a series of facts including more than mere bodily pain and the reflex of repulsion; for we have to consider a movement accompanying the latter and affecting the arteries of the central organ, and the connections of this correlated movement with the change in chemical relations—phenomena which are at the foundation of all nerve-phenomena. It will answer our present purpose to designate these chemical relations by the short expression: respiration of nerve-cells.

The solution of this problem would be reached by continuing the line of thought to which I have hitherto adhered, and by proving that the conjoined processes above referred to are already associated in the cortex as secondary processes with others involved in the mechanism of reviving associated images (or concepts).

Even though a decapitated frog respond to pinching of his skin with a kicking, repulsive movement, there is no need of supposing that a sensation of pain preceded this act. Nor are we compelled to regard the conduction of the cutaneous irritant to the muscles as the only process here set up, to which, if the brain had not been removed, sensation would have been added. We must remember rather that every sensory act produces a number of secondary effects acting upon the central nervous organ; and that such secondary effects, in default of fore-brain consciousness, are nothing more than the consequencc of an irritation which would be adequate to the excitation of pain.

First.—The experiments of Schiff and others have taught us that in animals in which the conduction through gray substance has been impaired, by experiment or otherwise, cutaneous irritation produces simply tactile or thermal sensations; in spite of the adequate nature of the irritation (burning) and the presence of the fore-brain, there is no sensation of pain. To this changed condition of irritability we apply the term Analgesia. We know, furthermore, that nerve-conduction through the network of gray substance meets with a certain resistance which can be

gauged by the time which elapses in the transmission of a peripheral impulse. With an increase in the number of muscular groups excited to action by a reflex irritant, an increase in the resistance to nerve-conduction goes hand in hand. The irradiation of any irritation so as to involve a large number of muscular groups, say those of the side opposite the cutaneous irritation, will depend upon the duration and intensity of the latter, and will have an influence upon the character of the pain-sensation resulting from said irritation. The sensation of pain, therefore, is attended both by a reflex movement and by an inhibition of nerve-conduction in the gray substance of the spinal cord. The strength of the resistance to be overcome, in the case of motor irradiation, increases, even in the case of the unconscious, decapitated frog, with the duration and intensity of the irritating cause. It is evident, then, that inhibition, resulting from resistances introduced in nerve-tracts, accompanies the simplest reflex processes, while consciousness in the main recognizes this inhibition as pain. In regard to inhibition, I wish to call attention to the retardation in the conduction of reflex nervous impulses. A nervous impulse takes, according to Helmholtz, about twelve times as long to travel through the gray substance as it does to be transmitted through the peripheral nerves. Transverse conduction largely increases the time required for the reflex act, as when a stimulus applied to the one side is to excite the muscles of the other side (Rosenthal, of Berlin). According to Exner, the stronger the stimuli, the less the amount of time required to effect a reflex action.

Secondly.—Irritation of a sensory nerve excites in decapitated animals not only a repulsive movement of the skeleton muscles, but exerts an influence also over the circular muscular apparatus of blood-vessels, the centres for which are located in the spinal gray matter. The ex- and in-tensity of this influence vary directly with the amount of irradiation of the original stimulant impulse. The dilatation of the blood-vessels in the web of a frog's foot continues steadily to increase as layer after layer of the spinal cord is removed (Lister). Goltz has demonstrated the functional activity of the spinal vaso-motor centres in mammals, and W. Schlesinger (Stricker, *Med. Jahrbücher*, 1879) has proved their presence by experiments with strychnia. We are justified in inferring that repulsive movement is attended by a reflex contraction of the spinal-cord arteries, similar to the one which takes

place in normal animals, and which is observed to result from an increase of blood-pressure in the carotid after the application of strong sensory stimuli. The rise of blood-pressure in the carotid following sensory stimulation was measured by Owsjannikow and Ditmar with the use of the manometer. This increase of pressure depends upon reflex contraction of the arteries (*vid.* p. ——). In this way physical pain produces swooning, and explains why in former centuries when a confession was extorted in court by torture, the person incriminated would fall asleep while undergoing the pangs of the rack. Ditmar believes that there is no better proof of the presence of sensory processes in animals than the rise of the blood column in the manometer, following upon external stimulation, and that this increase of manometrical pressure is caused by the reflex vaso-motor contraction set up by the excitation of sensory nerves.

Thirdly.—The constriction of the arteries, by impeding the respiration of the nervous elements, must necessarily engender a dyspnœtic phase of nutrition; it will modify the chemical changes going on in these elements, and as a further result of this we shall find the sensory stimulus associated with the irritation resulting from a certain degree of dyspnœtic intoxication. Dyspnœa of tissues is alone sufficient to excite repulsive movements. Inspiration is the most ordinary form of repulsive movement evoked by a dyspnœtic stimulus, which in extreme cases may, by irradiation, involve a number of muscles. But this dyspnœtic stimulus results not only from defective breathing, but also from increased arterial pressure, as in convulsions, or from arterial contraction, as in anæmia. The convulsions occurring in persons bleeding to death are an instance of the latter kind. The respiratory centres extend, according to Procop Rokitansky, into the cervical portion of the spinal cord.

From what has just been said we may assert that even in the spinal cord of decapitated animals movements of repulsion are connected with sensory excitation, inhibition of nerve-conduction, increased arterial pressure, and with dyspnœtic stimulation of nerve-cells.

Movements of aggression, also, can be demonstrated in animals that have forfeited the pros- and di-encephalon, and indeed in animals which have retained the spinal cord only.

In his "Contributions to the Study of the Functions of the Nerve-Centres of the Frog," Goltz remarks: "If on a fine summer's

evening, we hear the croaking of the frogs, we conclude correctly enough that these inhabitants of the marshes are thoroughly happy in the enjoyment of the tepid waters." We infer the same cheerful spirit, when we observe the playful aggressive movements of a cat engaged in pushing a ball or a mouse before it, and always endeavoring to recapture it; when we see animals frolicking and tumbling about incessantly on the grass and in the open air, or birds that give expression to their mirthful restlessness by their song, and direct their aggressive movements upon crumbs, seeds, or worms. All these convey the same impression to our minds. As soon as a stone is thrown into the pool the frogs cease their croaking, in view of the danger to which they are exposed; an enemy suddenly appearing before animals that have been tumbling about in the full enjoyment of their liberty will cause them to hide themselves, or to start movements of repulsion by taking to flight. The unhampered, purposeless movements of a lively animal, the song of a bird, the merry bark of a dog, are in reality movements of aggression. Goltz has excited similar movements of aggression in decapitated animals, such movements indicating a certain self-consciousness, attended by undoubted pleasurable sensations. He was able to elicit the croaking of frogs and the aggressive movement of clenching the female as in the sexual act. The stimuli which Goltz had to apply in this instance differed materially in character from those which elicit repulsive movements. The effective stimuli were of a gentle sensory and non-painful character. Gentle friction between the shoulder blades sufficed to provoke a croak in frogs deprived of their fore-brains; and (slight) pressure brought to bear on, or friction of, the breast and flexor surfaces of the arms was followed by an embrace of any thing which had been placed within reach of the arms. The transmission of such gentle stimuli through reflex gray substance could not take place in the face of any great resistance, and, being permitted, it compels us to assume the existence of a distinct centre which is reached at once by external stimuli. The "centre," excited in the croak-experiment, lies in the mesencephalon, while the reflex centre for the sexual embrace in male frogs must be located in the cervical portion of the spinal cord. The term "embracing spasm" (Umarmungskrampf) will do justice to the powerful muscular action, resulting probably from a hyperæsthesia of the frog's spinal cord, produced during heat by the nerves of the testicles, but existing for

some time after the removal of the testicles. The exciting cutaneous stimulus need be merely of the slight (unpainful) intensity mentioned above.

Hence we may infer that even in the case of frogs that are brainless as far as consciousness is concerned, the correlated effects (in the central organ) of aggressive movements and the accompanying circumstances differ from those attending repulsive movements, with which consciousness associates the sensation of pain. These two orders of correlated (secondary) effects are on the whole diametrically opposed to one another.

I.—The stimuli are gentle and not painful; they must be conveyed to certain centres direct without irradiating and without overcoming any resistance or inhibition. In the sexual spasm of the frog, the conduction of nerve-force was assisted, and not inhibited, by a periodic increase in the excitability of the centre. Just as the consciousness of a painful impression is based upon, or is attended by, inhibition of nervous impulses, so the consciousness of a pleasurable impression is attended by the free transmission of nerve-force.

II.—In the one case, the irradiation of a stimulus adapted to the excitation of pain, sets up activity in the centre for the vaso-constrictors followed by increased arterial pressure (active arterial anæmia), as concomitants of repulsive movements; and in the other case, there is no irradiation produced by external stimuli, no inhibition, and no increase in arterial pressure accompanying aggressive movements. Later on I shall be able to show that the movements of aggression are associated with a diminution of blood-pressure, a dilatation of the arteries entailing the so-called functional hyperæmia. Ditmar's reflection, that increased arterial pressure keeps step with the process of sensation, does evidently not apply to the generation of aggressive movements.

III.—The functional arterial dilatation necessarily produces an apnœtic phase, in consequence of the increased tissue-breathing of the nervous elements, and will bring about a chemical change also, differing from the one effected by a painful stimulus, which called forth a dyspnœtic phase of nutrition in these elements.

These antitheses are not artificial and far-fetched; they are suggested by the fact that in the reflex centres aggressive and repulsive movements inhibit one another, because of the different processes set up by the one order of movements or the other. Goltz has shown that the ordinary croak cannot be elicited, if painful

stimuli be simultaneously applied; and that the sexual spasm will be inhibited if any part of the frog's body be at the same time touched with acetic acid. And, on the other hand, the great excitability of the sexual spinal-cord centre under the influence of the testicle-nerves may, during the period of heat, inhibit the repulsive movements which would follow painful stimuli, were they not inflicted during the sexual act.

But have we any facts which will enable us to say whether the same accompaniment of vaso-motor innervation, of differences in the chemical changes of nutrition, attends the secondary mechanism of conscious movements, incited and set into action by subcortical reflex acts, which (movements) are based upon the revival of cortical images, and are effected through the mediation of association-tracts; and who will say whether among the impulses of the Ego, and within the bounds of free will, we shall be able to discover and to discriminate between a series of repulsive movements which had to overcome a resistance to nerve-conduction, and aggressive movements which have had free pass through the nerve-tracts engaged in their excitation or transmission?

Although it has been shown (p. 141) that the great expanse of cortical surface favors the restriction of certain functions to certain localities, it is certain that apart from the association through the arciform bundles, and on the supposition that its gray substance represents a network of gray fibres, the condition of its structure permits the irradiation of *stronger* stimuli, as is the case in the spinal cord and the remainder of the central gray substance. Association and Irradiation are two very different processes. We shall show that the process of irradiation in the cortex interferes seriously with that of association. As in the spinal cord so in the cortex, vaso-constrictor nerves will be excited by an irradiating sensory stimulus. Among German authors, Eulenburg and Landois,[1] as well as Hitzig, have shown that upon stimulation of the cortex the extremities of the opposite side grow cooler (through arterial constriction), and upon removal of the cortex the temperature of these parts increases (Hitzig) so markedly (through arterial dilatation) that it can be discerned by the hand placed upon the extremity of a dog so operated upon, and without the corroborative evidence of a thermometer.[2]

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[1] *Centralblatt f. d. med. Wiss.*, 1876.

[2] For full literature *vid.* Exner: "Grosshirnrinde"; Hermann: "Handbuch der Physiologie," Bd. II., p. 318.

Let us take up the example discussed above (p. 184), in which we supposed a brainless frog to be exposed to an intense sensory impression (pinching with forceps) and to display an inhibition sufficient to overcome the stimulus. We then discussed the influence of the stimulus upon the vaso-motor nerves, and the repulsive movements executed by motor nerves; but let us vary the example by supposing an animal to be in full possession of its brain.

A person who has been teazed with forceps, or who has undergone the pangs of an operation, will recognize this intense irritation as an impossible (unbearable) act of perception. Evidently irradiation meets with severe and widespread resistances in the gray substance of the cortex as well as in the central gray substance. In this respect the pain answers to a sensation of inhibition. The inhibition, obstructing the path of this irradiating stimulus, calls for an exhausting amount of excitation, and this effects inhibition of other cortical functions, and sets a limit to the activity of the cortex; it inhibits attention, thought, and the association of ideas as well. Secondary conscious movements of repulsion are incited (p. 184 *et seq.*) to ward off the hands or instruments that have inflicted the torture. As concomitant conditions, we get paleness, nausea, loss of consciousness, together with slowness of pulse, with or without convulsions, or unconsciousness together with rapid pulse and universal convulsions.

Loss of consciousness, attended by nausea and slowness of pulse, may be ascribed to irradiation affecting the vagus—the cerebral nerve of the heart,—and to anæmia of the brain, due to the suppression of the systole. Though restricting myself to the above-mentioned facts of experimental physiology as evidence of the vaso-constrictor influence of the stimulated cortex, and reserving other striking proofs of the fact (Kussmaul, Nothnagel) for the clinical chapters of this book, I have said enough to infer from the importance of the cortex as a vaso-motor centre, and from the above-mentioned relation between strong sensory impressions and an increase of blood-pressure, that the conduction of strong sensory stimuli into consciousness (into the cortical "gray") increases the arterial pressure and arterial constriction, thus setting up active anæmia. Whether this leads to actual unconsciousness or not, we may say that the sensation of pain is associated with increased narrowing of the arteries. But contraction of the arteries implies a chemical change, the dyspnœtic

phase of prosencephalic nutrition, and, united to the latter, the disagreeable sensation of pain. This is the less hypothetical, inasmuch as external chemical changes, such as accompany difficulty of respiration in impure air, are attended by a sensation of discomfort and restlessness, leading to repulsive movements, loss of consciousness, even to swooning with convulsions. It has been shown, therefore, that strong sensory stimuli excite in a reflex way conscious movements of repulsion, and in originating sensations of pain introduce inhibition, arterial contraction, and dyspnœa of the elements of the fore-brain.

It is not alone the perception of actual pain which incites movements of repulsion, but the mere sight or touch of, or a sound from, objects which are associated in the fore-brain with the idea of pain, danger, or death, excite, as the pain itself, movements of repulsion, and create in the cerebral cortex all the conditions of subjective torture which we have learned to regard as concomitants of real pain. If the mere sight of the sharp end of a knife, of loaded fire-arms, of a wild animal let loose, of a fire, a corpse, an operation on others, or the sight of blood, suffices to produce loss of consciousness or swooning attended by the sensation of inhibition of thought, or impels the witness to take to flight, we must suppose that our ideas of pain are intimately connected with the revival of reminiscences of these objects, and that this subjective pain is of sufficient intensity to arouse all the correlated physiological sensations accompanying genuine objective pain: namely, inhibition, increased arterial pressure, dyspnœtic phase of nutrition, and repulsion. Referring again to the former example of the consequences of an intense sensory irritation upon the spinal cord, we observe that the entire complicated primary form of the reflex mechanism is transmitted secondarily to the fore-brain. The instances cited immediately above referred to *associations* started by the actual perception of objects calculated to produce pain; but the momentary painful stimulus was lacking. Physiologically speaking, the stimulus bears a special characteristic sign, resulting from the excitation of peripheral sensory nerves, and, more particularly from excitation of their terminal apparatus; among such signs may be classed cutaneous irritants, dazzling light, unusually strong waves of sound, etc. Pain is classified with the *Feelings;* but it is distinguished from sensory perceptions by its widespread irradiation which interferes with localization.

Feelings without physical pain are termed emotions (Ergriffenheit). We are here concerned with painful emotion, psychical pain. That painful emotions depend solely upon associations, upon inferences pointing to the perception of pain, can be proven by a simple analysis of the objects which excite pain. The retinal images of a tame and of a wild animal, of an indifferent person or of one whom we fear, are projected upon the same retinal area, possess the same color and the same intensity of light. An indifferent red fluid and blood leave the same impression upon the retina. Mere perception itself cannot excite emotion, but the associations united to the former can. It is, therefore, the mechanism of the hemispheres only—the process of thought—which excites psychical pain and movements of repulsion, as well as the arterial contraction which may terminate in swooning, and in engendering fear and a feeling of incapacity for action (Unmöglichkeitsgefühl).

But sensory impressions are not needed to arouse the associations connected with emotions; recollection of painful impressions may revive such associations.

Boerhave relates a story in point: He says that he passed a spot where years ago the smell from the cadaver of a horse made him vomit, and that the mere recollection of this occurrence produced nausea anew. Without wishing to dilate upon such corroborative evidence, we may add that reflexes attending painful emotions, such as crying, may be excited by reminiscences, as is the case too with the centre for the contraction of the blood-vessels. Further details about the connection between reflexes and emotion may be called from Domrich: "Die psychischen Züstande" Jena, 1849. Explanations will be given later on.

Equivalent in value to cortial images are the symbols of language associated with these. The news of the death of a person whose image would frequently be revived in our brain by the most manifold associations, and which when presented to the brain would arouse all sorts of secondary presentations and pleasurable emotions, who was bound up with a good portion of our thoughts—such news, I repeat, would cause inhibition of all these associations, and the place of easily excited associations (through repetition) will be usurped by others that are not yet easily transmitted. Marked inhibition of nervous impulses from the forebrain excites, like the inhibited conduction of painful sensory stimuli, or the suggestion of torture, a concept of the impossibility of counteracting this inhibition which may ultimately lead to suicide. A physiological process occupying much time, and consisting in the dissolution of now purposeless associations and the formation of

new ones, precedes the introduction of this death-news into the web of associations. Inhibition is attended by emotion and psychical pain. With inhibition and psychical pain there is connected increase of arterial pressure, which during an emotion may, by mere presentation to the mind, produce swooning. Inhibition or resistances on the lines of nerve-conduction through the gray substance, as well as increased arterial pressure in consequence of strong sensory impressions, are physiological facts.

Lastly, that the impoverishment of the brain substance in oxygen (Hermann) has the effect of a chemical irritant which excites dyspnœtic respiration in the oblongata, and produces epileptic changes in the so-called convulsion-centre, is a well-established physiological fact. Since increased arterial pressure even in the cortex produces an impoverishment in oxygen, a dyspnœtic phase of nutrition will be set up in the cortex as soon as the conditions of painful sensations exist. Sensation itself is the subjective form of perception of all these physiological processes; it is, as it were, the expression of a special sense concerned with the nutritive phases of the cortex.

The stimuli and their effects, which interest us in this connection, may be of every conceivable degree of strength. The higher intensities of Feeling may be termed Passion, Emotion; the lower intensities, Moods, Temperament.

By calling the latter hampered and unhampered moods, we establish an evident analogy with the conditions which lead ultimately either to repulsive or aggressive movements.

If we are actuated by appropriate motives, the pursuance of a complicated process of thought produces in us a rapid change of mood, according as this thought is hampered or furthered. If a beginner wishes to determine the rank of a plant in the natural system, he must perceive and associate in mind all those characteristics which have been united in such a way in his brain as residual images, as to enable him to properly classify this object in the botanical system. If he discovers a single characteristic which is poorly developed, this cirumstance will inhibit the association; if he has forgotten the proper term for another characteristic, the flow of association will be checked also; if still another quality of this plant does not harmonize with the others which he thought would suffice to determine its rank, further work in this direction is hampered; and if he cannot recall all the peculiarities of the family to which he supposes the plant to belong, then the very

last step in the long process of association is rendered impossible —no conclusion can be reached. Confusion results, but confusion indicates an inhibited association of ideas. Displeasure is united with this inhibition of thought; the conception of a repulsive movement to give up the plant or to throw it away will probably follow very soon after. The hampered mood will grow more intense if the original motive was intense, say an examination in botany on the morrow. If the associations had not been checked, they would have formed a complete circle, beginning with the inspection of the plant, taking in all possible associations on the way, and ending by identifying the real plant with the one constructed in the brain. During the development of this process of thought, the student would have experienced a pleasurable sensation, and a certain degree of happiness would have accompanied the attainment of the conclusion reached through this chain of associations. Every scientific investigator who endeavors to work out the answer to certain problems, whether it be his aim to determine the correspondence of two cerebral acts, say between the perception of a natural phenomenon and the conclusion reached by a long line of association, in the course of which he endeavors to evolve the conditions of this phenomenon in such a way that they appear as the conclusion reached by his own mental activity; or any one who has successfully reached his Q. E. D. experiences a psychical happiness even while his thoughts are in full blast. This sensation (of happiness) is no doubt to be ascribed to a determination of arterial blood to the busied fore-brain, to a functional hyperæmia. Functional hyperæmia is the physical concomitant of thought, and in the succeeding chapter we shall endeavor to examine in detail the relation between these two processes. And the manner in which thought in general produces functional hyperæmia, I will endeavor to explain upon a physiological basis, and not merely by drawing an analogy between the fore-brain and other brain-organs when in a state of activity.

Goltz explains the inhibition of the croak-reflex in the frog through painful constriction of one leg, by supposing the reflex centres to form a single complicated apparatus; and having made the assumption, he contends that every mechanism will operate the more easily, the less the tasks it has simultaneously to perform. The croak-reflex is inhibited by the irradiation of another stimulus into the confluent gray reflex centres.

The cerebral cortex has two distinct tasks to perform: 1. The innervation of processes of thought and of movements connected with these; 2, the innervation of arterial vaso-constrictor muscles. The more inactive the brain is in the former respect, the more intense will be the constriction of the arteries. This latter process will be inhibited as soon as the first order of cortical activity is called into play; which means that arterial constriction diminishes during the innervation of mental processes. Hence a condition of functional hyperæmia is set up.

Although different sensory stimuli reach special cortical areas, it was shown above that a revived memory, constituting the act of recognition, must be regarded as a complex phenomenon associated with secondary concepts, derived from different areas of the cortex. The majority of mental processes are based upon reminiscences or memories which have engaged the functional activity of widely separated regions of the cortex. Whence it follows that the functional hyperæmia will invariably affect circumscribed areas at some distance from one another; and this is equivalent to saying that a condition approaching a universal hyperæmia of the fore-brain will be established.

A psychical condition, which engenders innumerable aggressive concepts, and puts no obstacle in the way of the expansion of associations, is attended by a feeling of happiness. Winning the first prize in a lottery will make the ordinary mortal happy; this feeling of happiness is the result of an unrestricted flow of associations. The wealth he has suddenly acquired puts a number of desirable objects within his reach; with a number of objects his personality can now form associations which could formerly not be established from the lack of wealth; a multitude of possible aggressive acts present themselves before his mind; his brain enters into a condition of great though easy and untiring activity, attended by an apnœtic phase of nutrition, thus standing in great contrast to the check put upon the flow of associations through the loss of persons or possessions.

We have seen that the concept of motion, the revival of sensations of innervation linked to a long chain of associations, can arise in the mind unaccompanied by movements or acts of any sort. We are, therefore, impelled to the conclusion that the execution of movements demands more powerful stimulation and stronger nutritive stimuli. The intensity of such motives for action vary with the feelings. It would be difficult to conceive of the

existence of an animal not actuated by feeling, and, indeed, to conceive of one that is not influenced by the two sorts of feeling, of which the one provides motives for movements of repulsion, and the other for movements of aggression. An animal endowed only with processes of aggression, and lacking the conception of repulsion, or the power of performing acts of repulsion, would succumb to the inimical influences of sensitive and insensitive beings; while an animal that possessed no conception of aggression, nor the power to perform aggressive acts, could not avail itself of the conditions of subsistence offered by nature.

The phenomenon of (personal) freedom depending upon the variety of possible deeds, is best exemplified by the impulses which intensity of feeling imparts to our secondary individuality. Within the realm of the primary ego, the destruction of one's own body—death—constitutes the extreme concept of repulsion; yet through the intensity of feelings, joined to the secondary ego, infliction of death may simply be an act of repulsion by which it is intended to ward off destruction from other portions of our individuality, as in sacrificing our own lives to save the life of a person so dear to us that he has formed part of our own individuality. Duty and Honor have become integral parts of the individuality, exceeding in the intensity of repulsive and aggressive acts which they arouse, the factors of the primary ego. Complications of the individuality may reach such an extreme that the reflection of the individuality in the brain of others becomes the leading motive; and the primary ego is sacrificed in order to preserve an image in accord with our secondary individuality in the brains of the survivors. This constitutes the desire for so-called immortality.

Let us turn now to the consideration of the anatomical corollaries and the results of the experimental investigation regarding the subcortical ganglia, which terminate cephalad in the diencephalon. The prosencephalic ganglion may be looked upon as a nodal mass among the centrifugal nerve-tracts of the cortex; its conditions of excitation keep step with those of the cortex. The relation between the trunk ganglia, beginning with the *thalamus*, and the fore-brain is such that, although excitation of the former produces sensory apperception in the cortex, the greater the cortical excitation following upon the independent revival of cortical memories and of associations, and upon the exercise of thought, the more the influence of the subcortical centres

will be diminished. *This is cortical inhibition.* I wish at this juncture to call particular attention to the incommensurability of cortical reminiscences with sensory perceptions—a fact of great importance in regard to all future discussions. Sensory perceptions are invariably referred to the external world, even in those cases in which, through blindness or amputation, the peripheral sensory surfaces have been removed. This is due to reasoning by analogy. By experience we have learned that excitation of subcortical nerve-tracts and ganglia, which transmit sensory perceptions to the cortex, is due, in the first instance, to a peripheral stimulus; and, therefore, excitation of these subcortical tracts and ganglia is invariably referred, by the laws of causality, to the external world. It never occurs to us, however, to suppose that the cortex is stimulated directly from the external world; whence it follows that cortical images, which are due chiefly to excitation of the cortex, can never be invested with the qualities of true sensory impressions.

That the peculiar formation of the prosencephalic ganglion depended upon its important connections with the anterior portions of the cortex was insisted upon on pp. 141 and 142; but although the nucleus caudatus and the nucleus lenticularis form one mass, their respective proportions are in striking contrast to one another. It is safe to say that the intraventricular expansion of the nucleus caudatus does not vary much in its relation to the brain-trunk throughout the mammalian series. In man its basilar portion, lying above the *lamina cribrosa anterior*, is flat, while in animals with highly developed olfactory lobes it is convex, and exceeds in size this formation in the human brain. Excess of development in this one particular is evidently dependent upon the presence in the basilar portion of the caudate nucleus of nerve-tracts coming from the olfactory lobes. Magendie was the first to recognize the corpus striatum as an organ connected with locomotion, and Nothnagel discovered in the corpus striatum of the rabbit a *nodus cursorius*, which, when excited, compelled the animal to run forward. The movements of animals possessed of highly developed olfactory lobes are influenced chiefly by olfactory impressions, for which reason we can readily understand the connection between these two physiological factors and their relation to the structure of the *nucleus caudatus*.

The lenticular nucleus is sparingly developed in mammals, in great contrast to the development of this ganglion in man and

monkeys. It is well developed also in the brains of the mole and bat—whose anterior extremities subserve special forms of motion. In cases of hemiplegia, due to destruction of the lenticular nucleus, paralysis of the upper extremity exceeds in intensity that of the lower. Climbing animals, including the monkey and man, have from the very first adapted their anterior extremities to the performance of complicated movements, and in man the upper extremity has learned to do the bidding of psychical impulses; but man and monkey are the two forms which are characterized by the possession of the most highly developed *nuclei lenticulares*. Quite recently three cases of encephalitis affecting the right island of Reil have been reported, which were followed by monoplegia affecting the left upper extremity (Brodeur, Raymond). Severe paralysis cannot, as a rule, be attributed to lesions of the cortex, and according to Munk the cortical area governing the movements of the upper extremity is situated at a distance from the island; this monoplegia must undoubtedly, therefore, be referred to the lenticular nucleus which stands in close contiguity with the island of Reil. Whence we conclude that in addition to its well-known relations to the hypoglossal and facial nerves, the lenticular nucleus has special relations to the movements of the upper extremity.

The remaining masses of gray substance do not form part of the prosencephalon, but lie within the walls of the primary medullary tube, which extends originally only as far as the anterior cerebral vesicle.

The relations of the powerful di-encephalic ganglia, the *thalami optici*, have already been discussed (p. 162), also their prominent connections with the optic tract. Due attention was bestowed upon the relations proved by physiological experiment to exist between the thalamus and the upper extremities, and thus the influence of one thalamus—whose mechanism is set into activity by retinal impressions—upon different muscular groups in both arms was explained anatomically by the origin in the thalamus of decussating and non-decussating spinal-cord tracts. I wish to add that the greater caudal expansion of the human thalamus, exceeding as it does in this respect the thalamus of all other mammalian forms, may possibly bear a definite relation to the greater use of the upper extremities.

The *anterior ganglion* of the thalamus is *not* more highly developed in man than in other mammals, and naturally enough,

too; for there is an evident connection between this part and the *gyrus fornicatus*, the cortical portion of which Munk connects with the sense of smell. This conclusion is borne out by its connection with the olfactory lobes, and the relatively great development of its substance. From an anatomical point of view, this anterior protuberance may also be considered a *nucleus caudatus*. The size of the human thalamus depends largely upon the development of the pulvinar, which arches over and beyond the corpus geniculatum externum, while in all mammals, with the exception of the monkeys, the corpus geniculatum externum tends upward toward the thalamus. But on the other hand the corpora quadrigemina are less developed in man. No ganglion has as broad connections on all sides with the cortex as the thalamus opticus; on superficial examination it appears to be connected with the entire corona radiata. And since this broad expanse of cortex joined to the thalamus is connected with almost every cortical function, we must infer that the thalamus has an important bearing upon functions of widely different character.

The functional activity of an animal which has not been deprived of its thalamus, is in no wise impaired, save that it lacks the customary centrifugal impulses dependent upon cortical reminiscences. There is good reason, therefore, to believe that all forms of sensibility are represented in the thalamus and corpora quadrigemina. In corroboration of this belief we might cite the very great influence sensory impressions exert upon movements as long as the thalamus remains intact. First and foremost we must recognize the projection of the retina upon the optic thalamus; and from Nothnagel's pathological experiments we learn that visual disorders result from lesion of the posterior segment of the thalamus—a conclusion which is in perfect accord with anatomical facts. As long as the thalamus is uninjured, and only then, animals are able to avoid obstacles thrust in their way, and birds that are thrown up in the air show by their behavior that they can measure with their eyes the distance to, and the direction of, the ground upon which they are bound to land. The possession of a thalamus enables an animal to creep through a narrow opening between objects placed before it—a fact known even in Magendie's day; or, as Goltz observed in frogs, enables an animal to jump past an object placed in its way, provided there be a sufficient stimulus for escape. Facial reflex movements seem also

to be dependent upon the thalamus. On the one hand pathological cases are on record in which, in spite of an existing facial paralysis, the reflex movements involved in laughing, crying, in giving expression to pain, and in the protective closure of the eyelids, were well executed (Nothnagel, "Topische Diagn. der Gehirnkrankheiten"); but in all such cases it has been remarked that the lesion did not affect either the thalamus or its medullary radiations. And on the other hand Longet and Schiff have called attention to the grimaces of cats (which have been deprived of their hemispheres) following the application of Tincture of colocynth to the tongue. I do not mean to defend the term "psychical reflex," nor to insinuate that the projection which receives its innervation from the hemispheres (from consciousness) suffers an interruption in the thalamus; for of all negative physiological truths relating to the thalamus, there is none more certain than that so-called volitional paralyses are entirely independent of thalamic lesions; and yet, if we do not wish to give too simple an interpretation to facts of great subtlety, we must keep in mind that the thalamus possesses a reflex mechanism of such a high order, of such marked *psychical* characteristics, that Goltz, who is not satisfied with the term "reflex," would designate the complex functions of these higher physiological mechanisms of the brain as "the power of adaptation." And then, too, the views I have expressed regarding the genesis of volitional paralyses, which were implied in the assertion that volitional movements are based upon the primary motor images derived from reflex movements, must not be accepted as a negation of the fact that the co-ordinating power of the fore-brain may enable it to exert an educational influence upon reflex actions.

Lotze was no doubt justified in giving the following explanation of Pflüger's so-called psychical spinal-cord-functions: He contends that, in the young animal, movements of expediency, like those of cortical motor acts, are not yet to be ascribed to the spinal cord, but that definite cerebral co-ordinations, which are accustomed to utilize certain spinal nerve-tracts, leave an impression of fore-brain activity of such a nature that, after the removal of the brain, reflex innervation is directed to the groups of nerve-tracts most frequently engaged in the transmission of cerebral impulses. Anatomically, this can be proved more readily for the spinal cord than for the thalamus, for the former is connected with centrifugal cortical nerve-tracts, while the thalamus is

not so connected. The thalamus itself is the centre for and origin of the centrifugal tracts in the tegmentum of the crus; their innervation is dependent upon stimulation of the thalamus. On the strength of the discussion at the beginning of this chapter concerning compulsory positions of the anterior extremities following lesions of the thalamus, we conclude that the fibres radiating from the cortex into the thalamus constitute centripetal nerve-tracts which conduct to the cortex the sensations of innervation created by motor processes started in the thalamus. We must necessarily, however, premise the existence of centrifugal, cortical tracts in the prosencephalic ganglion and in the internal capsule, initiating the same forms of movement, and emanating from the same areas of the cortex, to which the thalamic radiations conveyed the innervation-sensations of such movements. Though the co-ordinating fibres belonging to the cortex proper may refine upon and vary these forms of movements, they could not exert any influence over the mechanism of the thalamus unless we assumed the twofold conducting power of cerebral nerve-fibres—a power which Dubois-Reymond proved that the excised nerve possessed. The association-tracts of the fore-brain possess beyond a doubt such a twofold power of conduction; for of two associated cortical reminiscences, either one, when revived, will recall the other. I can find no grounds for denying a twofold nerve-conduction in the thalamic projection-systems conveying sensations of innervation to the cortex; and through these systems, movements which have been modified by cortical co-ordinations may react. But more of this later on. It was in regard to physiognomical expression, which is not confined solely to the facial nerve, but is a result of the activity of the muscular mechanism of our entire body, that Darwin asserted the apparently paradox principle that the form of volitional movements in the *ascendant* are changed to reflex movements in the *descendant*. The inheritance of physiognomical expression I do not consider proved. At all events Darwin could have made his views plausible only by showing that conscious movements originated in reflex actions. In that event a reciprocal effect might be conceived; reflexes might be proved to be the primary roots of the simpler manifestations of the conscious motor mechanism; and later on the cortical co-ordination might generate more complicated forms of movement which, from the presence of a twofold nerve-conduction, would react upon the motor functions of subcortical centres.

The multiplicity of relations of the thalamus as a centre of automatic movements, and as such, its relations to the sensations of innervation, its bearing upon the sense of smell (restricted to its anterior protuberance), and its relations to sight are in keeping with the anatomy of this ganglion as described in the first section of this book (pp. 31, *et seq.*, 48, 92, 101, 141, and 142). The dependence of physiognomical expression upon cutaneous sensibility leads us to look for the anatomical substrata of such expression in the nerve-tracts of the thalamus. At this juncture it is incumbent upon me to fill in a gap in the anatomical description given above. I wish to add that the fibres of the lemniscus, the fillet, derived from the trunk ganglia, do not issue merely from the corpora quadrigemina, but that some of its bundles, situated to the front (cephalad) of the corpus bigeminum superius (Figs. 55, 56, behind ss), and inseparable from the innermost bundles of the brachium corp. bigem. inferius, originate undoubtedly from the thalamus. In searching for the anatomical substratum of the possibly sensory functions of the lemniscus, we must necessarily keep in mind the quadrigeminal origin of the fillet from the brachium corp. bigem. sup. Bundles of the lemniscus constitute the anterior portion of the brach. sup. (p. 102), while the posterior margin of the latter contains fibres connecting the corpus geniculatum externum with the corpus quadrigeminum. These bundles of the lemniscus stand in close contiguity with the latter, centripetally conducting fasciculi of a sensory organ, and issue from the same regions of the cortex in which are contained optic radiations, as well as the sensory bundles of Türck which pass through the internal capsule and the pes pedunculi. There is no strict anatomical proof for the assumption that the occipital lobe is the chief central organ of sight; but other radiating fibres connected with this division of the cortex furnish ample proof, as was stated at the beginning of this section (p. 142), for the belief that it is connected with the special organ of touch (the skin). Following the track of the lemniscus into the spinal cord, we find that the fillet is continued into the outer portion of the funiculus lateralis (p. 134), which Mischer has conclusively shown to contain sensory tracts.

The lemniscus, therefore, connects the thalamus with the corp. quadrigemina through tracts conveying reflex influences of tactile stimuli. The anatomical connection of the lemniscus with the olivary bodies—from which the posterior columns emanate (p. 134)—

is also worthy of remark. According to Renzi, detonation provokes movements of the eyes in frogs possessing normal thalami; we must, therefore, suppose connections to exist with the sense of hearing. Remembering the entrance of central auditory tracts from the cerebellum into the superior peduncles, and on the other hand the connection proved by Wernicke to exist between the thalamus and the nucleus ruber of the sup. peduncle,—remembering these facts, we may say, although I wish to speak reservedly regarding the importance of these peduncles as an auditory chiasm, that a connection of the thalamus with the labyrinth is not beyond the bounds of anatomical possibilities. In the oblongata the voice- and auditory-centres crowd upon each other. Possibly the motor function which Bechterew ascribes to the thalamus in locating a centre for screaming in that ganglion, and the "croak centre" which Goltz locates in the region of the mid-brain, may argue in favor of the existence of anatomical connections between the VIII. nerves and the mechanism of articulation. Since voice manifestations in animals represent the acoustic factor in their physiognomy, we might consider a physiological connection established between this function of the thalamus and the above-mentioned function of reflex mimical expression. Possibly, also, the difference of opinion between Goltz and Bechterew regarding the voice-centre might be explained by supposing that functionally at least the thalamus and mid-brain are not strictly separable.

Caudad of the mesencephalon (mid-brain) begins the region of the oblongata, which cannot be separated easily from the pons, and which, properly speaking, does not contain centres for locomotion, but for restricted movements only. Goltz mentioned as characteristic of animals deprived of the mid-brain and cerebellum, in contradistinction to those possessing a spinal cord only, that the former could change from the dorsal to the abdominal position. Undoubtedly, however, the pronounced influence of sensations upon bodily movements, such as leads us to presuppose a centre (for the maintenance) of equilibrium, is to be ascribed to the region of the thalamus and mesencephalon. The possession of this centre enables a frog, deprived of its fore-brain, which had been made to squat on the palm of the hand, to change its position step by step when the hand is tilted downward, until it is landed on the dorsal surface. To the di- and mes-encephalon we must, therefore, look for the subcortical sen-

sory centres, which help to perfect all possible movements of the highest order, with the aid of impressions they receive, say, from the retinal image and the surface of the skin. In the modifications here imposed upon the forms of movement by retinal impressions, we may recognize the first beginnings of the visual impressions of space; though our fore-brain consciousness does not take cognizance of them until they have been handled by the mechanism of association.

The architecture of the corp. quadrig. (Figs. 38 and 39) showed that tracts leading to it from the main external terminal mass of the tractus opticus—the corp. genic. externum—through the posterior margin of the brach. corp. quadr. superius, take a longitudinal course in the mid-brain, thus avoiding a union with the formation of the lemniscus. But these longitudinal bundles are united to the gray substance of the aquæductus Sylvii in consequence of a radiating course which they enter upon, after taking up quadrigeminal cells, and then traversing the layer of the lemniscus. In this gray substance the nuclei governing the movements of ocular muscles are imbedded. This allows us to conclude that ocular movements are stimulated by retinal impressions, and that this mechanism constitutes a simple automatic apparatus. Since both the gray substance of the corpora quadrigemina and the nerves supplying the ocular muscles are projected upon the cerebral cortex, a union there takes place between the sensations of innervation derived from the ocular muscles and the impressions of different retinal areas, as was explained by Fig. 63, p. 181. The sensations of innervation of the ocular muscles, together with the projection of individual retinal areas, established in the cortex the local signs which help us to determine our whereabouts in space. Anatomical facts would go to prove the truth of the old view of Wundt, now, however, abandoned by him, that the mechanism producing the psychical conception of space is started into activity by reflex processes. The union of retinal impressions with muscular innervations in the corp. quadrigemina constitute, in my opinion, the primary reflex process assisting in establishing the conception of space. The nature of this reflex process would be similar to the one involved in the closure of the eyelids following upon conjunctival irritation (p. 156, and Fig. 59). When analyzed into its primary factors, this conception of space will be seen to consist of sensory perception and sensations of innervation which have been secondarily transmitted to the cortex. To the

entire di- and mes-encephalon Eckhardt's remark is applicable: that, "experience renders it highly probable that visual perceptions attain a certain degree of perfection in the thalamus."

But we have further evidence to show that in addition to its relation to the centre of equilibrium governing locomotion—a centre which may possibly be connected with the functional mechanism of the corp. quadrigemina,—the thalamus exercises an important influence over the movements of the upper extremities, as was demonstrated by the pathological case exhibited in Figs. 61 and 62; and this will be corroborated by the observation of Nothnagel, that after destruction of the thalamus, the fore-limbs, which had been extended, cannot be retracted. This is due to the loss of the focus for the sensations of innervation engendered by the movements of these limbs.

The gray substance at the posterior margin of the third ventricle and around the aquæductus Sylvii was investigated by Adamück and again by Hensen and Völckers. The latter contend that the centres for the intra- and extra-ocular muscles succeed each other in the following order: In the posterior portion of the gray substance of the third ventricle lies the centre of accommodation, to the front (ventrad) of the centre for the sphincter pupillæ, both centres being connected with the most anterior III. root. At the boundary between the III. ventricle and the aquæduct. we come upon the centre for the rectus internus, and to the outer side from this the VI. centre. At the cephalic end of the floor of IV. ventricle immediately below the corpora quadrigemina, the centre for the vaso-motor fibres of the iris is located, which, in the opinion of some, are solely responsible for the dilatation of the pupil by influencing the volume of the pupillary tissue, while others feel called upon to assume the presence of a special *dilatator pupillæ*. However this may be, this region (containing the above centre) lies immediately adjacent to the general vaso-motor centre of Owsjannikow, and, assuming irradiation to take place, we may be able to explain the simultaneous occurrence of dilatation of the iris and of constriction of the arteries.

Immediately below the gray floor we are confronted by the descending arm of the *formatio fasciculi long. posterioris*. Wernicke had ample reason to trace one origin of this latter system to the lenticular nucleus; the projection-system of this nucleus would thus take a shorter route to the central motor roots and nuclei of the cranial nerves scattered throughout the central

gray substance. The variable thickness of the posterior longitudinal fasciculus, its connections with the trigeminal and acoustic tracts, preclude the thought that it is principally the projection-system for the motor nuclei of the brain; its purpose seems rather to be functionally to unite different levels of the central gray substance and to effect a co-ordination of movements. It may contain nerve-tracts uniting the abducens with the topographically higher centres of co-ordination superintending the play of the ocular muscles. But the nerve-nuclei of the mesencephalon, of the pons and of the oblongata are joined by decussating *fibræ rectæ* to the cortical bundles of the pes pedunculi. As was exhibited in Fig. 43, *et seq.*, these fibræ rectæ, after traversing the deep transverse fibres of the pons, extend to the anterior longitudinal bundles and in the oblongata to the pyramids.

The oblongata, which but for its cerebellar relations, need not be considered apart from the pons, impresses us with its great importance as a vaso-motor centre. Owsjannikow has studied the oblongata most carefully from this point of view. This author has demonstrated that removing layer upon layer of the brain-trunk causes a fall of manometrical pressure, as measured in the carotid, even before the pons has been reached, which signifies that that portion of brain substance has been destroyed which, when normal, maintains the blood-vessels in a state of definite contraction. Blood-pressure does not depend altogether, as Bezold would have us believe, upon the heart and an increase of cardiac innervation, but in an opposite direction, chiefly upon the resistance which the contraction of the fine capillary vessels oppose to the forward movement of the blood. Stricker very properly remarks that we are here concerned not only with the contractility of the finer arteries, but also, as has lately been shown, with the smaller capillaries endowed with nerves, and even with the more delicate veins. The blood-pressure ceases to fall as soon as the sections have been laid within 3–4 mm. above the apex of the calamus scriptorius. If the destruction by layers has not transcended the level of the origin of the facial nerve, the diminished blood-pressure can be restored by irritating the sciatic, the trigeminal, or the auricularis magnus. But from this point on, the possibility of restoring the blood-pressure by stimulation of sensory nerves sinks until we reach the before-mentioned lower limit of the centre for the vaso-constrictors. Owsjannikow consequently distinguished between two vaso-motor centres: an

automatic centre extending farther cephalad, and a reflex centre extending farther caudad, but for the most part both centres occupy the same level.

He regarded the relations of these two kinds of centres to the innervation of blood-vessels very much as I did that existing between primary and secondary movements of skeletal muscles. He insists that the automatic centre is subject to psychical influences, as is shown by the influence of the emotions on the dilatation of blood-vessels; and that the other is a reflex centre for the vaso-constrictors. From an anatomical point of view we may make the following distinction: the one centre innervated from the cortex belongs to the anterior division of the brain-trunk (pes pedunculi and stratum intermedium), say, possibly to the region of the crus cerebri, and at all events to the anterior division of the pons; while the reflex centre is included in the various groups of cells which are interwoven with the posterior (tegmental) segment of the pons and oblongata. Ditmar thought the reflex centre might possibly be located in the superior olivary body of the oblongata. The extension farther forward of the centre governing psychical influences can be accounted for by the fact that the tegmentum begins to develop lower down than do the structures of the pes pedunculi; and the termination of this cortico-vascular centre at a higher level would be sufficiently explained by the fact that the pyramidal tracts get rid of their gray substance before reaching this level.

Upon the mooted question of vaso-dilator centres I will not now enter. It would appear as though they simply regulated the antagonistic influences of the circular muscles, and exerted a secondary influence upon the width of the vessels; furthermore, that a genuine dilatation resulted only from a lessened stimulation of the vaso-constrictors. It is, to say the least, very significant that if they (the vaso-dilators) are to be forced into action by stimulation of the sciatic, the latter must have been cut across several days previously, which compels us to assume that an antecedent condition of exhaustion of the vaso-constrictors paves the way for the subsequent preponderance of a vaso-dilator influence. The known phenomena of dilation proper have reference to the periphery—to cutaneous irritants. Inasmuch as these phenomena depend, according to Vulpian, upon peripheral ganglia, we can make no application of them to the central processes now under discussion. We take no notice for the present of an active pro-

cess of vaso-dilation which has been most carefully investigated by Goltz and Stricker.

The acoustic region occupies about the middle portion of the oblongata (Fig. 17, p. 32). Here our morphological attainments will stand us in good stead; for, as Burdach puts it, the structure and significance of cerebral organs are united by a secret bond. The auditory nuclei are spread along the entire line of those central motor masses from which the nerve-roots emanate, and which are engaged in the production of sound, including the facial, hypoglossal, and vago-accessory (laryngeal) nerves; also the respiratory and particularly the expiration-centres, which play an important rôle in this mechanism. Thus we find the conditions exceedingly favorable to the reflex origin of auditory communications; we have given a focus which functionally contains all the elements of speech, since speech is based upon the repetition of heard sounds. But this is not intended to be a teleological conception of our organization. Since sensory stimuli irradiate in the gray substance we must expect stimulation even of the lowest lumbar and sacral nerves to irradiate into other areas, including the sound-producing centre. This is shown in the reflex cry following in earliest childhood even, upon the traditional educational handling of the skin over the glutei.

According to Pflüger's laws, particularly favorable conditions exist for the translation of sensory stimuli into reflex movements of a special character, if the gray substance in which a sensory nerve terminates, and that from which certain motor nerves originate, lie in adjacent levels of the cerebro-spinal axis. Stimulation of the auditory nerve will, according to Pflüger's laws of reflexes, excite most readily movements of the sound-producing mechanism. The primary fundamental reflexes of speech are based upon a type of structure as simple as that of the ordinary spinal-cord section; upon centripetally and centrifugally conducting roots of gray substance. A sound constitutes an auditory stimulus, and a sound results from the excitation of this sound-producing mechanism. It is the function of the motor nerve-tracts engaged in this process to effect a form of movement which will reproduce the contents of the original stimulus which was a sound. This is a purely *imitative* process. Just as the reflex-centre, mediating between a conjunctival nerve and the *sphincter palpebrarum*, transmitted to the cortex through the cortical projection-fibres a sensory stimulus and sensations of in-

nervation, so, in the same way, the stimulating sound, the sensations of innervation derived from the muscles of this sound-producing mechanism, and the produced sound, are associated with one another in the cortex. Through association, an auditory stimulus must consequently lead to the imitative mechanism involved in the reproduction of sound. For the secondary motor mechanism of speech which goes on developing by an endless number of co-ordinating acts in the fore-brain, and for the methodical imitation of heard syllables which is at the very root of the acquisition of language, there is a good anatomical basis. This consists in the presence of a simple reflex-centre which effects and permits a joint action of the adjacent nuclei of VII., VIII., X., and XII. cerebral nerves with the nerves of expiration.

In the preceding section (p. 120 *et seq.*) I dwelt upon the connection existing between the *auditory* fasciculi and the cerebellum. Two physiological facts argue in favor of such a connection: the importance of the cerebellum as an organ of motor co-ordination is a firmly established fact; and equally well founded is the influence which auditory impressions exert upon the rhythmical evolution of co-ordinated movements in walking, dancing, as well as in the formation of notes in the rhythm of a song. But there is still another fact to be mentioned as corroborative of the above anatomical connection. According to all experiments, the *nervus vestibuli* is not auditory in function; but, as Goltz, Mach, and Breuer, who repeated Flourens' sections of the membranous semicircular canals of the labyrinth, have been able to determine, it is responsible for the cerebellar maintenance of equilibrium. Destruction of these membranous canals entails the forced movements attending static vertigo. Together with Brücke, I regard these movements as actions resulting from delusions which produce abnormal sensations of innervation, as I explained on p. 164 to be the case with regard to the forced movements resulting from lesions of the tegmentum and the optic thalamus. Flourens holds that similar forced movements are produced whether the semicircular canals of the labyrinth or certain portions of the cerebellum be cut across. He says: "If the horizontal semicircular canal be cut, the animal will turn on its own axis; if the anterior, the animal will perform a number of somersaults forward; and if the posterior canal be cut, the somersaults will be made backward. Similar to these movements are the rolling movements observed after section of the pons, and the running

backward and forward following upon section, in the same directions as above, of the anterior and posterior *pedunculi cerebelli.*" The direction of the movement would invariably be parallel to the course of the fibres; thus the rolling movements subsequent to lesion of the pons take place from one side to the other.

Huschke, quoting Hamilton, communicates a fact which has an important bearing upon cerebellar co-ordination. It is this: The cerebellum is far more developed in animals which are able to help themselves immediately after birth (such as the chick, pheasant, partridge, goat, colt) than in animals which are born blind, are helpless, and find great difficulty in learning to walk. In man the cerebellum is surprisingly undeveloped. If the brain-trunk be dissected out from the rest of the brain, as in the manner indicated in Figs. 15–17, and if the cerebellum be removed also, as shown in Fig. 17, then we shall be able to determine the proportional weights of three portions of the brain: (1) the brain-mantle, (2) the brain-nucleus from the island to the beginning of the spinal cord, and (3) the cerebellum. In the adult these parts hold about the following relation, 79 : 10.5 : 10.5; whereas in the brain of the new-born the proportions are, 83 : 11 : 5. Magendie and Demoulins found long ago that injury to the cerebellum produces backward movements. No one at the present day objects to the view that the cerebellum is a way-station for the muscular sense; ataxic phenomena may, but actual paralyses never do, result from pathological disturbance of this organ. The muscular sense is based upon sensations which, when modified by disease of the cerebellum, give rise to numerous delusions, such as falling into a pit, and so on. We must represent the matter to our minds somewhat as follows: Those movements which assume definite forms under the guiding influence of the cerebellum have their single acts associated with one another in the fore-brain from childhood up; and the sensations of innervations grouped together in the cerebral cortex are transmitted to the cerebellum through centrifugal tracts—say, the pontine fibres of the crus cerebri. The posterior columns originating in the cerebellum are enabled to convey to that organ sensations regulating the co-ordination of movements, making the intervention of the cerebral cortex in the execution of movements quite superfluous. Here the muscular sense comes into play in the manner described by Spiess. The varying sensations perceived through the posterior roots, changing with each phase of a motor act, with

the tension and relaxation of the skin on the extensor and flexor surfaces of the extremities, with the change in pressure due to contact of different portions of the skin, are transmitted to the cerebellum through the mediation of the posterior columns; and in the cerebellum, through the action of its association-system, are utilized as sensations regulating the form of movements. Taken in this sense, the *gymnastic* brain-organ is also an organ of feeling. Considering that the movements of the eyes and the extremities are accurately co-ordinated, as in taking aim with a gun, we can readily understand why cerebellar lesions should be followed by deviations of the ocular muscles, which would come under the head of forced movements in the sense in which the latter have been before referred to. Even the simplest forms of movement (such as changing from the dorsal to the abdominal position, disentangling the interlocked legs in the frog—Goltz) are performed fairly well after removal of the mid-brain, as long as the medulla remains; but they are executed with greater accuracy when the cerebellum is uninjured, in which case sensation plays an important rôle. Some authors have proceeded still further in making the cerebellum an organ of sensation. Eckhardt mentions, in a critical review which he gives of the subject, that Foville observed a general diminution of sensibility following upon disease of the cerebellum, that Renzi found that destruction of the cerebellum entailed impairment of the visual and auditory senses, while Lusanna noted visual destruction only following a similar lesion.

Among the remaining centres of the oblongata the so-called diabetes-centre is probably identical with the vasa-motor centre for the arteries of the liver, and the chemical results of the diabetic puncture are dependent altogether upon the paralysis of their circular muscles. In corroboration of this view, we may cite the fact that if after paralysis of the splanchnic nerve, which exercises an all-powerful influence over the blood-pressure in the abdominal cavity, a general hyperæmia is set up, there is not a sufficient hyperæmia of the liver to produce mellituria in spite of Bernard's diabetic puncture. Moreover, the oblongata is the centre for a number of forms of movement, partly or wholly independent of the will, which come within the domain of the nerve-roots originating in the oblongata. Closure of the lids, lachrymal secretion, deglutition, constrictions of the pharynx, of the larynx, and of the œsophagus, all are dependent upon the oblongata. Inasmuch as the lower portion of the calamus scriptorius in-

cludes the centres for in- and ex-piration, it contains also the centres for all the modified forms of respiration, under the influence of nerves starting from the oblongata such as laughing, crying, sighing, gaping, and sneezing.

Of greater importance is the existence in the medulla of a centre for the contractions of the uterus and the vagina, which is repeated, however, in the lumbar enlargement of the spinal cord. Goltz found that mammals whose spinal cord had been cut above the lumbar enlargement could still bear young.

The influence of the oblongata on the salivary secretion, through the n. lingualis and the chorda tympani, as well as upon the lachrymal secretion, depends upon its significance as a vaso-motor centre. According to the demands of an existing dyspnœa an irradiation takes place, from the mere innervation of the diaphragm such as is practised in ordinary breathing, to an innervation of all respiratory muscles; to the extremities for the purpose of fixing the thorax, to the muscles of mastication for the purpose of "snatching" air.[1] If there be a lack of oxygen the oblongata becomes a general convulsive centre; and this centre is situated, according to Nothnagel, between the lower portion of the pons and upper portion of the oblongata in man. The solitary bundle situated externally from the X. nuclei was termed respiratory bundle by Kraus.

Beyond a doubt the oblongata also contains in the tract of the vagus a centre regulating the cardiac nerves. Finally, we are told that a lesion of the oblongata along the auditory protuberance produces derangement of hearing, and Renzi speaks of a spatium opticum extending from the corpora quadrigemina to above the auditory protuberance, injury to which causes amblyopia. In regard to movements, most authors are agreed not to attribute to the oblongata the power of co-ordinating locomotion.

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[1] "Luftschnappen."

THE NUTRITION OF THE BRAIN.

In the preceding section (pp. 138, 145) we contended that in order to understand the functional activity of the brain, it is necessary to attribute but a single transcendental quality, *i. e.*, sensitiveness, to the ganglion-cell and its protoplasmic annexes. From this faculty of sensitiveness actual sensation and its concomitant or resultant states, representing the functional activity of the hemispheres, can be evolved, provided two conditions be met: there must be adequate nutrition of the ganglion-cell, and peripheral stimuli. As regards the latter, the external causes of perception—the stimuli—are influenced by the peripheral end-organs of the nerves. The central nerve-tracts, which effect the transformation of external stimulation into sensation, were determined by anatomical and physiological methods in the preceding chapters of this book.

On morphological grounds we reached the conclusion that the brain was composed of two grand divisions: the *cortex* with its medullary substance—the brain-mantle; and the *brain-nucleus*, enveloped by the brain-mantle, and consisting of subcortical centres and their nerve-tracts. We remarked also that association was favored by the broad expansion of the cortex, while the possibilities of irradiation were increased by the accumulation of the subcortical form of gray substance in the ventricular cavities, and in the walls of the medullary tube. As regards the nutrition of the brain, the ramification of the arteries meets the requirements of "association" and "irradiation." In my monograph on the structure of the cerebral cortex (published in 1868), I observed that the broad expansion of pia, answering to the extensive surface of the cortex, provided the latter with the largest possible number of arterioles, all of about equal diameter, entering adjacent portions of brain-tissue, and of which each one, represented to a certain degree, an independent circulatory area, and that in a mass of tissues supplied by a smaller number of larger arterial branches, *it would be quite impossible* for differences of arterial blood-supply to exist simultaneously in adjacent portions of that

tissue. Whence it is to be inferred that the broad expansion of cortical surface, and the large number of arteries descending vertically from the pia into the cortex, are well calculated to permit partial, functional hyperæmia of separate cortical areas. This peculiarity in the distribution of nutritive supply would allow us to suppose that the so-called cortical "centres" could be in a state of functional hyperæmia, at a time when the other cortical regions were enjoying a functional rest. But we must beware against ingenious exaggerations of this theory of localization. I have shown, when treating of the nature of residual images (p. 154), that in a single process of thought widely separated areas of the cortex are thrown into a state of functional hyperæmia. A detailed analysis of the complexity of residual images (special memories) with their manifold and widely distributed areas of functional hyperæmia, will lead us to accept an opinion of Fechner, which I referred to in my monograph on the cortex. The excitation and nutrition of the brain are subject to a change between two phases: one of sleep, and the other of waking. Sleep implies a universal diminution of activity, but waking by no means implies increased activity of every part of the cortex. Fechner looks upon the partially increased functional activity of the hemispheres in the condition of wakefulness—that is upon the phenomenon of restricted attention— as a limited wakefulness, and accordingly he supposes that during the state of cerebral activity extensive areas of the cortex remain in a state comparable to that of functional repose. Association as effected by the hemispheres does not therefore depend upon the possibilities of a single limited area of functional hyperæmia, but upon the hyperæmia of numerous cortical areas, united for combined simultaneous action by the aid of association-fibres. This end is furthered by the peculiar distribution of arteries derived from the pia. The multiplexity of cerebral functions cannot be explained by comparing the brain with any other organ whose physiological function is divided equally among all its parts, and of which every portion receives an equal supply of blood. We can explain why every portion of the spleen, of the liver, and of the lungs should receive an equal amount of blood, but we can understand also, why, in regard to the brain, all parts of which are never simultaneously active, the case should be different. The blood-supply in the brain is determined by the functional hyperæmia of the areas called into activity;

while in the case of other organs, blood-pressure and blood-supply are limited only by the resistance of their membranæ propriæ, or their trabeculæ of connective tissue. In the physiological condition the skull appears to constitute a rigid wall limiting the quantity of blood in cerebral vessels, and controlling any general change that may take place in this respect; by reason of which it becomes an important factor in the nutrition of the brain. A closer examination into the details of this subject will convince us that the skull regulates the pressure of the fluid within its cavity. If the brain were surrounded merely by rigid cranial walls, a partial change in the distribution of arterial blood would be conceivable. Functional hyperæmia resulting from arterial dilatation, set up and regulated by the brain itself, might be effected by a mechanism such as I have described on p. 195, and would be explained by the fact that the cortex itself is a vaso-motor centre. But within the cranium with its rigid walls a functional increase would be possible only upon one of two conditions: there would have to be either collateral arterial diminution (olygæmia), for which it would be difficult to suggest an appropriate mechanism, or a transfer of venous blood in the direction of the sinuses, thus leaving more room for the play of the arteries. But this sort of venous transfer would be altogether too slow; besides there could be no continuous action, for the repulsion of the venous current dependent upon the respiratory movements, would give rise to a frequently interrupted flow of venous blood in the brain. A different explanation must be attempted for the manifold rapid changes of functional hyperæmias, upon which depend cerebral excitation and the effectiveness of the mechanism of association. We shall see, however, that the brain does not completely fill the cranial cavity, but that the latter contains a number of spaces, filled with so-called lymphatic fluid. The skull is therfore not *per se* the cavity in which the brain rests, for on its basal side it contains a number of lymph-cisterns (Key, Retzius, Schwalbe). This explains why the forms of the convolutions should be imprinted upon the concave walls of the roof, and not upon the basilary (sphenoid) bone. The base of the brain would by its own weight rest upon this bone, and would leave impressions of its form but for the intervention of these water-cushions. Nor is the brain *quiescent* within the cranial cavity; it passes through three different phases of motion, as Burkhardt was able to demonstrate (in his

monograph on the movements of the brain) on four patients with defective skulls. The movements of the brain in these four cases were registered upon a rotating cylinder, and gave tracings: (1) of the systole and diastole of the pulse, varying between sixty and eighty in the minute; (2) of the expiratory rise and the inspiratory fall, numbering from fifteen to twenty in the minute (described before him by Ecker); (3) of the so-called vascular wave. This last is a peristaltic arterial movement, regulated by the vaso-motor centre, and occuring from two to six times per minute. These forces, affecting the intercranial pressure and the movements of the brain, are equally active in a normal closed cranial cavity, but do not produce any compression of the cerebral mass, for the lymphatic fluid, the more movable contents of the brain, recedes from or flows into cranial spaces as the compressing forces may demand.

It will be necessary, first of all, to consider the anatomical and physiological conditions affecting the quantity of, and changes in, cerebral blood-supply, and after that to discuss certain independent cerebral influences, resulting from the activity of the brain itself, in their relation to the distribution of blood; these influences unite with the former conditions in spite of variations of pressure due to peripheral causes, to perfect the nutrition and function of the brain.

We shall find that these cisterns, which are of variable volumes modify the cavity in which the brain is lodged, and that there is another mechanism by which an increase or decrease in the volume of the brain itself can be compensated. This consists of the venous spaces, described by Cruveilhier, adjoining the *sinus longitudinalis*, which, like the sinuses themselves, do not possess a wall proper, but merely a simple limiting endothelium. These venous spaces represent, according to Langer, cavernous spaces situated between the separated trabeculæ of the tissue of the dura. Varicosities of these venous spaces, by wearing away the vitrea, produce, as Langer and Trollard have shown, the *foveæ glandulares*, in the aged, in drunkards, and in subjects of cardiac disease. These *foveæ glandulares*, be it said, are not direct impressions of the Pacchionian dilatations of subarachnoidal spaces, to which we shall have occasion to refer later on. These cavernous spaces of Langer, Ludwig Meyer regards as a compensatory mechanism designed to secure at all times the repletion of the cranial cavity; they dilate as soon as anæmia of the brain sets in, and collapse with the

return of a full current of blood. According to Schwalbe, the arterial system of the skull and brain divides into two distinct halves, according as the arteries are branches of the meningeal or cerebral arteries. The ramifications lying in the *sulci arteriosi*[1] of the flat basilar bones are chiefly concerned with the nutrition of the bone and the dura mater, or at least with that part of the latter which acts as the periosteum of the cranial bones, and carries the blood-supply for the cranial walls. Besides investigating the cavernous tissues adjoining the sinuses, Langer has made a careful study of the dural arteries, and divides these into an outer and inner network. The outer network empties into the capillary net of the dura, and, which is quite remarkable, empties at once into very large veins, which grow narrower as they approach the finest arteries, while the inner network lying nearer to the surface of the cranial cavity, and forming a derivative net in contrast to the external nutritive one, does not divide up into small capillaries, but has its arteries empty directly into veins, thus warding off to a certain extent the effects of hyperæmia from the nutritive vessels of the dura. This observation of Langer is of a kind with the views of Schröder van der Kolk, who, as will be explicity stated later on, maintained that there was a direct communication between the larger arteries and veins of the pia on the surface of the brain, having the effect, as he puts it, of allowing a strong current of arterial blood to pass over the cerebral cortex directly into the veins, and permitting this vascular storm, as it were, to spend its force on the surface. Heubner's investigations have lent additional interest to this view. It will be shown that the increase and diminution of the volume of the brain in its cavity, as Burckhardt demonstrated in his four cases, bear significantly upon the nutrition of the brain, by transferring the waste products to the lymph-vessels, for which reason it will be necessary to consider the relations between the network of blood-vessels and the lymph-spaces of the brain. The external (subdural) lymph-space has very different dimensions in the spinal and cranial cavities, for the spinal dura is widely separated from the arachnoid membrane, while in the case of the brain a capillary space is all that remains between the dura and arachnoid; and this capillary space is lined by endothelium, communicates with the lymphatic glands of the neck, furthermore with subdural spaces which do not immediately surround the nerve-roots, but do

[1] Erroneously so-called (Langer), for each artery is accompanied by two veins.

so in common with the arachnoid and are connected with the lymphatic spaces of peripheral nerves. The most important of these lymph-spaces are those surrounding the auditory and optic nerves. As regards the former, it is found that the peri-lymphatic fluid of the labyrinth communicates with the subdural space. It is equally plain that the venous spaces of the sinuses and their surroundings communicate by a process of transudation with the subdural spaces in the Pacchionian granulations. The subdural space is connected also with the lymph-spaces in the tissue of the dura. The arachnoid membrane, both surfaces of which are covered with an endothelium, shuts off the subdural space. This membrane envelops the brain, without forming any duplicatures upon it, but is intimately connected by means of a network of threads and trabeculæ of connective tissue, and on its basilar aspect by means of perforated membranes, with the pia which covers every fold of the cerebral surface. Henle speaks of this network as physiological, hydropic connective tissue, which permits a complete interchange between all subarachnoidal spaces. These spaces are traversed at the summit of the convolutions by tense threads, and are narrower than over the *sulci*. On the basilar surface in particular, the subarachnoidal spaces are dilated, and in part devoid of trabeculæ. This explains the formation of cisterns (Key, Retzius Schwalbe).

The following cisterns belong to the surface of the cortex: The space of the *fossa Sylvii*, which is merely spanned by the arachnoid, and a space which separates it from the dorsal surface of the corpus callosum, which space extends on the basilar surface as far as the *linea terminalis* (of the central gray substance) situated beneath the corpus callosum. More caudad on the basilar surface we come upon the *cysterna chiasmatis* and the *cysterna intercruralis*, the latter dividing again into a superficial and deep reservoir. From the *cysterna intercruralis* and to the outer side wide subarachnoidal spaces extend across the crus cerebri to the corpora quadrigemina, *i. e.*, from the basilar surface to the dorsal surface of the trunk—the *cysterna ambiens*. Short trabeculæ unite the subarachoidal space just over the corpora quadrigemina to the surface of the latter. The most extensive subarachnoidal space on the dorsal side is the *cysterna magna cerebello-medularis*, extending from the dorsal surface of the oblongata to the cerebellum, on the superior surface of which exactly the same relations obtain as over the convolutions of the cerebrum.

The pia mater forms the inner wall of the subarachnoidal spaces, of which the *telæ chorioideæ*, in the superior cerebral ventricles, and in the fovea rhomboidea, constitute a part. This connection, and the penetration of the pia into the ventricles, are easily understood if we keep the fœtal brain (Fig. 1) in mind, and remember that the pia covers every part of the brain-surface. At the time when the hemispherical vesicle was situated to the front of the anterior cerebral vesicle, the pia mater passed from the former over the latter to the mesencephalic vesicle. But at a later period, when the hemispherical vesicles, enlarging caudad, had enveloped the anterior cerebral vesicle, the pia mater of the posterior surface of the vesicles of the hemispheres was, by mere flexion, made to lie upon the pia which covers the thalamic region (derived from the anterior cerebral vesicle). Just as the trabeculæ of subarachnoidal spaces pass between the duplicatures of the pia in the sulci between two convolutions, so the two laminæ of the pia, which accompany the invagination of the velum chorioideum, are fastened to one another by subarachnoidal trabeculæ. Behind the corpora quadrigemina, the arachnoid of the *cysterna ambiens* ascends to the upper wall of the *cysterna corporis callosi*. The flexion of the cerebellum over the oblongata produces, furthermore, a fold in the pia on its way from the cerebellum to the oblongata, the two laminæ of this fold giving rise to the *tela chorioidea* of the IV. ventricle. The foramen Magendie leads through the pia from this ventricle into the subarachnoidal space of the spinal canal. In regard to the III. ventricle, it is to be remarked that its membranous tela does not correspond to the superior wall of the primary cerebral vesicle, but that the only vestiges of this which remain are the epithelial cells of the plexus choroideus, at the lateral margin and on the inferior surface of the velum.

The larger branches of the arteries on the surface of the brain do not lie within the pia, but in the subarachnoidal spaces; the smaller branches only, enter the pia. Before describing these, we must stop a moment to note those prolongations of the subarachnoidal spaces, which are formed by the Pacchionian granulations. The latter occur in the course of all sinuses, particularly, however, alongside of the *sinus longitudinalis*. The sinuses and the veins adjacent to them are situated in the substance of the dura, and, according to Langer, are distributed in such a way that the veins of the anterior portions of the hemispheres meet with

the veins of the posterior lobes in the wall of the *sinus longitudinalis*, as though the former (veins) stood in the relation of *vasa vasorum* to the latter. The posterior cerebral veins take a similar longitudinal course forward, between the layers of the dura, so that the cerebral veins empty into the sinus for a distance of only 2 cm., and about below the middle of the parietal vertex. The Pacchionian formations push forward into the cerebral veins as diverticula of the subarachnoidal spaces. The veins lie intradural, and the subarachnoidal spaces are shut off from the subdural space. A definite brain-pressure, which we shall consider hereafter, forces the subarachnoidal serous fluid into the subdural space, whence, by a process of filtration, it empties into the veins and the sinuses. The subarachnoidal spaces communicate, moreover, with the lymph-channels of peripheral nerves, which encircle the roots, as does the dura also. From these subarachnoidal spaces we can throw injecting fluid into the lymph-space surrounding the optic nerve, into the perilymphatic space of the labyrinth, and the lymphatic vessels of the nasal mucous membranes. The *pia cerebralis* receives nerves from the plexus around the circle of Willis; these divide into small branches, which accompany arteries of only 1 mm. in diameter into the brain-substance. Bochaldek contends that branches from the III., V., IX., and XI. cerebral nerves join these vasomotor nerves. According to Kölliker, the plexuses do not possess nerves. The sensitiveness of the dura in all experiments proves that it has sensory nerves; they were demonstrated by Luschka and Rüdinger. On the other hand, Nothnagel's experiments, confirmed by Krauspe, show the relation existing between the nerves of the pia and arterial contraction, which is generally reflex in character.

The arteries of the fore-brain are derived from the carotid and vertebral arteries. The former supplies the *art. cerebri ant.* seu *corporis callosi* (the anterior cerebral), and the *art. cerebri media* seu *fossæ Sylvii* (the middle cerebral).

I. The anterior cerebral artery ramifies on the orbital surface over the convolutions which surround the sulcus rectus and the olfactory lobe; on the external surface, over a wedge-shaped region, which includes the second and third longitudinal convolutions (Fig. 9, L_2, L_3, cm., S.occ.) together with the uppermost portion of the central region as far as the occipital lobe; while on the median surface, the corpus callosum and the entire region

from the frontal apex to the sulcus occipitalis receive their blood from the anterior, median, and posterior internal arteries, all of which are branches of the art. corp. callosi.

II. The *arteria fossæ Sylvii* embraces, with its ramifications, the operculum and the superior temporal convolution; and extends to the convexity of the cortex, after sending off several secondary branches for the island of Reil. Charcot has designated the principal branch-arteries as follows: 1, the external frontal artery supplying the inferior frontal convolution; 2, the ascending frontal artery for the region of the anterior central convolution; 3, the ascending parietal artery for the posterior central convolution and the superior parietal lobule; 4, a parietal artery for the region of the parietal convolutions; and, lastly, temporal arteries ramifying over the first and second temporal convolutions.

III. The terminal branch (end-artery) of the vertebral artery —the *arteria profunda*—supplies the cuneus, the gyrus lingualis, the gyrus fusiformis, and the third temporal convolution, together with the uncus and the gyrus uncinatus.

Both Heubner and Duret deserve great credit for their methods of studying (by injections) the details of cerebral arterial distribution; but there is a great difference of opinion between these two authors regarding the significance of the *derivative* arterial network of the cerebral surface, which unites with veins of an equal calibre,[1] as opposed to the nutrient network of arteries, which connects with capillaries, and from which the end-arteries of the cortex and medullary substance of the fore-brain are derived. Duret's views are corroborated by Charcot.

Heubner does not consider the circle of Willis the final channel for effecting a collateral compensation of the cortical blood-current. After passing the subarachnoidal spaces into the pia, the cortical vessels issuing from the circle of Willis go on ramifying until the minute branches possess a diameter of but 1 mm. These branches then break up into a net of arteries, communicating one with the other, extending over the entire pia, each part of which can be supplied by one of the chief arteries. The resistance among these derivative arteries is said to be so slight, that it would be easier to inject the entire pia of one half of the fore-brain through one of the six large arteries, than to make a

[1] As was known to Schröder van der Kolk.

successful capillary injection of a circumscribed region of the brain. From this common reservoir issue the more delicate arterial nets of the pia, and, at right angles, the cortical arteries. Even arteries of the white substance, larger than the latter end-arteries, which traverse the cortex without dividing, but are at a greater distance from the injection-tube, can be injected more easily than the vessels of the cortical network. According to Heubner, therefore, the existence of this anastomosing net forbids our saying that an artery supplies this or that region or convolution, except inasmuch as more distant arterial nets in the pia and cortex cannot be as easily injected from one vessel as from one another. But these are differences which it would be difficult accurately to define. In opposition to this view, Duret held that the superficial anastomosing vessels have a diameter greater than 1 mm., and that the nutrient cortical vessels are in reality capillaries, as was maintained by Robin also. In proof of this Charcot and Duret refer to the destruction of small cortical areas, due to embolism. Whence it follows that the arteries supply definite nutritive areas, and that influences of the *derivative* network of arteries is not as powerful as Heubner would have it. Heubner, however, quotes in support of his views, cases in which embolism of the pia-arteries is not followed by softening of any sort. Charcot grants that there are such cases, but he thinks them very rare. The long course relatively stout arterial branches take before dipping even into the wall of the longitudinal sinus, as Langer has observed, would argue in favor of Heubner's views. Though the latter's opinion regarding localized nutritive areas may be more unfavorable to the cortex than that of Duret and Charcot, yet it is chiefly a question of difference in the number of cases of cortical softening due to embolism, which the various authors have had occasion to observe.

On another point, however, both authors are completely at one—namely, as regards the difference in the mode of arterial blood-supply for the cortex, and the subcortical masses which for the nonce include the prosencephalic ganglion. None of the cerebral arteries which unite with others to form the circle of Willis gives rise to larger arteries carrying blood to the subcortical organs, and diminishing in size after undergoing dichotomous division; but these subcortical masses are supplied with blood by a large number of arteries, which issue from the dorsal surface of the circle of Willis, differ but slightly in calibre from one another, and

resemble, in their arrangement and number, the so-called *laminæ cribrosæ* on the basilar surface of the brain. This sudden diminution in calibre of the *art. corp. call.*, of the *art. communic.*, of the *art. foss. Sylv.*, of the *art. prof.*, to a series of vessels but 1–1½ mm. in diameter, departing from the main arteries at right angles, and penetrating at once into the base of the cerebrum, affects about 2 cm. of the length of the three large cerebral arteries outside of the circle of Willis and the whole length of the *rami communicantes*.

There are no anastomoses existing between the larger branches of this system of trunk-arteries; and so these branches represent what Cohnheim termed end-arteries, none of which furnishes anastomosing branches before dividing up into capillary ramifications. Inasmuch as there is no derivative network beyond the circle of Willis, and as these arteries, because of their shortness, are under the more immediate influence of cardiac action, they are more liable to hemorrhagic rupture than the cortical arteries —a fact of great importance in cerebral pathology.

Following up the details of the distribution of arterial blood-vessels to the brain-trunk, we learn, according to Heubner, that the head of the corpus striatum (the nucleus caudatus), together with the anterior wall of the infundibulum and the anterior portion of the *chiasma*, is supplied [1] by arteries coming directly from the art. corp. callosi.; that the other portions of the caudate nucleus, together with the entire nucleus lenticularis and the anterior portion of the internal capsule, receive arteries from the trunk of the art. foss. Sylv., which have passed through the foramina of the lamina perforata anterior; while the *ramus communicans post.* is destined for the anterior tubercle of the optic thalamus, for the posterior portions of the caudate nucleus, the posterior wall of the infundibulum, the posterior portion of the chiasma, the medullary bodies, the ant. tubercle, and the gray substance of the third ventricle with its commissure. The area supplied by the *arter. chorioidea* would include the environs of the cornu infer., whereas its choroid plexus would be distributed to the posterior division of the internal capsule and the outer half of the anterior portion of the thalamus. The *art. profunda* (2 cm. in length) supplies the posterior half of the thalamus, the pes and tegmentum of the crus cerebri, the corpora quadrigemina, and the choroid plexus of the posterior horn and of the third ventricle. The pons and the medulla receive small branches from the adjacent basilar, vertebral and anterior spinal arteries. Heubner established these details of arterial distribution by showing that the (blue) injection-fluid thrown into the organ from definite portions of the basilar arteries would invariably extend to and through the same well-defined areas of the brain.

The veins of the brain run parallel to the brain arteries on the surface of the brain, and empty into the *sinus falciformis*. The veins coming from the vermis superior, and the *venæ magnæ Galeni* empty into the sinus rectus. Each one of the latter receives blood from an inferior vein of the corp. callos.; from veins of the caudate nucleus, of the choroid plexus, of the optic thalamus, and of a basilar and pos-

[1] Not regularly.

terior cerebral vein. Rüdinger found the sinus transversi and the jugular veins wide on the right and narrow on the left side in 71 cases; in 27 out of 100 cases the reverse was true, and in only 2 cases were they equally wide on either side. The broad sinus transversus receives its blood only from the cerebral surface through the longitudinal sinus; through the sinus rectus the blood from the surfaces of the ventricles is carried into the narrow sinus transversus.

No author has been as happy as Burckhardt in explaining the general relations between the membranes and blood-vessels of the brain, and their bearing upon the nutritive mechanism and the vital activity of that organ. Burckhardt's conclusions, based upon observation of patients with defective skulls, were published in his "Experimental Investigations of Brain Movements." The pulse-wave, the respiratory and vascular waves were familiar enough, as they are common to blood-vessels everywhere in the body. The respiratory waves, indicating a process of venous aspiration, point to one of the chief factors which determine the flow of venous blood to the heart. The movements of the arteries dependent upon the vaso-motor centre, and indicated by the so-called vascular wave of Mosso and Burckhardt, had been previously demonstrated on the ear by Schiff, on the web of the frog's foot, on the curarized tongue of the frog, and on the saphenous artery in the skin by Riegel, who gave a detailed account of these movements in a monograph on the influence of the nervous system upon the circulation of the blood.

Riegel insists upon the intensity of these peristaltic movements of the arteries under the influence of the vaso-motor centre causing not only capillaries, but quite broad arteries, to contract to such an extent as only to permit the passage of a single column of blood-corpuscles, or indeed temporarily to occlude the arteries altogether. The dependence of this form of movement upon a vaso-motor centre is proved for peripheral arteries by the effect upon them of section of the cervical spinal cord. Hering and others think it very probable that this form of peristaltic movement is the result of the respiration of the vaso-motor centre itself, but that the stimuli causing such contractions have not accumulated sufficiently to exert an influence with every respiratory act; and that special influences from other sources, acting upon the vaso-motor centre through stimulation of sensory nerves, disturb the rhythmic peristaltic movements of the arteries. But in the case of the brain, the fact that it is surrounded by rigid cranial walls, by the subarachnoidal spaces, and that it is placed under considerable pressure, modifies the effects of this

general vascular movement. Since the membranes surrounding the brain enclose spaces filled with lymph and cerebro-spinal fluid, these vascular movements constitute an important factor in the nutrition of the brain and in the exchange of metabolic products.

The brain is subjected to considerable pressure. This is proved by the fact that from other organs tracings of the pulse-waves can be obtained only by placing the sphygmograph upon the artery itself; but, owing to the pressure it is under, the whole mass of the brain is moved with such precision by the pulse-waves, that accurate and distinct tracings of a tricrotic or tricuspid pulse-wave are readily obtained by placing the pulsometer upon the mass of the brain which happens to protrude from an opening in the skull. The truthfulness of these graphic tracings is brought home to us by noting that tracings from the carotid are exactly like those representing brain movements; though the resemblance between the latter and the tracings from more distant arteries (say the radial) is not quite as striking. The details of the pulse-wave can be exhibited more clearly with Marey's apparatus than with the rotating drum.

As regards the radial pulse, Landois and Wolff considered the tricrotic the normal form; in this the descending line of the wave-like tracing, due to systolic contraction, exhibits a top-wave and two others traced nearer to the period of diastolic diminution. Mosso, on the other hand, contended that the tricuspid was the normal form, showing in its systolic (ascending) lines a point in front of the apex which corresponds to the one on the diastolic side of the pulse-wave. That the pulse-waves are not represented by well-rounded elevations and depressions, must be attributed to the sudden influence of arterial contraction at the beginning of the diastole, causing an acute angle to be formed between the ascending and descending lines; and the two elevations following the apex of the wave are explained by the closure of the semilunar valves, and by the bounding back of the blood-column against the valves (Mendel). Both act antagonistically to the depression which is due to the tonus of the vaso-motor centre, and which causes the rapid fall of the pulse-wave.

If we increase the contraction of a radial artery by immersing the elbow in cold water, we observe a distinct *tricrotic* pulse; if the other elbow be immersed in warm water, the arterial walls

will relax, and the radial artery of this side will give a distinct *tricuspid* pulse. In this case, the arterial contraction is so weak that the first leap of the pulse-wave does not prove to be the highest of the three, but the closure of the valves and the rebounding of the blood-current cause the second elevation to rise higher than the first, and the succeeding lower, pointed wave on the diastolic side of the pulse-wave dilates the artery to such an extent that the line reaches the level from which it was inadequately depressed through the influence of the vaso-motor centre. Burckhardt divides the cerebral vessels into subtentorial vessels in the posterior cranial fossa, and into basal and cortical vessels which are situated above the tentorium. The former resemble, as regards distribution, the blood-vessels of other vascular areas of the body, and supply cerebellum, pons, and medulla oblongata. The region provided by the basilar and cortical vessels includes the ventricles.

In order to understand the influence of the systole upon the pulsatory movements of the brain, Burckhardt shows that the arteries ascend for a long distance from the circle of Willis, and that the venous and arterial currents take the same direction. The systolic enlargement of the brain, in consequence of the engorgement of the arterial network of vessels extending as far as the capillaries and veins, begins at the base of the brain and increases in the direction toward the vertex. This enlargement of the brain increases gradatim in the direction of the vascular ramifications, so that at any one time all vessels at an equal distance from the circle of Willis are in the same phase of pulsation. The roof of the skull and the dural processes offer a direct resistance to the swelling convolutions with their shallow subarachnoidal spaces; for which reason the brain can only enlarge concentrically toward the ventricles. In consequence of the fact that the basal arterial trunks and the long arterial branches do not simultaneously fill with blood, the tumefaction of the basal walls of the ventricles diminishes at a time when the swelling, brought about by the engorgement of the vascular network which is supplied by the higher arterial channels, is beginning, under the opposing pressure of the cranial roof, to constrict the ventricles, the force being exerted in the direction from the vertex.

Since the basal and the dorsal portions of the ventricles are not simultaneously constricted, the pressure is partially neutral-

ized through the displacement of the cerebral fluid within the cerebral cavities. The concentric swelling of the brain is very nearly universal, since both the cortical and basal vascular ramifications tend toward the surface of the ventricles. But since the intraventricular dislodgment of cerebral fluid does not altogether neutralize the arterial pressure, fluid from the ventricles passes outward through the foramen Magendie, while the concentric pressure continues to exert its influence upon the contents of the ventricle, and, favored by the thinness of the gray substance of its floor, spends its force on the subjacent *cystern. chiasm.* and *interped.*, and, since the cisterns are confluent, upon all the cisterns in general. Through the pressure of the liquor cerebri the pulsation is transmitted to the *membrana obturatoria atlantis.* Still another portion of the systolic pressure which is responsible for the increase in the volume of the brain is neutralized, through the circumstance that the engorged parenchymatous arteries effect the exudation of lymphatic fluid from those perivascular spaces which lie between the blood-vessels and the adventitia, the latter being prolongations of the pia mater which accompany these vessels on their course through the cortex and white substance.

The *respiratory* act produces a fall of the pulse curve during inspiration, and a rise of this curve during expiration (depression and elevation of the pulse-wave). This curve depends upon the fluctuation of venous pressure. The expiratory curve-elevation is due to the blood-stasis in the jugular vein, owing to the insufficient aspiration of blood from the thorax, and is increased by the arterial blood-current, since the pressure in the aorta increases with the expiratory pressure prevailing in the thorax. The influence of the expiratory wave is noticeable in the cerebral curve, even during quiet respiration; but it is most marked during violent expiratory acts, such as coughing and screaming. The retrogressive stasis acts directly upon the rigid walls of the sinuses, and dislodges at once the venous blood column. The sinus rectus is the shortest sinus. Relatively to the length of the sinus, the veins of the choroid plexus which empty into the vena magna, are the longest. The stasis, which starts from the *torcular*, and is felt first in the *sinus longitudinalis*, and the *sinus rectus*, with the exception of the veins of the subtentorial cerebral parts, will tell sooner upon the veins of the cortex than upon the long, flexible veins of the ventricular

plexus. The stasis will also aid in producing the concentric swelling of the hemispheres, for its influence is felt last of all within the ventricle, and is similar to the effects of the pulsatory wave, with this difference, that it is felt from four to six times less frequently, and during quiet respiration is less in degree, than the influence of the pulsatory wave. This concentric tumefaction of the brain again causes compression of the *liquor ventriculi* against the basal cisterns, and its escape through the foramen of Magendie, whence it follows that the respiratory curve also will be noticeable at the *membrana atlantis*. The retrogressive stasis in the veins must necessarily interfere with the forward movement of the lymphatic fluid, and thus prevent its transfer by endosmosis into the blood-vessels. The brain, which has become enlarged by reason of this stasis, presses against the cranial walls, and exerts a similar influence upon the pressure in the direction of the ventricles, as in the case of the pulsatory wave ; but there is this distinction : The above pressure acts from the vertex downward, instead of from the base upward.

The vascular wave is the most powerful, but the least frequent ; it gives from 2–6 tracings per minute. In height it may exceed the pulse-wave, ranging from several millimetres to 1.5 cm. The vascular wave causes a hemispherical protrusion of the cerebral mass, followed by a bowl-shaped retraction. Height and length of this wave are not equal. The wave flattens in a cool bath, and is raised in a warm bath. Its lowest point (wave-depression) corresponds to the contraction, and its elevation (wave-summit) corresponds to the relaxation of the arteries. It is most distinct and regular during sleep ; during the hours of waking its regularity is interfered with. Moderately warm baths of 77–91° F. lessen the number of waves, but make each wave longer ; warm baths increase the number and shorten the single waves. Esmarch's bandage diminishes, galvanization increases, their number. According to Mosso the vascular wave is independent of the pulse and respiratory waves. But the vascular wave exerts a decided influence on the respiratory and pulse waves.

During vascular contraction (wave-depression) the pulsatory waves are lower, for the artery is already contracted, but during relaxation they are higher, more rounded, tricuspid in shape. During the stage of vascular depression the respiratory wave, too, seems weak.

All stimuli acting upon the sensorium create vascular move-

ments and disturb the periodic changes in the condition of the vessels. Elevation is brought about chiefly by psychical influences, and less by purely intellectual processes than by emotions. Burckhardt had opportunity to observe in his patients the influence of pain due to panaritium; the variations were marked, depression was persistent, the wave-length occupied one minute. Sudden fright, produced by an unexpected noise, caused a rapid rise in the curve, which was followed as quickly by a fall. While one of his patients was busy playing at chess, low but long extended waves with a few larger protuberances were noted. One of them was quietly reading (to himself) a humorous tale; while thus engaged the curve showed many irregular variations. The pronounced vascular movement in the ear of the rabbit is not noticeable unless the animal be frightened. While doing arithmetical work—a purely intellectual function—elevations were noted at the beginning and at the end, in between depressions were more frequent.

The vascular wave, an arterial systole and diastole, advances in peristaltic fashion. Burckhardt appreciated the importance of this wave, constituting, as it does with the aid of the rigid cranial walls, a motor-mechanism designed to carry off waste products through the lymphatic fluids by establishing currents within the brain fluid. To prove his views he refers to Quinke's cinnabar injections into the spinal subarachnoidal space. The greater portion of the cinnabar penetrated as far as the glandulæ Pacchionicæ, and also into the dura; a smaller portion passed into the sheaths of the cerebral nerves and into the cervical lymph-glands, but the injected substance did not reach the ventricles or the perivascular spaces.

The arterial systole, as was the case with the pulse-wave, begins at the circle of Willis, constricts the base of the brain, pushes it away from the floor of the cranium, and impels the blood forward toward the cranial concavity, into the superior arterial branches, which dilate because they have not yet experienced systolic contraction. The basilar constriction of the brain crowds the brain all the more against the cranial roof, and shuts off superiorly the advancing basilar *liquor cerebri*. The systolic contraction of the base compels a portion of the ventricular fluid to escape through the foramen of Magendie. The basal systole and the simultaneous collateral arterial diastole in the upper portions of the hemispheres, oppose the injection of cinnabar from the ven-

tricles, for the roof of the ventricles is compressed by the concentric swelling of the upper hemispheres, which are pressed tightly against the skull. The pressure under which the ventricular fluid stands in this first phase of the vascular systole, which starts from the base of the brain, causes another portion of it (not that which escapes by the for. Magendie), through a current of absorption, to flow into the veins of the choroid plexus.

Thereupon follows the second systolic phase—namely, the systole of the superior cerebral arteries which course along the concavity of the skull. The escaped ventricular fluid does not now return from the subarachnoidal space into the ventricle, for the basal collateral arterial diastole has set in simultaneously. In consequence of the swelling of the basal portion the diastole pushes the *liquor* past the upper cerebral parts (which have been removed to a distance from the skull by the arterial systole) into the Pacchionian bodies and the sinuses, and then into the basilar nerve-sheaths and into the cervical glands. The foramen of Magendie lies within the region of the basal vascular diastole, where the swelling then present prevents the entrance of the liquor cerebri spinalis, so that a current moving in the direction of the spinal canal keeps the injected cinnabar out of the ventricles. During the period of vascular systole in the hemisphere the ventricle itself is wide, for in the collapsed state the hemispheres do not crowd against the concavity of the skull, and do not present a concentric swelling toward the ventricle. The choroid arteries are in a state of diastole simultaneously with the basal arterial zone, and their dilatation produces secretion of ventricular fluid, the flow of which resists the return of the fluid that was expelled during the preceding stage of vascular systole.

It was stated above that Quinke's cinnabar injections did not pass into the perivascular spaces between the pia and media of the arteries. Burckhardt gives the following explanation for this phenomenon: If an artery, lying in the midst of a perivascular space which communicates with the subarachnoidal spaces, contract, lymphatic fluid will pass from the parenchyma into the perivascular space (in a direction opposed to the course of the injection from the cerebral surface into the perivascular space), for the passage to the subarachnoidal spaces on the convexity of the brain is now unobstructed; but if this artery in the perivascular space be dilated, it obstructs this passage by filling out the above space, and no cinnabar will be allowed to enter the subarachnoidal spaces.

During this stage the lymph-current is impelled toward the veins, as by the pulse-wave, which, with less success during cardiac systole, enables parenchymatous lymph fluid to be absorbed by the veins, and during cardiac diastole opens up the passage into the subarachnoidal spaces.

The lymph-current is opposed only during the stage of venous stasis in the respiratory wave, which stage is accompanied by a condition of cerebral tumefaction. This stage implies a constriction of the perivascular lymph-spaces in the parenchyma, and the advance of venous blood pressing in the opposite direction. The influence of this retrogressive stasis, however, is not to be rated too high, for, according to Burckhardt, the influence of the vascular wave far exceeds that of the respiratory wave, and produces greater variations in the quantity of blood.

Knowing that the vascular movements of the brain are responsible for the circulation of lymphatic fluid in the brain, we may infer from the regularity of these movements during sleep, that the refreshing influence of the latter is due not only to diminished consumption, but to a greater extent to the removal of waste products. On the other hand, the irregularities of vascular movements during waking indicate, as Burckhardt puts it, that the process described above can or must possess a certain independence in definite provinces of the brain, as is the case with regard to the (localized) reflex arterial constrictions on the surface of the body.

Later on I will dwell upon the corollaries to be drawn from the mode of vascular nutrition, both as regards the emotions, and in particular as regards the independence of functional hyperæmias, as far as the general vascular movements of the fore-brain are concerned.

The study of the modes of cerebral nutrition should be followed by an examination into the chemical nature of the substances and products of nutrition. But on this head our knowledge is far more fragmentary than it is in regard to the mechanism of functional tracts and the channels of nutrition.

The reactions showing the chemical composition of the brain can be carried on to a limited extent even in microscopical investigation, thus enabling us to discriminate between chemical substances belonging to the elements of the gray and the white substance respectively. Other facts, however, can be obtained only by an examination of the entire masses of the brain; and it is difficult, therefore, to make an absolute distinction between the gray and the white substance.

In the human brain the white substance constitutes the main mass of the fore-brain, while the gray substance is the chief ingredient of the brain-trunk. In order to judge of the distribution of the chemical bodies among the gray and the white substance, the simplest procedure would be to determine the largest number of elements in each, and to ascribe the form which preponderates in each case to the gray or the white substance. But such studies have never been carried on with the aid of *my method* of dissecting out the brain-trunk and cerebellum from the hemispheres—a method peculiarly adapted to such investigations (*cf.* Figs. 16 and 17). Danilewski is the only one who attempted to estimate the elements of the gray and the white substance, basing the estimate upon a comparison of the differences in specific gravity. He found that the sp. gr. of the gray substance varied between 1.029 and 1.038, and that of the white substance between 1.039 and 1.043. He investigated also the relative proportions of both substances in the brain of man, and found that it possessed 37.7 to 39 per cent. of gray substance, and 61 to 62.3 per cent. of white substance; while in the dog the gray and the white substances are present in the proportion of 50 : 50.

It was shown above that the preponderance of gray substance in animals as compared with the gray substance in man, depended by no means upon the greater number of nerve-elements, but upon the excess of amorphous connective tissue in animals. As regards the latter, we know that it is not, like other connective tissue, to be placed in the category of glutin-substances, but that this non-nervous substance is also albuminous in character. Boll, nevertheless, considers it allied to connective tissue, for, as he claims, all connective tissue contains remnants of albumin, derived from formative cells, and this non-nervous gray substance is simply distinguished from other connective tissue by the possession of a greater quantity of albumin. A very small quantity of amorphous connective tissue is, by the way, to be found, too, in the medullary substance of the fore-brain.

And as for the nerve-cells, of which the axis-cylinders of the entire nervous system are a uniform part, Kühne has already shown that both the nerve cells and the axis-cylinders give the reaction for albumin. This is based upon the reaction of the axis-cylinder with acetic and very dilute nitric acid, concentrated and diluted alkalies, in which the axis-cylinder swells and partly dissolves; and upon the contraction and yellowish discoloration of the axis-cylin-

der in hot nitric acid; and, furthermore, according to Rumpf, upon the characteristic reaction of the axis-cylinders of peripheral nerves, which are stained red by Millon's fluid. Among the various kinds of albumin, it was formerly supposed to consist of myosin, and then again to be identical with the contents in muscular fibres; but that is disproved by its insolubility in a ten-per-cent. solution of sodium chloride. From the investigations of Kundt, and the digestion experiments of Kühne, and Ewald, who used trypsin—the pancreas ferment,—we now know that the axis-cylinder is surrounded by a sheath, containing indigestible keratoid substances. These keratoid substances are contained in a lime-yielding substance of the axis-cylinder sheath, similar to Schwann's sheath, which surrounds the peripheral nerves. Accordingly, the medullary sheaths of peripheral nerves, as well as the sheaths of the axis-cylinders in nerves and in central medullary fibres, which lack Schwann's sheath, are horny formations, and those parts only which remain after the whole has been subjected to the digestion process deserve to be called keratoid sheaths. Rumpf demonstrated the axis-cylinder sheath by extracting the medullary substance of the nerves with alcohol and ether, and removing it with chloroform; or else by adding distilled water, which expels the medullary substance, causes it to foam and to divide up into globules of myelin. The expulsion of nerve-marrow by water can be explained on mechanical principles by the synchronous swelling of the axis-cylinder, which dissolves slowly in water, and pushes its horny sheath against the external sheath of Schwann, thus crowding out the white substance between the two.

The chemical nature of the nuclei of the ganglion-cells was revealed through Jaksch, who proved the presence of Mischer's *nuclein* in the gray substance of the brain; while Geoghegan showed that it was present in the proportion of 1.4 to every 1,000 parts of the entire cerebral mass. Although Jaksch did not thoroughly isolate the gray substance, he was able to prove the excess of nuclein in the gray substance relatively to the white.

The presence of albumin and nuclein in the gray substance implies the presence of phosphorus in the ganglion cells and the axis-cylinders. Meyer and Cornwinder proved that in plants, the quantity of phosphorus increased in direct proportion to the quantity of nitrogen, and Bischoff calculated that the urine of starving animals contained phosphoric acid in definite proportion to the

quantity of nitrogen—say, 1 : 6.4; while if an animal be properly fed, the quantity of phosphorus and nitrogen taken in with the food is greater than that in the excretions. From these facts Voigt infers that the albuminates and phosphates unite, so that we must classify the fundamental connective tissue, as well as the nerve-cells in the gray substance of the brain, with those substances which contain phosphorus. Direct chemical proof has been proffered of the high percentage of phosphorus in nuclein; and the quantity of nuclein varies in all the organs of the body with the number of cells and nuclei which they contain. Kossel showed that the liver and spleen yield more nuclein than muscle, which contains a lesser number of nuclei; that leucæmic blood with its wealth of cell-nuclei contains more nuclein than the blood corpuscles, which are devoid of nuclei. But, in the second instance, the quantity of nuclein depends upon the reproductive power of cells in which the division of the nuclei plays so important a rôle; so it happens that the percentage of phosphorus is higher in fœtal muscles and other fœtal organs than in the fully developed muscles; and the same obtains in plants with regard to the momentary foci of growth. The phosphorus of nuclein is attached to an albuminoid body which can be readily isolated by chemical means, because of its power of resisting digestive agents.

The preceding remarks apply to the phosphorous elements of the gray substance, which constitute an important factor in the chemical composition of the entire brain. Relying upon ash-analyses and the investigations which Schlossberger, Bibra, Pollak, and Jarisch have made on the various tissues of the body, a fresh brain contains 0.49 per cent., phosphoric acid in its gray substance, and 0.89 per cent. in its white substance, while the calf's muscles contain 0.48 per cent., woman's milk 0.38 per cent., human blood 0.10 per cent. The egg-yolk alone exceeds all, containing 1.15 per cent. phosphoric acid. In the brain of the dog, which, by the way, contains less white substance than the human brain, Forster found 0.83 per cent. phosphoric acid; in the muscles, on the other hand, only 0.48 per cent., in the blood 0.13 per cent., which is in thorough accord with the results of the different investigators mentioned above.

We are not warranted, however, in concluding that the nervous system contains an absolutely larger quantity of phosphorus. The quantity of phosphorus in the nervous system cannot be gauged by the amount of phosphorus in the excretions, for, as

Voit has determined, the entire nervous system of man contains but 12 gr. of phosphoric acid as compared with 130 gr. in the muscles, and 1,800 gr. in the bones; and, besides, we know, ever since Chossat's starvation experiments were published, that during starvation the nervous system shows no appreciable loss of weight.

Petrowski has determined the percentage of water in the brain, and has found it to amount to 81.6 per cent. of the gray substance, and 68.35 per cent, of the white substance.

Quantitative examination alone is able to furnish positive evidence of the nature of cerebral elements, for, as Drechsel has shown in Hermann's "Handbook of Physiology," substances varying in quality cannot be obtained in a pure state from one and the same brain; and the terms *lecithin*, *cholesterin*, and *cerebrin* designate mixtures only: of which lecithin applies to the substance composed of phosphorus which has been dissolved by ether and alcohol; cholesterin is the term given to the ethereal extract which remains after removing the lecithin; and cerebrin designates the substances which form crystals in hot alcohol, but are insoluble in cold alcohol.

The aqueous extract of the brain was examined by W. Müller, and was found to yield large quantities of *inosite*, 8 per mille; *lactic acid*, 5 per mille; *kreatin*, 4 per mille; in lesser quantities, *uric acid*, *xanthin*, *hypoxanthin*, *urea*, and *leucin*.

It is worthy of notice that the acid reaction of the brain, which becomes more acid as the brain dies away, is attributed by Gscheidlein to a fermenting lactic acid, which can be obtained in the form of a lactate of lime (Hoppe). The reaction of the white substance, however, is not acid, but neutral, turning alkaline with the onset of death. Consequently, the brain does not, as Funke supposed, give a purely acid reaction. Kossel derives the hypoxanthin from nuclein, which is obtained by weak reagents from the latter without setting up a general decomposition. He considers it a temporary product in the development of urea from the decomposition of more highly organized nitrogenous substances. Hoppe-Seyler found that caustic potash acting upon nuclein at a temperature of 200° Celsius, liberated prussic acid and ammonia; and Kossel remarks that the conditions for the development of the cyanides, which are intermediate products of the metabolic processes, are to be found in substances obtained from cell-nuclei. This chemical fact is interesting enough physiologically

as proof of the correctness of Pflüger's views, who held that certain phenomena due to irritation, such as epileptic convulsions, which are believed by Kussmaul and others to be caused by the withdrawal of arterial blood, could be explained by the retention of metabolic products exerting an influence similar to that of the cyanides.

Cholesterin is one of the chief products to be extracted by ether from the brain-substance. Of this body Hoppe-Seyler says that it is common to all living vegetable and animal cells, but that it plays no important part in the development of the cells; that it is in all probability merely suspended, and not dissolved, in protoplasm; that it is a product of decomposition resulting from the organic changes during cell-life.

One of the chief constituents of the brain is *protagon*, which was first obtained by Liebreich. It contains phosphorus, and that too in far greater quantities than nuclein, which was described above. Protagon and nuclein are the main depositories of brain-phosphorus. For this reason, if for no other, we might incline to the view, that other chemical products of the brain-substance, such as *lecithin*, first prepared from the brain by Diakonow, and Müller's *cerebrin*, are ingredients of Liebreich's protagon. The method of obtaining cerebrin was refined upon by Parcus, who divided cerebrin still further into *homocerebrin* and *encephalin*. This view was expounded first by Kühne, and later on Blankenhorn and Gamgee investigated the subject again, with the result of modifying the chemical formula of protagon. Very recently Drechsel expressed the conviction that this view was most probably the correct one, but that the atomic weights of lecithin and cerebrin did not suffice to make up a mixture or union of the nature of protagon, and that still a third substance, containing more nitrogen and less carbon, would have to be shown to exist, if Diakonow's and Hoppe-Seyler's views[1] are to be credited.

It has been urged that the percentage of phosphorus in protagon is exceedingly variable in quantity, and Diakonow contended that it contained no phosphorus at all, and in this respect resembled cerebrin. But Diakonow himself was unable to prove this, and the former objection is answered by the investigations of Blankendorf and Gamgee, who found that though protagon had been re-crystallized four or five times, the percent-

[1] That protagon is merely a mixture.

age of phosphorus remained the same; and this view is upheld by Drechsel. The formula of protagon, as determined by Blankenhorn and Gamgee is $C_{160}H_{308}N_5PO_{35}$. That it is present in the very earliest stages of brain development may be inferred from its importance as one of the main constituents of the brain, and from the fact that it is easily precipitated by weak chemical reagents as a crystalline precipitate. After extracting the cholesterin with ether, it is separated out by alcohol (85 per cent.) at a temperature of 45° C., after the dehydration of the residual brain-substance, amounting to 31.65 per cent. of the entire brain-substance; by gradual cooling it forms into needle-shaped or star-like groups. To the arrangement of these crystals in nerve-marrow, in a direction radial to its axis, Kühne attributed the double refraction of this substance. Ebner, in his studies on the anisotropia of organic substances, takes issue with Kühne, for he finds that treatment with cold ether destroys the double refraction, whereas protagon is entirely insoluble in ether. Lecithin and cerebrin are prepared by much more complicated chemical methods. To obtain pure crystals of cerebrin some thirty odd re-crystallizations must be performed, while lecithin (according to Diakonow) does not crystallize at all, or is precipitated with great difficulty only by ether at a temperature of 0° C.

The presence of a body like protagon in the brain is rendered plausible by the physical properties of the latter, which, as Kühne puts it, do well in participating in the composition of so peculiar a substance as the medullary sheath. Among these peculiar qualities is the power the medullary substance of the brain possesses, of reducing osmic acid, and turning a black color; but these peculiar qualities are common also to the myelin forms of protagon resulting from prolonged contact of protagon with water. Like nerves themselves, protagon develops forms of myelin in the initial stages of decomposition. Before protagon is thoroughly dehydrated by drying over sulphuric acid, it gains a waxy appearance; it swells in water, changing to a transparent, starch-like mass; when dissolved it invariably becomes opalescent. Hereafter we shall see that pathological conditions of nerves give rise to similar appearances.

Though lecithin and cerebrin (the latter a substance without phosphorus) exhibit the starch-like properties of solutions and myelin-like forms, there is not sufficient ground to doubt the origin of these substances from the protagon of the brain, but

their marked hygroscopical properties stand in broad contrast to the lack of such qualities in protagon. This was first mentioned by Diakonow and Müller, and has been insisted on since by Blankenhorn and Gamgee. If protagon were a mere mixture of cerebrin and lecithin, it would be difficult to conceive how a non-hygroscopical body could result from the union of two hygroscopical bodies. It would be more natural to suppose that the hygroscopical properties were the result of the more elaborate methods by which cerebrin and lecithin are recognized as secondary brain constituents, while protagon, a primary brain-substance, is obtained in advance of these.

The chemical composition of cerebrin is indicated by the formula $C_{69.08}\ H_{11.47}\ N_{2.13}$ (Parcus), and of lecithin by the formula $C_{44}\ H_{90}\ NPO_9$ (Diakonow). The formulæ do not contradict the premise of Liebreich and others, that protagon divides primarily into cerebrin and lecithin.

Hoppe-Seyler holds that lecithin, which is a phosphorous body, can be found in all cells capable of development, in rapidly proliferating pathological tumors, in sperm, and in the yolk of eggs, from which it has derived its name. Both lecithin and protagon split up at a temperature of less than 100° C. into glycerin, phosphoric acids, fatty acids, and the base, neurin, which lacks phosphorus, and is precipitated in the form of needle-shaped crystals. Protagon yields stearic acid, while the various forms of lecithin divide up into palmitin and oleic acids. Considering the small amount of nuclein, the phosphoric acid of the brain is certainly not confined solely to the two phosphorous bodies, for Geoghegan found, after removing the substances classed under lecithin, that the brain-ash still contained 23 per cent. of phosphoric acid.

Petrowski has made quantitative analyses of the gray and the white substance. Drechsel's critical observations regarding the inaccurate preparations of lecithin and cerebrin must be taken into account.

PETROWSKI'S ANALYSIS:

	Gray.	White.
Water	81.60	68.35
Solid residue contained therein	18.40	31.65
Albumin and glutin	55.37	24.73
Lecithin	17.24	9.90
Cholesterin and fats	18.68	51.91
Cerebrin	0.53	9.55
Substances insoluble in dehydrated ether,	6.71	3.34
Salts	1.45	0.57

According to Bernhardt, the percentage of water varies very much in the different portions of the brain. The cortex contains 86 per cent. ; the medullary substance of the hemispheres, 70 per cent. ; the oblongata, 74 per cent. ; while the cervical spinal cord contains 73 per cent. of water, the lumbar cord 76 per cent., and the sympathetic 64 per cent.

Kühne's and Ewald's *neurokeratin* is soluble only in a hot concentrated solution of caustic potash and sulphuric acid, and amounts to but 15 or 20 per cent. of the dried residue of the alcoholic or ethereal extract of the brain. Petrowski insists that lecithin and cholesterin found in the gray substance do not originate from the white substance mixed with it, but from the cells of the former. That the phosphorous substance in the medullary substance of the brain is not lecithin, but a body peculiar to the brain substance—say, protagon,—would seem to be proved by the fact that the biological importance which Hoppe-Seyler attributes to lecithin would presuppose an increase in the number of tissue elements. But for some time previous to birth there is no such increase of the elements of the normal brain-tissue. There is one occurrence, however, which could be held responsible for an increase of the tissue-elements, and that is the formation of fatty granular cells, preceding the development of medullary sheaths, and taking place about the time in which the original gray cerebral substance is transformed into white substance, and before the medullary substance has been developed. But the process is not re-enacted during normal life ; whence Hoppe-Seyler, following Kühne, infers that the white substance of the brain is intended for isolated conduction, and on the other hand points to the fact that rapid perception and movement are effected by medullated fibres, while the unstriated muscles (non-volitional) are supplied by non-medullated nerve-fibres.

Nowhere in the system, though widely scattered, is lecithin called upon to effect such conduction as falls within the province of the cerebral medullary substance. There is better reason, therefore, to presuppose the existence in the above tissue of a uniform but more complicated chemical substance. Pathological increase of nuclei, and possibly also of nerve-cells, certainly does occur; and as it is always preceded by division of the nuclei, we may look for a second phosphorous body well adapted to effect such changes of form, which could be naturally associated in our minds with an increase of such elements.

As regards the relation of protagon to the rapidity of conduction, we have two reasons for supposing the medullary substance of the nerve-fibres to be functionally connected rather with the nutrition of the fibres than with conduction. Rapidity of conduction might be held to depend upon favorable conditions of nutrition, furthered by the composition of the medullary substance. Conduction is effected by non-medullated fibres also. It is initiated at the periphery, where the terminal branches of the nerves, and probably of the axis-cylinders also, are non-medullated, and at the other end conduction is originated in the gray centres in which the axis-cylinder passes into the non-medullated processes of the ganglion-cell.

From the laws of Ritter we know that motor nerves, after section, begin to die at their central end, whence they have received their stimuli, and that cut sensory nerves begin to atrophy at their peripheral ends, for it is at the periphery that sensory stimulation is started. On the one hand, nutrition depends upon the non-medullated tissue of the axis-cylinder, which receives central and peripheral stimuli; and furthermore the stimulus itself supplies the incentive for nutrition. This would signify, according to Virchow, that the axis-cylinder exercised a powerful attraction upon the nutritive plasma, which is rendered most effective through the mediation of stimulation. We must look upon the medullated substance as a tissue favoring rapidity of conduction, and aiding the nutrition of the axis-cylinder. If the venous character of the blood which leaves the brain necessitates our considering a process of oxydation in connection with nutrition, then we may assume this medullated substance to be concerned in this, for this substance is able to reduce osmic acid by withdrawing oxygen, a chemical process in which its large percentage of phosphorus plays an important rôle. Kühne calls attention, from the chemical standpoint, to the slowness of nerve-conduction, first proved by Helmholtz. This slowness does not argue in favor of the conduction of a physical force such as electricity, but suggests rather the progress of chemical changes from section to section of a nerve, while it is acting as a conductor. The axis-cylinder alone, because of its continuity, can be engaged in nerve-conduction. The medullary sheath is not continuous; it is interrupted (only) in the region of Ranvier's constrictions; here the medullary substance appears interrupted, but not so the primitive sheath. Rumpf has shown, that if the medullary substance is forced out

by allowing the axis-cylinder to swell in water, that the white substance is checked momentarily in its course at the constriction-rings, but the current pushes on within the primitive sheaths through and beyond the constriction rings. Secondly, the septa of Lanterman divide the white substance into a number of segments, which seem as though they had slipped into one another like the two divisions of a box. The digestion experiments of Kühne and Ewald, and the investigations of Rumpf, have shown that the septa contain horny substance, which intervenes between the sheath of Schwann and the keratoid sheath of the axis-cylinder, and furthermore that a framework of horny substance traverses the white substance between the segments. Those complicated structures, which Stilling was the first to describe as a system of tubes and trabeculæ are probably synonymous with this keratoid network.

If the expression keratoid substance could be applied properly to the sheaths of the white substance and of the axis-cylinder, then the axis-cylinder could be considered isolated from the white substance by a body far less permeable than either the white substance or the axis-cylinder. The correct expression, horn-bearing sheaths, points to the fact that the keratoid substance is interrupted by substances favorable to a nutritive endosmosis. Since the axis-cylinder is better adapted during stimulation to attract chemical substances from the white substance, and in keeping with the greater rapidity of conduction in medullated fibres to increase the chemical processes involved in conduction, its sheath, consisting of horny and glutinous substances, may be held to represent a sieve which allows the nutritive plasma, as much at least as is attracted from the white substance, to fall upon the axis-cylinder, not with the intensity of a full current, but with the more delicate force of a rain; and we must regard the partial endosmotic permeability of the neurokeratin sheath as an apparatus regulating the physiological needs of the axis-cylinder. But the white substance of peripheral nerves also is surrounded by a similar horny sheath, and interrupted in its interior. The aforesaid regulation of the nutritive plasma applies to the sheath of Schwann as well. In this way the nutrition of the white substance is made independent of the plasma exuded by the blood-vessels, and a uniformity in regard to its chemical changes is established. This is suggested also by the peculiar conditions of nutrition, since the broad meshes of the vascular network of this comparatively

anæmic white substance are to be found only on the surface of complicated bundles, whereas the single nerve-fibres have no sort of contact with the blood-vessels from which the plasma that is exuded permeates the sheath of Schwann, and mingles with the white substance drop by drop, instead of pouring in upon the latter with its entire mass at once. The numerous interruptions through horny substance in the white substance would impede any simple mode of nerve-conduction, but would favor an endosmotic process, advancing slowly from segment to segment.

The electrical nerve-current is probably to be regarded merely as a secondary phenomenon accompanying chemical changes. This secondary phenomenon has been specially studied, however, by nerve-physicists. Dubois' (Reymond) nerve-current of rest, as is well known, is not connected with any process of stimulation. It suffers disturbance through negative variation. The chemical nature of nutritive processes could be studied by careful examinations of daily secretions; and many chemists have sought to determine the quantity of phosphorus contained in the excretions of the body, starting out on the supposition that the nutrition of the nervous system is to be held to account for a considerable portion of the phosphorus in the urine and fæces. On this head, Mendel's observations on the percentage of phosphorus in urine are specially worthy of notice, as well as some other observations to which Mendel refers in this same treatise. Mendel inquired into the variations in the quantity of phosphorus present in the urine during waking and sleeping. He found the nocturnal urine richer in phosphoric acid than the urine passed during the day; whence we infer that the waste products of the brain are increased during sleep. This fact is in perfect accord with Burckhardt's observations regarding the movements of the brain. Burckhardt established a direct mechanical relation between the vascular wave and the removal of the lymph-current; and maintained, moreover, that while the brain was awake and active—*e. g.*, while the brain was in a state of excitation—the effects of the vascular wave were interrupted and irregular; but that regular peristaltic vascular movements were peculiar to sleep, and that the complete chemical restitution of the brain during sleep must be ascribed to the increased deportation of its waste products. Mendel refers in his article to the observation of Wood, that mental activity slightly increased the alkaline phosphates of the urine, but that it caused a greater and decided diminution

of the earthy phosphates. He concludes, therefore, that nerve-tissue increases, like muscular tissues, during mental work, thereby entailing a diminution in quantity of the phosphates excreted. The chemical phase of excitation seems to him to involve a synthetical chemical process and a decrease of waste products. This view becomes attractive, if we remember that the phenomenon of memory is a positive action which has outlived the process of excitation, and it is much more conceivable that a synthetical chemical process should leave lasting functional consequences, than that functional acts should arise from the decomposition of waste products soon to be discharged. The nerve-current of rest, together with the increased products of chemical decomposition and the mechanical methods for the removal of waste products, exists also during sleep. If the functional excitation of the axis-cylinder, whether central or peripheral, results in the withdrawal of a phosphorous substance from the white substance through the horny sheath, and in utilizing this phosphorous substance in a synthetical chemical process, then the chemical process going on in the white substance and connected with the nerve-current of rest will be disturbed; and, furthermore, the electro-negative variation would correspond to a synthetical chemical process in the axis-cylinder and the nerve-cells as the very opposite of a metabolic process of division (Spaltungsvorgang).

Rumpf's investigations have shown that the nutrition of the axis-cylinder depends, apart from the possibility of isolated and rapid conduction through the medullary substance, upon stimuli, and consequently upon its connections with a sensory apparatus at the periphery, and with a central organ. Rumpf's observations were made on nerves which remained within the living body, but which were severed both at their peripheral and central ends. Under these circumstances the axial band disappeared and was dissolved, within twenty-four to seventy-five hours, even if the nerve had been kept in a proper menstruum. The influence of the medullated substance and the blood-vessels does not suffice for the nutrition of the axial fibre.

This experiment proved at the same time that the fibrillary structure of the axis-cylinder, which Max Schultze inferred from the striated appearance of the axis-cylinder and of the cell-processes, after treatment with silver, did not in reality exist, but that this striation was due simply to a precipitate of silver in the

folds of the keratoid sheath. Rumpf was able to demonstrate this same silver-striation in sheaths which we but just learned did not enclose axis-cylinders.

The keratoid sheath of the axis-cylinder and white substance might possibly, by reason of the pressure it exerts, be of some moment as regards the more delicate conditions of normal nutrition. This applies to the horny sheath of the axis-cylinders of the brain, but all brain fibres as well as all fibres of the optic nerve and of the spinal cord lack the sheath of Schwann. But in lieu of the pressure which the sheath of Schwann presumably exerts on the white substance, another force comes into play in the cranial and spinal cavities, which, as far as the medulla is concerned, is indicated by the tension of the *membr. atlantis.* From the chemical standpoint, the greater wealth of water of the brain and spinal cord must be borne in mind ; this might be thought to correspond to the greater quantities of plasma exuded in consequence of the absence of the sheath of Schwann.

This indirectness and independence in the matter of the nutrition of the axis-cylinder would seem to be a safeguard to prevent the disturbance of its function by cerebral hyperæmias. Under normal conditions of stimulation and attraction of the axis-cylinder, as well as of the ganglion-cells, and with an abundant ramification of wide arteries, the brain appears by its normal structure to be protected against the possibilities of anæmia ; for in a body wasting from starvation the central nervous system, it is claimed, suffers less in weight than other organs of the body, and it is well known, furthermore, that cerebral activity is possible in spite of general anæmia of the body.

In consequence of its larger percentage of water, the gray substance would influence nutrition in a very different way from the axis-cylinder, which, throughout its course in the central white substance, and in the peripheral nerves, has the function of a conducting organ. The variable nutritive conditions are dependent upon the gray substance to the extent that they are influenced by the blood-supply. Since albuminoid substances aggregate to more than one half of the chemical constituents of the gray substance, we may infer a direct relation to exist between the albuminoid bodies and the percentage of phosphorus, and the latter would be greater than in the case of other cellular tissues, for even the connective tissue of the gray substance contains more albumin than the connective tissue elsewhere does.

This then, is another factor accounting for the greater accumulation of brain-phosphorus.

Because of its greater wealth of cells, the gray substance contains a larger quantity of nuclein ; but nuclein stands next to protagon in the series of cerebral bodies containing phosphorus. Under normal conditions, and in the fully developed brain, nuclein does not seem to play an important rôle, as regards the increase of tissue, as it does in pus, in yeast, and wherever else it is found. After excluding this particular function, and in addition to its adding merely to the percentage of brain-phosphorus, we may insist on the fact that the nucleus exercises a nutritive influence over the albuminoid protoplasm. This nutritive function for the maintenance of the protoplasm is annulled in pathological processes of the brain as soon as the division of the ganglionic nuclei enables the nuclein to develop its faculties for regenerating tissue, while the protoplasm of the cell-body is diminished and finally destroyed.

The nutrition of the axis-cylinder, which is a part of nerve-cells and of their prolongations, some of which become axis-cylinders, is effected in a similar manner. Jastrowitz considers the gray substance (pp. 58, 59) the medium of isolated conduction, to the extent that such conduction is imposed upon the gray substance. If the striation of the axis-cylinder, and the striation which Remak observed on the ganglionic processes, and Schultze (p. 62) within the cell-protoplasm, indicate an identical process, (while, according to Rumpf, it is simply an expression of the folds in the keratoid sheaths,) then we should have to suppose such striation to exist also in the case of the nerve-cells and their protoplasm. It is quite conceivable also that a sheath surrounding ramified nerve-cells, which has as many points of attachment in the connective tissue as it has branches, should, if isolated and separated from these points of attachment, lose its normal tension, and be thrown into folds occupying all possible directions. The lines of Schultze, which Boll demonstrated, with the aid of osmic acid, in cortical cells also, both in those forms which extend from one process to the other and in the dark lines running concentrically around the nucleus, might be ascribed to simple folds without a minute fibrillary structure.

The larger quantity of plasma in the cortex depends upon its denser network of blood-vessels. The nutrition of the nerve-cells is regulated specially by the sieve-like perforations of the keratoid

sheaths, while the short distance which the naked nerve-fibre has to travel from its origin in the gray substance before it is surrounded by a medullary sheath, does not influence the rapidity of conduction. And on the other hand, the network of gray fibres does not become medullated either. But the very obstacles to irradiation, causing slowness of conduction in the gray substance (p. 185), might be explained by the dropping off of the medullated substance from the anastomosing processes of nerve-cells, since the medullated substance is justly considered to favor rapidity of conduction.

In order to comprehend the mode of nutrition during cerebral activity, we must, if we wish to avoid confusion, omit the consideration of irradiation in the gray substance, although there is no reason to suppose that any active cerebral process excites but a few nerve-cells only. For this reason we must presuppose an irradiation of moderate extent to take place whenever a number of cells unite for common action. The development of a single thought is effected by the functional activity of association-bundles, which unite in a very complicated way the component elements of a so-called residual image of the cortex. These groups of associated cells which harbor residual images, are the starting-point for the excitation of more comprehensive associations, constituting simple processes of induction (*Schlussprocesse*) (p. 153). It has been explained above that the entrance of numerous and comparatively independent arteries of the pia into the broad expanse of cortical surface favors the excitation of separate and well-defined groups of ganglion cells, and we must remember that every cortical image and every inference depend upon the union of special groups of cells. The projection-system alone stands under the influence of centres of excitation, for as soon as the fore-brain comes into play the activity of the association-fibres precludes the possibility of localizing the cerebral excitation. We must admit, therefore, that the localization is but an aid to the grouping of stimuli differing from one another in their relations to time and space; they are united for a common action by the process of association—a process which cannot be confined to any one portion of the cortex, as is amply demonstrated by the varying lengths of the association-bundles which unite the remotest parts of the cerebral lobes.

It is worthy of remark, that every process of thought ema-

nates from a residual image of the cortex, and that this image is connected with a large number of distinct cerebral foci. The individual mental act is so constituted, however, that the initiatory residual image enters into a lesser number of connections than the actual anatomical connections would warrant. In every mental act but a portion of the possible available association-tracts are employed. If the functional activity of the cortex implies a synthetical chemical process, then the active brain-cells and brain-tracts will require an increased quantity of plasma. We can understand the possibility of isolated conduction by attributing to the nerve elements a nutritive attraction along the course of the arciform bundles. If we accept Fechner's theory, that the cortical images and their connections may be stimulated to one of two variable degrees of intensity, and that in any particular mental act those images which are actively utilized stand *above the threshold* of consciousness while others remain *below* the level of consciousness, then accepting this theory, we may interpret it to mean that elements bearing processes standing above this level exhibit a greater nutritive attraction than those elements which are not then called into play. This is a distinction of degree, not of kind, for certain stimuli can be perceived without being clearly recognized by consciousness, and, furthermore, synchronous or successive stimuli can become associated. These associations may be formed unconsciously, *i. e.*, below the threshold of consciousness, and yet they may rise above this level, and into consciousness as complete inductions (inferences), if any groups of elements in these regions will by association stimulate nutritive attraction to such a degree of intensity, that these groups can pass from the condition of partial sleep to that of partial wakefulness.

From a consideration of the cerebral mechanism we learn that in addition to the influence of attraction, there exists a nutritive process which, apart from the influence of the heart, relies upon the effectiveness of the vaso-motor centre; whence it follows that functional hyperæmia cannot be put solely to the account of attraction. Analyzing the independent manner in which the vaso-motor centre influences the brain, as is exhibited by the vascular wave, we find that we get the vaso-constrictor influence with the arterial systole, and the vaso-dilator influence with the arterial diastole. But the mental processes are not interrupted by each arterial systole, for which reason they must, to a certain degree, be inde-

pendent of functional hyperæmia. This independence of mental acts may possibly be due to the fact that the cortex itself acts as a vaso-motor centre in its relations to subcortical centres. This cortical function is the very opposite of functional hyperæmia. If functional hyperæmia is caused by stimulation of the cortex, starting the mechanism of association, then the constriction of the blood-vessels is the result of cortical stimulation, and this dilation (p. 189) must be considered the result of inhibition of cortical function. We must look to another fact if we wish to understand the nature of the functional hyperæmia which helps and, for a certain length of time, enables the plasma to exhibit its phenomena of attraction.

Fechner denies the spontaneity of motor acts, which, if they were spontaneous, would not obey the universal law of the conservation of energy. According to this law, energy cannot be generated, except at a loss of other energy. He proves the applicability of this law to cerebral activity by referring to the common experience of all that muscular and mental energy cannot be generated simultaneously by the brain. A person who is engaged in physical labor will, as soon as a mental process is set up, allow an arm that was raised to fall; and, conversely, severe physical exercise disturbs any process of thought. The inference is, that functions of the fore-brain inhibit one another, according as one or the other happens to predominate in the fore-brain. Goltz demonstrated the inhibition of the croak-reflex in the frog through other stimuli acting simultaneously upon the gray substance.

But from the investigations of Burkhardt we learned that the influence of the vaso-motor centre upon the peristaltic vascular movements is modified by the activity of the hemispheres, and that when this activity is lowest, as it is in sleep, arterial systole and diastole succeed one another with the utmost regularity. It is evident from the influence of cerebral activity over the vaso-motor centre, that the vaso-motor nerves of the cortex do not reach the blood-vessels at once, but that they are interrupted in the subcortical vaso-motor centre; and that for the vascular innervation of the cortex, the subcortical centres must constantly be called into requisition.

I remarked above (p. 207) that the vaso-motor centres governing cortical influence must be referred to the gray substance of the anterior division of the brain-trunk, in which are

situated also the other motor tracts subject to centrifugally transmitted cortical innervation. If the cortex be excited in its capacity as a vaso-motor centre, the influence of the arterial systole upon the vaso-motor centre will be augmented, thus causing active anæmia of the brain, which, as a rule, remains entirely independent of the anæmia of the rest of the body. But since a functionally active cortex cannot impede the development of functional hyperæmia, we must assume that the physiological excitation of the cortex increases in a centrifugal direction the arterial diastole which forms part of a peristaltic movement. This would be quite comprehensible, not only if an active cortical process, such as a thought, would, as Fechner contends, interfere with the evolution of intense conscious movements, or *vice versa*, but also if the process of association would inhibit the second motor function of the cortex—viz., the constriction of the arteries.

I made mention of this division of cortical energy in favor of functional hyperæmia, in speaking of the relation of this hyperæmia to an aggressive emotion (p. 195). On the other hand, again, deficient or diminished cortical activity, as expressed in conscious movements, or in thinking, would be attended by an augmented excitation of the vaso-motor nerves connected with this very portion of the cortex, and would deprive the attraction of the nervous elements through exosmosis of adequate material, just as reflex impulses from the periphery cause a constriction of the cerebral arteries through the mediation of a subcortical vaso-motor centre, and thus influence the blood-supply as well as the chemical changes in the brain.

Figures 64 and 65 are intended to illustrate in a diagrammatic way the manner in which excitation of the cortex and excitation of the vaso-motor centre inhibit one another. Each one of the three different cortical regions performs two different kinds of work: Through the U-shaped bundles JA., JA., processes of association receive their innervation,—thought is rendered possible; while the projection bundles JV. and JN. transmit cortical stimuli to the vaso-motor centre CMU. and CVM.[1]

Figure 65 exhibits the association-bundles with the arithmetical sign > (larger) appended, and the vaso-motor bundles with the arithmetical sign < (smaller); in addition to this we

[1] The wood-engraver is responsible for this difference on the two diagrams in the lettering of parts that are identical.

note that the blood-vessels of the brain-substance are indicated, and are larger on Fig. 65 than on Fig. 64. This difference of innervation exists at all times, and the diagram is intended to show that increased functional activity of the cortex is followed by a diminution in cortical vaso-motor influences; whence it follows

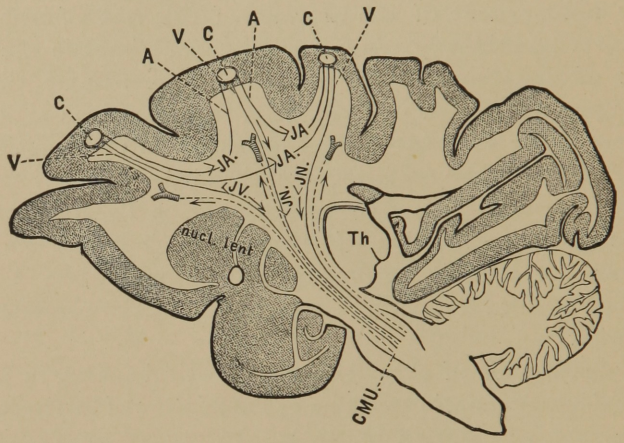

Fig. 64.

Diagram of Vascular Innervation during Increased Vascular Pressure.

C, C, C. Three regions of the cerebral cortex, connected with association-bundles A, and with vascular nerves V. A. Association bundles. > JA. Inhibited association. < JV. and < JN. Increased vascular innervation, consequently the blood-vessels are drawn narrow. *nucl. lent.* Lenticular nucleus. Th. Thalamus. CMU. Vaso-motor centre.

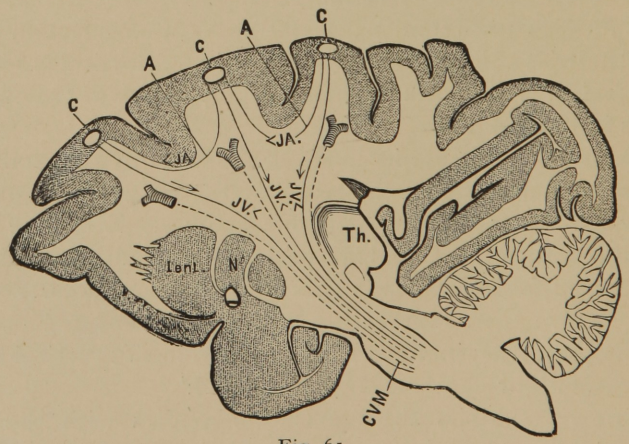

Fig. 65.

Diagram of Vascular Innervation during Functional Hyperæmia.

C, C, C. Three regions of the brain which are connected with association-tracts A, and vaso-motor nerves. < JA. Increased associations. JV. < Vascular innervation checked, consequently diagrammatic blood-vessels are dilated. *Lent. N.* Nucleus lenticularis. Th. Thalamus. CVM. Vaso-motor centre.

that a cortical process of association by inhibiting vascular innervation will result in immediate functional hyperæmia. In the diagram, Fig. 64, the association bundles have received the minority sign <, and the tracts for vascular innervation the plurality sign >. The three diagrammatic arteries are here represented narrower than in Fig. 65. The diagram signifies, furthermore, that if a slight functional activity of the association-tracts does not produce functional hyperæmia, the influence of the vaso-motor centre will not be checked. At the same time it is shown in both diagrams by means of arrows that the cortex imparts a centrifugal impulse to the vaso-motor centre, and that in some way or other this impulse is transmitted in a centripetal direction from the subcortical centre reacting upon the vascular system. A graphical statement of these facts would read thus:

Process of association > = vascular innervation <

and

Process of association < = vascular innervation > ||.[1]

Innervation of the arteries is invariably the result of the functional activity of a subcortical centre; from which we infer that the whole condition of functional hyperæmia is based upon the cortical inhibition (p. 197) of a subcortical centre. The existence of general cerebral fluxion during and after mental work forbids the inference that functional hyperæmia depends altogether upon the attraction of stimulated nerve-elements. That this fluxion extends beyond the brain would seem to be proved by the physiognomical phenomenon of blushing.

Blushing is often the concomitant condition of a multitude of associations. The wealth of simultaneously excited nerve-elements interferes with the orderly development of thought; for in this instance, too, the simpler the character of mental work the more unrestrained will be the flow of association.

A girl who recites a poem from memory will, by dint of cerebral association, be able to repeat words and verses in the proper order of succession. The child will not blush if she happen to recite the poem before children only; but the presence of the king would make it blush and stammer forth its lines in mere confusion. The sight of the monarch is connected with a larger number of associations which have reference to his unusual personality; his presence will start a number of indistinct associa-

[1] The author uses these signs rather oddly. The signs > and < denote "increasing" and "decreasing."—S.

tions. The sum of the cortical elements thus excited will be followed by paralysis of the vaso-motor centre, and will cause much more widespread functional hyperæmia of the brain than the task of reciting the poem did. This degree of general hyperæmia will, in consequence of the numerous and simultaneous inhibitory influences acting upon the vaso-motor centre from all sides, cause a paralysis extending beyond the domain of cerebral vessels, and will thus produce blushing; secondly, we may argue that the many different ideas started in the child's brain will inhibit one another and confuse the acts of the child.

Every one experiences a sensation of confusion at the beginning of a difficult mental task, for from the residual cortical images which are at the bottom of any special train of ideas, more association-tracts will be excited into action than can be utilized in the orderly evolution of these ideas. Excessive functional hyperæmia will be engendered, upon which will follow a state of mental confusion. Walking up and down, bodily exercise of any sort, the sight of green fields, will suffice to distribute a general hyperæmia to other parts of the cortex, by means of which the initiatory conception, with all the associations connected therewith, will be more sharply defined, and simplicity as well as precision of thought will be secured. It is only when the disturbing influence of superfluous hyperæmia has been removed, that the process of attraction will insure the development of thought to a purpose.

By injecting the vessels of the brain it can readily be demonstrated that the blood-vessels run a radial course parallel to the projection-systems, and an arch-shaped course along the association-bundles. The course the various systems of fibres take could be inferred from the distribution of the arteries as seen on corrosion-preparations. We can thus understand why functional hyperæmia should favor well-ordered attraction along the lines of association-tracts; but we perceive, too, that a large number of associations connected with the image just then above the threshold of consciousness will be equally favored; in which case many residual images will be called into activity—*i. e.*, will pass into a state of superior nutrition, but to no purpose whatever. Such secondary images can, however, be consciously utilized. There are easily aroused, though generally neglected, associations existing between each word and its assonances. If thoughts are to be expressed in rhymes, these assonances rise into consciousness

and are interwoven with the ordinary train of ideas to the extent that other associations will allow. Every oratorical effort is likely to be marked by secondary associations which were suggested by the thought in words alone. If we speak of certain ideas as bright, we are easily led to think of things that are bright, and we may compare such ideas to the light of the sun, and so on.

The physiological isolation of certain association-tracts, to the exclusion of the functional activity of secondary associations, may be explained somewhat as follows: A train of thought starts from a residual image in the cortex. All the associations connected with this image are, as it were, ready for action. But no sooner has the cortical image been revived than a second image is presented before our consciousness, which also exercises a definite attraction. The result is that the associations connecting these two images are under double attraction, and will consequently be more intensely excited than any others. The orderly evolution of any one thought implies a starting-point and a goal between which it runs its course. The two images are at either end of this course; and through a strict observance of this course a firm union is established between them. Just as a marksman, in spite of numberless objects around him, establishes a direct relation between his finger on the trigger and the bull's-eye which he is to hit, so a similar relation is established between the two terminal images, which controls the direction of the play of association. And at the same time other images from a parallel direction are perceived in the horopter, which, after the shot has been fired, may alter the circle of vision.

The so-called unity of consciousness may be likened to the activity of the macula lutea, and the secondary association to that of the horopter. Below the threshold of consciousness parallel presentations may arise, due to attraction exercised along association-tracts not connecting the starting-point with the goal of the thought then before the mind. Such parallel presentations may, but do not necessarily, arise from previously well-established associations. They may have terminal images of their own before rising to the level of consciousness. The forces of attraction which push them above this level find these images and associations well organized and ready for use.

I shall have more to say of these parallel images and associations in a later chapter of this book in which I propose to treat of the mechanism of Expression.

Both diagrams representing the inhibition of the vaso-motor centre through cortical function, and the inhibition of cortical function through the vaso-motor centre, apply, as was stated above (p. 195), to different stages of emotion. Burckhardt tells us, moreover, that the influence of emotion upon the vascular wave is far more intense than the influence of thought.

This greater intensity is easily explained if we remember that an emotion involves our whole individuality, and the functional excitation of the widest possible range of associations. Whether the arterial systole will be checked or increased will depend in the one case upon the proportionate number of functionally liberated nerve-elements, and in the other upon the number of nerve-elements already functionally engaged. This is true, above all things, of bodily pain. A finger dipped in water having a temperature of 50° Celsius will give rise to a sensation of warmth; if the arm or the entire body be immersed into water of the same temperature, the sensation of pain will be engendered, for in the latter instance a larger number of nerve-tracts will have been excited. So, too, moderate illumination of the retina effects simple vision; but the disc of the sun striking the eye produces actual pain, through the larger number of elements excited by irradiation from every optic-nerve fibre. The retinal images of a stranger, and of a person whom we love or fear, are entirely the same, yet the sight of the latter two may produce an emotion in us. For, in this instance, innumerable associations will be aroused which are connected with the images of these persons. These are associations of time and place when and where we met them; there will be a play of vascular innervation dependent upon the excitation of fettered or unfettered moods; many association-fibres above and below the level of consciousness will be called into activity,—all of which, and a complicated process it is, will be due to the sight of these two persons. The sight of the one beloved will excite an unfettered mood which is based upon a functional hyperæmia, and which will inhibit the vaso-motor centre at the beginning of the systole of its vascular wave. The sight of one we fear will excite a fettered mood, giving rise to associations, with sensations of vascular innervation, which increase the arterial systole of the vascular wave.'

The nutrition of the brain will be impaired by rapulsive emotions, for it is undoubtedly the arterial diastole which removes waste-products from the brain. We have learned to recognize

that the brain, by dint of the variable volume of the cranial cavity, with the aid of the muscular apparatus of its blood-vessels, contains within itself its metabolic mechanism; it is a pressure- and suction-pump, forcing out ventricular fluid, absorbing lymphatic fluid from the various tissues into the perivascular spaces, and pumping it from these into subarachnoidal spaces.

The state of the nutrition of the brain has an important bearing upon its weight which we must now consider without regard to its specific weight. Neglecting, for the present, the statements of older German authors, such as Huschke and Rudolf Wagner, we find, according to the valuable statistics of Bischoff, that the weight of the brain varies in man between 1,018 and 1,925 grammes; in woman, between 820 and 1,565 grammes. The average would be: For the male brain, 1,362 grammes; and for the female, 1,219. Pfleger's investigations have shown that this statement must be modified if the calculation is based upon adult brains alone, between the ages of 19 and 58, by which means we get rid of a possible error due to senile atrophy. Weichselbaum calculated the average brain-weight of 390 Austrian soldiers, between the ages of 20 and 48 years, to be 1,373 grammes; while Pfleger, who took the brain of men up to the 59th year, proved this weight to be but 1,321 grammes. This discrepancy I would not ascribe altogether to the ten years of more advanced age, but rather to the more powerful organization of soldiers, whose exalted nutrition would tell in the case of the brain also.

As regards sex, there is an undoubted difference of ten per cent. (according to Pfleger of thirteen per cent.), in favor of the male. Nor is this difference proportionate to the difference of stature. The average statures of man and woman are to each other as 100: 93.2, while the male and female brain hold the relation of 100: 90.93.

Furthermore, various authors, and among them Le Bon and Bischoff, are agreed to this, that there is a certain proportionate difference between the length of the body and the weight of the brain, but that the difference between the brain-weights of various individuals is far greater than could be accounted for by the relative lengths of the body alone; and that this difference must undoubtedly depend upon other conditions. It is worthy of note that short persons have a relatively larger brain than large persons. The largest brain relatively speaking, is that of the new-born

infant. Its increase is so marked during the first period of extra-uterine life, that Tuczek, basing his statements upon the investigations of Huschke and Bischoff, contends that during the first year of extra-uterine life the daily increase in the size of the brain amounts to more than one cubic centimetre,—*i. e.*, about the size of a bean. There is a direct connection between the growth of the brain, the size, and the quantity of blood of the new-born infant. According to Hermann, the blood of the new-born amounts to $\frac{1}{13}$, of the adult to $\frac{1}{19}$ only, of the entire weight of the body. There is a direct connection also with the greater width of the arterial system in the child, as was shown by Benecke; and there is no doubt that the greater number of pulse contractions has an important influence upon metabolic changes in the body. Benecke attributes these to the smallness of the infantile heart, for the cardiac contractions are effected by shorter muscular fibres in a shorter space of time. In the female, the lesser size of the heart and the narrowness of the vascular system are important factors in determining the growth of her brain, and to these factors must be added the higher percentage of water in her blood. Brücke quoting Valentin's tables on the sexual difference in the composition of blood, states that the percentages of water in the blood of man and woman are as 77.19: 79.11; of the solid residue as 22.1 : 20.89; the number of blood corpuscles as 14.1 : 12.79.

No positive conclusions can be drawn from the weight of the brain; the statistical average might be utilized, but the individual case certainly not. To take a single instance: The large size of the skull in taller persons depends more especially upon the general osseous system and the length of body (Pfleger). The brain filling this cavity need not necessarily contain a larger number of nerve-elements, but it is more likely that it will contain fibres of greater length, for their development will be hampered less, the greater the width of the skull. But that the greater length of nerve-fibres implies greater functional activity, as a larger number of elements would do, has not been proven.

I have given preference to the statistical results of Weichselbaum and Pfleger over those of other authors, simply because the former have enabled us to draw some conclusions as to the proportionate weight of the different divisions of the brain. They have made use of my method of dividing the brain: Following my example, they do not join the cerebellum to the pons and

other parts of the brain; and, furthermore, they regard the brain-trunk, including the prosencephalic ganglion, as the third important factor in calculating the weight of the brain. This method of separating the brain-trunk from its mantle, by cutting through the corona radiata, is illustrated in Figs. 16 and 17. The brain, together with its membranes, is weighed first, and its total weight is calculated from the sum of the weights of each division of the brain. The brain-trunk also is divided up in the manner I have indicated, into the *lobus candicis*, including the fore-brain ganglion and the island of Reil; into the optic thalamus, the region of the corp. quadrig. and crura cerebri; and into the pons and oblongata.

In the following table I propose to give (for the sake of comparison, and to bring out prominent and instructive differences in weight between the various divisions of the brain in man and animals) some statistics regarding the proportional weight of the different parts of the brain in various animals and in man. The animal brains here referred to were selected by chance rather than by intent, from a far larger (comparative) anatomical collection:

	Brain-mantle (Hemispheres).	Cerebellum	Brain-trunk.	Frontal lobe.	Parietal lobe.	Occipito-temporal lobe.	Lobus caudicis.	Thalamus opticus.	Mesencephalon.	Pons.	Medulla oblongata.
Man (adult)	780	105	105	420	230	350	58	19	6.5	12	4.5
" (new-born)	830	057	112	394	256	349					
Monkey	708	085	208	350	180	470	40	30	10	10	10
Elephant [1]	630	239	125								
Horse *a*	604	190	204				40	16.9	15.3	10.7	16.9
" *b*	698	105	196								
Seal	673	148	177								
Bear	644	146	209	300	255	444					
Dog	728	090	181	328	379	290	34.5	20.4	16.9	10.7	17.3
Pig	615	120	265								
Roe	622	122	255								
Cat	614	140	245				25	12.5	19	15	19
New-born rabbit	611	063	324								

In the preceding table, the proportional weights of the fore-brain constitute a progressive series, beginning with the new-born infant, ascending thence to adult man, and in due succession to the dog, the monkey, the horse, the seal, the elephant, and the bear; whereas one horse (*a*) follows after the pig, roe, cat, and the new-born rabbit. To make this series thoroughly instructive, we must note that the greater percentage of hemispheres in the new-born infant is due to the slight weight of its cerebellum; the same is true of the new-born rabbit. We must note, furthermore, that the other division of the fore-

[1] The total weight of the elephant's brain was 4,576 grammes; the brain-mantle weighed 2,906, the cerebellum 1,097, and the brain-trunk 575 grammes.

brain, the lobus-caudicis stands highest in the series, amounting to 58 per cent., or more than half of the entire brain-trunk.

From the point of view of comparative anatomy, we shall find that the larger the animal, the greater the weight of its cerebellum. The elephant excels in weight of cerebellum, both relatively and absolutely, doubling the weight of the human cerebellum, and having a disproportionate advantage as regards cerebellar percentage over other animals : On the other hand, among more closely allied mammalian forms we find that there is a difference of twenty *per mille* (as regards cerebellar weight) between man and a young monkey, in favor of the former. The new-born infant and the new-born rabbit stand greatly in arrears, as compared to adult man, the infant showing a difference of nearly fifty *per mille* (057). The preponderance of the elephant as regards cerebellar weights sets his hemispheres far back in the series ; the seal, and even the bear, going ahead of him. The recognition of such broad differences as these seems to me to be of far greater value than the consideration of refined minutiæ.

In the above table the frontal lobe is regarded as extending as far as the fissura Rolando ; the parietal lobe thence as far as the occipital fissure ; and the remainder is put down as occipito-temporal lobe. Comparing the development of these several divisions in man, the monkey, bear, and dog, we find that the frontal lobe is more highly developed in man than in the monkey ; that of the monkey stands higher in the series than the frontal lobe of the carnivora (dog and bear). The parietal lobe is also less developed in monkey than in man. His larger occipito-temporal lobe is due to the excessive development of the occipital portion. The bear, like all carnivora, distinguishes himself from man by the superior development of the parietal region. In the new-born infant, this region is proportionately larger than in the adult, a fact which can be explained by reference to the observation of Zuckerkandl, to be stated in full hereafter. Zuckerkandl states that the growth (lengthwise) of the median portion of the hemispheres is furthered by the two cranial sutures (the coronal and lambdoidal), which are responsible for the longitudinal growth of the skull itself ; but that there are no such transverse sutures favoring the unchecked development of the occipital and frontal lobes.

As regards the subcortical ganglionic masses from the thalamus on, we note that man is inferior to other animals as far as the thalamus, and the mesencephalon in particular, are concerned ; in the monkey the thalamic region stands higher than the mesencephalon. The greatest proportionate difference is found in the case of the medulla oblongata. Its relative size in the cat is four times that in man. This is due in part to the larger quantity of connective tissue in animals, and to the excessive development of the posterior division of the brain-trunk as compared with the pyramidal tract.

Taking into account the difference quoted above between the brains of two horses, and remembering that in another series of similar investigations I found the hemispheres—the brain mantle—in dogs and horses to amount to 67 per cent. of the entire brain surface, we may draw the inference that the difference, as regards brain-weight between animals of the same genus, is no less than between various human subjects. Satisfactory results must, therefore, be based upon a very large statistical collection. The greater difference will probably be found between species differentiated by a process of selection.

From Pflegers and Weichselbaum's statistics, based upon the weight of adult brains, we take the following table giving the absolute and proportional weights of the three grand and primary divisions of the brain :

Weight (in grammes).				Per mille. of the entire brain.			
Entire brain.	Brain-mantle.	Cerebellum	Brain-trunk.	Brain-mantle.	Cerebellum	Brain-trunk.	
1,373	1,092	148	133	795	108	97	From 390 soldiers of different nationalities, between the ages of 20 and 48 years. Average length of body = 171 ctm. = 5 ft. 6 in.
1,321	1,044	142	135	790	107.5	102	From 107 healthy (sane) men between the ages of 20 and 59 years. Average length of body, 166.5 ctm. = 5 ft. 4½ in.
1,189	936	131	122	787	110	103	From 148 healthy women between the ages of 20 and 59 years. Average length of body, 156 ctm. = 5 ft. 1 in.
1,154	908	128	118	787	111	102	From 377 healthy (sane) women varying between 20 years and old age. Average length of body, 155 ctm. = 5 ft. 1 in.

Pfleger insists on the relatively greater development of the hemispheres in man as compared with those of woman; the exact relation being as 795 to 787, on the scale of 1,000. Engel has shown that this assigns the larger cerebellum to woman during the prime of life.

No inferences can be drawn from the tables furnished above as regards the composition of the hemispheres; neither does the literature of the subject give us any clue either to the proportional weight of the several lobes of the hemispheres, or to the relative weights of the various subdivisions of the brain-trunk. I propose, therefore, to supply this deficiency, and to amplify the physiological law of brain-weights by an analysis of a large number of brains, which, though the brains of insane patients, were not characterized by any marked degree of atrophy. The subjects from whom these brains were taken were all classified in the official list of the Vienna Insane Asylum under the head of what Griesinger termed "Conditions of maniacal excitement." As Pathologist to that institution from the years 1866–71, I had occasion to weigh 733 brains, and from among these I have the notes of the brain-weights of forty-six male and seventy female subjects, who had been classed under the heading mentioned im-

mediately above. This group of cases comprises the heaviest brains, both male and female. For the sake of comparison, the absolute and relative weights of these "heaviest" brains are tabulated below.

Adopting Bischoff's method, I have also divided the cerebral hemispheres into frontal, parietal, occipital, and temporal lobes, and have ascertained the average weights of 400 frontal lobes, 235 parietal lobes, 135 occipital and 210 temporal lobes. A more rational division could, however, be made between the occipital and temporal lobes.

Weight in Grammes.

	Entire brain.	Brain-mantle.	Cerebellum.	Brain-trunk.	Frontal lobe.	Parietal lobe.	Occipito-temporal lobe.	Lobus caudicis.	Thal. opt.	Mesencephalon.	Pons.	Medulla oblong.
Male .	1,383	1,085	148	148	450	251	383	81.36	26.40	9.03	16.58	6.25
Female .	1,221	954	135	132	400	216	338	74.84	23.74	7.61	14 23	5.50

	Per Mille.										
	Brain-mantle.	Cerebellum.	Brain-trunk.	Frontal lobe.	Parietal lobe.	Occipito-temporal lobe.	Lobus caudicis.	Thal. opt.	Mesencephalon.	Pons.	Medulla oblong.
Male . .	785	107	107	415	231	352	583	188	064	118	044
Female . .	781	110	108	419	226	354	595	188	060	112	043

Wealth of cerebral convolutions is supposed to be an index of the superior nutritive development of the human brain. Facts of comparative anatomy are not in accord with this view; for the brains of the monkey, the dog, and the bear exhibit but few convolutions as compared with the brains of cloven-footed animals. But we must remember too that from the ordinary psychological point of view it is difficult for us to gauge the intelligence of an animal; for those that flock together and lead a social life, as it were, must needs adapt themselves to very different conditions from those that lead a solitary life in pursuit of prey. And, on the other hand again, no examination has been made of the nerve-elements of the abundantly convoluted brains of bi-ungulates, though I have shown that the vacant neuroglia-layer receives

a proportionately greater development in the cortex of the roe than in that of the monkey and dog. Furthermore, we shall soon have occasion to prove that the development of cerebral convolutions is governed by laws of mechanics. The convolutions are crowded together in certain directions within the cranial cavity, in consequence of which a check is imposed upon their free development, whence it follows that no direct inference can be made from the wealth of convolutions to the intelligence of an animal. And yet we must not fail to mention that within one and the same species a certain relation does exist between the number of convolutions and the grade of intelligence. Rudolf Wagner has insisted on the greater complexity of convolutions in the brains of men of unusual mental culture. Great difficulty is encountered in the attempt to give a detailed account of the cerebral convolutions of the human brain. Satisfactory results have been reached by those only who were guided by simple scientific principles. Rüdinger, who has won especial fame as the most prominent technical anatomist of the peripheral nervous system, was the first also to insist on such differences as exist in fœtal life between dolichocephalic and brachycephalic brains. This difference in form is claimed to be distinctly recognizable on both the skull and the brain of a fœtus four months old, just as Fehling has recognized sexual differences in the structure of the pelvis at this early age. Rüdinger lays special stress, even at this early period of brain development, upon the influence of mechanical relations, and directs attention not only to the skull, but also to a characteristic tension of the dura, due to a constriction at the coronal suture in dolichocephalic skulls. According to Lucae this constriction extends in the direction of the Sylvian fissure as far as the parietal vertex, and results, in the adult skull, in an excessive (5 *mm.*) thickening of the dura laterad of the small wing of the sphenoid bone. This one circumstance impedes the transverse growth of the brain, and necessitates the greater development of the brain in the longitudinal direction.

As regards sexual differences Rüdinger was able to conclude from an examination of the brains of thirty males and females, that there is a difference in weight even in the fœtus and the newborn child, in favor of the male. He adds, however, that Hecker's statistics, which are based upon a larger number of cases, show this difference to be far less marked. Differences in the development of the convolutions become apparent after the seventh or

eighth month of embryonic life. The same author holds that the parietal convolutions are developed earlier than those of the occipital and frontal lobes; that at birth the convolutions of the frontal lobe in the female are particularly backward; and that the brain of the new-born female infant approximates more nearly the fœtal type. Furthermore, this lesser (retarded) development of convolutions characterizes the female throughout life; so that the average wealth of convolutions is never as great in the female as in the male. Rüdinger increases the force of this statement by saying that sex is a more powerful factor than mere individuality in the development of the brain-surface. And yet, as a matter-of-course, among female brains which are far above the average there will be many that exceed in weight less highly developed brains of the opposite sex.

In one respect the lesser wealth of convolutions in the female is not at all a matter of sexual distinction; but is due rather to the frequent dolichocephalic formation of the female skull (Welcker). We shall see shortly that in dolichocephalic skulls the course of the longitudinal convolutions is in no wise impeded. The anastomoses, which give rise to an increased number of convolutions, can be explained on mechanical principles; for in short (brachycephalic) skulls the longitudinal convolutions cannot be extended to their full length. It was shown (page 14) that, with the exception of the primary (*typical*) radiating convolutions, the convolutions of the cerebral surface were not to be explained by any laws of brain-evolution; but that their development was governed by certain mechanical laws, operating even in early fœtal life, and influencing the formation of the brain within its inflexible bony capsule, the skull. These mechanical laws have been discussed by Henle, in more detailed fashion by Ludwig Meyer, and, as was stated above, by Rüdinger. The last-named author has clearly demonstrated the influence of dolichocephalic and brachycephalic skulls upon the growth of the brain during fœtal life. The direction of the earliest convolutions is, therefore, subject to these mechanical laws. According to Henle's simple hypothesis, the fissures of the surface of the brain will be developed in a plane vertical to those shorter axes of the skull which compress the substance of the brain. Thus in a narrow skull (and as such we must regard the dolichocephalus, since it is not distinguished by absolute length from non-dolichocephalic skulls) there will be but little opportunity for the development of transverse gyri, which

would help to broaden the brain. In brachycephalic skulls, on the other hand, there is a limit to the free development of longitudinal convolutions, and the cortical surface will have to have its duplicatures develop either in a transverse or in a vertical direction. Inasmuch as the *pia mater* follows the fissures between the convolutions, its expansion, and the nutrition of the brain will be modified, as Reichert stated, according as the cortex grows by simple extension and formation of convolutions, or by the formation of duplicatures. There can be no doubt about the influence of these nutritive and mechanical factors upon the development of the convolutions. They cannot be said, however, to exert any influence upon the functions of the cortex; for we have no reason to suppose that the function of nerve-cells varies according as they happen to lie either on the top of a convolution or in the depths of a fissure.

I have endeavored to gather proofs for this mechanical theory from a comparison of the forms of the brain among different animals. In doing this I was compelled to invent lines of measurement which differ from those which have come into general use through Welcker's investigations on the *human* skull. Owing to the differences between the skull of man and other mammals, I have selected "lines" connecting other but more practical fixed points than those of Welcker did. The brains of carnivora, of the fox, the dog, the cat, and the lion, can well be compared with one another. The skull of the fox is the only one which does not come within the order of brachycephalic skulls, for it has an index of 77 %, which expresses the relation of its transverse to its longitudinal diameter. The dog, on the other hand, has an index of 85, and thus falls within the limits of human *brachycephali*.[1] The cat and the lion exceed the latter, their skulls having transverse indices of 97.2 and 98.7. This peculiarity of structure is evident in the four-cornered appearance of the cat's skull. In keeping with these variations in skull-structure, we find, as we ascend in the series of carnivora, a greater and greater development of transverse convolutions. The fox possessing the (relatively) narrowest skull, exhibits a brain in which the longitudinal fissures are most abundantly developed. The dog, again, possesses transverse convolution-loops (Win-

[1] Those people who possess crania with a cephalic index of 80 and above are called *brachycephali*; those with a lower index are *dolichocephali*. For a succinct statement of these relations, see Huxley, "Anatomy of Vertebrated Animals," Am. ed., p. 420.—S.

dungsschlingen) and transverse anastomoses. But Leuret was the first to demonstrate that in the brains of the cat family all the longitudinal fissures are interrupted by typical anastomoses vertical to these fissures. The anastomosis connecting the superior margin of the first longitudinal arch with the second is, in fact, known as the "cat-fissure" (Fig. 9, between arc I. and arc II.; also p. 14). These anastomoses, transverse, as they are, are crowded, as it were, from the depths of the cortical fissures to the surface by a sort of longitudinal stenosis. The brains of the seal and the elephant are *hyper-brachycephali;* for their transverse diameters are greater than their longitudinal diameters. In the seal, the former (the transverse) bears to the latter the proportion of 118.8 to 100. In a young elephant the relation is 128.3 to 100, and in an old elephant, 123.3 to 100. In the seal the transverse axis of the brain is not great enough to compensate for the extreme shortness of the longitudinal axis. This compensation is effected, however, in the anterior portion of the brain-mantle, by the unusual *height* of the brain. This method of compensation is not feasible in the occipital region, where the cerebellum presses from below upwards against the occipital lobe. In consequence of the shortness of the longitudinal diameter of the seal's skull, its olfactory lobe cannot occupy a longitudinal position, but is forced to lie in a vertical direction against the anterior surface of the brain.

For the same reason the Sylvian fissure in the brain of a seal takes a vertical course, and not its customary oblique-longitudinal direction. As a result of the brachycephalic nature of their skulls, the operculum in animals curves downward (Fig. 7) instead of taking a straight longitudinal course; in the seal it has not even an inferior longitudinal margin, and like a wedge with its point downward, pushes its way in between the ascending limbs of the Sylvian fissure, thus making a heart-shaped formation of this fissure.

The skull of the seal, if not more convincing than the other facts of comparative anatomy alluded to above, offers the best illustration in favor of the mechanical theory of the development of brain-convolutions, as against any theory which would ascribe their special formation to purely embryological laws. In the case of the elephant, the necessary result of his brachycephalic skull, *i. e.*, convolutions vertical to the longitudinal axis of the cranium, was recognized by *Leuret*, who declared that the elephant's brain

had three transverse central gyri instead of two as in man, and two transverse central fissures instead of one. A transverse anastomosis between the superior and inferior parietal lobules back of the fissure of Rolando, might lend a similar appearance to the brain of man.[1] In this connection the recent publications of Zuckerkandl will be of great interest to us. This author attempts to explain why it is that the gyri at the frontal and the occipital ends of the human brain are the most tortuous, the narrowest, and most freely supplied with anastomoses, while those occupying the middle portion of the cranial cavity are broader, and develop more freely in a longitudinal direction even though they are cut *across* behind the coronal suture by the sulcus centralis—one of the *typical* fissures which is entirely independent of all mechanical influences. As we had occasion to remark above, there is no impediment to the full longitudinal growth of the median portion of the skull. The synostoses of the transverse coronal and lambdoidal sutures contribute greatly to this end. In this region the skull is broadest also, and the convolutions can therefore develop freely in both the transverse and the longitudinal diameters. In the frontal and temporal region of the hemispheres, however, the convolutions are necessarily crowded more closely together. A more liberal longitudinal development is characteristic also of the anterior temporal convolutions, for these convolutions lie within the middle cranial fossa, where the growth of the brain is in no wise impeded. Zuckerkandl has demonstrated, moreover, on pathological *akrocephali*, that the influence of the stenoses of the skull, due to the synostosis between the lateral portions of the coronal suture and the suture between the small wing of the sphenoid bone and the orbital portion of the frontal bone, was manifest in the greater tortuosity of, and the larger number of transverse anastomoses between, the corresponding convolutions. He demonstrated, furthermore, that, in consequence of the early synostosis of the sagittal sutures in dolichocephalic skulls, so prominent a transverse fissure as the *sulcus occipitalis internus* has its margins torn asunder lengthwise by the development of longitudinal convolutions, which seem by transverse pressure to be crowded out of the depths of this sulcus.

Even L. Meyer fully recognized the importance of mechanical relations. As a result of the sagittal stenosis in the occipital region of a skull, which he examined, he had occasion to observe

[1] Anzeiger der Gesellschaft der Aerzte, Wien, 1876, Nr. 29.

that the convolutions underneath covered one another after the fashion of lids. To this lid-arrangement he applied the term *operculum*, but it is needless to say, in view of the excellence of this author, that he did not think this an instance of an approach to the ape-type.

On pp. 240–243 we dilated upon the intimate relation between nerve-nutrition and the peripheral end-organs. v. Gudden, in a long series of experiments, has proved this relation to exist in the case of the *central* nerve-fibres. This investigator found that if means are taken to deprive a new-born animal of various sensory impressions, by uniting the opposing surfaces of the nostrils, by producing artificial *symblepharon*, etc., there would be a marked arrest in the development of certain portions of the brain. In regard to the sense of smell, he found that the olfactory nerves, the *bulbus olfactorius*, and the medullary substance of the olfactory convolutions arising from this *bulbus* (pp. 21, 41, 70) remained relatively undeveloped. A compensatory thickening was noted (on a frontal section of the skull) over the atrophied portions of the brain; it was observed also that neighboring parts of the brain had pushed forward to fill this void. This arrest of development became still more marked, if instead of excluding peripheral stimuli only, the nerves themselves had been destroyed by scraping out the mucous membrane, and extirpating the labyrinth, of the nose. But the *bulbus* was not affected either by the above experiment or by the unilateral extirpation of the olfactory lobe. This latter statement I am inclined to doubt, from a knowledge of the laws of nutrition; for the medullary substance from the *bulbus* undergoes atrophy, and this substance lies upon the basilar surface of the olfactory lobe. But the atrophy need not be very apparent, for the medullary fibres from the bulbus olfactorius constitute but a small portion of those fibres which enter into the depths of the *lobus olfactorius*.

Furthermore, we have it on the authority of Gudden that the anterior commissure does not diminish in volume after the extirpation of the bulbus olfactorius, for its nutrition is dependent upon the cortical substance of the olfactory lobe. The latter statement may serve to demonstrate the dependence of nutrition upon the central gray substance.

The anterior commissure does not begin to atrophy until the *lobus* olfactorius is removed. This Gudden accomplished at the same time that he removed the entire hemisphere. As a result

of this extirpation there was atrophy also of the corpus callosum, for the nutrition of the latter is dependent altogether upon central nutritive influences—that is, upon the cortex. The truth of this is demonstrated, moreover, by partial extirpation of the cortex,—by the removal of an anterior lobe, in consequence of which there is atrophy of so much of the corpus callosum as corresponds in length to the resected portion of the cortex.

Sewing up the eyelids of a new-born animal (thus excluding peripheral stimuli) was followed by moderate atrophy of the optic nerve, optic tract, and of the anterior corpus bigeminum of the opposite side. The corpus geniculatum internum remains unaffected; while the external geniculate body, lying in animals, upon, and being confluent with, the thalamus (pp. 32 and 33) was not a subject of observation. Extirpation of the retina was more effective; it resulted in gray degeneration (possibly also in arrest of development of the medullary sheaths) of the optic nerve, and the opposite optic tract; also in a more marked atrophy of the corpora quadrigemina. In rabbits which had been thus mutilated, the internal corpus geniculatum and the hemispheres were not affected. There *was* atrophy, however, of the *tractus transversus pedunculi* (Fig. 15, T.). Extirpation of both eyes even was not followed by a diminution of the hemispheres, thus proving again the central nutritive influence of the cortex. It was only in doves that Gudden observed diminution of the hemispheres in addition to atrophy of the optic lobes, following upon extirpation of both eyes. This is particularly instructive, for the atrophy must be attributed to fasciculi of the optic tract in birds, which pass by way of the pes pedunculi into the hemispheres without connecting with the optic lobes.[1] We may infer from this, and from the atrophy of the superior corpora bigemina, or of the optic lobes respectively, that the exclusion of peripheral nutritive stimuli does not tell upon the nutrition of more distant gray substance, which happens to lie beyond the (to it) nearer gray nodal masses in which the fasciculi terminate.

In addition to showing the effect of the removal of the cortex upon fibres of the corpus callosum, Gudden has demonstrated the central nutritive influence by reversing the plan of operation and extirpating the superior corpora bigemina. He found that just as in peripheral extirpations, so here, though in an opposite

[1] The optic lobes, though situated more latero-ventrad, are the substitutes in birds of the corpora quadrigemina.

direction, the operation was followed by a distinct, though less marked, arrest in the development of the optic-nerve tracts.

In an important monograph, Flechsig has discussed the influences of peripheral portions of the projection-system upon the development of more centrally situated members of this system. Flechsig has based his studies upon certain phenomena, to the scientific value of which I was the first, as he acknowledges, to call attention. In the brain of the new-born infant we find, as was well known even to previous investigators, that certain medullary areas are gray instead of white, which is due simply to the lack of development of medullary sheaths. Inasmuch as I was able to perceive the gray appearance of the *pes* pedunculi in the new-born, and the distinct white color of the fasciculi in the *tegmentum*, I inferred that these phenomena were related to the secondary development of *cortical* functions, which must necessarily be preceded in time by the functional development of *subcortical* masses. But the pes pedunculi (pp. 28 and 29) is intimately related to conscious actions (Bewusstseinsleben), whereas the tegmentum is related to those subcortical functions which go on undisturbed after the removal of the fore-brain. The maturing of these tissues seemed to me, therefore, to keep pace with the occasion of their first functional manifestations. Flechsig, in his thorough-going researches on the development of the medullary substance, has worked out this idea in all its details, and, as we must acknowledge, has left little for others to do in this matter. Flechsig discovered that the progressive development of medullary sheaths sustained a definite relation to the length of the fœtus. He proved, furthermore, that the medullary sheaths developed from below upward, and that in the spinal cord and oblongata the white substance became apparent in fœtuses only twenty-five centimetres in length, appearing earliest in the columns of Goll and Burdach. This again is instructive as regards the functions of these parts; for the centripetal nerve-tracts are the keys which start the mechanism of the entire central-nervous system, and we thus see that the peripheral nutritive influence is indicated by the special order in which nerve-tracts acquire their white substance.

Next in the order of development come the anterior columns of the spinal cord, which turn white when the fœtus has reached the length of from thirty to thirty-two centimetres. At this time, the pyramids are still gray. These two facts taken together simply mean that reflex movements are the immediate outcome of the

development of sensory tracts, but that the tracts along which secondary *cortical* impulses are to be transmitted are not yet matured. The peripheral nerves acquire their white substance equally early. The optic nerve, which resembles in structure the central white substance, its fibres having no sheath of Schwann, undergoes changes "within two or three days of extra-uterine life" (the length of the body being but twenty-six centimetres), which far exceed those changes which would take place during a much longer period of intra-uterine life. This shows most distinctly that the nutrition of central nervous tissues is greatly aided by sensory stimuli. Such stimuli are conveyed to a certain extent by the posterior roots of the spinal cord and the higher functionally similar fibres during intra-uterine life, but the influence of light is not felt until after birth. According to Flechsig, other nerve-tracts in addition to those in the spinal cord turn white during the intra-uterine period. The following order is observed: The oblongata, with the exception of the pyramids; the cerebellum, and first the medullary substance of the *vermis;* the *tegmentum* cruris; and next, those bundles of fibres which lie between the large ganglia, and which, judging from Flechsig's plates, correspond to the radiations from the thalamus and mid-brain. These are chiefly centripetal nerve-tracts (pp. 197–204). The white substance appears finally also in the parietal and occipital lobes.

After birth, when the body has attained to the length of seventy-six centimetres, white nerve-bundles appear in the pes pedunculi and the pons. "Soon, too, radiating white fibres, which pass from the brain-axis to the occipital and temporal lobes, lend a white appearance to various marginal areas of these lobes." These radiating fibres were determined by the anatomical researches of Gratiolet and myself (p. 48), and by the experiments of Hitzig and Munk (pp. 146–149), to be centripetal nerve-tracts. "Not until several months after birth does the white substance appear in the frontal lobes, and not until the end of the fourth month do these parts become as white as they remain through life."

The *secondary* development of cortical motor functions is entirely in keeping with the late development of those medullary tracts which are engaged in the performance of these functions. Flechsig was also able to observe that the central cortical area was the first to turn white, and that in proportion as the radiations from the brain-axis took possession of the cortex, the

medullary substance began to spread along the lines of the association-fibres lying within the cortex. This order of development marks the functional growth of the cortex; for the functions of the association-fibres are necessarily secondary to the stimuli from the outer world, conveyed to the cortex by the radiating nerve-tracts from the brain-axis. Upon the basis of the simultaneous or successive appearance of white substance, Flechsig has formulated the following axioms regarding the relations of the super-imposed divisions of distinct medullary systems:

1. Systems of fibres situated one above the other, which develop at very different periods (several months), are not directly connected, one with the other.

2. Mere juxtaposition of bundles which do not acquire their white substance simultaneously is not sufficient proof of any anatomical connection between such bundles.

3. Those fibres which are connected with higher cerebral centres develop latest.

In the clinical chapters of this work we shall have occasion to discuss the diagnostic value of Flechsig's methods of investigation.

APPENDIX.

THE MECHANISM OF EXPRESSION.

Through such movements as are involved in expression we obtain a clue to the inner mental life of others. Up to the present time we have considered movements in their simplest relations, just as we discussed in the simplest manner possible, in the second section of this volume, the formation of the processes of association and induction, which are at the foundation of the whole cortical mechanism. We proceeded in that chapter on the supposition that the cortex initiated volitional, causal, conscious movements only ; we distinguished, according to their purpose, between repulsive and aggressive movements, and concluded that the motives for such actions were supplied by emotions which were in turn intimately connected with movements of the muscular apparatus of blood-vessels. We established also biological relations between movements and the preservation of animal existence.

The laws governing our every movement are obscured only by the phenomenon of free will (page 172). If we attempt to study our movements in all their complexity, we shall discover that there are many which in other persons seem to be purposeless, and in ourselves, unintentional, or unconscious. We are concerned with an order of movements which are not to be explained on the score of expediency ; and yet, since these superfluous movements are entirely similar in many people, we may hope to formulate the laws governing their performance.

This surplus of movements comes under the head of physiognomical phenomena, which we may consider secondary to that large class of (conscious) actions and movements that have a distinct purpose. The old prejudice about the possibilities of inferring the peculiar and special activity of the brain from the configuration of the face or other parts of the body (and that not by reason of knowledge which every one can acquire but, as Lavater presumed to say, by dint of a special talent), does not deserve serious consideration. The special formation of the face is the result of a mechanism which is entirely independent of the brain, and which, as far as the bony structure beneath is concerned, may be modified by morbid conditions which exert an influence upon the nutrition of the whole body.

I shall have occasion in a later portion of this work to refer to such morbid types of features as admit readily of a simple explanation. But as for the movements constituting the mechanism of expression, they are comprehensible to all, since they are the same in others as in ourselves, and are the regular accompaniment of our thoughts and emotions. It will be my object, therefore, not only to study the change of physiognomical expression of the individual, but also to regard each such individual as himself a physiognomist. We shall have to deal with a large number of intelligible, though partly unconscious, and frequently delusional *inferences*, which are based chiefly upon secondary associations.

It is characteristic of movements of expression that they not only have no definite aim, but that they are performed unconsciously. But unconscious performance of

such movements does not necessarily imply that they are effected only by a subcortical motor mechanism, for the original stimulus for such movements is included within the mechanism of association, and this mechanism may operate, as was stated on p. 247, below the threshold of consciousness, and may transmit motor impulses to the periphery though the cortex be not in the state of partial wakefulness. And then again all cortical movements, and, in fact, all cortical functions are secondary ; the question, therefore, arises, whether movements of expression also have a subcortical origin.

Later on the reader will be told that, in accordance with Flechsig's investigations, the subcortical centres cannot be made subject to cortical inhibition, until the previously gray fibres of the cortex have attained functional maturity, *i. e.*, until they are enveloped by medullary sheaths. Subcortical movements are effected along tracts which have acquired their white substance earlier or during the intra-uterine period. The primary reflex movement underlying closure of the eyelids we know to be an experience of the very earliest period of infantile life (p. 156). Possibly we can, at this same early stage, discover the phenomena underlying the mechanism of expression.

In the first instance, then, we may argue that since, in the adult, the movements of expression vary with the emotions, these movements must be either of an aggressive or repulsive character; but in order to substantiate this statement we must determine which are aggressive and which repulsive. We will find, with regard to the child in particular, that all physiognomic phenomona come under these two heads.

Life begins with an inspiration, which is the first instance of the appropriation of external resources through muscular action. This inspiratory act dilates the cavity of the thorax. The respiratory movements have a great physiognomical value. Charles Bell, who up to the time of Darwin was the only scientific physiognomist, seems to have appreciated this fact, for he speaks of the facial—the nerve of mimical expression —as the respiratory nerve of the head. The second act, that of sucking, is also one through which the child draws upon the resources of the outer world. This sucking movement is effected by inspirations, and by the dilation of another body-cavity ; it is a movement of aggression. It is not based upon a reflex mechanism started by tactile stimuli. But it is more probable that the sense of smell, and possibly also the sense of taste, act as reflex stimuli. The participation of the latter sense is probable from the fact that while a child will not begin to suck at a breast which secretes watery milk, it will do so as soon as the milk is of normal concentration. Some maintain, also, that a solution of sugar put upon the nipples will make a child suck more vigorously.

Sucking dilates the stomach just as inspiration expands the thorax. In inspiration, one of the body-entrances—the nasal cavity—is dilated. In sucking, the cavity of the mouth opens and dilates. The acts of sucking and breathing together produce an apnoëtic phase of nerve-respiration, in consequence of the formation of blood and of oxydation. At the beginning the child, like an animal, is guided by its sense of smell only, and at that, imperfectly, for it lacks the power of locomotion. Its tactile sensations are blunt, as Soltmann has insisted ; it cannot see, for during the first three weeks at least its eye oscillates hither and thither, and it certainly has no perception of space.

Reflex movements can be well demonstrated on the upper extremity. Stroking the palm of a child's hand produces closing of the hand ; stroking the dorsal surface produces extension of the fingers. But there are no reflexes of the upper extremity which respond regularly to *stronger* stimuli. This is due, in all probability, to the marked irradiation of all impressions received into the subcortical gray substance. The chief reflex movement is screaming (Schreien), an irradiation upon the expiratory nerves, during which act the expiratory movements may become irregular, and may even be inhibited. Screaming, a repulsive reflex movement, followed by a narrowing of the thoracic cavity, is not attended by crying. But through irradiation screaming is

connected with another movement of repulsion, with closure of the lids, which narrows another body-cavity. Bell connected closure of the lids with respiratory movements. He thought that the former compressed the eyeball, and thus prevented the hyperæmia which might result from the pressure of expiration. But a condition of hyperæmia would be produced by laughing also, which is an aggressive reflex action; and yet there is no active closure of the lids accompanying that act. For this reason it will be better to suppose that closure of the lids is part and parcel of the repulsive reflex *per se*, and is calculated to screen the external world from the individual, instead of putting him, as it were, into possession of that world. Spasmodic closure of the lids, however, exert a pressure upon the lachrymal glands, and starts the secretion of tears. Later in life tears are started by emotions of a repulsive character, without mechanical pressure being exerted. But this is a phenomenon of association. Since the painful impulses leading to repulsive reflex actions have become associated with stimulation of the nerves governing lachrymal secretion, the *motive* of such a reflex act of repulsion will (through the mediation of its cortical image, which has become part of the mechanism of association) suffice to start secondarily the secretion of these glands.

In consequence of irradiation, and the lack of cortical inhibition upon the subcortical gray substance, we find in the child imperfect mimical expression; and in its stead we have pronounced spasmodic contractions, which, according to the spirit of the observer, are interpreted either as laughing or crying. The same is true of those afflicted with *dementia paralytica*. There is undoubtedly nothing akin to laughter in a child under three months of age, although certain contortions of the muscles of expression have been so interpreted. Indeed the question arises whether the union of laughter and pleasurable emotions be not the result of imitation. Laughter is far more conventional than crying, and in the adult does by no means point to an aggressive emotion. Not infrequently it is the concomitant of psychical pain.

In determining the character of the mechanism of expression, we have next to consider whether movements of aggression are not associated with the dilation of the portals and cavities of the body, and those of repulsion with the narrowing of the same. Pleasurable emotion is attended by exalted respiration, and, in the spasm of laughter, may lead to a considerable increase in the number of respiratory movements. Painful (hampered) mood diminishes the number of inspirations, and Charles Bell observed very correctly that sighing is a deep inspiratory movement, which is performed by way of compensation for the preceding diminished respiration, and in response to the dyspnoëtic stimuli acting upon the respiratory centre. The respiratory spasm in crying and sobbing also increases, it is true, the number of respirations, and to this we may ascribe the relief we get by crying during painful emotions. Two popular symbols may well be contrasted: the crescent shape of the mouth, with its convexity looking downward, serves as the expression of happiness; the crescent, with its convexity looking upward, denotes sadness. The crescent, with its convexity downwards, may be taken to be the result of the contraction of the *levator alæ nasi*, which helps to dilate the nostril. And, on the other hand, the muscles that depress the corners of the mouth, also depress the nostrils. The firm closure of the lips is due to the action of the *orbicularis oris*, the *musculi incisivi*, and the *levator menti*.

During a painful emotion the eyeball seems sunken within the orbital cavity; in an aggressive mood it seems to push outward as if to seize upon the world beyond. With the increasing pleasurable emotions of laughter, the cavities of the face widen still more. The nostrils bulge out, the lips separate, the teeth show, and possibly the entire cavity of the mouth may be widely dilated.

I wish to remark at this point that the expressions of emotion are too manifold to allow us to suppose that each has distinct muscular groups of the face at its disposal. The unprejudiced observer may be in doubt as to the meaning of extreme (exceptional) expressions of emotion. Showing of the teeth, and raising of the nostril may accompany the emotion of fury,[1] which is any thing but a pleasurable emotion. These are not the result of reflex action, but of cortical stimuli acting as secondary presentations.

Space-vision on the part of the child excites movements of aggression which aim at the possession of the things it sees ; but as it lacks the power of locomotion, it has no conception of distances. These aggressive reflexes of the upper extremities are no more coördinated in space than the movements of the eyes are before the child has learned to see. The aggressive emotion is attended by great frequency and irregularity of respiratory movements, and through irradiation these movements become general, leading to a tossing of the whole body, to kicking with all fours, and to cutting of grimaces. But these movements, though extravagant, are not spasmodic ; we must look upon them as the result of cortical impulses which have been interfered with by the process of irradiation.

As soon as movements of aggression have taught the child to take hold of things, it is evidently under the impression that it is living in a world of sweets ; it takes every thing to the mouth, and licks it.

A later aggressive movement—kissing,—like the first sucking movements, is probably based upon the act of bringing an attractive object to the mouth. This latter movement is clearly dependent upon a powerful secondary presentation aroused by its impressions, just as the sucking movements during sleep in early life denote secondary presentations excited in the course of dreams. At this period, the acoustic nerve also takes part in reflex impulses ; the child that hears others speak, or perceives other sounds and noises, has the desire to bring forth the same sounds and noises (p. 208). As its cortical functions improve, it develops the secondary idea that the sounds which it brings forth are similar to those of ordinary speech. In all aggressive movements it overestimates the possibilities of its powers ; it tries to force things that are too large into its mouth, to take hold of things that are beyond its reach, and places its incoördinated sounds on a par with the speech of adults. Experience and an improvement in the power of imitation correct these false conclusions. As soon as the child has reached that age at which all cortical fibres have acquired their white substance (Flechsig), the purely reflex movements and those due to irradiation diminish in number. The Darwinian doctrine that ideas are inherited and are not the result of perception and association, that movements, even mimical ones, are the result of innate motives, and have nothing to do with imitation and early reflexes, can hardly be applied to man. Not even his upright gait, which is surely a universal form of movement, is innate in man ; it is acquired with difficulty only through imitation and cortical coördination.

I shall have to refer again and again in the discussion on the pathological forms of physiognomical impulses to the many excellent observations of Darwin, whose views are based upon a larger number of facts than has been at the disposal of other physiognomists. But I must speak first of a few fundamental principles.

In the child the expressions of emotion may vary very much. Under the influence of the apnoëtic effect of the functional hyperæmia attendant upon pleasurable emotions, there will be movements of aggression, bespeaking the force of the child's own personality, or there will be spasmodic movements of repulsion (due to irradiation), such as screaming and crying. All these movements of expression, whether due to irradiation or not, despatch sensations of innervation to the cortex, which (sensations) are there

[1] Its mechanism will be referred to in the second part of this work.

turned into special "memories" and serve later on as impulses starting the entire groups of movements which are involved in expression. Consequently these movements of expression result primarily from stimulation of subcortical centres, just as simpler forms of reflex movements served as the foundation upon which the structure of more complex conscious movements is raised. As soon, however, as these irradiatory impulses, which excite the mechanism of expression, are put under the rule of an organ of motor coördination (the cortex), they acquire secondarily a higher value as psychical factors of expression. In the child pleasurable emotions result in general movements of the entire body ; and even in the adult, who dances for joy or performs other extravagant movements, we have a repetition of these primitive mimical movements of the child. That a state of excessive pleasurable emotion may pass into a condition of maniacal excitement, as the result of a dilatation of the arterial network of the brain, or that a state of pleasurable confusion may end in a transitory swoon (the probable result of subcortical vaso-motor stimulation), has been demonstrated by Darwin.

Wundt says correctly of animals that their speech consists of so-called sensory sounds, and this is true of children before they have acquired the faculty of imitating syllables. In the adult also there is something akin to this particular expression of emotion in the meaningless sounds and notes which are uttered in exultant shouting. A number of special forms of movement, which are associated in the child with pleasing or painful emotions, and are the expressions of aggression or repulsion, may be recognized in the features of the adult, and may be easily traced back to the innervation sensations of infantile movements. A pouting of the lips (rüsselartige Mundstellung), as in sucking, is associated with the expression of contentment, of approval, and may be observed also during the communication by another person of a pleasing thought or argument. On the other hand, an expression resembling faintly that of weeping may be noticed on the receipt of a disagreeable communication or of one from which the listener dissents. It is not probable, however, as Piderit would have us believe, that these peculiarities of expression are connected with secondary association of a sweet or bitter taste. Our "types" of expression are not precise enough to allow of such an exact interpretation.

As regards the movements of the arms, a pleasurable aggressive emotion may give these movements the character of an embrace, of an intention to seize upon the desired object, although the object exciting such emotion may be far beyond the reach of the arms. A repulsive emotion is attended by a repulsive movement of the upper extremity, even though there be no object near by to be repelled. Darwin states that the overflow of psychical excitation, even such as may originate in our thoughts, and which gives rise to a change in our features, is equivalent to an excess of nerve-force, which is exhibited in certain typical forms of expression. This excess of nerve-force we can define quite accurately. It is either the result of present impulses, or of cortical images associated with these impulses, and is dependent either upon irradiation or upon association. Through irradiation this excess of nerve-force may spread beyond the limits of consciousness, and may involve movements in nowise associated with the engaging thoughts of the moment, as is well illustrated in the irregular movements of an orator who has lost the thread of his argument. On the other hand, again, the impulses may represent nutritive processes in allied association-tracts, the functional activity of which is exceeded in intensity, and is inhibited, by the prevailing impressions, or by the conscious and strong, because purposeful, train of thoughts. Of this functional activity of secondary association-tracts consciousness takes no cognizance ; it is relegated to the domain of what Fechner calls partial sleep, and yet may be marked enough to be expressed by associated, though unconscious, movements of the features.

On this point Darwin gives a number of apt illustrations from his own experience

and that of other authors. In regard to the emotions, it is evident that fear is associated with movements which would accompany the actual experience of the evil feared. A person fearing an accident will wring his hands as he would have done if the accident had actually occurred. Rage is accompanied by movements which would be useful in destroying the obnoxious object; by biting movements, by showing of the teeth, by a pounding with the fist, and by movements such as those of treading upon a disagreeable object and trampling it under foot. These movements are the expression of allied (secondary) associations, and are frequently not recognized as conscious movements.

An equal interest attaches to other physiognomical movements which are the expression of allied associations, of parallel presentations attending any quiet train of thought. A vulgar man, or one lost in fruitless thoughts, who scratches his head, acts as though he were experiencing a familiar uncomfortable sensation. Gratiolet remarks, that a man who rejects a proposition will shut his eyes or turn away his face; he acts as though he did not or would not see the thing; but if he accepts the proposition, he will, by nodding, bring his head nearer to the speaker, and will open his eyes widely, as if he clearly saw the thing. Duchenne remarks, that a person in trying to remember something often raises his eyebrows, as if to see it.[1] Engel calls attention to the fact that a person who suddenly finds his thoughts checked will walk slowly or come to a complete halt; he will move on again, as soon as his thoughts move.

From the above we see that physiognomical expression is chiefly a matter of secondary presentations, which are evolved, like dream presentations, from the condition of partial sleep; and that expression is dependent altogether upon the simultaneous excitation of such secondary presentations as are associated with our emotions or our thoughts.

I have a few words yet to add in regard to the emotions, of which I have spoken repeatedly. I discussed their mechanism in the preceding chapter, but for the sake of simplicity did not go into details.

We had contrasted only the emotion of passive grief with that of joy and contentment. The emotion of passive grief is accompanied by ideas of repulsion in regard to the outer world, but not by active impulses of aggression. This emotion is expressed by a narrowing of the cavities of the face and by a dearth of movements—a failure to assert one's own personality among the objects of nature. The corrugators draw the skin under the brows inward, as if to form a roof to shut out the light; the lips are pressed together, the nostrils are depressed, for respiration is weaker, and the features are immovable, in consequence of a monotony of the thoughts. The expression may become complicated through the united action of the inner fasciculi of the frontalis and the corrugator bringing into prominence the so-called wrinkles of grief. The inner end of the eyebrow will be raised, and we then get an expression which, if dependent upon allied associations, may be interpreted to mean that the afflicted one is looking up at his fate or for help.

Passive grief is marked by inattention; the emotion of fear, by greater excitement and attention. In grief there is nothing like the defensive cry brought on by fear. In fear the eyes are kept open, and flight is the active expression of such fear. Movements of flight may be started by allied associations, even in the absence of real danger, and in spite of the will of a person. Fear is probably the neurosis of a subcortical centre (of the oblongata), excitation of which defies cortical inhibition. Darwin relates the following experience: "I put my face close to the thick glass-plate in front

[1] In this paragraph Meynert quotes almost verbatim from Darwin's "Expressions of the Emotions in Man and Animals." *Vid.* Am. ed., pp. 32 and 33. The translator has, therefore, rendered this passage largely in the words of Darwin.—S.

of a puff-adder in the Zoological Gardens. Every idea of danger was entirely secondary; but as soon as the animal struck at me, my resolution went for nothing, and I jumped a yard or two backward with astonishing rapidity."[1]

Fury is a painful emotion, which throws the entire cortex, including its sensations of innervation, into a condition of hyperæsthesia; and this hyperæsthesia is characterized by great tension of all the muscles, which are in readiness, as it were, to perform aggressive, destructive movements.

The phenomena of expression, which we considered hitherto, depended upon irradiation or secondary associations (concepts). But the thoughts and impressions of the physiognomist himself bear the stamp of secondary (parallel) associations. Recognition of an oft-repeated impression is effected with astonishing ease, and as surprising is the mass of physiognomical material stored up in our memories. My own eyesight is very good, and I can recognize at a distance a person whom I never thoroughly looked at. I recognize him, even if he be turning a corner at the very moment I spy him, by the peculiarity of his gait, by a movement of the shoulders, by the way he carries his head, all of which peculiarities have unconsciously been imprinted upon my mind. Physiognomical associations are based, therefore, upon innumerable details, which have been registered in the brain. The special features of a person aid us none in judging of his conscious actions, and yet we cannot help inferring similarity of volitional actions in two persons from similarity in their cast of features. Such conclusions—secondary associations—are the result of impressions which we can scarcely define in words, of innumerable images deposited in the fore-brain. The features of the face, the development of permanent wrinkles, will depend much more upon nutritive changes, upon tension or relaxation of the skin, upon the loss of its elasticity in old age, than upon fixed innervations representing actual forms of expression. Secondary associations (allied concepts) lead us to put an entirely erroneous interpretation upon movements of expression, which are indeed so variable that we are frequently unable to distinguish between the beginning of crying or laughter.

Hanns Virchow has succeeded admirably in suggesting a very fine physiognomical secondary association in regard to the interest attaching to the pupil of the eye. The pupil, he says, is the portal through which we look into the "innermost recess" of another person. A psychical secondary association is connected with the term "innermost recess." We are reminded of the sensation of an "unfathomable depth," which a child experiences on looking through the door of a cellar or down into a well. There can be no doubt, therefore, that our interpretation of expressions is simply a matter of secondary associations. Physiognomists—and all persons are such—are apt to be deceived as to *what* they really see. A person's voice and external appearance may remind us so vividly of another's that, at first sight, we recognize that she must be the sister of the second person. Placed side by side, these two sisters may present entirely different features; the resemblance will lie altogether in certain movements of expression, including those of speech, which one has copied from the other. But the physiognomist referred the resemblance to a similarity of features. I have referred to the condition of the observer—the physiognomist—in order to prove that his judgment is as largely dependent upon the secondary associations of partial psychical sleep as are the phenomena of expression which he has been observing. And to such a conclusion we can surely not ascribe the value of an unerring judgment.

There is another order of secondary concepts, exerting their influence in every phase of consciousness, and dependent upon those sensations of muscular innervation which represent one's own features and carriage, as copied by one individual from

[1] Darwin, *loc. cit.*, p. 38.

another. This image of the personality is subject in most people to certain unconscious æsthetic concepts, which help the individual to govern the innervation of his own features and movements. If movements of expression indicate, to the extent mentioned above, all possible relations to the outer world, or the lack of such relations, then the features and carriage of a person may be said to define his own personality independently of all external considerations. These æsthetic considerations modify personal appearance according to the power of the fore-brain over all innervation, in proportion to the influence of imitation, of taste or lack of taste, which are important factors in the matter of personal appearance, and according to the culture and mental calibre of the individual.

The control which a person possesses over the most movable body-opening—the mouth—may be taken as a measure of his mental strength. Uneducated persons lack this control altogether. The finest shades of expression, which cannot be aptly described in words, are indicated by changes in that depressed region of the face surrounding the lips, bounded above by the naso-labial and below by the genio-labial fold, which region, according to Langer, is never disfigured by the accumulation of adipose tissue.

By far more universal are those physiognomical symbols which the eyes offer and which vary with slight changes in pressure, with a change in the lustre, the position, and the shadow of the eyes.

Every one will be able to distinguish whether certain forms of expression, as indicated by the features or the carriage of an individual, result from unconscious innervation with the aid of secondary concepts, or from conscious innervation in a condition of partial wakefulness. Volitional mimical movements lack the character of spontaneity, and become ridiculous as expressions of foppishness or excite contempt as expressions of falsehood. Intentional movements of expression lack that very charm which is inherent in the unconscious mechanism of expression.

We shall gain a clearer insight into this subject from the study of the pathological changes of expression; and such changes we shall have reason to consider pathognomonic of certain morbid states of the mind.

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