the sensory conductors run in the columns of Goll (Flechsig). The columns of Goll, however, exist only in the cervical and dorsal regions.

The sensory conductors do not decussate at any particular point as do the motor conductors in the crossed pyramidal tracts. The fibres from the posterior roots of the spinal nerves pass to the sensory cells of the posterior cornua and decussate throughout the entire length of the cord (Brown-Séquard). If the cord be divided longitudinally in the median line, there is complete paralysis of sensation on both sides in all parts below the section (Fodéra, 1822, and Brown-Séquard). In this section, the only fibres that are divided are those passing from one side of the cord to the other. This decussation is by fibres prolonged from the cells of the posterior cornua, which cross in the gray commissure, around the central canal.

When one lateral half of the cord is divided in a living animal, sensibility is impaired or lost on the opposite side of the body, below the section, but there is hyperæsthesia on the side corresponding to the section. The exaggeration of sensibility has not been satisfactorily explained.

Relations of the Posterior White Columns of the Cord to Muscular Co-ordination.—It was noticed by Todd, many years ago (1839–1847), in cases of that peculiar form of muscular inco-ordination now known as locomotor ataxia, that the posterior white columns of the cord were diseased. Reasoning from this fact, Todd made the following statement with regard to the office of these columns:

"I have long been impressed with the opinion, that the office of the posterior columns of the spinal cord is very different from any yet assigned to them. They may be in part commissural between the several segments of the cord, serving to unite them and harmonize them in their various actions, and in part subservient to the function of the cerebellum in regulating and co-ordinating the movements necessary for perfect locomotion."

The view thus early advanced by Todd has been sustained by the results of experiments on living animals. If the posterior columns be completely divided, by two or three sections made at intervals of about three-fourths of an inch to an inch and a quarter (20 to 30 mm.), the most prominent effect is a remarkable trouble in locomotion, consisting in a want of proper co-ordination of movements (Vulpian). Experiments upon the different columns of the cord in living animals, however, are so difficult that physiologists have preferred to take the observations in cases of disease in the human subject as the basis of their ideas with regard to the office of the posterior white columns.

The characteristic phenomenon of locomotor ataxia is inability to co-ordinate muscular movements, particularly those of the extremities. There is not of necessity any impairment of actual muscular power; and although pain and more or less disturbance of sensibility are usual, these conditions are not absolutely invariable and they are always coincident with disease of sensory conductors. The characteristic pathological condition is disease of the posterior white columns (columns of Burdach). This is usually followed by or is co-existent with disease of the posterior roots of the spinal nerves

and disease of the cells of the posterior gray matter of the cord. As the cells are affected, there follows ascending secondary degeneration of the columns of Goll. It is fair to assume that the disease of the cells of the gray matter of the cord and of the posterior roots of the spinal nerves is connected with the disorders of general sensibility. The disease of the columns of Burdach produces the disorder in movements.

Reasoning from the characteristic phenomena and the essential pathological conditions of the cord in typical cases of locomotor ataxia, the posterior white columns of the cord, connecting cells of the gray matter in different planes with each other, assist in regulating and co-ordinating the voluntary movements. The fibres of these columns also connect the cord with the cerebellum, which has an important office in muscular co-ordination. It is probable that the appreciation of the muscular sense and the sense of pressure, if these can be separated from what is known as general sensibility, are connected with the action of the fibres of the posterior white columns.

Nerve-Centres in the Spinal Cord.

It has long been known that decapitation of animals does not arrest muscular action; and the movements observed after this mutilation present a certain degree of regularity and have been shown to be in accordance with well defined laws. Under these conditions, the regulation of such movements is effected through the spinal cord and the spinal nerves. If an animal be decapitated, leaving only the cord and its nerves, there is no sensation, for the parts capable of appreciating sensation are absent; nor are there any true voluntary movements, as the organ of the will is destroyed. Still, in decapitated animals, the sensory nerves are for a time capable of conducting impressions, and the motor nerves can transmit a stimulus to the muscles; but the only part capable of receiving an impression or of generating a motor impulse is the gray matter of the cord. If in addition to the removal of all of the encephalic ganglia, the cord itself be destroyed, all muscular movements are abolished, except as they may be produced by direct stimulation of the muscular tissue or of individual motor nerves.

The gray matter of the brain and spinal cord is a connected chain of ganglia, capable of receiving impressions through the sensory nerves and of generating motor impulses. The cerebro-spinal axis, taken as a whole, has this general office; but some parts have separate and distinct properties and can act independently of the others. The cord, acting as a conductor, connects the brain with the parts to which the spinal nerves are distributed. If the cord be separated from the brain in a living animal, it may act as a centre, independently of the brain; but the encephalon has no communication with the parts supplied with nerves from the cord, and it can act only upon the parts which receive nerves from the brain itself.

When the cord is separated from the encephalon, an impression made upon the general sensory nerves is conveyed to its gray substance, and this gives rise to a stimulus, which is transmitted to the voluntary muscles, producing certain movements, independently of sensation and volition. This impression is said to be reflected back from the cord through the motor nerves; and the movements occurring under these conditions are called reflex. As they are movements excited by stimulation of sensory nerves, they are sometimes called excito-motor.

The term reflex, as it is now generally understood by physiologists, may properly be applied to any generation of nerve-force which occurs as a consequence of an impression received by a nerve-centre; and it is evident that reflex phenomena are by no means confined to the action of the spinal cord. The movements of the iris are reflex, and yet they take place in many instances without the intervention of the cord. Movements of the intestines and of the involuntary muscles generally are reflex, and they involve the action of the sympathetic system of nerves. Impressions made upon the nerves of special sense, as those of smell, sight, hearing etc., give rise to certain trains of thought. These involve the action of the brain, but still they are reflex. In this last example of reflex action, it is sometimes difficult to connect the operations of the mind with external impressions as an exciting cause; but it is evident, from a little reflection, that this is often the case.

Reflex Action of the Spinal Cord.—Simple reflex action involves the existence of an afferent (sensory) nerve, a collection of nerve-cells, and an efferent (motor) nerve, the nerves being connected with the nerve-cells. In a decapitated animal, not only are the movements independent of sensation and volition, but no movements occur if the sensory nerves be protected from any kind of impression or stimulation (Marshall Hall, 1832 and 1833). If the cord be destroyed, however, no movements follow stimulation of the surface; and if either the afferent and the efferent nerves be divided, no reflex movements can take place. Experiments upon decapitated animals are in accord with the results of observations upon acephalous fœtuses and in cases of complete paraplegia from injury to the cord.

In the simplest form of a reflex movement, the muscular contraction is confined to the muscle or muscles which correspond, in their nervous supply, to the afferent nerve stimulated; but when the stimulus is sufficiently powerful or when the cord is in a condition of exalted excitability, the impression is disseminated throughout the gray matter, and the entire muscular system may be thrown into action. With feebler stimulation, one side only of the muscular system may respond. When the reaction extends to the opposite side, it is called crossed reflex. The extension of a stimulus conveyed by a single afferent nerve throughout the cord is called irradiation.

When a feeble stimulus applied to an afferent nerve is repeated frequently and at short intervals, general muscular movements are produced. This follows stimuli applied three times in a second, and the effect is increased up to sixteen shocks in a second, but not beyond this number (Rosenthal).

In studying the paths of conduction in the cord it has been seen that sensory conduction takes place through the gray matter and possibly through the columns of Goll, that motor impulses are conducted by the direct and the crossed pyramidal tracts, and that the columns of Burdach are connected with muscular co-ordination. The fibres of the cord that are specially con-

nected with reflex action are probably in the anterior fundamental fasciculi, the anterior radicular zones and the mixed lateral columns.

It is well known that the reflex excitability of the cord is exaggerated by removal of the encephalon. According to Setschenow (1863), certain parts in the encephalon, particularly the optic lobes in frogs, exert an inhibitory influence over the reflex acts of the cord, and as a consequence, the reflex phenomena are more marked when this influence is suppressed.

Various poisons, especially strychnine, have a remarkable influence over reflex excitability. In a frog decapitated and poisoned with strychnine, no reflex movements occur unless an impression be made on the sensory nerves; but the slightest irritation, such as a breath of air, throws the entire muscular system into a condition of violent tetanic spasm. The same phenomena are observed in cases of poisoning by strychnine or of tetanus in the human subject.

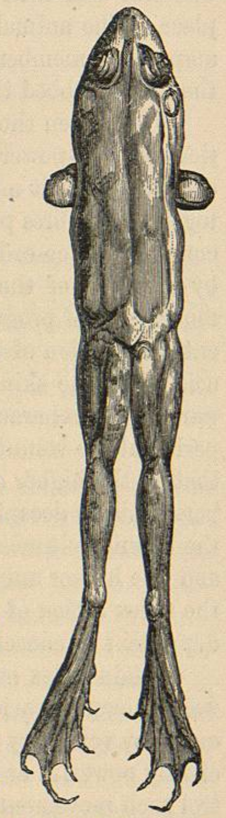

Fig. 218.—*Frog poisoned with strychnine* (Liégeois).

The inhalation of anæsthetic agents may abolish all of the ordinary reflex phenomena. Whether this be due to an action upon the cord itself or to a paralysis of the sensory nerves, it is difficult to determine. Ordinarily, in animals rendered insensible by anæsthetics, the movements of respiration continue; but these also may be arrested, as has been observed by all who have experimented with anæsthetics, especially with chloroform. A common way of determining that an animal is completely under the influence of an anæsthetic is by noting an absence of the reflex act of closing the eyelids when the cornea is touched.

It is only necessary, after what has gone before, to indicate in a general way certain phenomena observed in the human subject which illustrate the reflex action of the cord. It is a common observation, in cases of paraplegia in which the lower portion of the cord is intact, that movements of the limbs follow titillation of the soles of the feet, these movements taking place independently of the consciousness or the will of the subject experimented upon. Acephalous fœtuses will present general reflex movements and movements of respiration, and will even suck when the finger is introduced into the mouth. Observations of this kind are so familiar that they need not be cited in detail. Experiments have also been made upon criminals after decapitation; and although the reflex phenomena are not so well marked and can not be excited so long after death as in cold-blooded animals, they are sufficiently distinct.

General muscular spasms following stimulation of sensory nerves are pathological and take place only when the reflex excitability of the cord is much exaggerated. Examples of this action are the spasms observed in tetanus or in poisoning by strychnine. In experiments on the lower animals, particularly frogs, co-ordinate reflex movements are often observed, such as the movements of jumping or swimming. This is sometimes called purposive reflex action, as the movements seem to have a definite purpose or object. The following well known experiment illustrates a co-ordinate, or purposive reflex:

Pflüger (1853) removed the entire encephalon from a frog, leaving only the spinal cord. He then touched the surface of the thigh, over the inner condyle, with acetic acid. The animal thereupon rubbed the irritated surface with the foot of the same side, apparently appreciating the seat of the irritation, and endeavoring, by a voluntary effort, to remove it. The foot of this side was then amputated, and the irritation was renewed in the same place. The animal made an ineffectual effort to reach the spot with the amputated member, and failing in this, after some general movements of the limbs, rubbed the spot with the foot of the opposite side.

It has been thought that this experiment shows a persistence of sensation and the power of voluntary movements after removal of the entire encephalon; but it must be remembered that the cord contains cells connected together by fibres probably into groups which correspond to sets of muscles concerned in co-ordinate movements, and that many movements set in action by an effort of the will continue in an automatic manner, as the ordinary movements of progression. It is more reasonable to suppose that a persistent stimulation of the surface, such as is produced by the action of acetic acid upon the skin of a frog, can give rise to co-ordinate movements of a purely reflex character than to assume that the movements in Pflüger's experiment are voluntary efforts to remove a painful impression. It is certain that in the higher classes of animals after removal of the encephalon, in experiments on decapitated criminals and in patients suffering from paraplegia, there is no evidence of true sensation or volition in the spinal cord. In man and the higher animals, all muscular movements which depend solely upon the reflex action of the cord must be regarded as automatic and entirely independent of consciousness and of the will.

Certain reflex movements may be restrained by an effort of the will, as is well known; provided, always, that these be movements that can be executed by voluntary effort. Nevertheless, if the sensory impression be sufficiently powerful or be very frequently repeated, it is often impossible to control such movements by the will. Movements that are never in themselves voluntary, such as the ejaculation of semen, when excited by reflex action can not be restrained by a voluntary effort; while the reflex act of coughing, for example, may be measurably controlled. It is hardly proper to speak of inhibition of the reflexes, in the sense in which the term inhibition is generally used in physiology, for the reason that there are probably no special inhibitory nerves for these movements.

Various reflexes are made use of in pathology as means of diagnosis. The superficial reflexes are those produced by tickling the soles of the feet or by exciting other parts of the skin. The most prominent of the deep reflexes is the patellar reflex, or the knee-jerk, produced by percussion of the ligamentum patellæ.

The gray matter of the cord is not a single centre, but consists of a number of centres connected with each other and with the brain. Some of these have already been described in connection with the history of various physiological processes, and others will be considered hereafter under appropriate heads. In addition to those already described, are centres for defæcation, at the fifth lumbar vertebra in dogs (Budge), the erection-centre, in the lumbar region (Eckhard), and the parturition-centre (Körner), at the first and second lumbar vertebræ. All of the spinal centres act in accordance with the general laws of reflex phenomena.

CHAPTER XIX.

THE ENCEPHALIC GANGLIA.

Physiological divisions of the encephalon—Weights of the encephalon and of certain of its parts—The cerebral hemispheres—Cerebral Convolutions—Basal ganglia—Corpora striata, optic thalami and internal capsule—Tubercular quadrigemina—Pons Varolii—Directions of the fibres in the cerebrum—Cerebral localization—General uses of the cerebrum—Extirpation of the cerebrum—Facial angle—Pathological observations—Reaction-time—Centre for the expression of ideas in language—The cerebellum—Physiological anatomy—Extirpation of the cerebellum—Pathological observations—Connection of the cerebellum with the generative function—Medulla oblongata (Bulb)—Physiological anatomy—Uses of the medulla oblongata—Respiratory nerve-centre—Cardiac centres—Vital point (so called)—Rolling and turning movements following injury of certain parts of the encephalon.

The encephalic ganglia are collections of gray matter found in the encephalon, or what is commonly known as the brain. This part of the cerebro-spinal axis is situated in the cranial cavity. It is provided with membranes, which are similar to the membranes of the spinal cord and have been described in connection with the cord and the general arrangement of the cerebro-spinal axis. The gross anatomical divisions of the encephalon are the cerebrum, cerebellum, pons Varolii and medulla oblongata. As regards their physiological uses, the cerebellum, pons and medulla are to a certain extent subordinate to the cerebrum. In treating of the physiology of these parts, it will be convenient to take up first the cerebrum, or the cerebral hemispheres, with their anatomical and physiological connections and their relations to the other parts of the encephalon.

All parts of the encephalon which act as nerve-centres are more or less intimately connected with each other anatomically, and are finally connected, through the medulla oblongata, with the spinal cord. The exceptions to this rule are the centres of olfaction, vision, audition and gustation, which will be considered fully in connection with the physiology of the special senses. The spinal cord, as has been seen, is capable of independent action as a nerve-centre or collection of nerve-centres, also serving as a means of connection between the brain and the parts, through the spinal nerves. The motor and sensory cranial nerves are directly connected with the encephalon.

A detailed anatomical description of the brain would be out of place in