HUMAN PHYSIOLOGY.

CHAPTER I.

THE BLOOD.

Quantity of blood—General characters of the blood—Blood-corpuscles—Development of the blood-corpuscles—Leucocytes—Development of leucocytes—Blood-plaques—Composition of the red corpuscles—Globuline—Hæmaglobine—Composition of the blood-plasma—Inorganic Constituents—Organic saline constituents—Organic non-nitrogenized constituents—Excrementitious constituents—Organic nitrogenized constituents—Plasmine, fibrin, metalbumen, serine—Peptones—Coloring matter—Coagulation of the blood—Conditions which modify coagulation—Coagulation of the blood in the organism—Cause of the coagulation of the blood.

With the progress of knowledge and the accumulation of facts in physiology, the importance of the blood in its relations to the phenomena of animal life becomes more and more thoroughly understood and appreciated. The blood is the most abundant and highly organized of the fluids of the body, providing materials for the regeneration of all parts, without exception, receiving the products of their waste and conveying them to proper organs, by which they are removed from the system. These processes require, on the one hand, constant regeneration of the nutritive constituents of the blood, and on the other, its constant purification by the removal of effete matters.

Those tissues in which the processes of nutrition are active are supplied with blood by vessels; but some, less highly organized, like the epidermis, hair, cartilage etc., which are called extra-vascular because they are not penetrated by vessels, are none the less dependent upon the blood, as they imbibe nutritive material from the blood of adjacent parts.

The importance of the blood in the processes of nutrition is evident; and in animals in which nutrition is active, death is the immediate result of its abstraction in large quantity. Its importance to life can be readily demonstrated by experiments upon the inferior animals. If, in a small dog, a canula adapted to a syringe be introduced through the right jugular vein into the right side of the heart, and a great part of the blood be suddenly withdrawn from the circulation, immediate suspension of all the so-called vital processes is the result; and if the blood be then returned to the system, the animal is as suddenly revived.

Certain conditions, one of which is diminution in the force of the heart's action after copious hæmorrhage, prevent the escape of all the blood from the body, even after division of the largest arteries; but after the arrest of the functions, which follows copious discharges of this fluid, life may be restored by injecting into the vessels the same blood or the fresh blood of another animal. This observation, which was first made on the inferior animals, has been applied to the human subject; and it has been ascertained that in patients sinking under hæmorrhage the introduction of even a few ounces of fresh blood may restore the functions for a time, and sometimes permanently.

Quantity of Blood.—The determination of the entire quantity of blood contained in the body has long engaged the attention of physiologists, without, however, any absolutely definite results. The fact that physiologists have not succeeded in determining definitely the entire quantity of blood shows the extent of the difficulties to be overcome before the question can be entirely settled. The chief difficulty lies in the fact that all the blood is not discharged from the body after division of the largest vessels, as after decapitation; and no perfectly accurate means have been devised for estimating the quantity which remains. The estimates of experimenters present the following wide differences: Allen-Moulins, who was one of the first to study this question, estimated the quantity of blood at one twentieth the weight of the entire body. The estimate of Herbst was a little higher. Hoffmann estimated the quantity at one fifth the weight of the body. These observers estimated the quantity remaining in the system after opening the vessels, by mere conjecture. Valentin was the first to attempt to overcome this difficulty by experiment. For this purpose he employed the following process: He took first a small quantity of blood from an animal for purposes of comparison; then he injected into the vessels a known quantity of a saline solution, and taking another specimen of blood some time after, he ascertained by evaporation the proportion of water which it contained, and compared it with the proportion in the first specimen. He reasoned that the excess of water in the second specimen over the first would give the proportion of the water which had been added to the whole mass of blood; and as the entire quantity of water introduced was known, the entire quantity of blood could be deduced therefrom.

The following process was employed by Lehmann and Weber, and was applied directly to the human subject in the cases of two decapitated criminals: These observers estimated the blood remaining in the body after decapitation, by injecting the vessels with water until it came through nearly colorless. The liquid was carefully collected, evaporated to dryness, and the dry residue was assumed to represent a certain quantity of blood, the proportion of dry residue in a definite quantity of blood having been previously ascertained. If it were certain that only the solid matter of the blood was thus removed, such an estimate would be tolerably accurate.

The process just described gives an idea of the probable quantity of blood in the body; but the most serious objection to it is the possibility that certain solid constituents of the tissues are washed out by the water passing through the vessels, and it is generally thought that the estimate by Lehmann and Weber, that the quantity of blood is equal to about one eighth of

the weight of the body, is too high. More recent observations have been made upon the inferior animals, by various methods, which are all more or less open to objection, and which it is not necessary to describe in detail; but the results of nearly all of the experiments made within the last few years show a less proportion of blood than was estimated by Lehmann and Weber. Remembering that all estimates must be regarded as approximate, it may be assumed that in a person of ordinary adipose and muscular development the proportion of blood to the weight of the body is about one to ten. The relative quantity of blood is less in the infant than in the adult and is diminished in old age. It has been found, also, in observations on the inferior animals, to be greater in the male than in the female.

Prolonged abstinence from food, except when large quantities of liquid are ingested, has a notable effect in diminishing the mass of blood, as indicated by the small quantity which can be removed from the body, under this condition, with impunity; and it has been experimentally demonstrated that the entire quantity of blood is considerably increased during digestion. Bernard drew from a rabbit weighing about two and a half pounds (1,134 grammes), during digestion, ten and a half ounces of blood (300 grammes) without producing death; while he found that the removal of half that quantity from an animal of the same size, fasting, was fatal. Wrisberg reported a case of a female criminal, very plethoric, from whom nearly twenty-one and a half pounds of blood (9,745 grammes) flowed after decapitation. As the relations of the quantity of blood to digestion are so important, it is unfortunate that the conditions in this respect were not noted in the observations of Lehmann and Weber. It is evident that the quantity of blood in the body must be considerably increased during digestion; but as regards the extent of this increase, it is not possible to form any very definite idea. It is shown only that there is a marked difference in the effects of hæmorrhage in animals during digestion and fasting.

General Characters of the Blood.

Opacity.—The opacity of the blood depends upon the fact that it is not a homogeneous fluid, but is composed of two distinct elements, a clear plasma and corpuscles, which are both nearly transparent but which have each a different refractive power. If both of these elements had the same refractive power, the mixture would present no obstacle to the passage of light; but as it is, the rays, which are refracted in passing from the air to the plasma, are again refracted when they enter the corpuscles, and again, when they pass from the corpuscles to the plasma, so that they are lost, even in a thin layer of the fluid.

Odor, Taste, Reaction and Specific Gravity.—The blood has a faint but characteristic odor. This may be developed so as to be very distinct, by the addition of a few drops of sulphuric acid, when an odor peculiar to the animal from which the blood has been taken becomes very marked.

The taste of the blood is faintly saline, on account of the presence of a considerable proportion, three or four parts per thousand, of sodium chloride in the plasma.

The reaction of the blood is always distinctly alkaline. It is not easy, however, to demonstrate the alkalinity of the blood, on account of the red color of the blood-corpuscles; but the difficulty may be avoided by using certain precautions. The following method, employed by Schäfer, is quite satisfactory: A drop of blood is put upon a piece of glazed, reddened litmus-paper. After a few seconds the blood is lightly wiped off with a damp cloth, leaving a spot of a distinctly blue color. According to Zuntz, the alkalinity diminishes rapidly after the blood is drawn from the vessels. The alkaline reaction is due to the presence of sodium carbonate and sodium phosphate in the plasma.

The specific gravity of defibrinated blood is between 1052 and 1057 (Robin), being somewhat less in the female than in the male. The density varies greatly under different conditions of digestion.

Temperature.—The temperature of the blood is generally given as between 98° and 100° Fahr. (36·67° and 37·78° C.); but experiments have shown that it varies considerably in different parts of the circulatory system, independently of exposure to the refrigerating influence of the atmosphere. By the use of very delicate registering thermometers, Bernard succeeded in establishing the following facts with regard to the temperature in various parts of the circulatory system, in dogs and sheep:

1. The blood is warmer in the right than in the left cavities of the heart.
2. It is warmer in the arteries than in the veins, with a few exceptions.
3. It is generally warmer in the portal vein than in the abdominal aorta, independently of the digestive act.
4. It is constantly warmer in the hepatic than in the portal veins.

He found the highest temperature in the blood of the hepatic vein, where it ranged between 101° and 107° Fahr. (38·33° and 41·67° C.). In the aorta, it ranged between 99° and 105° Fahr. (37·22° and 40·55° C.). It may be assumed, then, in general terms, that the temperature of the blood in the deeper vessels is between 100° and 107° Fahr. (37·78° and 41·67° C.).

Color.—The color of the blood is due to the corpuscles. In the arterial system it is uniformly red. In the veins it is generally dark blue and sometimes almost black. The color in the veins, however, is not constant. Many years ago, John Hunter observed, in a case of syncope, that the blood drawn by venesection was bright red; and more recently, Bernard has demonstrated that in some veins, the blood is nearly if not quite as red as in the arterial system. The color of the venous blood depends upon the condition of the organ or part from which it is returned. The red color was first noticed by Bernard in the renal veins, where it contrasts very strongly with the black blood in the vena cava. He afterward observed that the redness existed only during the activity of the kidneys; and when, from any cause, the secretion of urine was arrested, the blood became dark. He was led, from this observation, to examine the venous blood from other glands; and directing his attention to those which he was able to examine during their activity, particularly the salivary glands, he found the blood red in the veins during secretion, but becoming dark as soon as secretion was arrested. In the submaxillary gland, by Faradization of a certain nerve, called the motor nerve of the gland, Bernard was able to produce secretion, and by stimulating another nerve, to arrest it; in this way changing at will the color of the blood in the vein. It was found by the same observer that division of the sympathetic in the neck, which dilates the vessels and increases the supply of blood to one side of the head, produced a red color of the blood in the jugular. He also found that paralysis of a member by division of the nerve had the same effect on the blood returning by the veins.

The explanation of these facts is evident in view of the reasons why the blood is red in the arteries and dark in the veins. Its red color depends upon the presence of oxygen in the corpuscles; and as the blood passes through the lungs it loses carbon dioxide and the corpuscles gain oxygen, changing from black to red. In its passage through the capillaries of the system, in the ordinary processes of nutrition, the blood loses oxygen and gains carbon dioxide, changing from red to black. During the intervals of secretion, the glands receive just enough blood for their nutrition, and the ordinary interchange of gases takes place, with the consequent change of color; but during secretion, the blood is supplied to the glands in greatly increased quantity. Under these conditions, it does not lose oxygen and gain carbon dioxide in any great quantity, as has been demonstrated by actual analysis, and consequently there is no marked change in color. When filaments of the sympathetic are divided, the blood-vessels are dilated, and the supply of blood is increased to such an extent that a certain proportion passes through without parting with its oxygen—a fact which has also been demonstrated by analysis—and consequently it retains its red color. The explanation in cases of syncope is probably the same, although this is merely a supposition, Even during secretion, a certain quantity of carbon dioxide is formed in the gland, which, according to Bernard, is carried off in solution in the secreted fluid.

It may be stated, then, in general terms, that the color of the blood in the arteries is bright red; and in the ordinary veins, like the cutaneous or muscular, it is dark blue, almost black. It is red in the veins coming from glands during secretion, and dark during the intervals of secretion.

Anatomical Elements in the Blood.

In 1661, Malpighi, in examining the blood of the hedgehog, with the imperfect lenses at his command, discovered little floating particles which he mistook for granules of fat, but which were the blood-corpuscles. He did not extend his observations in this direction; but a few years later (1673), Leeuwenhoek, by the aid of simple lenses of his own construction, ranging in magnifying power between forty and one hundred and sixty diameters, first saw the corpuscles of human blood, which he minutely described in a paper published in the Philosophical Transactions, in 1674. To Leeuwenhoek is generally ascribed the honor of the discovery of the blood-corpuscles. About a century later, William Hewson described another kind of corpuscles in the blood, much less abundant than the red, which are now known under the name of white globules, or leucocytes.

Without following the progress of microscopical investigations into the constitution of the blood, it may be stated that it is now known to be composed of a clear fluid, the plasma, or liquor sanguinis, holding certain corpuscles in suspension. These corpuscles are of three kinds:

1. Red corpuscles; by far the most abundant, constituting a little less than one-half of the mass of blood.

2. Leucocytes, or white corpuscles; much less abundant, existing only in the proportion of 1 to 750 or 1,000 red corpuscles.

3. Blood-plaques; varying in size, shape and number.

Red Corpuscles.—These little bodies give to the blood its red color and its opacity. They are organized structures, containing organic nitrogenized and inorganic matters molecularly united and a little fatty matter in union with the organic constituents. They constitute a little less than one-half the mass of blood, and according to the observations of all who have investigated this subject, are more abundant in the male than in the female.

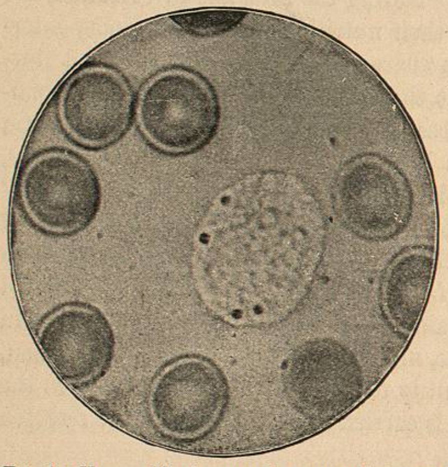

FIG. 1.—*Human blood-corpuscles; magnified* 1,450 *diameters* (Sternberg).
This figure also shows a leucocyte containing four fatty granules.

The form of the blood-corpuscles is peculiar. They are flattened, biconcave, circular disks, with a thickness of one-fourth to one-third of their diameter. Their edges are rounded, and the thin, central portion occupies about one-half of their diameter. Their consistence is not much greater than that of the plasma. They are very elastic, and if deformed by pressure, immediately resume their original shape when the pressure is removed. Their specific gravity is between 1088 and 1105, considerably greater than the specific gravity of the plasma, which is about 1028.

When the blood has been drawn from the vessels and coagulates slowly, the greater density of the red corpuscles causes them to gravitate to the lower portions of the clot, leaving the white corpuscles and fibrin at the surface. If coagulation be prevented by the addition of a small quantity of sodium sulphate, there is quite a marked gravitation of red corpuscles after standing for some hours.

The peculiar form of the blood-corpuscles gives them a very characteristic appearance under the microscope. Examined with a magnifying power of between three hundred and five hundred diameters, those which present their flat surfaces have a shaded centre when the edges are exactly in focus.

This appearance is an optical effect due to the form of the corpuscles; their biconcavity rendering it impossible for the centre and edges to be exactly in focus at the same instant, so that when the edges are in focus, the centre is dark, and when the centre is bright, the edges are shaded.

As the blood-corpuscles are examined with the microscope, by transmitted light, they are nearly transparent and of a pale-amber color. It is only when they are collected in masses that they present the red tint characteristic of blood as it appears to the naked eye. This yellow or amber tint is quite characteristic. An idea of the color may be obtained by largely diluting blood in a test-tube and holding it between the eye and the light.

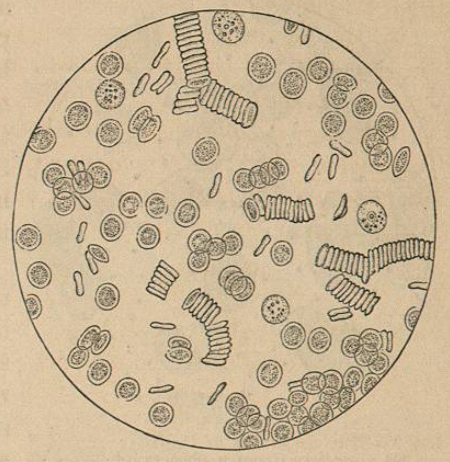

FIG. 2.—*Human red blood-corpuscles, arranged in rows* (Funke).

In examining blood under the microscope, the corpuscles are seen in many different positions, and this assists in the recognition of their peculiar form.

It has long been observed that the blood-corpuscles have a remarkable tendency to arrange themselves in rows like *rouleaux* of coin. This appearance is due to the following conditions:

Shortly after removal from the vessels, there exudes from the corpuscles an adhesive substance which causes them to stick together. Of course the tendency is to adhere by their flat surfaces (Robin). This phenomenon is due to a post-mortem change; but it occurs so soon, that it presents itself in nearly every specimen of fresh blood, and is therefore mentioned in connection with the normal characters of the blood-corpuscles.

The diameter of the blood-corpuscles has a more than ordinary anatomical interest; for, varying perhaps less in size than other anatomical elements, they are often taken as the standard by which an idea is formed of the size of other microscopic objects. The diameter usually given is $\frac{1}{3500}$ of an inch (7·17 μ). The exact measurement given by Robin is $\frac{1}{3437}$ of an inch (7·3 μ). Very few corpuscles are to be found which vary from this measurement. Kölliker, who gives their average diameter as $\frac{1}{3600}$ of an inch (7 μ), states that "at least ninety-five out of every hundred corpuscles are of the same size."

Measurements of the blood-corpuscles of different animals are important, from the fact that it often becomes a question to determine whether a given specimen of blood be from the human subject or from one of the inferior animals. Comparative measurements also have an interest on account of a relation which seems to exist in the animal scale between the size of the blood-corpuscles and muscular activity. In all the mammalia, with the exception of the camel and llama, in which the corpuscles are oval, the blood has nearly the same anatomical characters as in the human subject. In only two animals, the elephant and sloth, are the red corpuscles larger than in man; and in all others, they are smaller or of nearly the same diameter. In some animals, the corpuscles are very much smaller than in man, and by accurate measurements, their blood can be distinguished from the blood of the human subject; but in forming an opinion on this subject, it must be remembered that there is some variation in the size of the corpuscles of the same animal. The blood of the human subject or of the mammals generally can be readily distinguished from the blood of birds, fishes or reptiles; for in these animals, the corpuscles are oval and contain a granular nucleus.

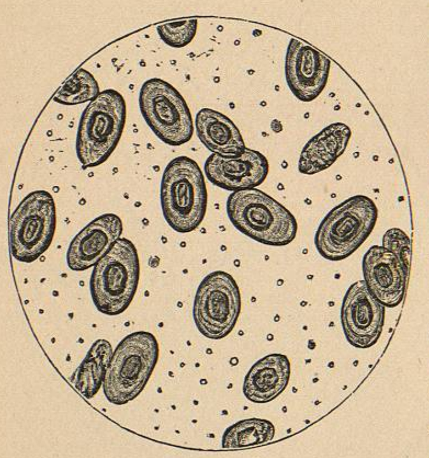

FIG. 3.—*Blood-corpuscles of the frog; magnified 370 diameters* (from a photograph taken at the United States Army Medical Museum).

Milne-Edwards has attempted to show, by a comparison of the diameter of the blood-corpuscles in different species, that their size bears an inverse ratio to the muscular activity of the animal. This relation holds good to some extent, while there certainly exists none between the size of the corpuscles and the size of the animal. In deer, animals remarkable for muscular activity, the corpuscles are very small, $\frac{1}{5000}$ of an inch (5 μ); while in the sloth they are $\frac{1}{2800}$ (8·9 μ), and in the ape, which is comparatively inactive $\frac{1}{3400}$ (7·7 μ). On the other hand, in the dog, which is quite active, the corpuscles measure $\frac{1}{3500}$ of an inch (7·17 μ), and in the ox, which is certainly not so active, the diameter of the corpuscles is $\frac{1}{4200}$ of an inch (6 μ). Although this relation between the size of the blood-corpuscles and muscular activity is not invariable, it is certain that, the higher the animal in the scale, the smaller are the blood-corpuscles; the largest being found in the lowest orders of reptiles, and the smallest, in the mammalia. The blood of the invertebrates, with a few exceptions, contains no colored corpuscles.

Enumeration of the Blood-Corpuscles.—In most of the quantitative analyses of the blood, the proportion of moist corpuscles to the entire mass of blood is stated to be a little less than one-half. This estimate is necessarily rather rough; and it would be useful to ascertain, if possible, the normal variations in the proportion of corpuscles, under different conditions of the system, particularly as these bodies play so important a part in many of the functions of the organism. Actual enumerations of the blood-corpuscles have been made by Vierordt, Weckler, Malassez and others. It is stated by Malassez that the error in his calculations is not more than two or three per cent. The process employed by Malassez is the following:

The blood to be examined is diluted with ninety-nine parts of a liquid composed of one volume of a solution of gum-arabic of a specific gravity of 1020 with three volumes of a solution of equal parts of sodium sulphate and of sodium chloride, also of a specific gravity of 1020. The mixture, containing one part of blood in one hundred, is introduced into a small thermometer-tube with an elliptical bore, the sides of the tube being ground flat for convenience of microscopical examination. The capacity of the tube is to be calculated by estimating the weight of a volume of mercury contained in a given length. The tube is then filled with the diluted blood, and the number of corpuscles in a given length of the tube is counted by means of a microscope fitted with an eye-piece micrometer. In this way, the number of corpuscles in a given volume of blood can be readily estimated. In man, the number in a cubic millimetre of blood—a millimetre = about $\frac{1}{25}$ of an inch—is estimated to be between four and a half and five millions.

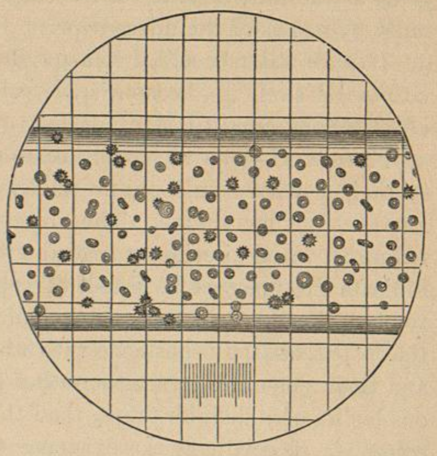

FIG. 4.—*Artificial capillary, filled with a sanguineous mixture, seen under a quadrilateral micrometer* (Malassez).

According to the observations of Malassez, the proportion of corpuscles is about the same in all parts of the arterial system. In the veins, the corpuscles are more abundant than in the arteries. In the venous system, the blood of the splenic veins presents the largest proportion of corpuscles, and the proportion is smallest in the blood of the hepatic veins. These results favor the idea that the red corpuscles are formed, to a certain extent, in the spleen and that some are destroyed in the liver; but further observations are necessary to render this view certain.

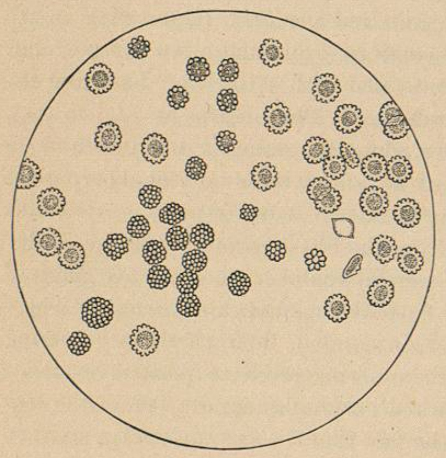

FIG. 5.—*Human blood-corpuscles, showing post-mortem alterations* (Funke).

Post-mortem Changes in the Blood-Corpuscles.—In examining the fresh blood under the microscope, after the specimen has been under observation a short time, the corpuscles are observed to assume a peculiar appearance, from the development, on their surface, of very minute, rounded projections, like the granules of a raspberry. A little later, when they have become partly desiccated, they present a shrunken appearance and their edges are more or