shoots, about an inch in thickness, are peeled in lengths of about a foot. Each quill is usually the bark from half the circumference. The outer bark is not carefully scraped away as in the last, but is roughly and imperfectly shaved off with an instrument resembling a spoke shave. The quills are dried and packed separately. The description of this species is as follows: "In quills of varying length and about 1 mm. or more in thickness; nearly deprived of the corky layer; yellowish brown; outer surface somewhat rough; fracture nearly smooth; odor fragrant; taste sweet and warmly aromatic." This variety tends much more to bitterness and astringency than the last. Its better grades also contain more sugar and gum. Its yield of oil is ordinarily less, and this is usually not quite so fine, though it is the ordinary commercial sort. The special feature of this cinnamon is its variability. Its best varieties are rather sweeter than the last in flavoring, but the taste does not endure so well. Its poorer varieties are scarcely fit for use. The best varieties are the "Java" and "Batavian." They are very carefully prepared from young shoots. The outer bark is entirely removed, the color is a pale yellow-brown, the taste fragrant, sweet, and very mucilaginous. The latter character rather disqualifies it for pharmaceutical uses, but makes it better, if anything, for culinary purposes. The poorest grades are the cheap "Chinese Mats." In preparing them, each packer has three lots of material to draw upon. First, some long quills of fair quality; second, some broken material and chips of very inferior grade; third, sand or other heavy foreign material. These he uses in regular proportions and packs neatly, with the good bark in a thin layer upon the outside. Two small rolls are sewn into a mat. Cassia is the cinnamon almost exclusively used in the household, and the most of this is of the poorer grades, besides which the ground article is enormously adulterated.

SAIGON CINNAMON, CINNAMOMUM SAIGONICUM, "GOD'S CINNAMON."—To this variety also the name *Chinese Cinnamon* is applied. "The bark of an undetermined species of Cinnamomum" (U. S. P.). We are entirely ignorant of the botanical origin of this variety. Although it has frequently been assumed that it is from the same plant which yields the last, its characters almost certainly prove the contrary. For many years we heard of a cinnamon in the unvisited regions of Southern China which was unknown in civilization, and of wondrously fine quality. Its curative properties were almost deified by the Chinese. At length some small lots were brought out, and it has now become a regular article of commerce. Little is known of the methods of its collection or drying. It comes in single quills of a foot in length, none of the outer bark being removed. These are tied neatly in bundles about ten inches in diameter. Each case contains rolls made up of bark of different respective thickness, the intermediate being the best. The thinnest is smoothish and of a dark red-brown. The others are gray or gray-brown and rough, the intermediate granular, the thickest fissured. Saigon cinnamon sometimes comes in chips of very thick bark, sometimes a third to a half inch thick. At its best, this entire thickness is free from astringency and bitterness, fragrant and very sweet, differing markedly in this character of the outer layers from either of the others. It is also peculiar in its sugary sweetness. Its aromatic property also is quite distinct, being biting rather than mild. Altogether, it is the sweetest and strongest of the cinnamons, but at the same time the least permanent as to flavor and odor. It is clearly nearer to cassia than to Ceylon cinnamon. Its best grade is much the most expensive variety of cinnamon. It is subject to substitution by a false article, very closely resembling it, both naturally and in its packing. This article is a cinnamon, and looks as though it might be selected from unpeeled cassia. The intermediate size is that adopted by the Pharmacopœia, and is thus described:

"In quills about 15 cm. long, and 10 to 15 mm. in diameter, the bark 2 or 3 mm. thick; outer surface gray or light grayish brown with whitish patches, more or less rough from numerous warts and some transverse ridges and fine longitudinal wrinkles; the inner surface cinnamon-brown or dark brown, granular and slightly striate; fracture short, granular, in the outer layer cinnamon-colored, and near the cork with numerous whitish striæ forming an almost uninterrupted line; odor fragrant; taste sweet, warmly aromatic, somewhat astringent."

Some other cinnamon species and products, including the oil of cinnamon, will be discussed at the close of the article.

Composition.—The general composition of the bark has already been given. The only constituent that can by any reasoning be classed as medicinally active is the oil, which exists in the proportion of one-half to one and one-half per cent.

Action and Uses.—Aside from its use as a condiment, and as an adjuvant in the pharmacy, its properties and uses are entirely those specified under the title of the oil.

Preparation.—The only medicinal preparation, strictly speaking, other than those of the oil, is the ten-per-cent. tincture, made from the Ceylon variety, the dose being 4 to 8 c.c. (fl. ʒ i.–ij.). The dose of powdered cinnamon of any variety is 0.5 to 2 gm. (gr. viij.–xxx.). Ceylon cinnamon enters into the aromatic powder, and cassia into the compound tinctures of cardamom, catechu, and lavender, but none of these are proper preparations of cinnamon as such. Saigon cinnamon enters into no preparation.

Cassia Chips.—These are the trimmings of cassia bark which cannot be utilized as cinnamon, but which yield a certain amount of oil upon distillation.

Cassia Buds or Cassia Flowers are the unripe fruits, not only of the species above named, but also of *C. Tamala* Nees ab Eberm. and *C. dulce* N. ab E. *C. daphnoides* Sieb. and Zucc. and *C. Loureirii* Nees yield a very poor quality of a false cinnamon. The leaves of *C. obtusifolium* Nees, *C. iners* Reinw., *C. nitidum* Hook., *C. Tamala* N. ab E., and some other species have been articles of commerce under the name of Malabathrum leaves. The bark of various species have found minor uses in medicine, chiefly as anti-diarrhœal agents, acting partly by their tannin and partly by the volatile oil.

Henry H. Rusby.

CINNAMON, OIL OF.—OLEUM CINNAMOMI. The origin of this oil has been sufficiently explained. Our Pharmacopœia directs that it be distilled from cassia cinnamon, not because that of Ceylon cinnamon is unsatisfactory, but because the two, if first class, are hardly to be distinguished, and practically all of the oil of commerce comes from cassia. Much of the commercial oil is said to be distilled from the leaves. While ordinary oil of cinnamon can be had for two or three dollars a pound, that of the Ceylon brings twenty, and is no better. The following is its official description:

"A yellowish or brownish liquid, becoming darker and thicker by age and exposure to the air, having the characteristic odor of cinnamon, and a sweetish, spicy, and burning taste. Specific gravity, 1.055 to 1.065 at 15° C. (59° F.). Soluble in an equal volume of alcohol, the solution being slightly acid to litmus paper; also soluble in an equal volume of glacial acetic acid. When shaken with a saturated solution of sodium bisulphite, it solidifies to a crystalline mass. If four drops of the oil, contained in a test tube, be cooled to 0° C. (32° F.), and then shaken with four drops of fuming nitric acid, crystalline needles or plates will be formed. If a portion of the oil be shaken with water, and the liquid passed through a wet filter, the clear filtrate should give, with a few drops of basic lead acetate T. S., a white turbidity, without a yellow color (absence of oil of cloves). If four drops of the oil be dissolved in 10 c.c. of alcohol, the subsequent addition of a drop of ferric chloride T. S. should produce a brown, but not a green or blue, color (absence of oil of cloves or of carbolic acid). If 1 c.c. of the oil be mixed with 3 c.c. of a mixture of three volumes of alcohol and one volume of water, a clear solution should result; and if to this solution there be gradually added 2 c.c. of a saturated solution of lead acetate in a mixture of three volumes of alcohol and one volume of water, no precipitate should be produced (absence of petroleum, or of colophony)."

The active constituent of this oil is *cinnamic aldehyde.* It should contain not less than seventy-five per cent. of it, and eighty-five per cent. is easily attainable. Since the relative values of different samples are exactly proportional to the percentage of this substance, and since the latter can be purchased and its purity readily determined, a great gain would be made by using it instead of the oil. It is readily oxidized into cinnamic acid. Oil of cinnamon possesses the ordinary properties of volatile oils (see *Active Constituents of Plants*) and is peculiar among them because of its being generally regarded as the most agreeable, and because it is probably the most highly antiseptic of them all. The dose is ♏ i. to v. We have two official preparations, the water, strength one-fifth of one per cent. and dose 15 to 30 c.c. (℥ ss.–i.), and the spirit, strength ten per cent. and dose 0.5 to 2 c.c. (8 to 30 m.).

Henry H. Rusby.

CINNAMYL-META-CRESOL. See *Hetocresol.*

CIRCULATION OF THE BLOOD.—I. COMPARATIVE AND HISTORICAL INTRODUCTION.—The term circulation as applied to the blood was first used in physiology by Cesalpino (1569) to describe the true path taken by it in its passage from the right to the left side of the heart. The Galenic doctrine, according to which this passage was made by way of pores in the intraventricular septum, was accepted without question until Servetus (1553) and Vesalius (1555) established anatomically the soundness and impermeability of the septum of the heart. The idea of the actual path by way of the pulmonary vessels seems to have suggested itself immediately, this course being correctly described in the writings of Servetus and Columbo (1559); and although a pure surmise from the logical necessities of the case and unsupported by experimental proof, it quickly gained acceptance and was named "circulation."

By extension the term has come to be applied to the motion of the blood in animals generally, however irregular and variable this may be. The comparative physiologist speaks of the circulation of the blood even in those invertebrate animals in which neither heart nor vessels exist, and in which a sluggish ebb and flow of the blood through irregular tissue spaces and perivisceral cavities alone occurs, the movement being the result of contractions of the alimentary canal and the body generally. Etymologically the word circulation would be applicable only to the conditions found in the fishes, birds, and mammals. The accompanying diagrams of the vascular systems of the crayfish, fish, frog, and mammal will serve to illustrate some of the fundamental differences found in the animal series in respect to these organs.

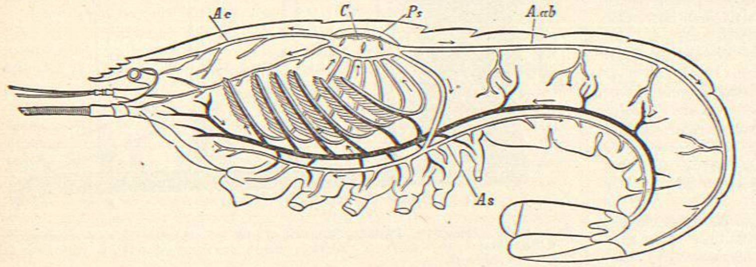

FIG. 1325.—Heart and Blood-Vessels and Gills of the Crayfish. *c*, Heart in a blood sinus, with *Ps*, several pairs of ostia; *Ac*, cephalic aorta; *A.ab*, abdominal aorta; *As*, sternal artery.

As to the invertebrate type, represented here by the crayfish, two distinguishing peculiarities are to be noted. In the first place, the heart and blood-vessels do not form a closed system of channels. However highly developed the vascular system in them may be, it will be found that in some part or parts of the body the vessels terminate and the blood flows into so-called "lacunæ" or tissue spaces not bounded by any limiting membrane. This condition obliterates the distinction between blood and lymph and leads to the use of such terms as "hydrolymph" and "hæmolymph" for the blood of these animals. The other characteristic feature consists in the fact that the blood returns to the heart from the respiratory apparatus where one is present, instead of from the body generally, constituting a so-called "arterial heart."

Compare in both these respects the diagrams of the circulation of the lobster (Fig. 1325) and fish (Fig. 1326). In the latter the system of vessels is a closed one, and the heart functions as a venous organ. In the air-breathing vertebrates further changes in the circulatory organs accompany the appearance of pulmonary respiration. The tubular heart of the fish, with its four consecutive chambers, is replaced by an organ with a median partition. In the frog (Fig. 1327) the right and left auricles are completely separated in this way, while the ventricle remains a single chamber. A partial ventricular septum of increasing proportions is found in the turtles, snakes, and lizards, becoming complete only in the highest of the reptilia, the crocodiles, as it is in birds and mammals.

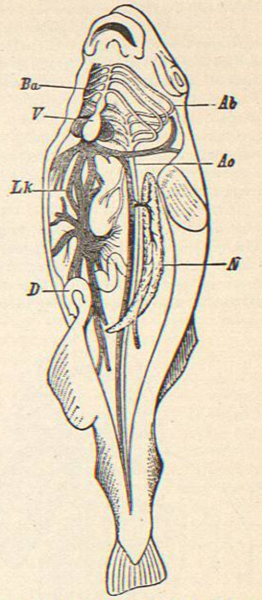

FIG. 1326.—Diagram of the Circulatory Organs of an Osseous Fish. *V*, Ventricle; *Ba*, aortic bulb, with the arterial arches which carry the venous blood to the gills; *Ao*, dorsal aorta, into which open the vessels from the gills or branchial veins, *Ab*; *N*, kidney; *D*, alimentary canal; *Lk*, portal circulation.

The above variations in the structure of the heart are attended by certain changes in the arrangement and connections of the main vessels arising from it, especially as regards the extent of the communication between the aortic and pulmonary arteries. The result of both series of changes is to secure an increasing amount of separation between venous and arterial blood. The venous blood of the right auricle in frogs mingles rather freely with the arterial blood of the left auricle when they reach the common ventricle. This occurs, to a diminishing extent, as the interventricular septum develops; but even in the crocodilia, in which it is complete, the mixing of the two kinds of blood is not wholly avoided, since there remains a communication—the foramen of Panuzzi—between the right and left aortic arches.

In birds and mammals the motion of the blood again becomes a true circulation, and a particle of it starting at any point of the system must make a complete circuit before it passes that point again. Accomplishing this it will traverse at least two capillary networks, the systemic and the respiratory, as was the case in fish also; but besides, it passes twice through the heart, in this respect differing from the fishes. The venous heart of the latter has been replaced by a double organ with a right venous side which transfers the blood from the systemic veins to the pulmonary arteries; and a left arterial side, which returns it again from the pulmonary veins to the aorta, each half being further subdivided into an auricular and a ventricular chamber.

A third set of capillaries may be interpolated in the course of a single circuit. Thus, the blood which supplies the stomach, intestines, pancreas, and spleen is collected in the portal vein and must pass through the capillaries of the liver before it can reach the heart. This constitutes what is known as the "portal or the hepatic portal circulation," and the arrangement is universal among all the vertebrates. An analogous condition is found in the "renal portal circulation" of the reptiles, amphibia, and fish.

The perpetual motion of the blood in a circle through the heart, arteries, and veins was discovered by William Harvey in 1616. Guided by the important anatomical discoveries of the preceding century, the true significance and import of which he first correctly appreciated, the illustrious Harvey succeeded by a series of wisely planned and skilfully executed experiments in overcoming the prevailing misconceptions and in giving us an account of the circulation which in all its general features remains substantially correct after the lapse of more than three centuries. Beginning with the heart, he studied both the rhythm and the sequence of its beat, and emphasized the fact that the systole constituted the active phase while the diastole was passive. He noted the beginning of the beat in the auricles, which contracting together, discharge their contents into the ventricles; that these then follow with their contraction, the right ventricle driving the blood into the pulmonary artery, the left ventricle into the aorta. The lesser circulation through the lungs having been described before, Harvey could only confirm this fact by new evidence from comparative anatomy and embryology. His essential contribution consisted in tracing the fate of the blood pumped into the aorta, and showing that this travelled peripherally in the arteries, was transferred somehow to the veins, and in them was carried in a centripetal direction back to the right auricle. The nature of the connection between the arteries and veins at the periphery Harvey was unable to make out, although the fact of its existence was indisputably established. This last link which was needed to complete the circuit came with the discovery of the capillaries by Malpighi (1661), four years after Harvey's death.

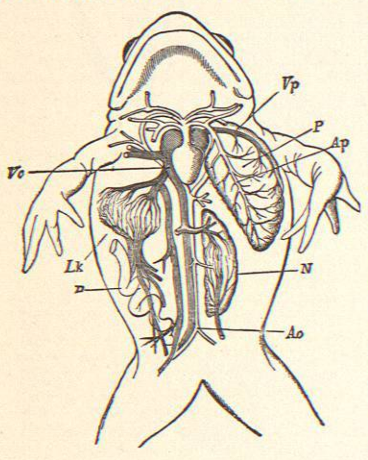

FIG. 1327.—Circulatory Organs of the Frog. *P*, Left lung—right lung is removed; *Ap*, pulmonary artery; *Vp*, pulmonary vein; *Vc*, vena cava inferior; *Ao*, dorsal aorta; *N*, kidney; *D*, alimentary canal; *Lk*, portal circulation.

Confirmation of the work of Harvey soon accumulated from various sources. Leeuwenhoek (1669) saw the circulation of the blood in the vessels of the bat's wing, the tail of the tadpole, and the fins of fishes. About the same time the methods of injection were carried to a high degree of perfection, so that Swammerdam and Ruysch by this means also demonstrated the continuity of the arteries and veins at the periphery. Our knowledge of the circulation has been extended and perfected since that time in many directions. Some of the more notable advances include the discovery of the lacteals (Asselli, 1662) and lymphatics, of the cardiac (E. H. and E. F. Weber, 1845; von Bezold, 1860–1866; M. and E. Cyon, 1866; Schmiedeberg, 1870) and vaso-motor nerves (Cl. Bernard, 1849) and the introduction and application of the graphic method to the study of the movements of the heart and blood-vessels (Ludwig, Marey, etc., etc.).

II. MECHANICS OF THE CIRCULATION.—The closed system of channels through which the blood circulates includes the heart, arteries, capillaries, and veins. The first of these is essentially a muscular force pump whose rhythmical strokes at the rate of about 72 per minute drive the blood through the vessels in a constant direction with a considerable velocity. Before taking up the action of the central pump, it will be convenient to note the general features of this blood current.

Its study is essentially a physical problem in hydrodynamics whose complete theoretical treatment is rendered practically impossible by the complex arrangement and mode of branching of the vessels, by the constant change in the physical properties of their walls along their length, and by the continual interaction of their physiological activities. An account of the mechanics of the flow in the vessels must be based mainly on empirical data, and the fundamental laws of hydrodynamics which are here introduced are intended merely to assist in the interpretation of these data.

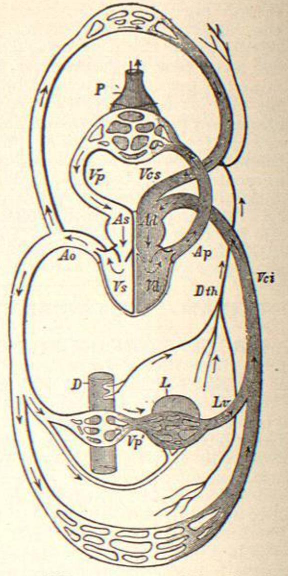

FIG. 1328.—Diagram of the Circulation in an Animal with a Completely Separated Right and Left Ventricle and a Double Circulation. (After Huxley.) *Ad*, Right auricle receiving the superior and inferior venæ cavæ, *Vcs* and *Vci*; *Dth*, thoracic duct, the main trunk of the lymphatic system; *Ad*, right auricle; *Vd*, right ventricle; *Ap*, pulmonary artery; *P*, lung; *Vp*, pulmonary vein; *As*, left auricle; *Vs*, left ventricle; *Ao*, aorta; *D*, intestine; *L*, liver; *Vp*, portal vein; *Lv*, hepatic vein.

A. *The Flow of Liquids in Rigid and Elastic Tubes.*—Torricelli's theorem states that when water escapes from an aperture in the side of a reservoir filled to a constant level, the velocity of outflow theoretically is given by the formula $V = \sqrt{2gH}$, in which g equals the acceleration of falling bodies produced by gravity and H equals the height of the column of liquid above the aperture. The actual velocity is obtained by dividing the amount which flows out in a unit of time by the cross section of the aperture, and experiment shows that this is less than the theoretical value. A part of the energy of position represented by the column of liquid H is lost at the aperture through the mutual interference of the particles of water as they approach the opening from different directions, the result of which is the so-called "contractio venæ" near the beginning of the jet. If the lost fraction of the total energy be represented by a column of liquid equal to h_0, and the energy spent in giving velocity by h, then the total height $H = h_0 + h$. Now suppose a horizontal, rigid tube of some length attached to the aperture in the reservoir (see Fig. 1329). The velocity of outflow from the end of the tube can again be calculated from the volume of outflow and the cross section of the tube; then by substituting this value of v in the formula $v = \sqrt{2gH}$, it will be found that h, the portion of the total energy of position H that is available for velocity, is less than in the case of the free aperture. A second portion of H has been consumed in overcoming the resistance in the tube. Call this part h_1, then $H = h_0 + h + h_1$.

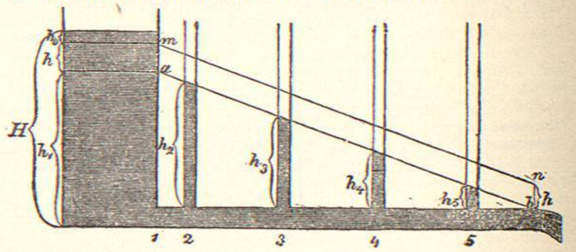

FIG. 1329.—Diagram Illustrating the Flow of Liquids in a Horizontal Rigid Tube of Uniform Calibre, when connected with a reservoir. (From Rollett.)

When liquids wet the sides of the tube through which they are flowing, the layer of particles next the wall of the tube may be considered practically at rest on account of adhesion. The layer next within moves along slowly, the next a little faster, etc., the velocity increasing with each successive layer to the axis of the tube, where it reaches a maximum. By the velocity of the whole stream as calculated for the tube above is meant the mean or average velocity of all the layers, and it has been shown that when the bore of the tube falls within certain limits so that the movement of each particle of liquid is parallel to the axis, this mean velocity equals one-half the axial or maximal velocity.

The resistance to the flow of liquids in tubes thus appears as a case of internal friction, as if the whole column of liquid were made up of a series of concentric cylinders, each moving a little faster than the next larger, and the outermost one completely at rest against the sides of the tube. This internal friction constitutes a resistance which retards the flow and puts the liquid under tension felt as lateral pressure against the walls. Gauges arranged along the tube (h_2, h_3, h_4, h_5, Fig. 1329) to indicate this pressure show that at each point it is proportional to the amount of resistance beyond and that it becomes zero at the free outlet. In tubes of uniform calibre the lateral pressure drops uniformly; but where narrower and wider sections alternate, the fall is irregular for obvious reasons.

Liquids being incompressible, the amount of fluid passing each cross section anywhere along the tube in a second must be the same; the rate of flow, therefore, at each point will be inversely proportional to the width of the tube. The more rapid flow and consequent increase of internal friction in the narrow portions make heavier draughts on the store of available energy, and the lateral pressure falls more quickly here than in the wider portion.

In a system of tubes like the blood-vessels, in which the main channel subdivides dichotomously into numerous smaller branches whose total sectional area far exceeds that of the original trunk and in which these branches are gathered again into a single small tube, the velocity is determined by the same law of inverse proportion to the width of the bed, and is therefore slowest in the smaller tubes where the total area is greatest. On account of the slowness of the current, the pressure should fall slowly in this region; but the increase of surface in the numerous narrow channels operates the other way, so that the actual rate of fall in the pressure will depend on the relative magnitude of these two opposing factors.

As regards the nature of the tube, the same laws apply with equal force whether the walls are rigid or elastic provided only the flow is continuous and uniform. When, instead of the steady, continuous pressure of a column of liquid, an intermittent force is used to drive the liquid into the tube, the character of the wall makes its influence felt. The capacity of a rigid tube being invariable, the inflow and outflow must be synchronous and equal in amount; an intermittent charge necessarily implies an intermittent discharge. An elastic tube when short and wide behaves in the same way; but if from increase of length or constriction at the outlet resistance arises, the outflow no longer corresponds in time to the inflow. The injected liquid is partly retained by the tube, whose walls yield to the distending force of the lateral pressure, and is discharged only in the succeeding interval by their elastic recoil.

If the intermittent influx is rhythmically repeated at sufficiently short intervals, each new charge arriving before the previous one has been displaced, the outflow becomes continuous. By properly adjusting the resistance in the tube to the force, rate, and stroke of the pump, an elastic tube can be made to convert a rhythmic intermittent current into a continuous even stream, just as the elastic air cushion does in the ordinary fire engine.

B. *The Blood Flow in the Vessels.*—1. General Account of the Vascular System. The arteries and veins physiologically are merely conducting channels to and from the capillaries, which alone are fitted by the structure of their walls to bring the blood into nutritive relation with the tissues and enable it to fulfil the function of an internal medium. The arteries possess stout walls which are both elastic and contractile. Their elasticity is slight but perfect, yielding readily to a distending force, but returning to their original size as soon as the distending force is removed. As in skeletal muscle, the coefficient of elasticity is not constant; it increases with the load, and the curve of extensibility is approximately an hyperbola. The result is that the distention of the arteries under the influence of a rising blood pressure soon approaches the point where any further increase of size requires a disproportionately great rise of pressure. The cohesion of the vessel walls is also considerable and capable of withstanding many times the strain normally put upon them in the body. The carotid of the sheep, for example, is ruptured only when fourteen times the usual pressure it is called upon to bear is put upon it, and the human carotid resists a pressure of eight atmospheres. The relative proportion of muscular and elastic tissue varies in different arteries, the elastic tissue predominating in the larger arteries near the heart, while the smaller ones nearer the periphery are eminently muscular and contractile. It appears from the data available up to this time that for a given rise of pressure the distensibility of the arteries increases with their distance from the heart. These physical properties evidently adapt the arteries to the work of converting the intermittent discharges of the heart into a continuous and steady flow in the capillaries and of regulating the distribution of the blood according to the needs of the several organs. As they leave the heart the arteries continually break up into smaller branches until they terminate in the capillaries. At each point of bifurcation the resulting branches individually are smaller than the parent vessel, but taken together their area is greater. Hence the sectional area of the arterial bed increases steadily toward the capillaries, the total cross section of which is several hundred times that of the aorta.

The capillaries with their delicate endothelial walls are elastic, and yield readily to changes of internal pressure. This alone would account for the observed variation in the size of their lumen within the wide limits of 5 to 20 μ; but in addition they are believed to possess the power of active contractility. The veins have thin walls in which white fibrous tissue predominates, but in which some elastic and muscular elements also occur. Their curve of extensibility is similar to that of the arteries, while their cohesion is even greater. Given a vein and an artery of the same thickness, a greater pressure is required to rupture the former than the latter. The elasticity and contractility of the veins serve mainly to adapt the capacity of the whole vascular system to variations in the quantity of blood, and thus to regulate the filling of the heart in diastole. The cross section of the bed again diminishes in the veins in passing from the capillaries to the heart; but since the venæ cavæ together have nearly twice the area of the aorta, the total capacity of the veins far exceeds that of the arteries. The veins, in fact, can

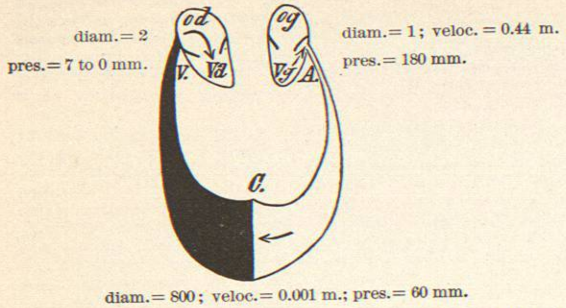

FIG. 1330.—Schema of the Major Circulation. *AC*, Arterial cone; *CV*, venous cone; *C*, capillary expanse.

easily hold the total blood of the body, as is practically the case after death when the arteries are empty, and in the paradoxical experiment of bleeding an animal to death into its own veins.

2. The Blood Pressure. Familiar experiences of daily life have long since made some of the differences between the character of the current in the arteries and in the veins a matter of common knowledge. The arteries present to the finger a sense of resistance which increases rhythmically at each heart beat and expands their walls—producing the so-called "pulse." When an artery is severed, the blood spurts from its central end with considerable force, the jet being continuous but not equable. Finally when an artery is ligated, it swells on the proximal side, while on the distal side the pulse disappears and its walls collapse. Compare with all this the behavior of the veins: they are soft and easily compressed; there is no pulse; the blood issues in a gentle, continuous stream from the distal cut end, and a ligature distends them on the peripheral side. These facts demonstrate a difference not only in the direction of the current in the two kinds of vessels, but also in the tension or internal pressure.

Stephan Hales first measured the pressure in the arteries of living animals (1733). His method was to connect the central end of an artery with a vertical tube and to read off the height to which the blood rose. Owing to the error from loss of blood and to inconvenience from frequent clotting in the tube, the original method is not suited for prolonged and accurate observations. The mercury manometer was substituted by Poiseuille (1828) to meet these difficulties, and this instrument, with a float and writing style added, marks the beginning of the use of the graphic method in physiology. The mercury manometer satisfies the requirements in all cases involving questions of mean blood pressure and remains in general use for this purpose. On account of its great inertia, however, it cannot record with accuracy the finer shades of variations, especially when sudden and extensive, like those produced by the systole and diastole of the heart. Various forms of spring manometers have been devised to register these changes of pressure, some of them having developed the capacity of responding accurately to a change of 10,000 mm. of mercury per second.

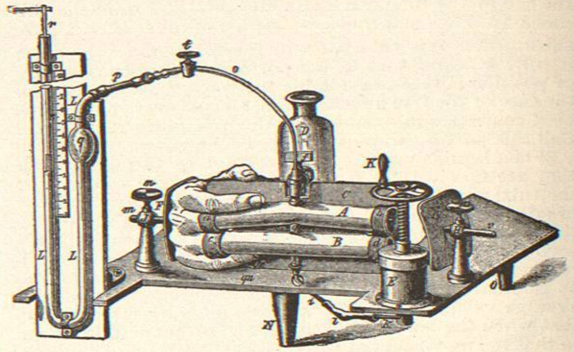

FIG. 1332.—Sphygmomanometer of Mosso.

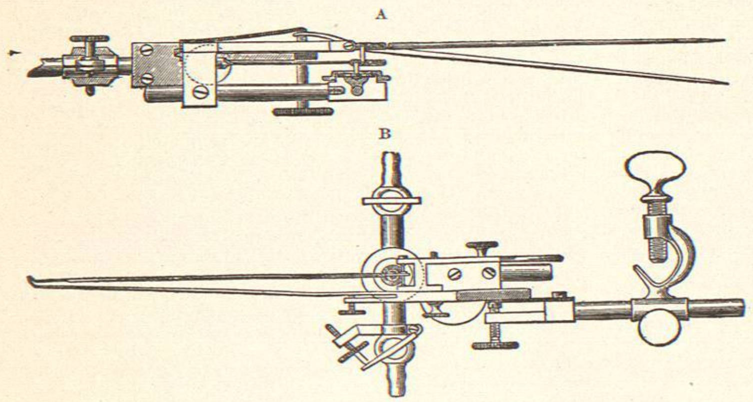

FIG. 1331, A and B.—Hürthle Spring Manometer.

These methods are rarely applicable to man as they require vivisection, and special devices had to be invented to obtain records of the blood pressure in human beings. Among these the sphygmomanometer of von Basch has been found of some practical value by clinicians. The instrument in reality determines the pressure required to obliterate the pulse beyond the point of application, and gives therefore only an approximate idea of the blood pressure; it can, moreover, be used only on superficial arteries whose position provides for a firm background. While the absolute values which it gives are unreliable, the limits of error extending from 32 to 78 mm. Hg (Tigerstedt), it is fairly well adapted for obtaining relative values for a given individual and within certain time limits.

More recently Hill[1] and Mosso[2] have constructed instruments which promise better results. They are based on the principle that the amplitude of the pulse oscillations is greatest when the blood pressure on the inside of an artery is exactly balanced by pressure from without. These instruments also have their practical limitations, but valuable data are confidently expected to accumulate when they become more widely known.

Direct measurement by one or another of the methods enumerated above shows that: First, the mean blood pressure is highest in the aorta, and that it diminishes along the arterial tract from the heart toward the capillaries. For example, aortic pressure in the dog = 130 to 180 mm. Hg; rabbit = 100 to 130 mm. Hg; horse = 150 to 200 mm. Hg.

In man the aortic pressure cannot be determined directly; but in view of the comparatively small differences among mammals of all sizes, it is usually assumed to be about 150 mm. Hg, an estimate which is entirely consistent with the results obtained on more

peripheral arteries as given by various observers. Thus Albert[3] found the pressure, in the tibial artery of a boy, 100–160; von Basch,[4] in the radial of man, 135–165;

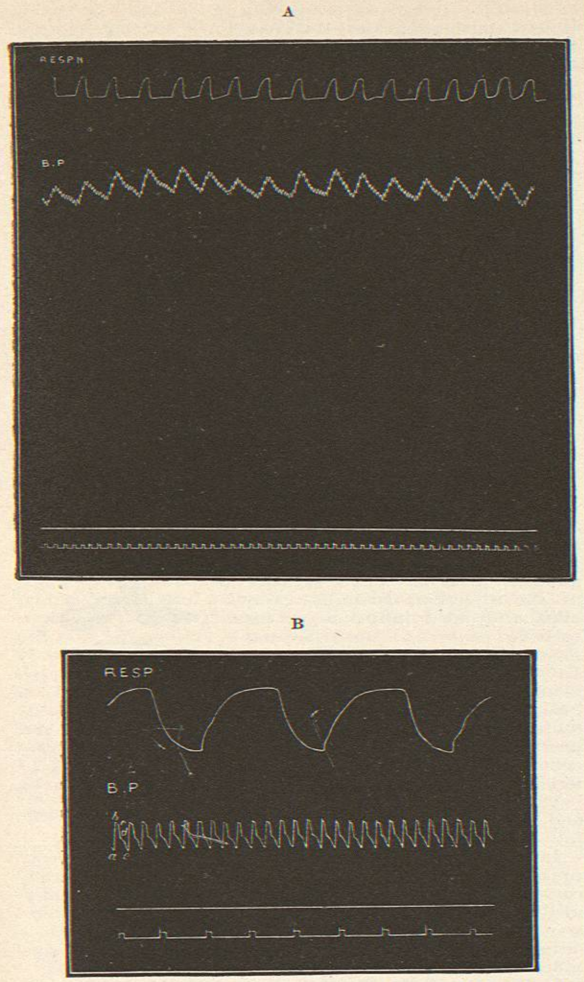

FIG. 1333, A.—Tracing of the Blood Pressure from a Rabbit Taken by the Mercury Manometer. *B.P.*, Curve of blood pressure. The horizontal line at the base shows the position of the zero pressure. Time tracing in seconds. B.—Normal Blood-Pressure Record Taken from the Rabbit with a Hürthle Manometer. The horizontal line again shows the position of the zero pressure. Time in seconds.

Faivre,[5] in the brachial of man, 110–120; Hill,[1] in the brachial of man, 100–120; and Mosso,[2] in the digital artery of man, 100.

The pressure in the arteries shows, moreover, rhythmic oscillations synchronous with the systole of the heart. The relative extent of these variations as compared with the mean blood pressure was recognized only after the introduction of spring manometers, as the inertia of the mercury largely damped the individual beats. Compare, for example, the following records:

In the aorta of a rabbit Hürthle found the difference between diastolic and systolic pressure to equal 40 to 50 mm. Hg, *i.e.*, about one-third the total mean pressure. These oscillations diminish in amplitude as the distance from the heart increases, and disappear altogether in the capillaries and veins under ordinary circumstances.

Secondly, the mean pressure is low in the veins throughout, but higher in the small veins, gradually becoming less toward the heart; in the external jugular and similar vessels close to the heart it may even fall below zero.

Thus, in the sheep the following figures have been obtained: Pressure in the external facial vein, 3 mm. Hg; pressure in the brachial, 4 mm. Hg; branches of brachial, 9 mm. Hg; crural vein, 11.4 mm. Hg.

The pressure in the capillaries must be determined by indirect methods. Valuable indications of changes of pressure within them are gained from simultaneous records of the pressures in the corresponding artery and vein. To obtain a measure of the absolute capillary pressure von Kries applied pressure to the skin or mucous surface and determined the weight necessary to produce a visible change of color (blanching), which was taken to mean collapse of the capillaries. The result, which he places at 33 mm. Hg for the rabbit's gum, is regarded as a rough approximation, but it is sufficient to indicate that the capillary pressure is intermediate between that of the arteries and veins respectively.

There is consequently a continuous though irregular decline of pressure from the aorta to the right auricle. The fall is slow and gradual in the arteries and veins, but between the small arteries and small veins, *i.e.*, in the region of the arterioles, capillaries, and venules, it is marked and sudden. The curve of pressure would, therefore, have some such form as that represented in Fig. 1334.

The circulation in the peripheral region, where the greatest changes obviously take place, can be directly observed in transparent organs with a microscope. The blood is there seen to pass in a continuous stream from the small arteries through the capillaries, to the veins. The velocity is greater in the arteries than in the veins, and greater in both than in the capillaries. Faint pulsations synchronous with the heart's beat are also visible in the arteries, but these disappear in the capillaries and veins. In the small capillaries the corpuscles are pressed through in single file and occupy the whole bore, but in larger capillaries, and especially in the small arteries and veins which permit the passage of more than one corpuscle abreast, the red corpuscles run in the middle of the channel, forming a colored core, while a colorless layer of transparent plasma is left between it and the sides of the vessel. These are known respectively as the "axial current" and the "peripheral zone," or "Poiseuille's space."

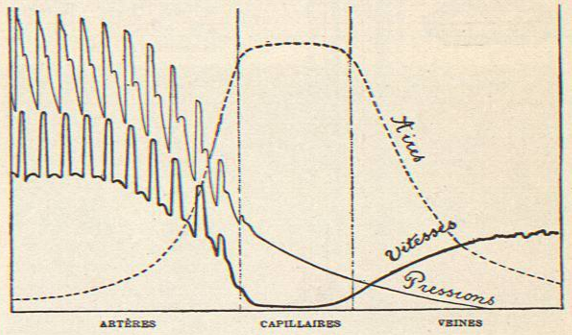

FIG. 1334.—Schematic Representation of the Variations of Pressure, Velocity, and Sectional Area of the Different Parts of the Circulatory System. (Modified from Gad.)

In the plasmatic layer white corpuscles are frequently seen clinging to the sides of the vessel, sometimes rolling slowly along, and in general having an irregular motion with frequent temporary stops. In all cases the blood as it passes through the capillary stretches and expands the walls, and the flow is subject to many variations.