THE

LAWS AND MECHANICS OF CIRCULATION,

WITH THE

PRINCIPLE INVOLVED IN ANIMAL MOVEMENT.

BY

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Was nicht bewiesen ist
Das braucht Man nicht zu glauben.

NEW YORK:
J. H. VAIL & CO.,
1885.

ATKIN & PROUT, PRINTERS,
Nos. 16 and 18 Chambers Street, New York.

DEDICATION.

TO

DR. ALBERT GÜNTHER,

The distinguished author and naturalist, British Museum, in recognition of his great services as an original investigator, and for his kindly heart, quick perception, and swift foot to lighten the labors of others, which rounds out and perfects character—a star in the galaxy—this work is reverently and affectionately dedicated by

THE AUTHOR.

anatomy, very creditable to the anatomists and histologists, but of no earthly use in the physiologies, not being explained or elucidated as means to ends, which anatomy purely is, consisting of relative adjustments for special work, since it all relates to work, for which they are the relative adaptations.

3. The Harveian theory of the circulation, 1628, but no explanation of the portal circulation and for maintaining it in correspondence with the absorptive processes for producing a balance, otherwise impossible; no explanation of the tissue-circulation or that connected with the cell-brood, the objective point for all the commerce, the cells being the workmen in the tissues; a vaso-motor system of nerves, but not competent to explain the phenomena manifested through them; no attempt to explain the numerous muscles and nerves (unknown to Harvey) to the vessels.

4. Numerous physiological experiments upon the nerves, muscles, blood-vessels, etc., by means of which deeply interesting phenomena are developed, but their relevancy to any fundamental circumstance in the organism, or connection with one another by reason of any principle in the mechanics, *not* shown; illustrated by explanatory cuts showing the mode of procedure.

Traube's Curves are beyond its reach; so also the blood-pressure curves and the curves of intra-thora pressure. It offers no solution for the existence of "inhibitor" and "accelerator" nerves to the heart. It cannot explain the anatomy in the intestines, and why there should be a diaphragm in the mammalia only. It cannot get fat, albumen, alcohol or *any* non-dializable substance into the body, yet they are rapidly absorbed and the explanation easy.

More or less remarks upon muscular irritability and contractility, but nothing of dualism in the muscles, without which musculation would be utterly impossible, etc., etc. The books large enough, too; some of them a thousand pages, nearly, fine press. No grasp, no continuity of relations, all differing, but as far as possible from a philosophy. Each one following the train of facts he is most familiar with (compelled to it in the absence of a guiding principle), fitting the others into the text as best he can to make a book, at times apparently as though tumbled in at random till the book is big enough; vain strivings for order and method, however, discernible. The result *nil.* (I would like to make exceptions, but cannot; though some of the books have remarkable excellence, and it wounds one to the heart to say aught against them.) With all this, wrong teaching most pernicious, doing irreparable harm to some minds, worse than night-blindness, for *that* would suffer the unfortunate to see by daylight, but *this* by *no* light whatever; but to *any* mind the work of *un*learning and starting afresh is most difficult, next to impossible, accomplished only by persistent and heroic effort. For example, respiration and circulation form a connected movement for supplying the cell-brood in the tissues and removing waste products; but the physiologies treat them separately, basing circulation upon the heart, respiration upon the diaphragm. By what right is *that* done? No right; none.

The birds, reptilia, and the rest of them, have no diaphragm; nevertheless, they respire; besides, produce vocal resonance characteristic of them, showing that respiration is also under voluntary control, the same as in mammalia. Air is got into the lungs by means of a pleural vacuum—speaking more correctly, a "negative pressure in the pleuræ"—distending the organs in the first place by this means, then producing inspiration by contracting the diaphragm and intercostal muscles, then expiration by relaxing the muscles. It will not answer, and is not the method, as is fully proven in the text by the most incontrovertible evidence. Furthermore, the birds, etc., have no such explanation, passing them by; but this cannot be done in physiology; it all must be explained. And in the case of the worms, we have a complex circulation carried on where there is *no* heart, the vessels at the same time expanding and contracting regularly and rhythmically, possessing automatism the same as the heart, being also furnished with muscles and nerves for increasing force in them commensurate with the physiological requirements. You cannot *begin* at the *end* of animal life to write about circulation any more than respiration. In the embryo, but for the power to produce circulation independently of the heart, the heart itself could not be developed, while vascular development goes on *simultaneously*, the intestinal canal and other organs also, the heart-force coming in subsequently for increasing the action simply, the vessels growing *pari passu* with it. The theory breaks down and will not answer the physiological requirements; is therefore incorrect. Then, again, the heart is used as a force-pump, which involves a *suction* with a *driving* force, but entirely ignoring the former by using contraction in the cardiac muscles simply; whereas the organ would *first* have to be *filled* by *diastole before* one may speak of forcing the blood out of it by *systole*, thus producing a current through the organ, while expansion and contraction are correlated forces in Nature, therefore inseparable.

It is needless to extend the matter, for physiology could not be more impotent; nor can help come by scalpel and microscope: *their* work has been well done, the body taken down to the very cells themselves and polarizing lenses are set to *them*. In short, analysis may be said to be complete, but the key to animal structure and function *not* forthcoming, not to be forced by scalpel or microscope, or rather the latter, for the work is now in micro-organisms and cells. Nor can physiology remain where it is. The ground sinks, no firm foothold, every effort but sinking you deeper in the morass. A change must come, else there is *no* hope. The key to be found at all? Of course it should. The arrangements are visible and persistent, and for their full and complete interpretation requires only that the proper method be adopted.

Set physiology in the *opposite* direction, or toward *synthesis* and *re*construction, and you *will* find it, for this will take you to *the organic law upon which the animal organism is based*, and *that* is the key; for it is as utterly impossible to explain the mechanics in the absence of this principle as to explain *any* mechanism in the *absence* of the principle *it* involves, and the animal body *is* a mechanism. And though it differs from all others in that it is automatic, nevertheless this would not do away with the necessity for a principle upon which to base the mechanics, as must appear obvious.

Life so mysterious! Granted. But life works in matter, and matter has laws eternal and inflexible regulating it. What law have you, then, as the basis of animal mechanics with which everything in the organism must have adjustment and every piece its place and relative value, in the very nature of things? None. Then, it is manifest that you cannot explain the mechanism or write a physiology. In order to do this, the principle would have to be forthcoming *first*, and from *that* stand-point it is all made intelligible; otherwise, is utterly inexplicable. But you cannot *begin* with animal or even floral life, for the principle is not confined or pent up in them, extending into the very mechanics for producing circulation in air and water, out of which living organisms are evolved. Commencing with this, thence through flora and fauna, noting the method for increasing it in the latter commensurate with the force expended in them ; when it will turn out that physiology is but natural philosophy, anatomy means to ends, the functions resultant phenomena ; or, in other words, physiology is the descriptive anatomy and functions in the organs, the former being the special adaptations of means to ends in correspondence with the character and amount of work performed, since it all relates to work which must have its equivalent in force *there* and *then* ; the whole evolved out of circulation, while this in turn is regulated by law which is being incessantly invoked in the measure of the requirements. Comprehensive it is, but easily understood.

Finally, why should it be deemed an incredible circumstance to have a fundamental principle in animal life, upon which the phenomena are based, seeing that everything in the visible universe is regulated by law, and that there is systematic and persistent arrangements in the structures ; otherwise inexplicable? Furthermore, method *implies* principle. And when similar arrangements in the structures and movements in the parts habitually occur in great classes of animals, we may rest assured that a common principle underlies it all ; and in order to interpret the phenomena it would be absolutely necessary to first make out the mechanical principle that applies. And since the whole relates to work, there should be no difficulty in determining this circumstance.

Such, in brief, is the course adopted in this work, commencing with the laws and mechanics of circulation as applied to the pumping movements in lungs, heart and vessels, which undoubtedly relate to rhythmical changes in pressure for increasing circulation commensurate with the force expended in the organism, seeing also that these movements are in correspondence with the activities, rising and falling with the swell in the activities, the whole forming a connected movement in the very nature of things. And while there is automatism in the organs and the heart continues to beat for a time after respiration is suspended, it is no infraction of this principle, for in no other way could a balance be maintained in the organism, the heart and vessels being simply a carrier between the cell-brood and lungs, while respiration is the great pumping action for compelling the commerce in the organism. In short, that respiration answers to the pendulum in the clockwork, while the heart and vessels are set to this as the minute hand to the hour hand ; so that it all works together harmoniously and in perfect concord, to the end that a stream of commerce may be maintained between the cell-brood and environment, from which all the supplies are obtained, and into which in due time waste products are returned for *re*distribution, the eternal order of things.

Beginning, then, with the principle for producing circulation in air and water, and for pulling the molecules into position and locking them in the structures, or similar to what takes place in crystal structure (which is approximated in plants and bones, while in the soft tissues there is provision for freer molecular action) you come into immediate contact with that all-absorbing question, What is Life? I cannot make out aught else than a *form* of force —wonderful metamorphoses in force ; using present terminology, Life is an "eddy" in force. With force, itself, *there* we stop. The *ultima Thule!* But this we know of a surety, that force is controlled by laws eternal and inflexible, while matter manifests them, and is *energized* by force. Nor need we fear to follow to their logical conclusions the fundamental principles in Nature. A stream cannot rise higher than its source ; and man intelligent, it follows there must necessarily be intelligence in Nature—all-pervading intelligence ; further I cannot say ; *das ist genug.*

In conclusion : This work, as the name implies—Life : Its Laws and Mechanics —would include *all* vital phenomena, but as circulation underlies it all (furnishing the materials for elaborating structure and evolving force, but involving the principle concerned in animal movement, in order to *increase* circulation), this would naturally have precedence, the rest following in regular order, to be published as a serial, beginning with "Gravitation and Development," gravitation being *pivotal,* so to speak, in development, showing the intimate relations it sustains to the latter to the very minutia in tissue-structure, the organs of circulation with those of respiration, locomotion, etc., but most manifest in the frame-work of support to the soft tissues or bony skeleton ; a very notable circumstance being the mode of conserving the central nervous system by supporting it upon a "water-bed" formed of the cerebro-spinal fluid and the fibrous leaflets in the "*falx cerebri*" and "*tentorium cerebelli,*" with the nerves running into them for regulating tension, so as to obviate concussion in locomotion, leaping, etc. ; the principle involving the articulations themselves, for the brain must be protected against jar. But all the organs exhibit adjustments with gravitation. The great development of the vascular system in land animals, the numbers of the muscles and nerves in the heart and vessels, have similar explanation, the fluids tending constantly to the earth. In fine, *every* movement in the mass and molecules must necessarily involve a struggle with this force, as must appear obvious. Nay, to the very mode of rising up and lying down, the animals doing it differently by reason of the special adjustments that obtain in the viscera, the ruminants elevating the hinder parts first, then bringing up the fore parts, reversing the action when lying down ; whereas, the other animals elevate the fore parts first, then bringing up the hinder parts, reversing the action when lying down. And that it is not awkwardness in the ruminant which causes it to take the course it does, is proven by the fact that the fleet deer and nimble antelope go through the same movements. Finally, strange and fanciful as it may seem, nevertheless, the relative stages in development in the anthropoid apes are readily determined by it, beyond the shadow of a doubt, and gorilla is closest to man of any existing species, which is not a figment of the mind born of a lively imagination, but a sober fact wrought in the bony skeletons of the animals, very plain and easily to be seen. We would not anticipate, however, but let the present work serve as earnest of that engagement.

Nature works by laws immutable, and everything is determined by law, while order and method are made inevitable. And the very fact itself that so much is explained within the compass of the present work, is conclusive proof that correct lines have been adopted.

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CHAPTER I.

MECHANICS FOR PRODUCING CIRCULATION IN AIR AND WATER, AND FOR CONNECTING THEM WITH CIRCULATION IN LIVING ORGANISMS.

The Fundamental Fact at the Basis of Living Organisms—Living Organisms Evolved from Substances Contained in Air and Water—Mode of Suspending Atmospheric Matter in Space, and the Principle for Producing Movement Among the Molecules—Experiments of Dufay and Faraday with Electricity and Magnetism—Action of Gravitation Overcome by Electrical Force—Transformations of Heat into Electrical Force for Energizing the Polar Forces Among the Molecules, the Fundamental Principle for Producing Circulation in Air and Water—The Prodigious Force which is Involved for Producing Circulation in the Atmosphere and in Water—The Mechanics Connected Through and Through by Means of Electrical Force—Electrical Phenomena in Storms—Mode of Effecting Changes in Pressure for Increasing Circulation in the Atmosphere—The Action in Water—Principle in Diffusion, *Osmose* Capillarity—Organic Connection Subsisting Between Circulation in Air and Water and in the Living Organism.

Logically as well as scientifically, the fundamental fact at the basis of living organisms is the one of circulation, since it is by means of this the materials are furnished for elaborating structure and evolving force; otherwise, neither the building itself could have construction, nor could the special vital phenomena be produced, since they are all evolved out of circulation from substances which are brought into the organism by this means, and which, of course, would include the psychical with the rest, being a variety simply, and as much dependent upon circulation as any of the others. In other words, should circulation stop, it all stops, and which is a matter so obvious that it needs no argumentation.

In the second place, the nutritive and force-producing elements are contained in air and water, notably oxygen and hydrogen, carbon and nitrogen, together with the alkaline earths and minerals. Moreover, are incessantly in motion in every conceivable direction, both the fluids themselves and the molecular and atomic constituents, so that it may be truly said they are *never* still save when locked in crystal and living structure ; and even here a degree of movement takes place, but more in the latter than in the former, and more in animal than in vegetal structure, while the freest motion is that which obtains in the conditions of air and water in which the molecules and atoms have the widest action, the atoms with the molecules. Notwithstanding, it is all organized, the air and water with floral and animal life, a definite molecular constitution being maintained throughout. Thus, in the case of the atmosphere the relative proportion of the constituent gases remains the same, or about 77 parts of nitrogen, 21 of oxygen, and 2 parts made up of watery vapor, carbonic acid, ammonia, etc., in the 100. This, notwithstanding the enormous sources of disturbance in the countless flora and fauna, inclusive of the chemical reactions taking place in the earth itself, together with the combustions and chemical reactions effected through the agency of man, which are constantly absorbing and giving out the gases in prodigious amount, and which proves beyond the shadow of a doubt the action of an all-pervading force for effecting it, or for compelling the molecules into their relative positions in the atmospheric envelope. In short, that a principle obtains among the individual atoms and molecules for producing movement in them, and acting in such wise as to compel definite arrangements among them, to the end that the atmosphere and living structure may be organized and a balance maintained throughout, otherwise is inexplicable.

In the case of water, we find that here also the same principle applies for producing movement in the atoms and molecules for compelling absorption and solution of the salts, so as to effect the chemical and physical constitution that obtains in this fluid, and in order to maintain a balance which tends incessantly to be disturbed, at the same time, producing perpetual motion throughout in the mass and in the molecules the same as in the air ; using an expressive term, the whole seeming, as it were, "alive." The ultimate fact in the deep mystery is the one of motion itself, the manner it is produced, with the principle it involves; for life is evolved by means of it, and may be characterized as a metamorphosis of force ; seeing also that when life terminates the whole breaks up into its atomic and molecular elements and goes back whence it came, and there is nothing left.

While to this, again, must be added the deeply suggestive fact that *organic* unity implies *similarity* in force. So that continuity in force, which undoubtedly exists, would imply that vital force is but a variety of the force which produces molecular action in air and water, an organic connection subsisting between them for producing the currents in and out the organism in the measure of the requirements, otherwise impossible; at once indicating the nature of the force for effecting the nutritive processes, together with the other phenomena, the whole being electrical and polar. Thus, in the flora, in which life has simplest expression, the nutritive and force-producing elements are pulled into the organism by the action of the polar forces upon the principle which obtains in a magnet, while for expelling waste products the action is simply reversed. In the transit the component atoms and molecules are pulled into position and locked in the structures by the action of the polar forces upon the same principle precisely which obtains in crystal structure, only the action is more complex; while the waste products are borne out for redistribution by action of the same forces, distribution with redistribution being the eternal order. In animal life there is still greater complexity, which is involved in producing the characteristic phenomena, notably the multitudinous actions taking place in them. At the same time, a special arrangement obtains for increasing circulation commensurate with this circumstance, and for producing a balance, which the scheme calls for; for everything is evolved out of circulation from substances brought into the organism by this means, as before remarked.

Finally, since all this motion involves mechanical work, it would seem both reasonable and natural that the principle underlying it should be susceptible of formulation and distinct mental presentation A force in such universal and constant action should surely be detectable, if only we go about it in the proper way.

In the first place, let us take up the action in the atmosphere.

This matter settled, and there will be no difficulty in accounting for circulation in living organisms, which is but an extension of the same principle in mechanics, as we shall very plainly demonstrate in the succeeding pages, the matter being one of variety simply.

Concerning the Force for Effecting the Suspension of Atmospheric Matter in Space and for Producing incessant Motion in it against the Force of Gravitation:

Commencing at the *bottom*, then, so to speak, and dealing only with the forces in Nature, the first question which presents itself to the thoughtful student concerns *the mechanics for effecting the suspension of atmospheric matter in space and the production of incessant motion in it against the force of gravitation, which tends to pull it to the earth in a compact mass.* In short, why should there be an atmosphere at all upon the globe? and how is motion produced in it?—facts which are certainly needing explanation.

The atmospheric molecules do not touch each other, as in the case of a solid; on the contrary, they are far removed from each other, so that even at the earth's surface, where density is greatest, the atmosphere would require to be compressed fully 700 times to reduce it to the density of a liquid, while the molecules recede farther and farther from each other with the distance from the earth till the outermost limits are reached (Fig. 1). In point of fact, the molecules are relatively as far apart in proportion to *size* as the very stellar masses themselves: furthermore, when forcibly compressed, react with equal force, at once springing back to the original distances the moment pressure is relieved, proving thereby inter-molecular action from the presence of a force radiating from molecule to molecule, otherwise is inexplicable. Now, then, this fact being indisputable, the question which naturally presents concerns the nature of this force. What is it? This must be established *before* progress can be made in the mechanics of circulation, forming, as it were, the basis of the mechanics, and by means of which the nutritive and force-producing elements are set in motion for elaborating structure and evolving force, the whole connecting through and through, the matter necessarily involving continuity in force in order to effect these results.

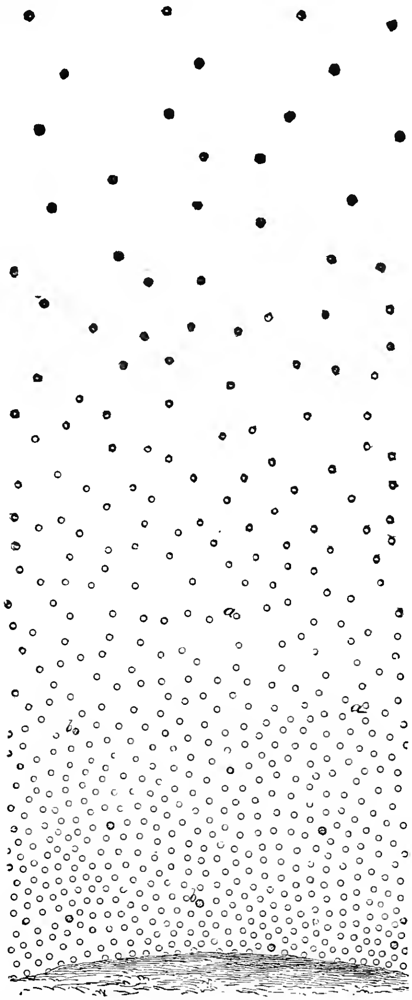

Fig. 1.—An Ideal Section of the Atmosphere, showing the *Suspension* of this Matter in Space against the Force of Gravitation. *a*, *a*, Molecules of Nitrogen, Oxygen, Carbonic Acid, etc.; *b*, *b*. Aqueous Molecules.

In this we are materially assisted by the celebrated experiment of Dufay for proving the existence of two electricities, or positive and negative, which is plain enough. For example, he discovered, by means of a glass rod excited by rapid friction, that a gold or silver leaf, when liberated near it, is both attracted and repelled by it. At first, is powerfully attracted, dashing impetuously toward it, and, suddenly stopping, dashes in the opposite direction, when it again stops suddenly, remaining stationary from two to three inches from the rod, suspended in the air (Fig. 2). And if one so mind, he may chase it round and round the room for hours without permitting it to fall to the ground. The knob of a charged Leyden jar, or the conductor of an electrical machine in action, has the same effect; and which proves the action is due to electricity. The use Dufay made of this experiment was to demonstrate the existence of *two* electricities, or positive and negative, whereby substances are attracted and repelled from each other, according to whether they are charged with opposite or the same kind of electricity.

The attraction in the first instance was due to opposite electricities, while the subsequent repulsion was due to the passing over of some of the electricity from the more highly electrified glass to the metallic leaflet, whereby their properties were assimilated; hence this repulsion. The point where it remains stationary represents, of course, equilibrium in the polar forces. But, then, this describes only a part of the phenomena embraced in this experiment, which admits of much wider application than proving the existence of two electricities simply; notably, *the mechanical work* which is involved in *sustaining* matter in space, *and producing movement in it* against the force of gravitation, which tends to pull it to the earth. Thus two great and important elements in this electrical experiment are entirely overlooked: 1. The fact that matter may be held up and sustained in space by electrical force simply. 2. That motion can be produced in it by a change in polarity effected through electrical induction—facts which are incontrovertible.

Now, then, proceeding cautiously, feeling the ground, as it were, to make sure of its firmness: Is there any other force in Nature for thus suspending matter in space and producing movement in it against the force of gravitation, save electricity and the interaction of the polar forces which electricity serves to intensify? Not that we know of. No, not any force whatever may be spoken of in this connection, save electricity alone. And making deduction from this upon the mechanics in the atmosphere, it follows that electricity is the force we are in search of for effecting the suspension of atmospheric matter in space, and for producing movement in it, no other force applying for the purpose. This fact conceded, the next question concerns the *source* of electrical supply, together with the manner of its action, which is also obvious. Thus the sun functions as the source of electrical

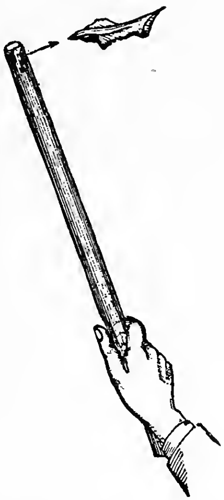

Fig. 2.—Showing *Matter Suspended in Space* by interaction of the Polar Forces, *intensified* by electrical induction.

supply, by means of which the Leyden jar in the earth itself is kept constantly charged with electricity, whence it radiates through the atmosphere by the principle of electrical induction for effecting suspension of this matter in space (Fig. 1), and for producing movement in it. In other words, heat, impinging against the earth, *undergoes transformation into electrical force*, which is the motor in the mechanics. That heat *per se* is not the motor, is at once made obvious by the fact that *rarefaction in the atmosphere increases with the cold and the distance from the earth* (Fig. 1), being greatest at the outermost limits in the atmosphere where cold is enormous, whereas the very opposite should obtain by the laws of radiation, the surface being the *first* chilled, producing condensation—an increase in density. In short, producing a compact mass. In lieu of this, however, the inter-molecular distances are vastly increased, showing conclusively that heat is not the force for effecting this action. In point of fact, the atmosphere is nearly transparent to heat, and but for the aqueous vapor suspended in it, nearly the whole of the solar beam would reach the earth. And allowing for this circumstance, Professor Tyndall estimates the invisible rays or the heat portion of the solar spectrum to approximate that in the spectrum of electric light, or nearly eight times the visible rays (Fig. 3), which will give some idea of the enormous rôle which heat performs in terrestrial mechanics. Furthermore, it is illusory to imagine that all this heat radiates into space, since a prodigious amount undergoes transformation into mechanical work and electricity, which is the dynamic force for producing molecular action by increasing the polar forces in the molecules, and which applies to living as well as to non-living matter. Perhaps we might illustrate this circumstance better by drawing from the early experiences in animal temperature. For example, after Lavoisier had established the fact that animal temperature is the result of oxidation, upon the same principle precisely as obtains in a grate and the burning of coal, physicists made great efforts to determine the equality between the theoretical heat as indicated by the amount of carbonic acid discharged and the quantity of heat furnished by the animal, and which, of course, was illusory, for it made no allowance for the large amount which disappears by conversions into mechanical work and electricity for producing the multitudinous actions taking place in them. And making the same deduction for the solar beam and the mechanics for circulating air and water, inclusive of the actions in living organisms, it at once becomes obvious that a vast amount of heat must necessarily disappear in the transformations.

Then, again, one-half only of the earth presents to the sun at a given time, and as electrical force may make the circuit of the earth in one-tenth of a second (as the solar beam travels nearly 12,000,000 miles in a minute), it follows that this should call for corresponding increase in the transformations of heat for energizing the actions in the dark portions of the

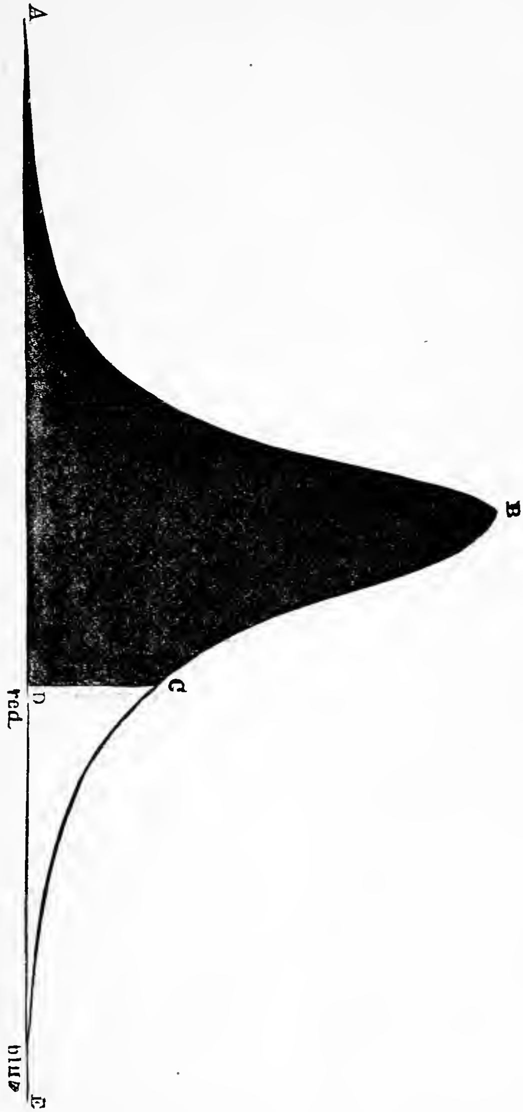

Fig. 3.—Spectrum of Electric Light (Tyndall). *A, B, C, D*, invisible heat portion; *C, D, E*, visible radiation.

earth, and which would reduce in proportion the radiation into space. Hence, we must conclude that the greater proportion of the heat in the solar beam *is utilized in the terrestrial mechanics*, since *every* movement calls for corresponding expenditure of force. Finally, these conversions of heat into mechanical work and electricity are facts which are universally conceded in science, being fully established and incontrovertible. Impinging against the earth, then, this invisible portion of the solar beam rebounds as electrical force through the atmosphere, driving and scattering the molecules in every possible direction. In fine, the impact of the solar beam against the earth fractures and scatters the atmospheric envelope in accordance with well-known physical laws, or as a hammer does a piece of glass, the force radiating from the point of impact and driving the outermost fragments furtherest apart. Hence, rarefaction in the atmosphere increases with the distance from the earth. This fact, then, would explain *that* circumstance, and no other could. And each molecule of the constituent gases being charged by the Leyden jar in the earth itself, becomes in its turn a centre of force which is readily affected by the polar forces in the earth, so that the conditions obtain for producing movement in them, the whole matter depending upon changes in polarity. It is needless to add that *no* amount of cold could affect *this* action, which is precisely what the circumstances in aërial mechanics calls for, since *incessant motion pervades it all.*

Some idea of the enormous force which is involved in aërial mechanics may be had from the atomic weight of the constituent gases—notably nitrogen, 14; oxygen, 16; aqueous vapor, 18; carbonic acid, 44, or nearly two and one-half times greater than water; while the pressure of the whole is equal to 33 feet of water spread over the entire surface of the globe. And yet it is all lifted up in space and borne hither, thither, in every possible direction, with the utmost ease and celerity, under the action of electrical force, as illustrated by the rubbed glass and silver leaf, only that in the present instance the action is automatic. And proceeding upon this line of investigation, we will now take up some of the actions in the atmosphere, both as regards the currents which exist in it *and the inter-molecular movements for maintaining its organic constitution*, together with the currents which set in and out the flora and fauna, all which respond readily to treatment, and while the action is complex, it unravels easily by the key furnished in the polar forces

Given that atmospheric matter is held in space by the interaction of the polar forces (and which must be conceded, since there must be a force for overcoming gravitation), it follows that the various movements which pervade the atmosphere must also be due to this circumstance ; or, in other words, they flow out of the polar forces as water from a fountain, *which cannot rise higher than its source.*

And the molecules, thus resting upon the polar forces, *as the*

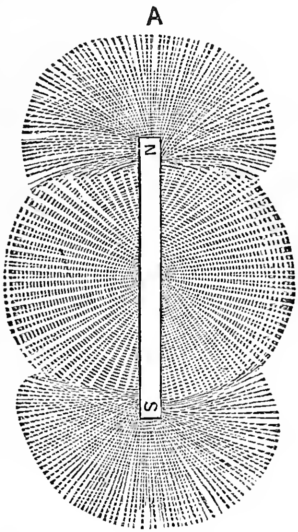

Fig. 4.

floor of support against the action of gravitation, it follows that *any* change in polarity must necessarily affect the relations of the molecules. It could not be otherwise, in the very nature of things. Now, then, taking this as the basis of the mechanics (and everything must have a basis), we will begin with the larger movements first, proceeding thence to the inter-molecular for maintaining organic unity, thence to the actions in living organisms.

Concerning the Currents in the Atmosphere:

In this investigation we are materially assisted by the researches of Faraday, by means of which the action in the atmosphere is brought clearly into view. For example, he

Fig. 5.—Magnetic Lines of Force.
From a Photograph by Professor Mayer.

discovered, by placing a sheet of smooth paper or glass over a bar-magnet and showering fine iron filings upon it,* that they would arrange themselves in systematic order and in beautiful curved lines, extending from pole to pole (Figs. 4, 5, 6). Now, by applying this circumstance to the earth itself and the actions taking place in air and water, notably the currents setting in and out of the poles, together with *the formation of the cloud strata*, are at once made intelligible. If the earth itself be a prodigious magnet (which

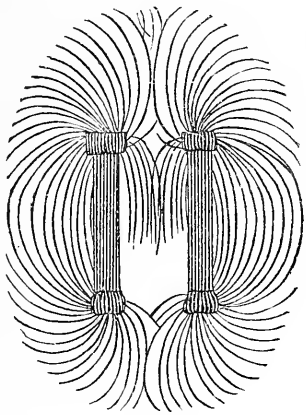

Fig. 6.—Showing the "Lines of Force" extending from Pole to Pole.

no one should deny, since it could not otherwise be held in space, nor motion be produced in it), and atmospheric matter is suspended in space by inter-action of the polar forces, as alleged, it follows that similar arrangements should obtain among the molecules as in the iron filings, the same law applying for both. Furthermore, that there are such "lines of force" stretching their long arms between the terrestrial poles,

* The iron filings being very heavy, and consequently not free to move, in order to facilitate the action "the sheet is gently tapped from time to time so as to release them for a moment, and enable them to follow their tendencies."

is fully established by the action taking place in the magnetic needle, which, the moment it is suspended and free to move, trembles, oscillates and rocks from side to side, nor pauses till it is brought into correspondence with the magnetic meridian, one end pointing north, the other south, while every atom and molecule feels the pull in these polar forces; and should they be free to move as the molecules in air and water, can it be doubted for a single moment but that they would be pulled to their respective poles, the positive going one way and the negative the other; since it is reasonable to assume the forces which coerce them in mass should be equally effective upon the individual molecules? This, then, would explain that matter, and no other could. Faraday! thou incomparable! we thank thee! This experiment of yours with the magnet puts iron through the logic. The cloud strata, the currents in the air, and the currents in the ocean are explicable by polar action only, while it all represents forms of conversion of force. Passing rapidly over the actions, for the sake of brevity, it would explain the following phenomena, otherwise inexplicable:

1st. Why the storm-centre does not follow the isothermal lines, pursuing an erratic course, and going in every possible direction.

2d. The occurrence of violent storms in the polar regions, and their greater frequency in the temperate zones during winter.

3d. It would account for whirlwinds, in which the air pursues a violent rotatory motion, since this is one of the phenomena which accompany electrical excitement. Moreover, a miniature whirlwind is readily reproduced.* And since electricity increases magnetism, this circumstance would explain the cohesive power, so to speak, among the molecules, which imparts corresponding firmness and strength to the atmosphere,

* A curious "object-lesson" is that by which Professor Douglass, of the Michigan State University, shows his classes the operation of a cyclône. He suspends by silken cords a large copper plate, which is heavily charged with electricity. The electricity hangs down underneath the plate like a bag, and is rendered visible by the use of arsenious acid gas, which gives it a green color. The formation is a miniature cyclone as perfect as any started in the clouds. It is funnel-shaped, and whirls around rapidly. Passing this plate over a table, the cyclone snatches up copper cents, pith balls and other objects, and scatters them on all sides.

whereby solid masses of great weight are caught up and transported to great distances in the funnel of the whirlwind.

4th. It would explain why thunder-storms are accompanied by vivid electrical phenomena and the fall of the thunder-bolt. The electrical force which suspends water in the atmosphere being withdrawn, an amount of electricity representing this circumstance passes at once to the earth, and striking the object most highly charged at the time with opposite electricity, diffuses itself through the earth for producing equilibrium. In fine, water falls because the thunder-bolt falls, the one producing the other.

5th. It would account for the cloud corona resting over islands in the sea, and why vegetation should milk the clouds. All these circumstances, then, have ready explanation by this mechanics, and they can be explained in no other way. But we are by no means done yet; a multitude of phenomena otherwise inexplicable remain for mention.

The following forcible excerpt will be appreciated:

"The experiments of Faraday show that the magnetism of the air changes with temperature; that it is least near the equator, and greatest at the poles of maximum cold; that it varies with the seasons, and changes night and day; nay, the atmosphere has regular variations in its electrical conditions, expressed daily at stated hours of maximum and minimum tension Coincident with this, and in all parts of the world, but especially in sub-tropical latitudes, the barometer also has its maxima and minima readings for the day. So also, and at the same hours, the needle attains the maxima and minima of its diurnal variations. Without other time-piece, the hour of the day may be told by these maxima and minima, each group of which occurs twice a day and at six-hour intervals. These invisible ebbings and flowings—the diurnal change in the electrical tension—the diurnal variation of the needle, and the diurnal rising and falling of the barometer, follow each other as closely and as surely, if not quite as regularly, as night the day. Any cause which produces changes in atmospheric pressure invariably puts it in motion. giving rise to gentle airs or furious gales, according to degree; and here, at least, we have a relation between the movements in the air and the movements of the needle so close that it is difficult to say which is cause, which effect, or whether the two be not the effects of a common cause"*

The mode of increasing the action in the air is by changing pressure, notably by developing areas of low pressure with an increase in pressure in adjacent localities, whereby fluid equilibrium is invoked, the fluids rushing in to equalize pressure. And the greater the difference in the low and high pressures, the more violent the storm, while the whole is due to electrical disturbance. Taking the area of low pressure as the storm centre, we must regard this as due to a flood of electrical force which, by increasing polarity among the molecules causes them to recede farther and farther from each other, and in proportion producing aërial expansion with corresponding fall in pressure, while the adjacent fluids flow into the locality till pressure is again uniform. So, then, for producing the atmosphere itself, we need the action of electricity; and for producing currents in it, we need the action of electricity; finally, for energizing the movements for producing the rapid currents, we need the action of electricity. The curious circumstance that pressure falls when the air is saturated with moisture, is to be explained in the same way.

Thus for effecting evaporation, electrical force is, so to speak, piled up in the aqueous molecules which, by riving them widely asunder, floats them off into the atmosphere, but in place of increasing density, pressure falls in correspondence with the degree in saturation by reason of the fact that the aqueous molecules, by acting as centres of electrical force, react upon the molecules of the constituent gases, causing them in turn to recede farther and farther from each other, so that expansion and low pressure are made inevitable. Thus we have the conditions for producing expansion in the atmosphere, for increasing circulation correspondingly inherent in the very mechanics of evaporation, and the wonderful utilitarian methods in Nature, have striking illustration, the matter being also self-adjusting. In this manner the flora and fauna are fed out of the seas and the earth is watered. Finally, this

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* The Physical Geography of the Sea, pp. 152, 153. Maury.

mode of increasing circulation in the air by rhythmical changes in pressure effected through the action of electrical force extends as well into living organisms; notably animals, in which it performs an enormous rôle, as indicated in the rhythmical expansions and contractions taking place in the organs for pumping the fluids through the structures commensurate with the force which is expended in them. Otherwise the universal pumping actions going on in the body would be meaningless. This *en passant*, as we would not anticipate.

Granted that the atmospheric molecules are suspended in space by electrical induction propagated from the earth, and moving hither and thither by the action of the polar forces, and the whole is at once made intelligible, together with the currents setting in and out of the poles, the culminating points of polar force in the earth, while it all forms, so to speak, a magnetic sea in incessant motion under the action of the polar forces, which determine all the movements. And since rhythmical changes in polarity inhere in polar action, it follows that incessant movement is made inevitable. Then, again, the unequal distribution of solar heat produced by the spherical form of the earth, which presents only a moiety of the surface at a time to the solar beam, together with the rotatory motion upon its axis, should tend to increase the action, not only as between the equator and the poles, and opposite sides of the earth, but also the perpendicular movements as well, the atmosphere and earth possessing opposite polarities, the latter being negative, the former positive. And in this connection it may not be amiss to call to mind the important fact, equally suggestive, of the air circulating in the very crust of the earth itself, as also in the waters, since it forms an essential part in the economy of Nature and is needing explanation; and were polar force eliminated from these actions, it would be utterly impossible to explain them. For example, the metals are nearly all oxidized, and numerous salts are formed, while subterranean waters are highly charged with the gases, notably carbonic acid; and making due allowance for the action of water, these results, in the main, are undoubtedly due to the action of the atmosphere, which is the source of the free oxygen and carbonic acid; while in the ocean itself air passes in a constant stream to the very floor for evolving and sustaining the life which is produced in this locality, otherwise impossible. A circumstance which is also deeply interesting, since it proves incontrovertibly the existence of interstices in water; and being nearly incompressible, it follows that water is formed of globular or spheroidal bodies in actual contact, but leaving interstices, as a matter of course, and similar to what occurs when shot are heaped together, through which fine sand is readily sifted to the bottom by means of agitation, gravitation compelling this circumstance. But the simile fails at this point, however, for the air goes down to the floor and returns in a constant stream, otherwise a balance in the gases could not be maintained. From the very nature of the mechanics this circulation is difficult. And here comes in the great utility of the "tides" for effecting rapid admixture of the atmospheric gases in the water, and not a wave occurs in the ocean but contributes its part for maintaining equilibrium in the oceanic gases, while the grand scheme in Nature receives additional emphasis; at the same time, the very principle in tidal movement shows incontrovertibly that water is dominated by polar force, the all-pervading principle in Nature for maintaining continuity in force. In proof of this, we have only to look from the actions in the mass to those taking place among the molecules, of which water furnishes eloquent example.

The Actions Taking Place in Water:

The prodigious force which disappears when oxygen and hydrogen combine in the form of water (H_2O)* prepares the mind for its marvelous performances. This substance is never still, the nearest approach being when locked in crystal structure, while perpetual motion is the eternal order; going this way, that way, and in every conceivable direction, under action of

* Faraday estimated the electrical force involved in the decomposition of a single grain of water to be equivalent to 800,000 discharges of his large Leyden battery in the Royal Institution. Weber and Kohlrausch estimate the quantity of electricity associated with one milligramme or the $\frac{1}{65}$th of a grain of hydrogen in water, if diffused over a cloud 1,000 metres above the earth, would exert upon an equal quantity of the opposite electricity at the earth's surface an attractive force of 2,268,000 kilogrammes, or about 5,000,000 foot-pounds.

the polar forces and to which nothing is comparable save the actions taking place in animal organisms, and in which the deeply suggestive fact is disclosed that it forms fully three-fourths of the structures, the gray matter of the brain being 80.5 decimals water; while the nutritive and force-producing elements *are suspended in its midst*, and transported through the channels of the circulation by this means. *Mirabile dictu! Mirabile! Mirabile!* Rising up from the ocean in enormous volumes from the action of electrical force, it swims away in the magnetic sea, and descending to earth from a change in polarity or abstraction of force, it feeds the flora and fauna, the excess flowing off the water-sheds back again into the ocean, and so making the circuit of the globe in this manner under action of the special polar forces which apply; but also rising and falling continually from the earth at the same time, while heat serves for energizing the movements by increasing polarity among the molecules, as before remarked; otherwise is inexplicable. And sailing in the great round of its circulation in the air, at times spreading out so as to become invisible, but coming together again and again to form the cloud strata and the rain from responsive changes in polarity, it is at once perceived that the whole mechanics connects through and through by means of this all-pervading principle; while electricity is the dynamic force for effecting the changes in polarity. Take another example. At a temperature of 212 degrees Fahr., water expands 1,700 times its volume, while 1,000 degrees of temperature *disappear*. But how expand? and what *form* of force does temperature assume? We have seen that the *only* means for suspending matter in space, and for producing movement in it, is by electrical induction effected through the action of the polar forces which electricity intensifies, and by applying this circumstance to evaporation and the action taking place in boiling water, the phenomena are at once made intelligible. Thus in the case of boiling water, as in simple evaporation, heat undergoes metamorphosis into electrical force, which becomes piled up as it were, in the molecules, riving them farther and farther apart, and floating them up in the magnetic sea, the greater density in the air also serving to expedite the movement; since *no* other force applies for suspending matter in space and producing movement in it save electrical force, into which heat is transformed or converted.

And thus supported by electric force, it follows that when this is withdrawn, as happens when clouds of opposite polarities come in contact, the water must again condense itself and fall to the earth from the action of gravitation. Hence the electrical phenomena which accompany rain. All which is readily intelligible.

Diffusion: Take the mechanics in diffusion as further illustration of this principle in molecular action, and see how readily this also responds to treatment.

It is seen to great advantage in dissolving sugar. For example, if a lump of loaf-sugar be held against the side of a glass of water and suffered to dissolve, a current of fine saccharine matter, in form of a white cloud, is seen to issue from every portion of the mass and circle round and round the limits in the glass, going first toward the bottom, seemingly from the action of gravitation, but crossing over and ascending on the opposite side till near the surface waters, comes back again to the mass, then down again toward the bottom, as before, in a continuous circuit, nor pauses till all the sugar is dissolved or the water becomes fully saturated.

Now, then, if polar force were eliminated, how would it be possible to explain this action? Moreover, should some arrangement obtain for removing the sugar as fast as introduced, no reason exists why it should not be perpetual, or why it should not belt the globe itself, had the water such extension.

Here, then, we have circulation produced by polar force simply, while heat serves for energizing it by increasing polarity among the molecules, and in this manner disappearing in mechanical work. In short, diffusion, whether it relate to atmosphere or water, or to substances undergoing solution, is universally the same, being due to the action of the polar forces, and which is fully corroborated by the fact that heat serves to energize the action in all of them, and showing the principle is all-pervading.

Osmose and Capillarity: Continuing the inquiry, take *osmose* and capillarity, circumstances so much relied upon for effecting circulation in living organisms, but, examined critically, what essential principle does either represent?

As a matter of fact, they express nothing further than that fluids pass through membranes and traverse interstices, while they leave out altogether the potential factor for compelling them to do so, and why heat should energize these actions also; not to mention the manner of connecting them with the great circulation taking place in the globe itself, upon which they are dependent and with which organic unity is maintained. At the same time, however, we have to note the curious circumstance that physiologists, in seeking to explain osmotic action, have constant recourse to the nomenclature in polarity, which at once concedes the point at issue, if, forsooth, language means anything at all. In fine, the endosmometer is based upon the "affinity" of the fluids for one another, and the powers of "attraction" exerted on the part of the membranes for the fluids. And should "affinity" and "attraction" be eliminated, what would become of osmotic action and the endosmometer? Then, again, in speaking of diffusion, which is essential to osmose, we note language of similar import, to wit: "When the water reaches the inner surface of the membrane (containing alcohol), it instantly diffuses itself into that fluid, partly in consequence of the mutual *repulsive* force of its own particles, and partly from their *affinity* to those of the alcohol." Italics are added. Further comment is unnecessary.

Now, then, in regard to capillarity. Is it not true that water, after passing into a corner of a dried sponge and diffusing itself through the mass, passes out again at the surface to join the great mechanics in the atmosphere, expanding and rising up in this by what is known as evaporation? while heat energizes the movement. That so long as this relation of the parts shall continue, so long will this miniature circulation be maintained. Ceasing, by removal of the sponge from the water, the former speedily becomes dry and crisp again, as the flora in fatal drought.

But the rapidity with which water *at first* enters the sponge! —how is that circumstance to be explained? The answer is also readily given: The old relationship subsisting between them being broken up, asserts itself the *first* opportunity that presents, the water rushing into the sponge under the powerful action of the polar forces intensified by electrical induction, the atmosphere being more highly electrical; otherwise it would not be a gas. The dried sponge, then, compels water into itself with great avidity when connection is made, *not* by reason of the canal system and interstices existing in it, which facilitate the transit only, but because of the energy in the polar forces of its molecules, which are highly charged with opposite electricity, the aqueous molecules passing on immediately the affinities are satisfied, to make room for those pressing on behind in ceaseless procession, passing out at the surface again into the great mechanics; the supply ceasing, the sponge speedily becomes dry and crisp again, the *pulling-force* in the atmosphere and the *pushing-force* in the sponge produced by repulsion, compelling it all out to the very last molecule It is all simple enough. In fine, all these actions must be accounted for in a theory of circulation, and if polar force were excluded, it would be utterly impossible to explain them. Last, but not least, with the extinction of the solar beam as the source of electrical supply, there could be no molecular actions as involved in the movements in fluids, consequently there could be no life, showing conclusively that the principle underlying it all is electrical and polar.

CHAPTER II.

THE FLORAL CIRCULATION.

Principle in the Floral Circulation—Action of the Polar Forces and the Mode of Increasing it—Physiological Experiment Demonstrating the Energy of the Polar Forces in Flora—Circulation in Flora Comparatively Slow—Deduction to be Drawn Therefrom—Explanation for the Rapidity of Circulation in Fauna and the Amount of Food Consumed by Them.

Perceiving an organic connection subsisting between circulation in air and water and circulation in living organisms, we have only to apply the preceding principles to circulation in trees in order to make this also intelligible and easily understood.

For example, one end of the growth is rooted in the earth, while the other extends to variable distances in the atmosphere, and the former being negative and the latter positive, the conditions obtain for producing circulation between the two ends. Furthermore, the laws of electrical induction should tend to increase this action, for the reason that the atmosphere being positive, this should compel the positive electricity in the bole and branches into the roots and rootlets and pull all the negative electricity in the latter into the bole and branches and terminal leaflets ; and being thus differentiated in electrical force, the highest conditions obtain for producing circulation in-and-out the two ends, since it would effect opposite polarities in the branches and the atmosphere and in the rootlets and the juices in the earth, thus connecting the mechanics through and through, and producing continuity in force, which the scheme calls for. The fluids being in immediate contact with the cell-walls in the two ends, the molecules are readily drawn through the thin places in the walls left for the purpose, and being once in the channels of the circulation, pass readily up and down the structure under the action of the polar forces, upon the same principle precisely as obtains for producing circulation of air and water in the globe itself, out of which the growth is evolved. Furthermore, it would explain the enormous force which is involved for producing circulation in mammoth trees; *e. g.*, the giants of California, some of which are said to be *four hundred and fifty feet in height and ninety feet in circumference*, and in which tons upon tons of sap are kept in motion from end to end of the mighty growths, since the force which maintains air and water in a ceaseless circuit round the globe itself is commensurate with this circumstance.

Then, again, it would explain the oscillations in this circulation with the waxing and waning of solar force, heat being necessary for energizing molecular action by increasing the polar forces. Thus, with the return of spring, the vernal heat and moisture, the sap leaps up the tree, and the whole noiseless clockwork is again set in motion, the buds swelling and bursting into foliage, while the deep sleep of winter is brought to an end; the matter obviously depending upon temperature for energizing the polar forces. But take the action in the cell itself as further example. Thus when the cell of a succulent plant is examined under the microscope, a distinct circulation is seen to be taking place within it, the fluids passing first up one side, across the upper end, then down the opposite side of the cell in a continuous circuit under the action of the polar forces; a miniature, in short, of the great circulation taking place in the globe itself, out of which it had been evolved. And looking thence to the circulation taking place in the plant itself, it is at once perceived that this also is but an extension of the same principle of motion, the fluids in the cell-empire, as in the case of the individual cell, passing first up one part, then down another part of the growth, and so round and round the limits in the plant in a continuous circuit under the action of the polar forces, while heat serves for energizing the movement, the same as in air and water.

This circumstance may be seen to great advantage in a maple orchard in the early spring, when the sap is running up. With the object of obtaining this sap, holes one-half inch in diameter and about one and one-half inches in depth, so as to penetrate the newest wood, are made in the bole of the tree by means of an auger. A large tree, or one approximating two feet in diameter, contains about 24 such holes, with elder spouts for conveying the water into a receiving vessel at the foot, commonly an excavated section of a tree improvised for the purpose, and remaining from year to year, though, of course, fresh holes are made every year. The water trickles through these spouts in a tiny stream. Now, then, the point we wish to make is, that during night-time, when temperature falls, the flow nearly ceases, and when this approaches the freezing point, it stops altogether; while during the day-time, when temperature rises, it sets in again, increasing more and more as day advances, till about 3 P. M., when the maximum is reached, which corresponds with the maximum of temperature. From this time on it grows less and less, with the decline of solar force, till night sets in, when the sudden fall in temperature brings it nearly to a standstill. On a bright, warm day following a cold night the flow is very rapid, a very striking illustration, indeed, of the intimate relations and direct dependence of the floral circulation upon temperature, and which, of course, must act by increasing polarity in the plant and fluids; otherwise is inexplicable. Finally, a ready means obtains for measuring the energy of the polar forces in the plant, by repeating the physiological experiment adopted by Hales. For example, he discovered "that a vine, cut in the bleeding season, will push its sap up a glass tube as high as 21 feet above the surface of the stump." Now, then, since there are no leaves to draw upon the sap by evaporation, it follows that the lifting-force to this great column of sap, and which, of course, would include the air standing upon it in the open end, must be due to the action of the polar forces simply, no other force applying for producing it. Some evaporation takes place in the open end, it is true, but the circulation is greatly in excess of this, the sap rapidly accumulating till a column 21 feet in height is reached, where the point of equilibrium is reached, and a balance is struck between the action of gravitation and the action of the polar forces, the two being antagonistic; the weight in this column of fluid being the measure of the energy of the polar forces in the terminal ends or poles in the vine, otherwise is inexplicable.

Of course, evaporation from the surface of the leaflets involves corresponding absorption in the rootlets, for maintaining a balance in the circulation, in this manner increasing circulation in proportion to the evaporation taking place; but it would not explain why the tree fills up with sap *before* there are any leaflets and out of which the leaflets themselves are formed; while it leaves unexplained the principle in evaporation for connecting the internal with the external mechanics, which the scheme calls for, continuity in force demanding this. And not water only, but the oxygen which is disengaged in the nutritive processes from carbonic acid, and is passing out from the surface of the leaflets in a constant stream, the molecules promptly taking up their relative positions in the atmosphere; while carbonic acid is compelled in the tree by the same means.

n fine, that there must be some universal and all-pervading principle in nature for connecting the prodigious clock-work through and through, and bearing upon every piece to the very molecules and atoms themselves, since it is through them the masses, living or non-living, are built up and sustained, or are pulled down and again redistributed. There is no difficulty, then, in accounting for circulation in flora any more than there is in accounting for circulation in the air and water out of which they are evolved, while all the phenomena fall readily into line in regular order and succession, and leave no outstanding quantity refusing absorption. And in this connection we should not fail to notice a deeply suggestive fact, namely: why water should pass out at the leaflets in a constant stream by evaporation, and if not as rapidly renewed by a similar stream passing in at the rootlets for maintaining a balance, the plant would speedily become dry and crisp, as occurs in fatal droughts. This also is easily answered. Since water is the medium of transportation for the nutritive and force-producing elements, it follows when these are withdrawn by the nutritive and functional processes, that a corresponding proportion of water should be discharged in order to make room for the fresh water and supplies coming into the organism; the one involving the other, as in no other way could a balance be maintained, water being the medium of transportation Otherwise nutrition and function would have arrest from the absence of the gases and the alkaline earths and minerals dissolved in it by action of the polar forces. In the fauna a comparatively large amount of water is being thus discharged from the surface for the purpose of regulating body-temperature, for which a physiological balance obtains in the organism, being the most effective means of doing this, a high temperature being inimical to life. Thus during exercise, which tends to put up temperature, the skin becomes flushed for cooling the blood; at the same time is bathed in perspiration. But this matter is more fully treated in another place.

Concerning the Rapidity of the Floral Circulation and the Deduction to be drawn therefrom: The fluids having to pass from cell to cell by means of thin places in the walls left for the purpose, each cell forming a separate and distinct compartment in itself, it follows that circulation in flora is comparatively slow. Still, this is sufficient for the nutritive processes simply, which require a slow circulation to afford opportunity, so to speak for crystallizations to take place in the formative processes; whereas, in animal life, the very opposite obtains, the purpose here being the generation of *force*, which is expended in producing the multitudinous actions taking place in them, since everything is evolved out of circulation, which is made commensurate with the special physiological requirements. Hence, the differentiation of a vascular system, together with the special arrangements that obtain in them for compelling circulation to be in correspondence with the amount of force which is expended in producing the various movements, and which are classified as voluntary and involuntary, or animal and organic, but all of which are directly dependent upon circulation, as must appear obvious.

The point we wish to make is, that the nutritive processes require a *slow* circulation, and in proof of this fact, we have overwhelming evidence furnished in the flora, notably in the case of a pumpkin weighing 265 lbs., which was produced in a period of less than 60 days from the time of flowering, and that upon a vine but a little more than an inch in diameter.*

* All the buds are pinched off save the one selected.

In succulent plants, such as grasses, peas, beans, etc., growth is very rapid. And in many others as well; *e. g.*, melons, gourds, roots or tubers. The fruits also. So, then, nutrition *per se* does *not* require a rapid circulation, and sufficient only to effect the accretions and crystallizations for producing growth, inclusive of the arrangements in the structures for producing motion which animal life involves. And we make the deduction for animal life, for the reason that the principle in nutrition is the same, and must be so in the very nature of things. Namely, the action of the polar forces for pulling the molecules into position and locking them in the structures, a slow circulation favoring this action. Consequently, nutrition goes on most rapidly during sleep and repose, when circulation is slowest. But for evolving force in the organism for producing the multitudinous actions taking place in the body, calls for a rapid circulation to make it commensurate with this circumstance, the two being necessarily in correspondence, for in no other way could a balance be maintained.

It calls for considerable expenditure of force; hence, the amount of food consumed, especially by warm-blooded animals, the maintenance of temperature alone calling for large supplies, as this approximates 100 degrees Fahr.; in many animals, birds especially, it runs a number of degrees higher. In this, too, there is variety, as in everything else, animate and inanimate, variety being the one pronounced circumstance in Nature.

This brings us to the means for increasing the animal circulation, commensurate with the force which is expended in them.

CHAPTER III.

THE ANIMAL CIRCULATION.

Principle in the Animal Circulation—Adjustment with Pressure and the Power of Producing RAPID RHYTHMICAL CHANGES IN PRESSURE, THE LAW IN THE ANIMAL CIRCULATION—The Movements in Respiration: Heart, Arteries, etc., *Pumping-Actions* for Increasing Circulation, the Whole Forming a Connected Movement for Increasing Circulation Between the Cell-Brood and Environment, whence the Nutritive and Force-Producing Elements are Derived, and into which the Waste Products are Returned—Explanation for the Correlation of the Vaso-Motor and Voluntary-Motor Centres with the Respiratory Centre—Mechanics in Inspiration and Expiration—Two Respiratory Movements Performing at the Same Time; One in the Lungs, the Other in the Tissues—Physiological Experiments, Showing that Pressure is the Fundamental Circumstance in the Animal Organism, with which Everything has Adjustment, and that the Actions in the Lungs, Heart, Vessels and Hollow Viscera *Relate to Changes in Pressure* for Compelling Movement in the Contents: *i. e.*, for Increasing Circulation—Otherwise are Meaningless.

We are now in a position to take up the animal circulation and explain the phenomena appertaining to it; notably, the actions in respiration and in the heart and blood vessels, together with the whole scheme in animal structure and function.

But in addition to the mechanics for effecting circulation in plants—namely, the action of the polar forces—we will now have to introduce the principle of *change in pressure*, before alluded to for increasing circulation in the air, only that the action is here confined within narrow limits and is rapidly repeated, said circumstance being announced by the pumping movements in respiration and in the heart and blood vessels, which relate to rhythmical changes in pressure for increasing circulation commensurate with the physiological requirements, hence rising and falling in correspondence with these; otherwise are meaningless. In short, THE ANIMAL CIRCULATION IS BASED UPON PRESSURE AND THE POWER OF PRODUCING RAPID RHYTHMICAL EXPANSIONS AND CONTRACTIONS IN THE ORGANS FOR CHANGING PRESSURE, WHEREBY THE COMMERCE IS COM-

PELLED IN THE VESSELS AND THROUGH THE TISSUES WITH CORRESPONDING ENERGY, THE FLUIDS FLOWING FROM HIGH TO LOW PRESSURE IN CONFORMITY WITH ORGANIC LAW. Hence the mechanical principle in respiration for compelling the air in and out of the lungs, is the same as in the heart and blood vessels for speeding the blood between the lungs and the cell-brood, the workmen in the tissues and objective point of all the supplies. Moreover, they form a connected movement, as in no other way could a balance be maintained. In other words, the pumping action in the lungs and abdomen for compelling the force-producing and nutritive elements in the vascular channels calls for these pumping actions in the heart and vessels for circulating them, for in no other way could it be produced. And but for this power of producing rapid rhythmical changes in pressure in the organs and tissues for increasing circulation development would inevitably have arrest at the flora, since *no* other means obtains for increasing circulation commensurate with the physiological requirements in animal organisms; while the speed of the currents thus produced has determination, by the rapidity and energy of the pumping actions taking place in the organs, and pervading the entire body, exclusive of the bones and cartilages (the framework of support to the soft tissues), in which circulation is analogous with that in plants. And while the scheme is comprehensive, involving multitudinous arrangements in the organs and tissues for producing the actions and for unifying them, still it is all simple enough and easily understood. Of course, it would naturally include the digestive and assimilative functions, with the secretory and excretory, for it all relates to circulation and the maintenance of a balance in the organism. And since pressure, by reason of the compressibility of the tissues, is transmitted through the body upon all the organs to the minutest histological elements and cells, it is at once made available for increasing circulation, commensurate with the physiological requirements. Hence, the universal pumping actions taking place in the body, as before remarked. This necessity for increasing circulation in the fauna, over and above what takes place in the flora, in order to make it commensurate with the force which is expended in them, is sufficiently obvious; since every variety of motion involves a corresponding expenditure of force for producing it, while this in turn is evolved from the chemical combinations of substances which are carried into the organism by circulation—notably oxygen and carbon—the waste products being carried out by the same means. Hence, the greater the expenditures of force, or the more rapid the voluntary movements, the more rapid are the actions in the lungs, heart and blood-vessels for making circulation commensurate with this circumstance, the whole being in correspondence, for in no other way could a balance be maintained. Thus, in the recumbent position, the action in the lungs, heart and blood-vessels is lowest; but the instant the erect position is reached, there is considerable increase in the action for promptly supplying the increased expenditures which this calls for, while there is progressive increase in correspondence with the swell in the activities, therefore is greatest when the animal is *running*. In other words, pressure is invoked in the measure of the requirements by means of these pumping actions. But in the absence of this law of pressure upon which to base the mechanics, it were as utterly impossible to explain the relative phenomena, anatomical and physiological, as it would be to account for the strong, bony skeleton, with the powerful levers and muscles, for effecting locomotion in land animals in the absence of gravitation for compelling this circumstance; the one no more than the other. Proceeding upon this line of investigation, then, we shall pass in brief review the scheme in the animal circulation, thence to the special phenomena in detail, in which will be clearly shown the admirable simplicity and marvelous perfection which characterize the mechanics throughout, and why everything is just as it should be for producing the mechanical work involved in the circulation, thus furnishing overwhelming proof of the correctness of the premises, making the argument unanswerable. We begin with the nervous centres for operating the mechanics and unifying the movements, in itself furnishing the highest order of evidence in support of the theory, being means to ends.

Explanation for the Existence and Correlation of the Three Great Nervous Centres at the Base of the Brain in the Medulla Oblongata, notably RESPIRATORY, VASO-MOTOR *and* VOLUNTARY-MOTOR CENTRES:

This relation which the animal organism sustains to pressure enables us to offer a scientific explanation for the existence and correlation of the three great nervous centres at the base of the brain in the medulla oblongata for operating the mechanics, or the respiratory, vaso-motor and voluntary-motor centres; otherwise inexplicable, and which is briefly as follows:

Respiratory Centre.—Since respiration is the great pumping action for compelling the fluids in the organism, it is manifest that this calls for a common nervous centre for producing and coördinating the action in the lungs and containing walls, to the end that air and blood may be pumped through the lungs for respiratory purposes, and which would also include the force-producing elements in the intestinal canal, since it is by chemical combination of oxygen with carbon that force is generated, a measure of oxygen calling for a measure of carbon in order to effect it. Hence, this respiratory centre, together with the large pneumogastric nerves extending thence into the abdomen for connecting and coördinating the viscera with respiration. Of course, there must be a philosophic reason for these nervous combinations, or one based upon organic law, as they are persistent and universal. It does not follow that heat is generated in the lungs, which is not the case, only that intestinal absorption *should be* in correspondence with respiration for maintaining a balance, otherwise impossible.

Vaso-Motor Centre.—Several reasons make the existence of the vaso-motor centre an absolute necessity, namely: 1. It is necessary for coördinating the blood-vascular system with respiration in order to produce an uninterrupted current of the blood from the lungs to the tissue territories for maintaining a balance between supply and demand; otherwise this could not be done. In other words, the pumping actions in the heart and blood vessels must have adjustment with the pumping actions in the lungs for producing correspondence, the one necessarily having adjustment with the other, as must appear obvious. Hence, the existence of this centre, together with its correlation with the respiratory, for in no other way could continuity in force be produced. 2. Since the vessels expand and contract upon their contents for increasing or diminishing the blood for regulating the local actions which are ever changing, it follows that there must be a means for *limiting* the local supplies and regulating the movements throughout so as to maintain a balance; otherwise, some parts of the system would have more blood than necessary, while other portions would suffer from dangerous anæmia; hence, this vaso-motor centre for compelling circulation in the measure of the requirements. 3. Last, but not least, the high pressure in the arterial system for increasing circulation in the capillaries tends to produce dangerous accumulations in the venous system, where pressure is low, and since there is a nôrm of blood which is kept in constant motion, it follows there must be some means for regulating the *capacity* of the venous system, which is something like four times as great as the arterial; hence this vaso-motor centre for regulating that circumstance also. Finally, the whole is set to respiration, for this is the great pendulum movement in the clockwork with which everything must have adjustment, since it is the means for compelling the commerce in the organism, while the heart and vessels function as a carrier.

3. *Voluntary-Motor Centre.*—The existence of the voluntary-motor centre, together with its correlation with the respiratory and vaso-motor centres, is also easily understood. Thus, since every movement involves a corresponding expenditure of force for producing it, and this is evolved out of circulation from substances brought into the organism by this means, it follows that respiration and the actions in the heart and vessels must be in correspondence with the voluntary movements in order to maintain a balance between supply and demand, for in no other way could this be done; hence the correlation of this nervous centre with the other two centres so as to produce continuity in force, which the scheme calls for.

In fine, respiration and circulation together form the basis of the activities, consequently the latter must have adjustment with the former. Hence the correlation of these nervous centres in the medulla oblongata.

The necessity for producing and coördinating the voluntary movements would, of course, explain the existence of the voluntary-motor centre, but at the same time it would not account for the correlation of this centre with the other two centres. In this manner, then, that vexed problem in physiology has scientific explanation, and it is at once seen these nervous combinations in the medulla oblongata are inevitable from the very nature of things, the law in the circulation and continuity in force alike compelling this circumstance.

Thus with a common law underlying it all, and the same principle in mechanics for increasing circulation—*i. e.*, *rhythmical changes in pressure*—it is manifest that correspondence in the structures is also made inevitable, or that similar arrangements should obtain in the animals for producing circulation and the voluntary movements. And this would include not only the systemic mechanics, but the anatomical dispositions in the walls of the organ as well ; while this again would have determination by the character of the work, the nature of the contents, and the amount of force which is required for compelling movement in them in the rôle of the special functions, so that all is readily explained and made intelligible. Indeed, this principle for increasing circulation must apply to the very cells themselves, which expand and contract under stimulus for producing afflux and efflux of the fluids in which they are submerged, for in no other way could circulation be increased within the cells for increasing metabolism.

Finally, each organ by possessing separate and independent local nervous centres appertaining to its own special functions, but connecting with the systemic apparatus, enables the local actions to be increased or diminished as occasion may require, without interfering with the general functions. As the mechanics are fully brought out and explained at the proper time and place in the text, it will not be necessary at this early stage to do more than briefly refer to the cardinal circumstances in order to prepare the mind of the student for the radical changes introduced in present physiology, and which he will at once see are not only logical and necessary, but unavoidable. First of all, however, let him get himself right by emancipating and disenthralling his mind of all prejudice tending to mar the judgment and obscure the mental vision, to the end that he may listen to reason and weigh evidence dispassionately; otherwise, at very best he is but partly rational, his opinion to be little depended upon and unworthy of respect. After he has done that, let him lay firm hold of this law of pressure underlying the animal organism if he would understand the phenomena in animal mechanics, since they all relate to this fundamental force in nature. Now, then, it being true the body has special adjustments with pressure, while the law in the circulation consists in rapid rhythmical changes in pressure, it remains to inspect the phenomena from this standpoint, commencing with respiration, the initial action for compelling the commerce in the organism, as before remarked.

Import of Inspiration and Expiration.—Briefly, Inspiration is the effort to develop a lower pressure in the lungs than exists externally; in consequence, the air and blood flow into the low-pressure area till pressure is uniform, the amount so flowing in being the exact measure of lung expansion; no more and no less: while Expiration is the effort to develop a higher pressure in the lungs than exists externally, when the air and blood in consequence flow out of the organs till pressure is again uniform, the amount so flowing out being the exact measure of lung contraction; no more and no less. In this manner, then, a *dual* circulation of air and blood is maintained through the lungs for respiratory purposes, the former flowing in by way of the trachea and the latter through the right side of the heart and pulmonary artery during inspiration; but during expiration the air flows out by reflux action through the route of ingress to the environment, while the blood itself passes through the four pulmonary veins into the left side of the heart and arterial system on its way to the cell-brood in the tissues. But the great inertia in the blood calls for the expenditure of considerable force for bringing it into correspondence with the circulation of air in the alveoli, the obvious purpose being to maintain FRESH air and VENOUS blood in *close* proximity for effecting mutual interchange. Hence the numerous muscles and nerves in the heart and blood vessels for increasing circulation in the lungs and in the tissues and for coördinating them with the actions taking place in *both* localities, a circumstance which is fully brought out further on. But in order to produce these dual circulations of air and blood through the alveoli, it is absolutely necessary for the lungs and containing walls to expand and contract together or simultaneously, for in no other way could the requisite changes in pressure be produced within the alveoli for compelling afflux and efflux of these fluids, neither could a balance in pressure be maintained in the pleuræ for obviating effusions in these cavities, otherwise inevitable; and which should speedily put an end to respiration by preventing lung expansion; such concert of action in the parts being effected by the nervous apparatus, notably the pneumogastric, intercostal and phrenic nerves and the so-called organic or sympathetic system, which is intimately connected with the lungs, and undoubtedly serving for coördinating these actions. The mechanics is comprehensive but easily understood, the law in the circulation compelling these arrangements for maintaining a balance and keeping the fluids within their channels; otherwise impossible, since they flow from high to low pressure in conformity with universal law. And all these nerves being correlated in the medulla oblongata, harmonious action throughout is readily produced. And which, of course, would include the vasomotor system, together with the nerves to the heart for bringing the blood into correspondence with the circulation of air in the lungs. In this manner, then, these wonderful nervous combinations in the medulla oblongata are readily explained, and they can be explained in no other way. And not this circumstance only, but *all* the anatomical dispositions which obtain in the organs for producing these actions as well, being means to ends simply; furthermore, they cannot be explained in any other way. Thus everything is in correspondence, and nothing is left out. And this should be the case, since the mechanism is necessarily founded upon law; hence *every* piece in the comprehensive clockwork must have definite adjustments and relations with the rest, as must appear obvious. In short, a physiology which does not explain anatomy is no physiology at all. But in the absence of the fundamental principle upon which the mechanics is based, of course this would be impossible.

The animal organism being founded upon pressure, while the law in the circulation consists in rapid, rhythmical changes in pressure, as alleged, it follows that the pumping action in the lungs should compel simultaneous afflux and efflux of air and blood in the alveoli, since both fluids freely communicate with these chambers through a special tubular system arranged for the purpose, the heart not interfering with but rather assisting this mechanics by putting additional force upon the blood, and which its greater inertia calls for, as before remarked; at the same time the heart itself is coördinated with the lungs, both doing inspiration and expiration, so that in nowise is the action in the lungs interfered with by the action in the heart, the special functions in which will be described later on, and their true relation to the circulation fully shown.

The following diagram of the venous system, showing the relations it sustains to the lungs (Fig. 7), will serve for impressing the matter For example, the air (*L*) and the venous blood (*A*, *A*, *A*) freely communicate with the alveoli; hence, when the lungs expand during inspiration for reducing pressure in the alveoli, the air and blood, coming from opposite directions, must flow into these chambers *simultaneously* till pressure is uniform, pressure compelling them to do so. Upon the other hand, when the lungs contract during expiration for increasing pressure in the alveoli, the air and blood must flow out of these compartments *simultaneously* till pressure is again uniform, the one by reflux action through the route of ingress, the other into the left chambers of the heart and arterial system, the valves at the right side of the heart compelling this circumstance by preventing reflux, as in the case of the air in the air passages. From this arrangement, then, it is very readily perceived that currents of air and blood should flow in and out of the alveoli simultaneously during respiration, the one necessarily involving the other. But to this we must add the arrangements in the heart and vascular system for bringing the blood into correspondence with the circulation of air in the alveoli, there being a given measure of each, for which special adjustments obtain in the compartments, as also for producing an *uninterrupted* flow of blood through the lungs, and the whole scheme in respiration will be readily apprehended. First of all, let it be understood that the generation of *force* in the organism

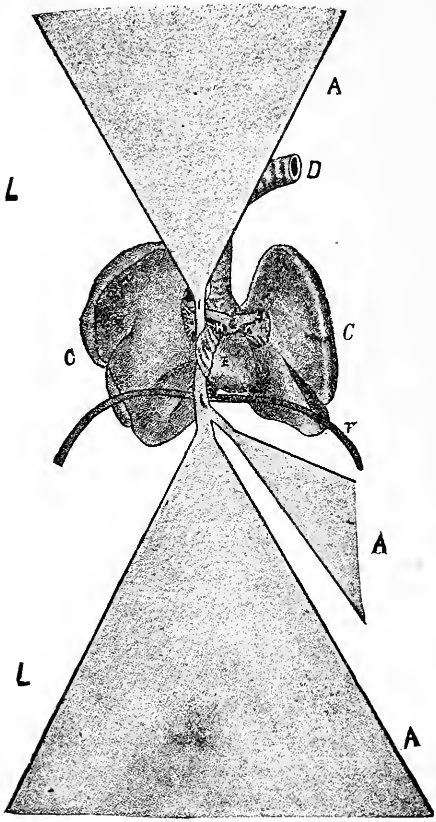


Fig. 7.—Diagrammatic representation of the Venous System, showing the relations it sustains to the Lungs. *A*, *A*, *A*, venous system represented as pyramids, with the bases in the tissues and the apices at the heart and lungs (*E*, *C*) ; *B*, pulmonary artery ; *D*, trachea ; *F*, diaphragm ; *L*, atmosphere.

is the purpose of all these arrangements, and this can only be done by means of the pumping actions in the lungs, with which everything must have adjustment ; hence would include the intestines with the blood-vascular and lymphatic systems, since it all relates to circulation and the supply of the cell-brood in the tissues, through whose agencies the special phenomena are evolved.

Finally, we have to mention the existence of two respiratory movements performing at the same time in the body, notably one in the lungs, the other in the tissues; the former for pumping the commerce in the organism, the latter for pumping it in and out of the tissues for the due supply of the cell-brood and removal of waste products; while the vascular system, inclusive of the heart, functions as a carrier between these two poles in the circulation, with which they are coördinated by means of the nerves extending over them and connecting them with the medulla oblongata, the vaso-motor and respiratory centres, whence force is propagated over all the structures, to the end that a current of blood may be maintained between the cell-brood and environment for the due supply of the nutritive and force-producing elements and removal of waste products. The composite character in the arterial tracings, or the existence of respiratory, cardio-arterial and dicrotic or capillary *waves*, which are *superposed*, one upon the other, in the order named; or the respiratory, by the cardio-arterial, and the latter by the capillary or dicrotic waves, is to be explained by this circumstance. In fine, these *waves* or respiratory pulsations are throbbed over the vessels from the respiratory centre in the medulla oblongata, by means of the nervous plexuses, extending over the vessels. "Traube's Curves," together with the physiological problem connected with the curves in arterial and intra-thoracic pressure, are readily explained. By means of this law of pressure underlying the organism, then, all this is easily accounted for and made intelligible; otherwise is utterly inexplicable. The most incontrovertible evidence of rhythmical expansions and contractions taking place in the arteries and capillaries, synchronous with respiration and the action in the heart, is submitted, placing this function in the vessels, beyond the shadow of a doubt or the possibility of mistake, at the same time the common relation which it all sustains to pressure is too obvious for controversy.

Last but not least, we have to note the deeply significant fact of *an increase of pressure in the arterial system with progress in development*, notably in warm-blooded animals. Thus, when a cold-blooded animal is decapitated, the blood issues very slowly out of the open ends of the vessels, oozes and wells out simply, trickling down in a tiny stream upon the ground, dark and venous in appearance ; whereas in the case of a warm-blooded animal it spurts out to a considerable distance from the body in a sustained stream, which issues *per saltam* or in a succession of leaps, the latter being due to rhythmical contraction in the vessels for increasing pressure, while the former is due to the permanent high pressure which exists in the arterial system for increasing circulation in the tissues, at the same time it functions as the *vis a tergo* to the venous system for compelling the venous blood toward the lungs, thereby assisting the action in those organs and in the heart, which act as a suction-force upon it and constitute the *vis a fronte;* to which must be added the action in the veins themselves, which are muscular and richly supplied with nerves connecting with the vaso-motor and respiratory centres. Well, the blood in the arterial system of warm-blooded animals is not only under high pressure, but is also more highly oxygenated, being of a bright red color, the two going together—the high pressure with the increase in oxygen. So that we have an arrangement for increasing circulation in the tissues with an arrangement for increasing metabolism, the two being in correspondence. And we can see why this also should be as it is. Since it relates to the generation of force, there would be nothing gained by increasing circulation in the tissues in the absence of the oxygen ; hence, this special combination for evolving force in the organism. But why in the warm-blooded animal more than the cold ? This also is easily answered. Thus, in the case of the cold-blooded animal the body lies prone upon the ground, the movements are sluggishly and awkwardly performed, while respiration is imperfect and digestion slow and delayed. On the other hand, in the case of the warm-blooded animal the body is suspended off the ground by means of the crura, which involves a tremendous struggle with gravitation, while the animal is in constant motion and the movements energetic, and which, of course, would call for a corresponding amount of force for effecting these actions ; hence the increase in the respiratory and digestive functions, together with the high pressure in the arterial system for increasing metabolism, for in no other way could it be done. Again everything is in correspondence.*

A highly interesting and important fact in the animal circulation is the presence of iron in the red corpuscles in the form of hæmoglobin, for increasing polarity, whereby oxygen is more readily pulled into the organism and carbonic acid expelled from it ; since it is not a chemical union which is effected with these gases, but one in which the molecules are in light contact simply, the hæmoglobin readily yielding up the oxygen in the tissues, while the carbonic acid is easily displaced by the oxygen when the venous blood is exposed to the air. And by reducing pressure simply, as in a receiver and air-pump, oxygen escapes from the corpuscles. The great complexity in this albuminous compound (C 54.0, H 7.25, N 16.25, Fe 0.42, SO .63, O 21.45—Hermann), and which, of course, is necessary for producing the polar conditions spoken of, makes this one of the most wonderful adjustments in the body. But this matter is more advantageously treated in connection with development, to which the reader is referred, the more immediate object in hand being to show the law in the circulation and the relations it sustains to pressure.

Showing that the Animal Fluids Respond to Changes in Pressure.—Before proceeding to make application of the preceding principles for elucidating vital phenomena, anatomical and physiological, it might not be amiss to call to mind familiar circumstances of every-day occurrence, which establish incontrovertibly the important fact that *the animal fluids respond to changes in pressure*, and showing conclusively that it is fundamental in the animal organism, thus fully preparing the mind for what is to follow in the text. For this purpose we have prepared the following illustrative diagram (Fig. 8). For example, it would scarcely be contended for a single moment even that the principle which applies for aspirating the secretions in the mammary gland by means of the breast-pump

* For the rest the reader is referred to the work "On Gravitation and Development," where many other matters come up in this connection.

(*B*) is not identical with that in the ordinary syringe (*A*), the fluids in both cases flowing into the instruments *by reason of the low pressure which is developed within them and with which they communicate,* till pressure is uniform. Indeed, the very tissues themselves are compressed, pushed and squeezed into the breast-pump in order to equalize pressure, external force compelling this circumstance. But a yet more forcible illustration is furnished in the case of the ordinary cupping-glass (*E*). In this contrivance the air in the cup is rarified simply by the burning alcohol, when the instrument is suddenly inverted over the parts, which are *at once* forcibly compressed into it, the blood at the same time flowing rapidly into the imprisoned structures in order to equalize pressure, till the distended and swollen capillaries burst with their contents, producing the characteristic ecchymoses, so great is the energy in this force when suddenly developed. And since there is *no* power in the body to prevent this abnormal current in the blood and juices, it follows that pressure is the fundamental circumstance in the organism with which everything must have adjustment. Indeed, it furnishes a crucial test of this fact; while the actions taking place in respiration, in the heart, arteries and hollow viscera, are to be interpreted from that stand-point; otherwise are meaningless.

In fine, but for this adjustment, with pressure and the power of producing rapid rhythmical changes in pressure, animal life would be utterly impossible.

And it applies not only to respiration and the actions in the heart and vessels but to deglutition, defecation, urination—in short to all the hollow viscera, since they all relate to circulation, and the maintenance of a balance in the organism; otherwise these actions also would be meaningless. Thus in the case of the nursing infant (*D*) can it be doubted for a single moment even that the same principle applies for compelling the mammary secretions in the mouth-cavity, as in the chamber of the breast-pump (*B*), or the production of a lower pressure in the cavity than in the mammary gland, the fluid flowing from high to low pressure in conformity with universal law? (And it is more than probable, as the secretions are being thus withdrawn, that the irritations propagated from the skin-surface are reflected thence upon the milk ducts, which causes them to contract for increasing pressure, whereby the flow into the mouth-cavity is expedited). Furthermore, that the same principle applies for compelling them thence into the stomachal cavity represented in the

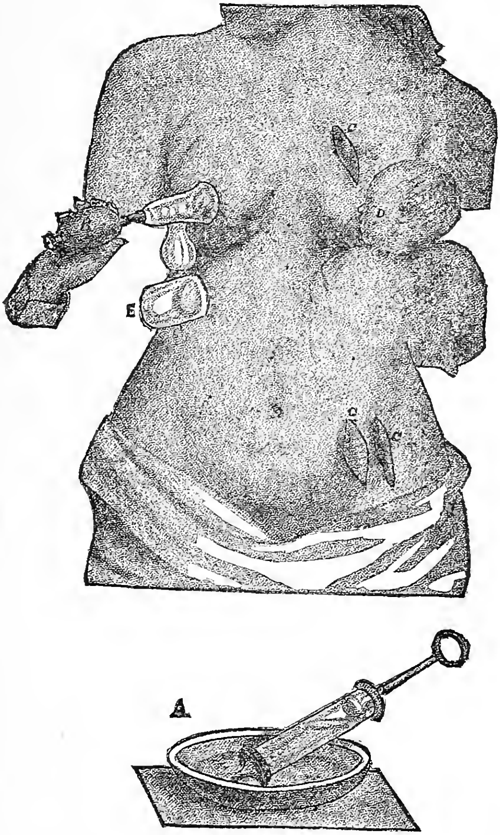


Fig. 8.—Familiar Modes of Pumping the Fluids out of the Body, showing that they respond to changes in pressure.

waves of deglutition, which consist in an anterior expansion for diminishing pressure with a posterior contraction for increasing it, whereby the journey of the fluid or the bolus along the canal is greatly expedited, the *waves* following each other in rapid succession till the stomachal cavity is reached. In short, that deglutition is based upon rhythmical changes in pressure, otherwise is inexplicable. Also, that the same applies for the sucking leech (*c*), which is feeding in the capillaries of its victim, while the undulations coursing along its tubular body from the mouth-cavity are analogous with deglutition, of which it is archetypal, the principle in mechanics being the same for both, while the structures are fundamentally the same, of which more anon.

Finally, that pressure is transmitted through the body upon all the organs is also of easy demonstration. Notably the instrument of Dulafoy for aspirating depots of pus and collections in the deep tissues and organs of the body, furnishes a crucial test of this circumstance. For example, it establishes the important fact that an empty air-tight vessel when placed at the bedside of a patient, and made to communicate with an internal collection by means of an elastic tube and canula, will aspirate the collections the moment that pressure is reduced within the instrument by pumping out some of the air it contains, till the very last portions are removed. Furthermore, that it will do this at a distance from the body; this in the absence of any other means for assisting it through the tubing, the difference in pressure in the two localities being sufficient for the purpose.

The practical deduction to be made from this circumstance is, that the extensive arrangements which obtain for reducing pressure in the lungs during inspiration should have the effect of aspirating the venous system at the same time that it aspirates air, while the action in the heart should greatly expedite it, whereby correspondence is produced between the circulation of air and blood in the alveoli, as before remarked. It is needless to extend the matter.

In conclusion, the power of producing the rhythmical expansions and contractions for effecting the requisite changes in pressure in the organs and tissues for expediting circulation and producing the voluntary movements (the principle is the same in both) inheres in protoplasm itself, which expands and contracts with great facility; moreover, expansion and contraction are correlated forces in Nature. The molecular action it involves will come up at the proper time and place. (See closing chapter.) Hoping we have made ourselves understood sufficiently, let us now turn our attention to the circumstances in development explanatory of this fundamental principle in the mechanics of circulation, taking the vital phenemena, anatomical and physiological, as the text, and the law of pressure underlying the organism as the key for construing and interpreting them, or as means to ends simply. And since there is increasing differentiation in the organs and tissues with progress in development, for the sake of simplicity and effectiveness, it were best to begin with the lowest organisms, taking the action in undifferentiated protoplasm itself as the first visible expression, proceeding thence as rapidly as possible till the highest forms are reached. Indeed, one must proceed from the simpler to the more complex forms in order to make the latter intelligible. In this manner the whole is illuminated, and everything made plain and easily understood.

CHAPTER IV.

RESPIRATION IN DIFFERENT STAGES IN DEVELOPMENT.

Import of Amœbæ Movement—The Alternate Extension and Retraction of the Branched Processes, a Pumping Action for Increasing Circulation—Why Locomotion Should Increase Circulation Correspondingly—The Pumping Movements Analogous with Respiration—The Action in Vacuoles and the Radiating Canals, an Early Indication of the Mechanical Principle in the Heart and Arteries, the Latter Expanding as the Former is Contracting, and *vice versa*—The Action in Gastrula—Necessity for Coördinating the *Mucous* with the *Skin-Surface*, in Order to Produce Afflux and Efflux of the Fluids in the Body-Interior—This Circumstance Further Illustrated in the Worms for Producing the Undulations which Course Along the Body During Imbibition—The Principle Applied to Respiration and the Action Taking Place in the Lungs—Illustrated in the Frog, in which it is Demonstrated Experimentally that the Lungs Expand and Contract Regularly and Rhythmically Synchronous with the Action Taking Place in the Muscular Envelope or Containing Walls, in Order to Produce Afflux and Efflux of Air and Blood in these Organs for Respiratory Purposes; Otherwise Impossible—The Manner the Parts are Coördinated—Dependence of the Portal Circulation upon Respiration—The Same Principle in Mechanics for Every Stage in Development—The Action in Birds—The Special Adjustments in the Viscera—Portal Circulation in.

This relation which animal life sustains to pressure, and the law for increasing circulation by rapid rhythmical changes in pressure, would afford a ready explanation for the alternate extension and retraction of the branched processes in amœbæ, and which function as temporary *villi* for pumping the commerce in the organism. For example, when an amœba is placed upon the slide in the field of the microscope, and a drop of water suffered to fall upon it, it *at once* begins to extend and retract the branched processes in rapid succession, and in *every* direction from the undifferentiated body, appearing and disappearing, now here, now there, in the protoplasmic substance. It is not trying to get away, but trying rather to *live* and sustain existence by means of these branched processes and this pumping action thus set up in them. In short, the animal is simply *feeding;* nay, feeding and respiring at the same time, the one involving the other; and which should be the case for maintaining a balance in force, the same principle for generating force applying for it as for the higher stages in development, and must necessarily apply for every stage. These so-called pseudopodia (false feet), then, are not for effecting locomotion simply, as their name implies, but for sustaining existence; at the same time, they are available for locomotion, though this is laboriously and indifferently performed. Furthermore, it is readily perceived that this also should increase circulation correspondingly, since it involves more extended and energetic action in the branched processes for effecting it, whereby the requisite force is generated for producing this action; otherwise impossible. In this manner a balance is maintained, one adjustment involving the other.

In fine, when the amœba extends a branched process, it develops a lower pressure within itself than exists externally, when the fluids immediately adjacent rush into the low-pressure area until pressure is uniform, and which corresponds with inspiration. But when the branched processes are retracted, this compels the contents into the body-interior, at the same time expelling waste products, and which corresponds with expiration. Of course, the more rapid the action the more rapid is this circulation. The in-going current contains the nutritive and force-producing elements, and the outgoing the waste products; while water is the vehicle or medium of transportation for the commerce, at the same time it enters into the molecular arrangements for forming the structure itself. In addition, water is a powerful stimulus for exciting the pumping actions and arousing latent energy, so that the moment it touches the amœbæ it begins to pump, and thus compelling it into itself, the whole mechanism becomes "alive."

But remove the water, and the pumping action stops and life is in abeyance. No one can tell what water is—extending as it does into the depths of force—further than to speak of some of its performances and the conditions which determine them, notably the polar actions and the means of energizing them, inclusive of the law of pressure for increasing the action in the manner spoken of, or by rhythmical changes in pressure for compelling it in and through the organism in the measure of the requirements. Furthermore, by extending and retracting the branched processes from different portions of the body-surface, the amœba is enabled to effect a short and direct journey of the fluids to the portions where they are most needed, and which subserves the purpose of a vascular system for effecting the same ends in the higher stages in development; at the same time, it also involves an amount of motion of the fluids *within* the body, whereby metabolism is expedited. Thus, when a branch process is being extended, the low pressure which is thereby developed within this portion produces afflux of the fluids in *two* directions—one from the body itself, the other from the environment—coming from opposite directions simultaneously to the low-pressure area till pressure is uniform; while in the body itself a special force applies for increasing the action, notably the contraction which sets in simultaneously with extension in the branched process, should effect a corresponding increase in pressure for compelling the contents into the branched process, the body fluids flowing into this more rapidly in consequence. On the other hand, when the process is being retracted there is commensurate expansion in the body in order to effect it, the former producing high, the latter low pressure; hence, the fluids must flow out of the branched process into the body-interior with corresponding energy. Thus, a churning movement is produced in the fluids for hastening metabolism. The following forcible illustration by the distinguished biologist at Heidelberg (Fig. 7, *A*, *B*) will serve for impressing the matter. It represents an amœba at two different moments during movement. By fixing the eye upon the food particle, we can very readily perceive how the contents are affected by the pumping action in the processes. Thus, in the case of *B*, in which a branched process is extended, the body is narrow or contracted, while the food particle is moved down to the root of the process; but in *A*, in which the process is retracted, the body is considerably widened or expanded, and now the food particle (*i*) is moved up to near the central portions of the body. Thus, a to-and-fro movement is established between the fluids in the body and the branched processes, thereby effecting more rapid disintegration and assimilation of the food, at the same time that it pumps the fluids in and out of the body for respiratory purposes, inclusive of the nutritive elements in a state of solution Hence the rapid absorption of fine coloring matter, which passes into the amœba with great rapidity.

Finally, that this pumping action in amœba relates to the nutritive and functional processes is sufficiently obvious, there being no other means for increasing circulation. Moreover, the same action is seen in Bathybius—enormous masses of retiform protoplasmic substance covering the floor of the ocean, in places to many feet in depth—which does not locomote nevertheless performs similar movements when a fragment is placed in the field of the microscope, and a drop of water is suffered to fall upon it, the action undoubtedly indicating respiratory movement for increasing circulation in the

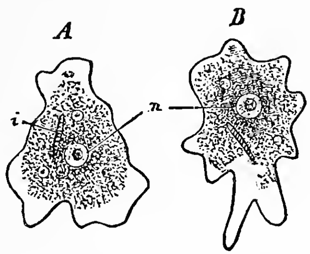


Fig. 9.—An Amœba figured at two different moments during movement; *n*, nucleus, *i*, ingested food. Some vacuoles may also be noted.—Gegenbaur.

protoplasmic substance and interstices, the surrounding fluids flowing in and out through these.

Modes of Introducing Solid Food in Amœbæ.—The mechanical principle which applies for absorbing solid food in amœbæ is the same as for producing the pumping actions, notably by expanding and contracting upon it, only it has different expression, and which varies with the stage in development. Thus, in the lowest amœbæ, in which the body-surface is naked and undifferentiated protoplasm, solid food is absorbed in two different ways: either by extending branched processes around the solid particle, when the soft substance flows together again, and so engulfing it; or else by the body itself *opening* at the point of contact for receiving it, the food at the same time sinking into it from the action of external pressure till fully submerged, when the substance closes over it. In either case involving expansile and contractile action in the protoplasm in order to effect it; while this in turn is referable to the action in the molecules, and which, of course, is regulated as occasion may require. And any portion of the body-surface may thus function as a mouth or receiving organ for the food, just as any portion may serve for extending and retracting the branched processes for pumping in the fluids, while pressure applies alike to both actions for making them effective. Thus, when the surface opens in response to the stimulus of the food brought into contact with it, a suction force is at once produced for compelling it into the organism, and which necessarily results from the act of expansion, the particle sinking deeper and deeper with progress in expansion, till finally it reaches the locality where it is to undergo digestion and assimilation, there being no stomach or digestive cavity for receiving it when the protoplasmic substance closes over it. Likewise, when a cortical layer and external organs are differentiated (Fig. 10), the same principle applies.

In this case the radiating processes (*e*) serve as tactile and prehensile organs for directing the food to the part which is to function at the time as a mouth or receiving organ, holding it against the surface (*a*) till the requisite changes can be made in the adjacent parts, when it is compelled into the body under the action of external pressure, where their function ends in this respect. And let it not be thought for a single moment even that they can compel the food into the body, for this rude mechanics is not only wrong in principle, but must inevitably prove disastrous, since the action necessarily involves appropriate internal arrangements for receiving the food, while the parts yield of *their own* accord under the stimulus of the food. a change *at once* setting in at the point of contact, and extending thence to the adjacent protoplasm, which in like manner recedes before it till it reaches its destination, all the parts acting in harmonious concert to this end. In other words, *room* is made for the food as it progresses into the body, while the very effort to make this room invokes the *force* of external pressure for compelling it into the body. And from the moment it starts upon the journey till it reaches its destination, such is the case. And one morsel after another being thus taken in, when the amœba is made to eat, the limit in expansion is finally reached when no more food can be taken into the body, a circumstance, indeed, which is forcibly illustrated in a higher stage in development, *e. g.*, the gorged leech (Fig. 17). But we will not anticipate. When there is a mouth. however (Ciliata), this is expanded when brought in contact with the food, pressure, of course, forcing it in simultaneously, whence it passes into the soft parenchyma as previously, as there is no enteric tube for conveying the food masses, the parts again contracting and closing over it. Indeed, the powers of expansion possessed by these low organisms is something extraordinary, some of the more ravenous infusoria, for example, actually swallowing other

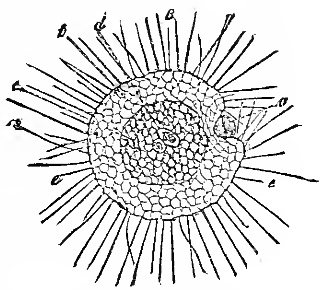


Fig. 10.—Actinosphærum (Gegenbaur). *a*, A morsel which has been taken in as food, and just pushed into the soft cortical layer *b*, by *a change in pressure* ; *c*, central parenchyma ; *d*, other food which had previously been thus introduced ; *e*, pseudopodia of the cortical layer.

infusoria *nearly as large as themselves.* The mouth being brought in contact with the prey, is suddenly expanded upon it, which at once develops a suction force for compelling it into the cavity, when the mouth contracts again for completing the act. Other infusoria (Suctoria) possess hollow radiate processes (Fig. 11, p. 55), which pass through the envelope of the body and function as suckers, so to speak, and which are made to penetrate the body of other infusoria for aspirating the fluids into themselves, flowing into them in the form of drops, thus feeding upon the juices of the victim simply, not possessing a mouth. But for aspirating the fluids, of course the body must expand for reducing pressure, the fluids in consequence flowing into themselves from the body of the victim where pressure is higher.

Finally, since there is no means for compelling food into the body save by changes in pressure, it follows that but for this power of expanding and contracting, which inheres in protoplasm, that the food must inevitably remain out of the body, for in no other way could the requisite changes in pressure be produced. In fine, that animal life would be impossible.

The Action in Vacuoles and What it Involves.—The hollow cavitary spaces filled with a colorless fluid and known as vacuoles (Fig. 11, *v*, *v*), is the first foreshadowing of a specialized vascular apparatus for distributing the fluids through the body. while the phenomena manifested in them possess special significance with reference to the principle that obtains in the heart and arteries. Thus, the vacuole expands and contracts regularly and rhythmically like the diastole and systole in the heart, while a system of radiating canals (at present invisible) receive and discharge the fluids from the pulsating vacuole, expanding and contracting alternately with it, so that during systole in the vacuole there is diastole in the radiating canals, and *vice versa* ; the vacuole itself, like the radiating canals, coming into view during diastole, from the presence of the fluids, which give it definition, and disappearing again with systole when the fluids are in the radiating canals, the two alternately appearing and disappearing in this manner and in regular order and succession, while the fluids flow from high to low pressure in conformity with universal law. The following lengthy excerpt, however, will place the matter fully before the reader :

* "More definite respiratory arrangements are seen when, as in many protozoa, water is taken into the body. Cavities, which are filled with a fluid, and which gradually *contract* and *completely empty themselves, after having reached their maximum of distension*, appear within the protoplasm ; when empty they seem to disappear. These vacuoles, like the vacuoles in the cells of certain tissues, are partly variable structures, now

* Elements of Comparative Anatomy, pp. 85, 86—Gegenbaur.

appearing and now disappearing, and partly constant. When they are constant, their function is increased, and they often *expand* and *contract* regularly and rhythmically, like the cardiac systole and diastole. Contractile vesicles of this kind are often seen in the amœbæ (Difflugia and Arcella), and are very common among the infusoria. They are also known as vacuoles. The fluid which collects in the vesicles is drawn from the parenchyma of the body and is returned to it, or passed out to the exterior on the contraction of the vesicle Fine communications with the exterior have been made out, so that the latter course is the probable one ; but we need not, on this account, conclude that water does not enter by the same passage.

"In the infusoria the vesicles lie in the cortical layer, generally just under the delicate cuticle, and at definite points. If only one vesicle is present, it lies either anteriorly or posteriorly ; if two, there is one near each end of the body. Trachelius ovum is remarkable for a large number of small vesicles. No special membranes can be made out on the wall of the vesicle nor in the canals which pass off from it. Like the vesicle, the canals can only be made out while they are filling. The vesicle and canals contract *alternately*. In Paramæcium the canals *enlarge* at the *commencement* of the systole and approach one another as the vesicle diminishes in size, so that they form a stellate figure at the moment when its systole is most complete and the vesicle has disappeared. While the vesicle is *filling*, the canals look like small diverticula on it, and are not again fully distended until *the diastole is complete*. The number of the canals, which is limited in P. aurelia to eight or ten, is increased to thirty in Bursaria flava, and is much higher in Cystostomum leucas. In these forms the canals have a wave-like course, and ramify at their extremities Canalicular tracts are formed by the fusion of several spaces filled with water into longer tracts, as in Stylonychia (St. mytilus), and they empty themselves into the contractile vesicle by definite passages. The long canals of Spirostomum ambiguum, which are also visible for a time only, but which are longer than these, are like them, so that we can make out a continuous series from the first appearance of an apparently indifferent cavity *to a definitely arranged system of tubes.*" Italics are added. There can be no doubt, then, that the function of vacuoles relates to the distribution of the fluids through the body, and which involves not only respiration and expulsion of waste products, but the nutritive processes as well, the fluids containing both nutritive and force-producing elements. But the point we wish to make, however, concerns the mechanical principle which applies for *filling* and *emptying* the vacuole and radiating canals, and which is undoubtedly rhythmical changes in pressure. Thus when the vacuole *expands* it develops a lower pressure within itself than exists externally; hence the fluids from the adjacent parenchyma and environment (Fig. 11, *v*, *v*.) flow into the low-pressure area till pressure is uniform; but when contraction sets in, the high pressure which this develops within the vacuole causes them to flow out again, passing thence into the radiating canals, which expand simultaneously for reducing pressure and so obviating reflux; thence into the environment during contraction and development of high pressure in the latter. And so by alternate expansions and contractions in the vacuole and radiating canals, the fluids are pumped through the body for respiratory purposes; otherwise is meaningless. In short, it represents a *suction* and a *driving* force, acting alternately; the one produced by *diastole*, the other by *systole.* The eminent anatomist and naturalist would seem to emphasize *systole*, but the fluids would *first* have to be gotten into the vesicle by diastole, and the development of low pressure which this produces, *before* one may speak of systole for driving them out again; the one necessarily involving the other. But exclude pressure and the power of producing rhythmical changes in pressure, and these actions would be meaningless. Now, then, principles do not and cannot change; hence this law for increasing circulation remains the same for every stage in development. And in this primitive circulation, in which not so much as a living membrane is made out, either in the vacuole itself or the radiating canals, which are wrought, as it were, in naked and undifferentiated protoplasm, the principle in the heart and arteries is clearly indicated; the one expanding as the other is contracting, and *vice versa;* while the valves serve for obviating reflux; and leaving not the shadow of a doubt upon the mind of the power in Nature to effect these adjustments.

But when we come to the blood-vascular system, however, ample proof will be furnished of this circumstance. Suffice it to say, the law applies everywhere. And the more one reflects over this circumstance, the more wonderful it grows. This will serve for illustration. And we will now carry the matter a little further, pushing the law in the organism to its logical results.

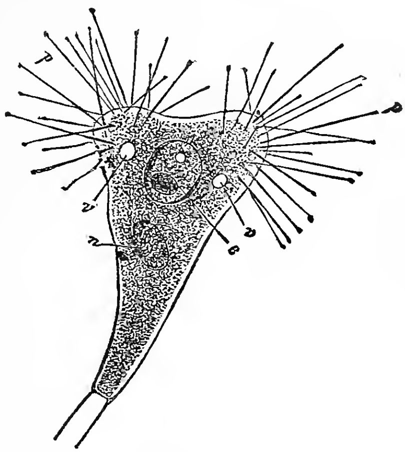


Fig. 11.—An Acineta, with part of its stalk (Gegenbaur); *p*, pseudopodia-like, but stiff, tentacles; *v*, vacuoles; *n*, nucleus; *e*, aciliated young form lying in the so-called broad cavity.—Gegenbaur.

The Action in Gastrula.—This brings us to the next stage in development, or the primitive compound organism (Fig. 12), from which in due time the higher organisms are evolved by the processes of growth and differentiation. Here the cell-colony is first grouped in two separate and distinct layers, forming the walls of the little animal (*B*), the one constituting the internal layer, or entoderm (*i*), the other the skin-layer, or exoderm (*e*); while the fluids flow in and out of the little stomachal cavity thus formed through the oral orifice (*o*) during the rhythmical expansions and contractions taking place in it. Flowing in, of course, during expansion and the development of low pressure which this produces till pressure is uniform, and flowing out again by reflux action through the route of ingress during contraction and the devolopment of high pressure which this produces to equalize pressure; in this manner readily producing afflux and efflux of the fluids in the stomachal cavity: while the changes of *form* which this involves *in the individual cells*, in order to produce these actions should increase circulation in *them* correspondingly, and which the scheme calls for in order to generate the force which is expended in these actions, the one involving the other. All of

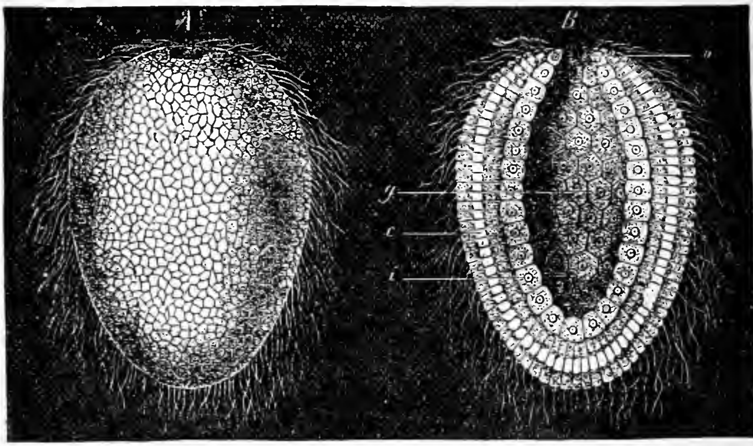


Fig. 12.—Gastrula of a Chalk-sponge (Olynthus). *A*, from the outside; *B*, in longitudinal section through the axis; *g*, primitive intestine; *o*, primitive mouth; *i*, intestinal-layer, or entoderm; *e*, skin-layer, or exoderm.—Haeckel.

which is plain enough. But the circumstance in which interest culminates is the one of coördination in the cell-colony, so as to compel the two layers to expand and contract simultaneously, in order to swallow the food and effect the pumping action for producing afflux and efflux of the fluids in the primitive intestine (*g*); otherwise impossible. In short, the inner layer (*i*) or intestine expands and contracts snychronously with the outer wall or skin-layer (*e*), which answers to the muscular envelope in the body-walls in the more advanced stages in development, the two acting in harmonious concert to this end, as is the case in the later stages; only there is no nervous apparatus for effecting coördination, the walls expanding and contracting of their own accord under the stimulus of the fluids in which the little animal swims and sustains existence. The intimate relations the walls sustain to each other enable this to be done, as the inter-molecular action in the two cell-layers could thus be connected for producing uniformity throughout. But with progress in development, however, the layers become more and more differentiated and separated from each other; consequently, other modes for effecting coördination must be had recourse to; hence the nervous apparatus which is developed and differentiated with progress in development for coördinating the structures and unifying the molecular actions, to the end that a balance in force may be maintained, and which cannot be done unless the mechanics is made to connect through and through. It is comprehensive, but easily understood. In this archetypal form, then, we have early indication of the principle in the mechanics.

Indeed, the very existence of this law of pressure in the organism is sufficient in itself to establish that circumstance, now that attention is directed to it. But a few pointed examples will serve for impressing the matter.

Leaving the Gastrula, then, we take up the case in the Worms, in which development is considerably advanced. Here the external layer (exoderm) is differentiated into a dermo-muscular layer, and the internal (entoderm) into the intestine (Fig. 13, *A*, *B*, *m*, *v*); but are still more or less intimately connected by means of connective tissue fibres running from one to the other, a cœlon or visceral cavity not yet being differentiated, the vestiges only presenting in rudimentary spaces adjacent to the intestine, in which the fluids collect and pass into the vascular system. For producing and coördinating the movements in the two surfaces, and maintaining uniformity, we have a double ganglionic chain of nerves extending along the ventral surface from the cephalic to the caudal end (Fig. 14), each ganglion serving as a separate centre of nervous force for producing the movements in the contiguous parts into which the nerves are distributed, so that reflex action is readily excited in them by means of sensory impressions propagated from the mucous surface by the stimulus of the food, without involving other portions, and which is necessary in order to produce the *undulations* passing along the body of the worms during imbibition and the passage of food along the canal ; at the same time, the whole are readily coördinated by means of the nervous links or commissures extending from ganglion to ganglion for connecting them with each other and with the encephalon (Fig. 14) for producing the voluntary movements and maintaining a balance in the organism. There is considerable complexity, arising from the necessity of maintaining the local actions in correspondence with the physiological requirements, but the principle underlying it all is readily apprehended.

Now, then, in order to produce the *undulations* which course along the body of the worms during imbibition, and which answer to the passage of the food along the intestinal canal,

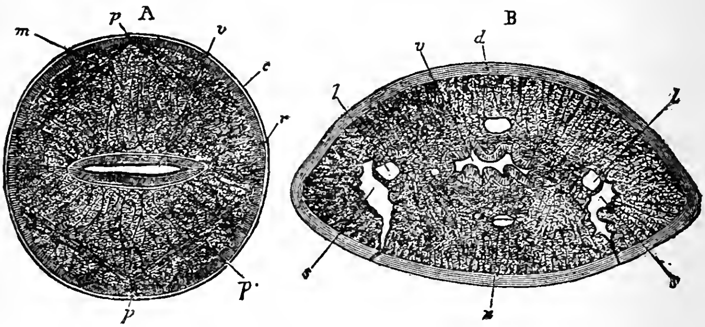


Fig. 13.—Transverse section of Ascaris Lumbricoides, A, and of Hirudo, B. *c*, Cuticular layer ; *m*, muscular layer ; *r*, lateral line, with the excretory organ ; *p p*, upper and lower median line ; p^1, oblique fibres ; *v*, enteron ; *d*, dorsal ; *l*, lateral vascular trunk ; *s*, vesicle of the excretory organ ; *n*, ventral nerve-chord.—Gegenbaur.

both of these layers must expand and contract together and simultaneously, as in gastrula, for pumping the fluids into and out of the cavity of the intestine ; only that in the present case this has been prolonged into a canal, but for obvious reasons the principle is maintained, since the whole relates to pressure and the power of producing rapid rhythmical changes in pressure. In fine, the worms may be likened to a *string* of gastrulæ with the ends merged in each other, while the fluids are passed from one to the other by means of rhythmical expansions and contractions till the terminal end is reached, every pair of nervous ganglia, with the nerves extending thence into the adjacent structures, representing one of these enlarged gastrula-territories. In point of fact, however, a single gastrula had formed the basis of it all, the structures being gradually elaborated from this with progress in development; but it will serve the purpose of illustration. But the same mechanical principle applies for producing afflux and efflux of the fluids in the intestine of the worms as in the primitive intestine of the gastrula; only, in place of escaping through the oral orifice by reflux action during contraction, it is passed onward into the next adjacent gastrula territory, which expands simultaneously for reducing pressure in order *to compel it* in *this* direction; otherwise, it would escape through the oral orifice by reflux action as in gastrula. And thus, by producing areas of low and high pressures *contiguous* to each other, a dual force applies in the worms for increasing the action in the fluids, at

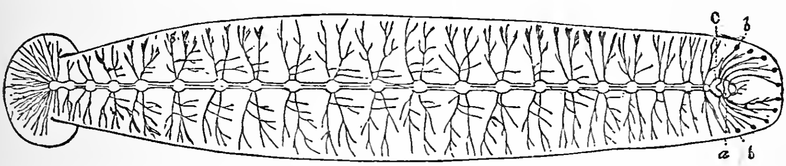


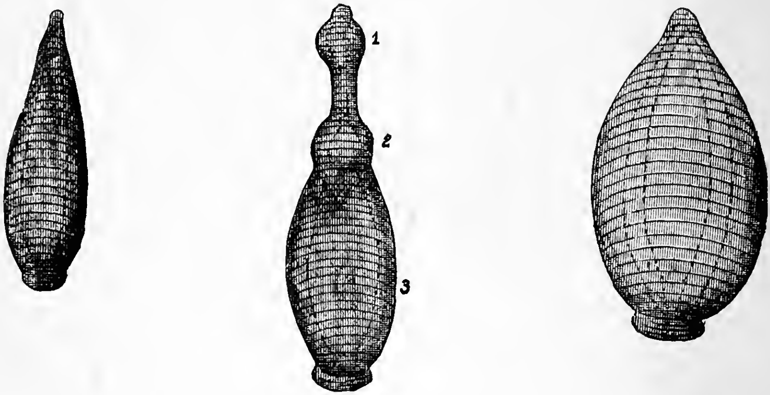
Fig. 14.—Nervous System of the Leech (Owen); *a*, anterior cerebral ganglia; *b b*, the 10 ocelli arranged around the margin of the upper lip; *c*, posterior cerebral ganglia.

the same time compelling them to move onward in the canal, and flowing always from high to low pressure in conformity with universal law: the one acting as a *pulling*, the other as a *pushing*-force upon the food, acting simultaneously. This, then, is the explanation for the undulations which pass along the body of the worms during ingestion, *indicating the passage of the food along the canal of the intestine*, as before remarked. Nothing could be more simple or more effective. The principle is not new either, but old—old as Nature! Only it had not been applied to the animal body for elucidating the vital phenomena; as though the body could be outside and independent of this fundamental force in Nature for controlling the movement of the fluids upon which the very body itself is based.

One other circumstance, of great importance in this connection, remains for mention, namely:

The Progressive Increase in Size with Ingestion.—As there is no unoccupied space in the body, it follows there must be corresponding increase in *size* with ingestion, a circumstance which also has forcible illustration in the worms (Figs. 15, 16, 17); the gorged leech, for example (Fig. 17), being several times the natural size in the empty condition (Fig. 15). This is all brought about gradually, the *waves* of expansion passing from the mouth-cavity along the body of the sucking

Fig. 15. Fig. 16. Fig. 17.



Three cuts of the Leech, showing the appearance *before* imbibition, *during* imbibition, and *after* imbibition.

Fig. 15.—Appearance before imbibition.

Fig. 16.—Appearance during imbibition; 1, oral sucker, expanded; 2, wave of expansion passing along the body to the hinder portions; 3, where they are added up in the general expansion which takes place.

Fig. 17.—Appearance after imbibition, and when the animal is fully gorged with blood and further expansion is impossible.

leech (Fig. 16, 1, 2), being merged in the general expansion (3) which results. In other words, *room* is made for the food as it progresses in the body; otherwise the balance in pressure could not be maintained, and the food would regurgitate. And this thing continues till the limit in expansion is reached, when no more food can be taken (Fig. 17).

And but for the fact that the internal and external parts are in correspondence, how otherwise could this action be produced? Thus, the stomach, which extends nearly the whole length of the body, is not forcibly *pulled* open by the action in the muscular envelope, but *expands of its own accord* in harmonious concert with the muscular envelope; while for effecting this action in the walls, as also for producing the local actions, is the office of the double ganglionic chain of nerves upon the ventral surface, with the nerves extending thence into the parts, whereby the utmost concert of action is produced, so that not only the requisite changes in pressure for swallowing the food may be readily effected, but at the same time a general expansion in the body commensurate with the food ingested, for maintaining a balance in pressure, may also be produced—the one involving the other; as the requisite *room* must be made in the body as fast as the food is taken in, in order to maintain a balance in pressure; otherwise impossible.

All of which is plain enough and easily understood. Of course, as the food is removed by the absorptive processes, the intestine contracts correspondingly, while the fullness in the vessels which this produces effects corresponding expansion in *them*, for which a special physiological adjustment obtains in the organism, the whole being regulated by nervous force, to be spoken of further on. We are now prepared to take another important step in the physiological adjustments, notably:

The Action in the Lungs.—This necessity for maintaining correspondence between the internal and external surfaces, in order to produce afflux and efflux of the fluids in the body-interior, must now be applied to the mechanics for producing afflux and efflux of air and blood in the lungs for respiratory purposes, the principle being the same In a word, the lungs and containing walls expand and contract simultaneously, as before remarked, and which is not only true logically, but it also admits of actual demonstration.

For this purpose selection is made of the frog, which has neither diaphragm nor ribs for assisting the action in the lungs, the ribs remaining in an undeveloped and rudimentary condition (Fig. 18); and the lungs being contained in the common visceral cavity, offer exceptional advantages for studying respiration, which is thus, so to speak, exposed and laid bare. It is the common impression among physiologists and naturalists that the frog respires by pumping the air in and out of the lungs by means of the throat-apparatus, but which is only partially true, the arrangement in the throat serving to assist it simply; and that it is not the fundamental circumstance in batrachian respiration, I have fully proven by excising a portion of the floor of the mouth, so as to lay the cavity open and effectually destroy it as a pumping apparatus for pumping air into the lungs: notwithstanding this, however, the animal continued to respire, ultimately recovering from the wound, which closed by cicatrization in the course of two weeks. The immediate effect of the

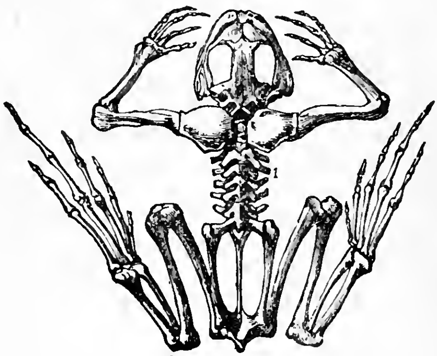


Fig. 18.—Skeleton of the Frog.—Owen.

operation was very characteristic, the body suddenly collapsing like a pricked balloon over the whole lung-region (Fig. 19), the spine and the stumps of the undeveloped ribs standing out in great prominence, produced by the soft tissues upon the sides being forcibly compressed under them, imparting an excavated appearance to the lateral regions; while the abdominal portions (2) appeared round, full and pendulous from compression of the envelope around them, making them also stand out prominent. The collapse was so sudden and unexpected as to startle me. Fully expecting him to die outright, which I thought a matter of course, and saying to myself, "I am not going to prove anything by you," I dropped him into a waste-bucket containing a thin stratum of water and some loose, wet paper; and the night being far advanced, I at once sought my couch, deeming the experiment over and done with. The following morning, however, upon glancing into the bucket, the animal, to my unspeakable amazement, was sitting up, fully expanded, head high, and looking at me out of his great luminous eyes, as natural to all appearances as ever, save the wound in his throat (Fig. 20). That thin stratum of water in the bucket, together with the loose wet paper, under which he could creep to keep himself moist, were the best possible conditions for promoting recovery after the operation, though I was not conscious of this at the time when I threw him into it with a

Fig. 19.

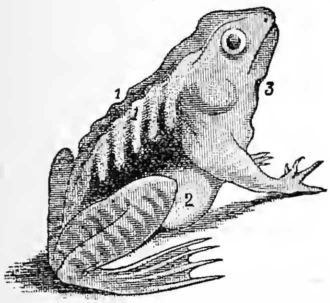
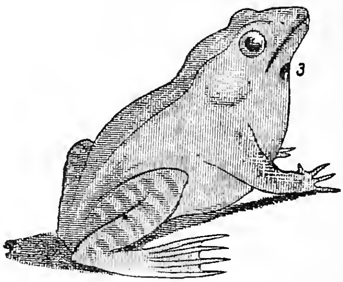


Fig. 20.



Two cuts of the Frog, showing the *collapsed* condition of the body produced by destruction of the throat-apparatus, and the subsequent *expansion* which takes place.

Fig. 19.—Appearance after destruction of the throat-apparatus; 1, 1, outline of the undeveloped ribs; 2, abdominal viscera; 3, opening in the floor of the mouth.

Fig. 20.—The Frog expanded to its normal size, notwithstanding the opening in the floor of the mouth.

feeling of sore disappointment at my heart over the untoward result of an experiment from which I had expected so much, and, as I thought, reasoned out so carefully. And, after all, there he was, fully alive, and on the *qui vive*, too, as though expecting me But other surprises were in store for me, if possible of a still more agreeable nature. Thus, I found while the throat-apparatus continued to move to and fro, the wound alternately widely gaping and contracting, but still leaving a considerable opening, at the rate of 120 to 130 per minute, that another much larger and slower movement was pervading the body itself, from 20 to 30 times per minute. And that this was the true respiratory movement was proven by the fact that it corresponded with the action in the alæ nasi, which expanded and contracted synchronously, as is the case in impeded respiration, and which at once stamps its true character. The destruction of the throat-apparatus and the embarrassment to respiration which this produces, brings into prominence the action in the lungs and containing walls, especially in the lateral dorsal regions, where it is conspicuous. In times of excitement, both movements are increased, but the relative frequency is maintained; showing that they are also connected.

Upon taking him up, however, he struggled violently in my hands and again collapsed, presenting in all respects the same appearances as at first. But replacing him at once in the bucket, he filled himself out again with air as before. Of course, the action is necessarily comparatively slow, from the absence of "ribs" and special muscles for assisting the lungs by the leverage they afford for reducing pressure; still, he accomplishes it, nevertheless, filling the lungs completely and restoring the natural rotundity (Fig. 20). Moreover, he seemed to acquire more power in the larynx for holding the air, not collapsing so readily as at first, an amount of compensation for the injured throat-apparatus taking place in this way.

Eight days after the operation, in exhibiting him to Dr. Gunther, the distinguished naturalist of the British Museum, and others, and holding him firmly by the hind legs for the purpose, by a sudden and energetic movement leaped out of my hands, and falling with great impact against the floor, again collapsed as previously. It produced a sensation. The wound had contracted considerably, but the top of the larynx was easily visible through the opening. A week subsequently, however, it had closed entirely, and the old condition was completely restored. But there was some deformity in the throat from loss of substance and contraction of the wound, bringing the contour of the larynx into prominence, and showing something like an Adam's apple. But he was thoroughly recovered, hale and hearty, and swam with greatest eagerness in the tank when placed with the other frogs at the shop where I obtained him.

It is scarcely necessary to add that the results of this operation prove incontrovertibly that the lungs expand synchronously with the containing walls; otherwise it were utterly impossible for the animal to have inflated them or filled them with air, having neither diaphragm nor "ribs," nor a throat-apparatus for compelling air into the lungs. And since air flows from high to low pressure, it follows that the lungs must expand in order to produce afflux of air in the organs; otherwise impossible. But, then, might not expansion in the muscular envelope itself effect it? No; this should produce low pressure in the visceral cavity, and thereby speedily bringing life to an end by causing afflux of the fluids in the cavity, and arresting the functions in the lungs. In short, the low pressure must be made *within* the lungs themselves in order to produce afflux and efflux of air and blood in the organs for respiratory purposes, at the same time keeping them in their respective channels; otherwise impossible At any rate, however, the muscular envelope expands; and if this expands, there is no reason on earth why the lungs may not do likewise—nay, must do so in the very nature of things, the law compelling this circumstance.

Explanation for the Sudden Collapse of the Body-Walls.—In batrachians the tongue is applied to the posterior nares in the form of a valve, which converts the mouth-cavity into an air-tight chamber and enables the pumping movements to be made in the throat for assisting respiration, at the same time it prevents escape of the air when rude force is applied, as when the animal leaps; the absence of "ribs" for imparting solidity and firmness to the walls rendering this necessary. Hence, when the air chamber is destroyed, the animal struggling, collapse is inevitable, the larynx itself not being sufficient for the purpose. It subserves other important uses also. Thus it enables the animal to remain for considerable periods under the water, by pumping the air to and fro, or backward and forward, between the chamber and the lungs, till fully exhausted of its oxygen, when it returns to the surface for more; the air being, so to speak, bottled up during this time.

Chelonia and crocodilia all possess this power; so also cetacea; the enormous chambers forming the tortuous nasal passages in the latter, which are closed externally by means of a plug projected from the side, subserving this purpose and enabling the animals to disappear for long periods beneath the surface

In the seal the external nares are closed by powerful muscles, which are promptly contracted at the moment of disappearance. Other animals are similarly endowed. Being air-breathers, the air *must* be thus forcibly retained during the time of submergence; otherwise they could not live.

Mode of Effecting Coordination.—The mode the lungs are coördinated with the muscular envelope or containing walls, together with the changes and mode of distribution of the nerves to the parts, is also easily explained. In the worms, for example, we have seen that coördination of the internal and external parts forming the enteron and muscular envelope or containing walls, is effected by means of a double chain of nervous ganglia extending along the ventral surface, whence the nerves, which are given off laterally, also symmetrically (Fig. 14) proceed *directly* into the adjacent structures, passing from one to the other, the intimate relations they sustain to each other enabling this to be very readily done; but with progress in development and the differentiation of a visceral cavity, however, which is necessary for increasing the action in the viscera in connection with the special functions, it is manifest that this calls for fresh arrangement in the nerves for coördinating the viscera with the muscular envelope and containing walls, since they are now completely separated. Hence, the pneumogastric nerves which are sent down from *above* for connecting the viscera with the medulla oblongata (Fig. 21);* and being correlated with the spinal nerves to the external parts, concert of action is readily produced, so that the whole performs as but a single organ only for pumping air and blood through the alveoli for respiratory purposes. And in the later stages in development, when a diaphragm comes into the scheme for separating the viscera in the abdomen from the viscera in the chest, likewise the phrenic nerves (Fig. 91, *F*) for coördinating this portion with the external parts, so that the utmost harmony is produced throughout,

* For the purpose of illustration simply being fundamentally the same as in the frog.

the correlation of all these nerves in the medulla oblongata enabling this to be very readily done. There is increasing complexity, but the principle in the mechanics furnishes a key for easily unraveling the structures, which are means to ends simply. The existence of the pneumogastric nerves, then, is readily accounted for. The rôle they perform in the

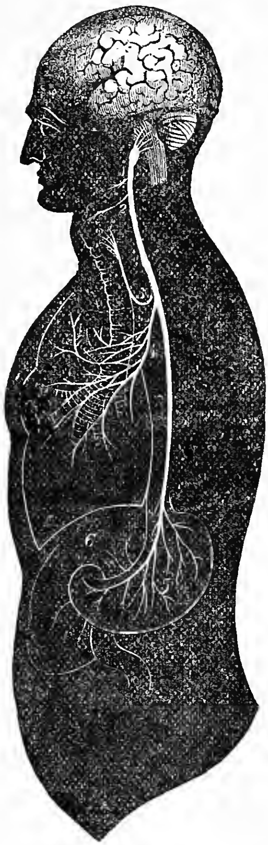


Fig. 21.—Left Pneumogastric Nerve, in diagram (Dalton). 1, pharyngeal branch; 2, superior laryngeal; 3, inferior or recurrent laryngeal nerve; 4, pulmonary branches; 5, 6, stomach, liver, etc.

viscera in the abdomen will come up later, but its importance would be difficult to overestimate. In the fishes we have the analogue of this in the opercula and branchia, together with the branches of the 8th pair (Fig. 166) for setting up the pumping actions for producing afflux and efflux of the water and blood in these organs for respiratory purposes, while the other portions are continued on into the abdomen and the external muscular walls (Fig. 158, 3, 4) for coördinating them with the branchia and opercula, or the same as in the air-breather, the principle being the same. And so likewise down the whole chain in development to where a visceral cavity ceases to exist, similar arrangements obtain for coördinating the viscera with the muscular envelope appropriate to the stage in development and the requirements in respiration and circulation, in order to evolve the force expended in them. But for the sake of brevity, we pass over the details, the matter being so very obvious.

Dependence of the Portal Circulation upon Respiration.—Finally, we have to mention a circumstance of deepest import in the mechanics of circulation, namely: *The rhythmical compression of the viscera in the abdomen synchronous with respiration*, and *which is produced by respiration*, for increasing the portal circulation correspondingly, and which it would be difficult to overestimate, since the portal circulation could not be carried on without it; neither could a balance be maintained in the absorptive and oxygenating processes which the scheme calls for, and which requires the absorptive processes in the intestine and the portal circulation, to be connected with respiration in such manner that the effort to respire *must* necessarily increase the two correspondingly. It is easily apprehended. Thus, the muscular envelope forming the walls of the common visceral cavity functions as *the floor of support* to the viscera in the abdomen, which are everywhere in contact with them, gravitation compelling this circumstance (Figs. 19, 2; 25, *E*), hence are necessarily affected by *every* movement in the walls for effecting the changes of pressure in the lungs for producing afflux and efflux of air and blood in the organs for respiratory purposes, and which, of course, should increase the portal circulation correspondingly. It could not do otherwise, in the very nature of things. They are forcibly compressed during expiration for producing high pressure in the lungs, being compressed against them for this purpose, when the heart serves as a suction-force upon the portal blood, which thus flows from high to low pressure; while during inspiration the suction-force in the lungs is added to this, which greatly increases the action by means of which the portal circula tion is readily carried on; otherwise impossible. For showing the dependence of the portal circulation upon respiration, the following physiological experiment possesses fresh interest, and is certainly very conclusive upon this matter: *

" Two frogs are slightly curarized and placed side by side in the supine position. In both, the heart and great vessels are exposed, as in the preceding section. It having been ascertained that the circulation is normal in each animal, and the frequency of the contractions having been noted, the brain and spinal cord are destroyed in one of the frogs, by inserting a strong needle into the spinal canal immediately below the occipital bone, and then passing it upward and downward. This may usually be accomplished without much loss of blood. If now the frog which has been deprived of its nervous centres is compared with the other, it is seen that in the former, although the heart is beating with perfect regularity and unaltered frequency, it is empty, and in consequence, instead of projecting from the opening in the anterior wall of the chest, it is withdrawn upward and backward toward the œsophagus. The emptiness of the heart is not limited to the ventricle and bulb. The auricles are alike deprived of blood; and if the heart is drawn forward by the apex, it is seen that the *sinus venosus* and *vena cava inferior* are in the same condition. The state is therefore not dependent upon any cause inherent in itself but on the fact that no blood is conveyed to it by the veins. To make this still more evident, the rest of the visceral cavity may be opened, when it is seen that although the vena cava is collapsed, the intestinal veins are distended."

The distinguished physiologist and experimentalist, in casting about for an explanation of the preceding phenomena, conceived the idea that the non-arrival of the blood in the heart was due to relaxation or expansion of the arterial system from vaso-motor paralysis; and while this undoubtedly was a factor

* Hand-book for the Physiological Laboratory.—Burdon-Sanderson.

in the case, it would certainly not account for a portion of the phenomena—notably, the turgescence in the portal vessels. If loss of tension in the arterial system produced *emptiness* in the lower cava-system then, how could it produce the *opposite* condition of turgescence in the adjacent portal system? If true in the one, it should be true in the other also. We take it, however, that *suspension of respiration* was the principal cause of the phenomena, for the reason that it *arrested* the pumping action in the *lungs* for aspirating the systemic capillaries, and the *rhythmical compression* of the viscera in the abdomen, which this produces for increasing the portal circulation.

The extent and firmness of the liver-structure, the character of the portal vessels, and the *firm* adhesion of the walls of the hepatic veins to the liver-substance for maintaining patency, all tend to show this circumstance. And since there is no other means for increasing circulation *but* by rhythmical changes in pressure, it follows that the liver *must* be rhythmically compressed for increasing circulation in it. Moreover, it should be borne in mind that the portal vessels are sandwiched, so to speak, between two extensive capillary systems: one in the intestines, in relation with the mucosa; the other in the liver-substance. Hence the necessity for this *direct* application of force for increasing circulation in the liver and portal vessels.

The flow of the portal blood into the heart when the two are connected by a canula, serves to establish two important facts: 1. That the portal circulation is obstructed in the liver when respiration is suspended, the blood in consequence rapidly accumulating in this system of vessels. 2. That the action in the heart is inadequate for the portal circulation, which requires a greater force than this for effecting it In short, the body being based upon pressure and the power of producing rapid rhythmical changes in pressure, nothing short of the pumping action in the abdomen, which is set up by respiration, and the rhythmical changes in pressure which this produces in the viscera, would be sufficient for the purpose. And when we get a little further on in the mechanics, it will be shown how this action in the abdomen for increasing the portal circulation is made to connect with the action in the intestines for increasing the digestive and absorptive processes for producing correspondence and maintaining a balance in this circulation, inclusive of the action in the lymph-channels, which cannot be omitted in the scheme. The rapid absorption of fat, albumen, alcohol, which are non-dialyzable, hence will not pass the membranes without mechanical force, are alike included in it. In fine, the explanation of the portal circulation, to be satisfactory, should embrace the entire mechanics for increasing circulation in the abdomen, and for maintaining this in correspondence with the physiological requirements in the organism; and which, of course, should include the extensive nervous connections subsisting in the viscera, together with the arrangements of the structures in the organs as means to ends All of which have ample explanation. It comes to this, then, that the heart is not able to carry on the portal circulation, as is fully proven by the above experiment.

But that is not *all* that is proven by this experiment. Nay! not by half and more. Put this great fact in the foreground of the mental picture: *When* the respiratory centre is destroyed, *both* the systemic and portal circulations are *promptly arrested;* this notwithstanding the heart is beating with perfect regularity and unaltered frequency! The mechanical work this organ is capable of is far too inadequate for the enormous labor which is involved in the circulation, the non-arrival of the blood at the heart, the empty condition of the chambers, the "collapsed" venæ cavæ, together with the swollen and turgid portal system, are all eloquent of *that* fact; showing conclusively that the cardinal circumstance in the circulation is *the great pumping movements which are set up by respiration, extending from the lungs to the tissue-territories and from surface to surface of the body;* for to the movements taking place in the *chest* and *abdomen* there are rhythmical expansions and contractions of the arterial and capillary systems, inclusive of the venous, synchronous with respiration for producing correspondence and maintaining a balance in the circulation; otherwise impossible.

But with progress in development "ribs" are differentiated in the external walls, or muscular envelope, with a system of "internal" and "external intercostal muscles" for operating them in connection with the action in the lungs, the other muscles in the envelope also powerfully assisting, whereby the action in the lungs is greatly increased. This arrangement subserves a double purpose: it protects the lungs against the rude experiences to which the animal is exposed, so as to prevent "collapse" of the organs; at the same time it enables the expansions and contractions to be more readily effected. In short, it *energizes* the action in the lungs. But as the action in the "ribs" is exhaustively treated in existing works, it will not be necessary to consider it here further than to refer to the action the diaphragm exerts upon them, which will be taken up after briefly referring to respiration in birds, the matter having escaped attention.

Respiration in Birds.—Passing, for the sake of brevity, over the intervening stages in development, as the action is fundamentally the same throughout, and for the reason, also, that it is so conspicuous in them, moreover so abundant and accessible, we take up respiration in the birds; and being, also, warm-blooded, this brings us nearer to the higher animals, where interest culminates. The structures in birds are homologous with the reptilian and mammalian, upon either side of them, the special modifications that obtain in them being adaptive changes to the stage in development simply. But as yet *no* diaphragm appears for separating the viscera in the abdomen from the viscera in the chest, which comes into the scheme in the succeeding stage in development as a special adjustment to the altered mechanics in the intestinal canal for increasing the digestive and absorptive processes, the portal and lymph circulations which will be taken up after the systemic circulation shall have been disposed of as they can be treated more advantageously by following this method; besides, *that* method should be adopted in the treatment which would connect *all* the phenomena, anatomical and physiological, in one harmonious whole, and make everything plain and easily understood. The point we wish to emphasize in this connection, however, is, that, notwithstanding the *absence* of a diaphragm, the birds respire easily and readily, can produce high vocal resonance, carry whole notes, and make all the varied sounds peculiar to them, showing that respiration is not only under voluntary control, and all the parts fully coördinated, but at the same time is very energetic. And as development is by addition and differentiation, in order to understand respiration in mammalia, respiration in birds and reptiles would *first* have to be understood. The question, then, resolves itself into this: What is the mechanics for producing the rhythmical changes in pressure *within* the lungs of birds for compelling afflux and efflux of air and blood in the organs for respiratory purposes?—when it will be in order to inquire as to the rôle in the diaphragm for still further increasing the action. Briefly, respiration in birds is accomplished by means of rhythmical expansions and contractions in the *abdomen* and chest, producing a *to-and-fro* movement of the viscera in the longitudinal axis of the body; the viscera in the abdomen being in contact with the lungs, fitting accurately against them and moving in and out of the excavation, piston-like, under the action of the muscles in the abdomen; while the lungs are in concert with this movement, expanding and contracting simultaneously and synchronously, whereby low and high pressures are alternately produced *within* the lungs *themselves*, which the scheme calls for for producing afflux and efflux of air and blood in the alveoli, at the same time confining the fluids *within their channels;* otherwise impossible. This, then, is the explanation of the pumping action in the abdomen of the birds; the expansile action corresponding with inspiration, the contractile with expiration. And when at rest upon the ground, the hinder parts are raised and lowered alternately by this action in the abdomen, and is so conspicuous that the respirations may be readily counted at a distance from the body; rising during inspiration and falling again during expiration. Brief reference to the anatomy is necessary.

Descriptive Anatomy.—In the first place, the costal framework forms an ovoidal cavity; the small contracted end presenting anteriorly at the root of the neck, while the large expanded end, presenting posteriorly, is open and in free communication with the abdomen, some of the viscera lying within it (Fig. 22). The skeleton itself, however (Fig. 23), gives no idea of the extensive abdominal cavity which forms the large end of the common ovoidal chamber. But by contrasting the cuts a mental picture may be formed. For example, the long, narrow innominata (Fig. 23, *s*, *s'*, *s''*), one for each side, together with the narrow *os sacrum*, form the roof of the cavity; while the posterior (*p*) and lateral walls are formed of soft parts, principally muscles, which are homologous with those in the higher animals. But in order to fully expose the

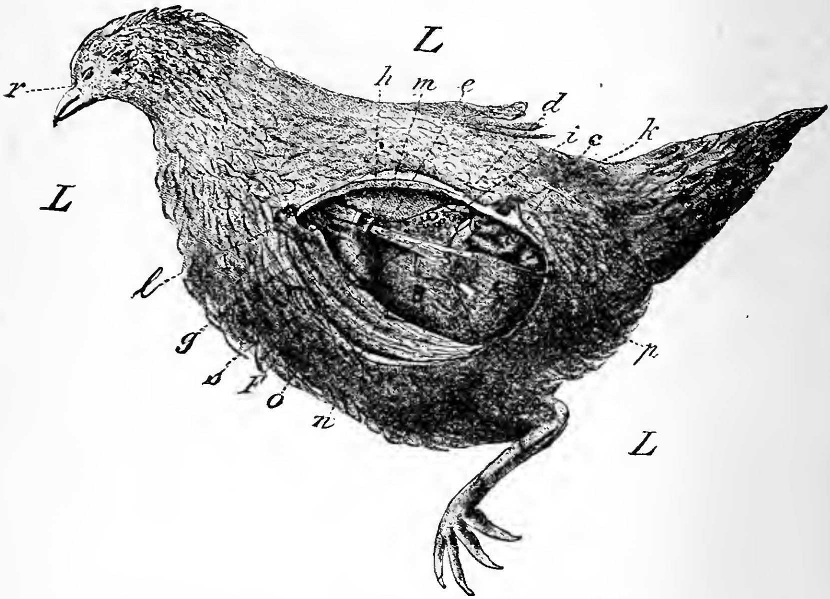


Fig. 22.—Longitudinal section of the Thoracic-Abdominal Cavity in the Hen, showing the viscera *in situ*. The outline of the ovoidal cavity is impaired by allowing the acetabulum (*k*) to remain. *A*, ventriculus callosus; *B*, liver; *c*, intestines; *d*, kidney; *e*, lungs; *F*, heart; *h*, left pulmonary artery; *g*, left anonymous artery; *i*, ovisacs; *k*, acetabulum; *l*, glenoid cavity; *m*, ribs; *n*, process of sternum; *o*, pectoral muscles; *p*, abdominal walls; *r*, nasal orifices; *S*, proventriculus; *s*, œsophagus; *L*, atmosphere.

whole of the abdominal portion of the chamber, however, the whole forming a perfect ovoid, the innominatum also would have to be removed, thus bringing into view the whole of the intestines, a few coils only now presenting (Fig. 22, *c*), the rest being contained in the pelvic excavation. The anterior extremity of the bone corresponds with *d*, the posterior with the

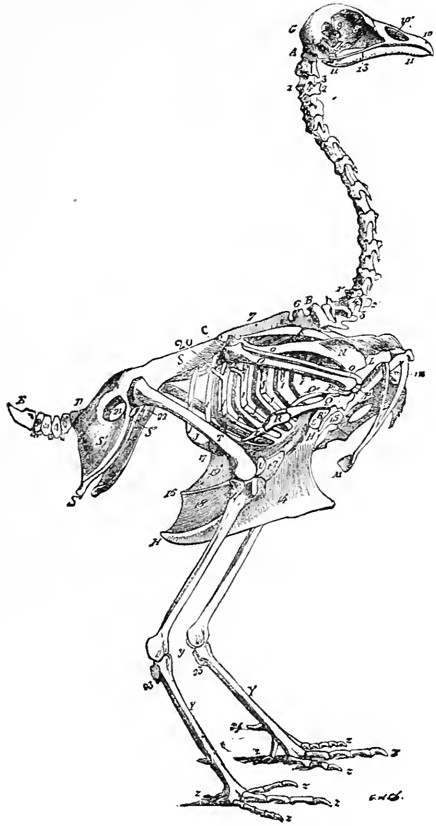


Fig. 23.—Skeleton of a Fowl.—Chauveau. From *A* to B, cervical vertebræ—1, spinous process of the third vertebra ; 2, inferior ridge on body of the same ; 3, styloid prolongation of the transverse process of the same ; 4, vertebral foramen of the same : 1′, 2′, 3′, 4′, the same parts in the twelfth vertebra. From *B* to *C*, dorsal vertebræ : 6, spinous process of the first ; 7, crest formed by the union of the other spinous processes. From *D* to *E*, coccygeal vertebræ ; *F*, *G*, head ; 8, interorbital septum ; 9, foramen of communication between the two orbits ; 10, premaxillary bone ; 10′, external openings of the nose ; 11, maxilla ; 12, square bone ; 13, jugal bone ; *H*, sternum ; 14, brisket, or keel ; 15, episternal process ; 16, internal lateral process ; 17, lateral external process ; 18, membrane which closes the internal notch ; 19, membrane of the external notch ; *I*, etc., superior ribs ; 20, posterior process of the fifth ; *J*, inferior ribs ; *K*, scapula ; *L*, coracoid bone : *M*, furculum ; *m*, *m*, its two branches ; *N*, humerus ; *O*, ulna ; *o*, radius ; *P*, *P′*, bones of carpus ; *Q*, *Q′*, bones of metacarpus ; *R*, first phalanx of the large digit of the wing ; *r*, second phalanx of the same ; *R′*, phalanx of thumb ; *S*, ilium ; *S′*, ischium ; *S″*, pubis ; 21, sciatic foramen ; 22, foramen ovale ; *T*, femur ; *U*, patella ; *V*, tibia, *X*, fibula ; *Y*, single bone of tarsus ; *Y*, metatarsus ; 23, superior process, representing a united metatarsal bone ; 24, process supporting the claw ; *Z*,etc., digits.

commencement of the soft abdominal walls, midway between *p* and *k*.

By contrasting the corresponding parts in the skeleton (Fig. 23) some idea may be formed of the length and depth of the pelvic excavation, and the great extent of the muscular structures forming the sides and floor of the abdomen. Now, then, in regard to the mechanics in respiration. As will be seen, the solid and heavy viscera, notably the ventriculus callosus and liver, are at the very bottom of the cavity, the liver resting against the projecting sternal processes (Figs. 22, *A*, *B;* 23, *H*, 16), with all the other viscera resting upon them as their floor of support, the ventriculus itself resting entirely upon the soft abdominal walls (Fig. 22, *A*, *p*). The sternum, by projecting long, slender processes toward the abdomen, aids considerably in supporting the liver, but the weight in the greater portion of the viscera is sustained by the abdominal muscles simply, and these, by being inserted in the sternal processes, aid in supporting the liver also, together with the overlying viscera, so that all are necessarily affected by the action in the walls. Finally, the stomach (ventriculus) and liver are firmly secured to the posterior walls by means of duplicatures of the lining membrane (Fig. 22, *A*, *B*, *p*), the lobes of the liver extending far down the sides of the ventriculus in form of a saddle, and secured by means of connective tissue and the overlying peritoneum, so that the two are compelled to move together under the action in the walls. It results from this arrangement in the parts, that with every expansion in the abdomen the viscera are pulled downward and backward, gravitation and the traction from the retaining ligaments compelling this circumstance: while during contraction they are pushed in the opposite direction, or forward and upward. In the former, they tend to pull away from the lungs, thereby tending to produce low pressure in the visceral cavity itself; but as this would defeat the end in view, the lungs expand simultaneously and *pari passu* with expansion in the abdomen for maintaining the intra-abdominal pressure, keeping in close apposition with the viscera for this purpose; which has the effect of confining the low-pressure area *within the lungs themselves* for aspirating the air and blood for respiratory purposes, otherwise impossible, since the fluids flow from high to low pressure, in conformity with universal law. During contraction, however, when the action is reversed, the viscera are firmly compressed against the lungs, which *maintains* intra-abdominal pressure, at the same time that high intra-pulmonic pressure which this produces causes the fluids to flow out of the organs again till pressure is uniform, the lungs also contracting *pari passu* with contraction in the abdominal muscles for increasing the action. Finally, for effecting co-ordination we have the pneumogastric and spinal nerves, or the same as in the frog, the principle being the same. So, then, at no time is there any difficulty in producing the requisite changes in pressure in the alveoli for compelling afflux and efflux of air and blood in the chambers for respiratory purposes, at once the object and purpose of all these arrangements. But did not the lungs expand during inspiration in the manner alleged, the effect would be to develop low pressure *within the abdomen* itself, which would defeat the end in view by causing afflux of the fluids in this locality, in consequence rapidly putting an end to life. Not outside of, then, but *within* the lungs themselves must low pressure be made during inspiration, in order to keep the fluids in their relative channels, as before remarked.

This, then, is the explanation for the pumping action so conspicuous in the abdomen of the birds; and having no diaphragm for pulling the viscera away from the lungs during inspiration, they are fastened by means of duplicatures of the lining membrane to the posterior abdominal walls, thereby obviating the necessity for a diaphragm. And with the *big* end of the excavation, containing the greater portion of the viscera, the heavier at the bottom, the whole inclined at an angle of about 30 degrees (Fig. 22),* gravitation would necessarily favor inspiration, enabling expansion to be more readily made by adding its force to the force in the muscles, thereby imparting energy to the movement. The result of this action is to compel the air (*L*) to flow into the air-passages and alveoli through the nasal orifices (*r*) till pressure is uniform, the ve-

* In the skeleton, the student must look from the abdomen upward, filling out the soft tissues in his mind, in order to get the angle of inclination.

nous blood at the same time flowing into the alveolar plexuses from every portion of the body, the heart serving to assist the action, as has already been stated:* while for compelling them out again, we have simply to reverse the action in the abdomen and lungs in the manner as stated—the one flowing out by reflux action through the route of ingress, the other into the left chambers of the heart and arterial system on its way to the cell-brood, the heart, of course, assisting the action; otherwise it were impossible to produce the high pressure in the arterial system for increasing the capillary circulation commensurate with the physiological requirements, in order to generate the force which is expended, the maintenance of the upright position itself alone demanding rapid circulation for effecting it, and which, of course, would involve rapid respiration, as in no other way could a balance be maintained. Hence the rapid pumping action in the abdomen of the birds. But while this action is going on in the abdomen and lungs, however, the chest itself expands and contracts simultaneously for increasing the action, thereby enabling the lungs to expand *outward* as well as downward, which the action in the lungs calls for. But it is not so extensive as the action in the abdomen, save in the portions contiguous to the abdomen, into which the muscles of the latter have insertion, notably the long, slender sternal processes (Fig. 23, *H*, 16, 17) and adjacent ribs, and which, of course, are compelled to respond to the action in the muscles, thus making the movement in respiration conspicuous in them; the *length* of the muscles in the abdomen being the explanation of this circumstance, since the amount of elongation and shortening in the muscles is determined by their length; hence, the rhythmical expansions and contractions in the abdomen during respiration are necessarily much greater than in the chest.

Morever, the ribs in birds do not partially revolve around the long axis for flaring them open upon the sides, as in other animals, the long costal processes (20) effectually preventing it, this, together with the forked articulations to the spine, for

* The author indulges the hope that the importance and gravity of the subject will serve as apology for frequent reiteration of the cardinal points in order to enforce attention and stamp them indeliby upon the mind.

imparting firmness to this portion of the framework, as the base of support to the wings. At the same time, however, we have to note a compensatory arrangement for maintaining expansile and contractile action in the chest; and this consists in a series of cartilaginous articulations in the mid-costal region, dividing the ribs into two portions, or "superior" and "inferior" ribs (Fig. 23, *I*, *J*), which join each other at an obtuse angle, forming an elbow; while below they connect with the sternum by terminal cartilages, in the usual way; so that the chest can readily be expanded or contracted by the overlying muscles, being forcibly compressed by means of the contracted abdominal muscles during expiration, and springing forcibly out again with expansion in the muscles during inspiration; the pectoral muscles also assisting in the action, especially during flight. And as this arrangement in the ribs occurs only in birds, it is highly probable this is the case; so as to compel respiration to be in correspondence with the increase in the activities. Thus, the powerful pectoral muscles covering the whole anterior and lateral portions of the chest, have their broad points of origin in the keel (Fig. 23, 14) (the widely-expanded process projected from the central portions of the sternum for this purpose), while the points of insertion are in the head and proximal portions of the shaft of the humerus; hence, every effort to extend and retract the wings would tend to expand and contract the chest correspondingly, the points of origin and insertion being movable; consequently, would have to be separated or approximated by the expansions and contractions in the muscles, as this would increase or diminish their length correspondingly. In this manner, then, respiration is increased with the flight, which is the physiological finality in this adjustment; at the same time, however, it enables the energetic action in the lungs, for producing loud vocal resonance, to be more readily made. In this condition the posterior portions of the chest are forcibly compressed by the energetic contraction of the abdominal muscles, thereby diminishing the transverse with the longitudinal axis in the visceral cavity, and which, of course, must effect corresponding compression of the lungs for producing the high intra-pulmonic pressure which is essential for producing the vibrations in the vocal cords; the one involving the other. And in order to obtain some idea of the enormous rôle performed by the viscera and the muscles in the abdomen in respiration, one has need only to watch the action of these parts in the screaming parrot, and he will perceive that the viscera are more and more compressed into the chest-excavation by the action in the muscles as the notes are prolonged or raised in volume, the abdomen in consequence becoming more and more flat and reduced in size, till at the end of the note the greater portion of the viscera are in the chest excavation; at the same time, the lower chest-walls are firmly held down by the muscles in the abdomen, that the force may be concentrated in the lungs. At the end of the effort they fly back to the original positions under the energetic expansion in the muscles, aided by the resiliency in the ribs, in which force is stored during contraction, to be yielded up again during the subsequent expansion, so that nothing is lost, but only carried over from one rhythmic movement to the other

In quiet respiration, however, the motion in the trunk seems limited to the abdomen and the proximal portions of the chest. In addition to this mode of respiration in the lungs, the birds are provided with air-sacs, the whole thoracic-abdominal cavity being divided by septa of serous membrane into numerous inter-communicating chambers, all of which are freely supplied with air, brought into them through the bronchial tubes, which open upon the lung surface, passing through and through the lung substance for this purpose (Fig. 24, *a*, *e*), the air being admitted to the very bones themselves; and in birds of powerful flight penetrating even between the muscles of the neck and limbs. And it is easy to perceive how the action in the abdomen and chest should increase this circulation also by expanding and contracting the air-sacs correspondingly, at the same time compelling the air into and out of the bones with afflux and efflux of air in the lungs, and enabling them to readily inflate the sacs for buoying them in the media when swimming or flying, by diminishing the body-density, and increasing surface correspondingly. It is needless to extend the matter.

In conclusion: It is manifest, from this relation of the parts in the abdomen, that the pumping action in respiration should increase the portal circulation correspondingly. Thus, the liver substance being spread out, as it were, against the firm

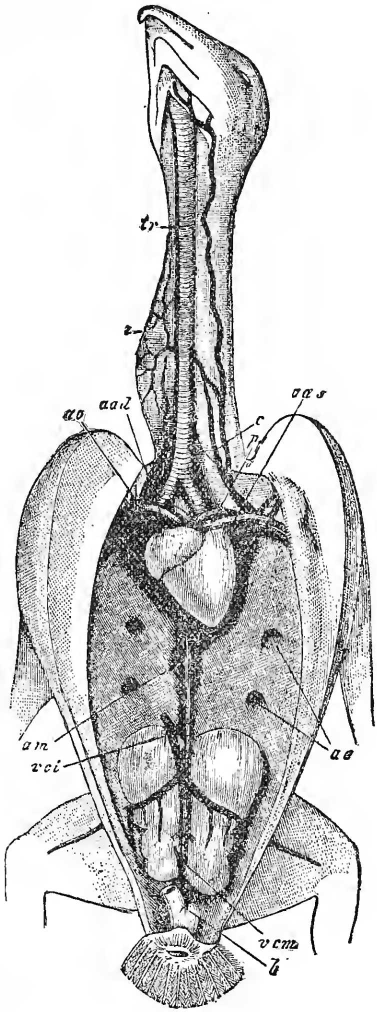


Fig. 24.—Lungs, Heart, and Great Vessels of *Buteo Vulgaris*.—Gegenbaur. *tr*, trachea ; *i*, crop ; *ae*, communication between the air-sacs and the lungs ; *b*, bursa fabricii ; *ao*, aortic arch : *aad*, art. anonyma dextra ; *aas*, art. anonyma sinistra ; *ps*, art. pulmonalis sinistra ; *c*, carotid ; *am*, visceral artery ; *vci*, commencement of the inferior vena cava : *vcm*, vena coccygeo-mesenterica.

ventriculus (Fig. 22, *B*, *A*), with the other viscera resting upon them, must necessarily undergo a degree of compression with every expiration, and increasing till the end of this, which would tend to force the blood through the open hepatic veins, the aspiratory force in the heart, which is close to the organ, being added to this; while during inspiration the organ, by springing back again to the original shape, should produce a suction-force upon the portal blood, at the same time the suction force in the lungs is added to that in the heart for aspirating the blood in the liver; so that inspiration must necessarily increase circulation in the liver. It must do so, in the very nature of things. Of course, the same applies for the viscera in the abdomen, connected with the lower cava system.

CHAPTER V.

RESPIRATION IN MAMMALIA.

Respiration in the Mammalia Fundamentally the Same as in Birds and Reptiles, the Lungs and the Muscles in the Abdomen Expanding and Contracting Simultaneously—Office of the Diaphragm and the Occasion for it—The Action in the Diaphragm Alternating with the Muscles in the Abdomen, the One Contracting as the Other is Expanding, and *Vice Versa*—The Action the Diaphragm Exerts Upon the Ribs, Bending and Flaring Them Open Upon the Sides During Inspiration, and *Vice Versa* During Expiration—Mode of Coördination, Inclusive of the Lungs, the Whole Moving in Perfect Concert—Circumstances in the Vital Phenomena, Anatomical and Physiological, which Make it Absolutely Certain that the Lungs Expand and Contract Regularly and Rhythmically Synchronous with the Actions in the Diaphragm and Containing Walls—Physiological Experiments Proving This Circumstance—The Action in the Tracheal System—Mode of Maintaining Cleanliness in the Alveoli and Air-Passages—Significance of a Cough—The Action of the Trachea in Vocalization—Explanation for the Devious Course of the Recurrent Laryngeal Nerves, which *First* Descend Into the Chest to Connect with the Lungs *Before* Proceeding to the Larynx and Vocal Cords, Ascending Thence *Upon* the Trachea for This Purpose, No Matter How Long the Neck May Be ; *e. g.*, the Giraffe.

This brings us to Respiration in the Mammalia. From what has preceded, it follows that the first thing to engage the attention of the student of physiology is the relation which the viscera sustain to the muscular envelope or containing walls, since it is by means of the rhythmical expansions and contractions taking place in the latter that the relative changes in pressure are produced in the former for compelling afflux and efflux of air and blood in the aveoli for respiratory purposes ; the viscera, of course, being responsive to the movements in the walls in order to effect these results, and in close contact with them all the while. In short, that the principal force for producing the requisite changes in pressure for effecting respiration in mammals *inheres* in the muscular envelope itself, with which the internal parts are coördinated by means of the nervous apparatus, as obtains in the preceding stages in development, the principle being the same ; only there is increasing differentiation in the organs, with the development of a special organ or structure (diaphragm) for separating the viscera in the abdomen from the viscera in the chest, and which is rendered necessary by the changes which have occurred in the intestines for increasing the digestive and absorptive processes commensurate with the force which is expended in these animals, which are womb-bearers, and occupy a higher plane in development. In present physiology the *weight* in the viscera receives little attention, which is a great oversight, as the whole of them, with the entire body itself, have adjustment with gravitation, so that it would be utterly impossible to explain the phenomena in the absence of this essential factor. Now that attention is called to it, the necessity for this strong floor of support to the viscera in the abdomen will at once appear obvious, since the folds of lining membrane forming the ligaments for retaining them in their relative positions, at the same time permitting free movement in them in connection with the special functions, contain the nerves and blood vessels to the viscera, which would at once inhibit much traction upon them; otherwise inevitable but for this floor of support. The weight, too, is very considerable, approximating one-fifth of the weight in the body.

So, then, we can readily understand why the heavy viscera should occupy the bottom of the cavity, while the floor of support should be substantial, the liver itself resting against the sternum, with the stomach and intestines against the muscular walls. But in order to fully appreciate the mechanics, it will be necessary to again refer to the special anatomy in the parts.

Descriptive Anatomy.—As will be seen, the muscular envelope still functions as the floor of support to the viscera (Fig. 25, *E*), though the relative positions they sustain to each other are somewhat changed. Thus, while the liver (*L*) is still in front of the stomach (*S*), and resting against the sternum and ribs, as in the birds (Fig. 22, *B*), it is not intimately attached to the stomach, but is attached to the incurvated surface of the diaphragm instead by duplicatures of the lining membrane; while the stomach itself, now widely expanded, is in easy contact with it simply, and free to move in the visceral cavity, that it may function both as a receptacle for the food and at the same time effect digestive action in it; and that the intestines, also greatly increased in size, are not now resting upon the liver and stomach as the floor of support (Fig. 22, *c*, *c*, *B*, *A*), but occupy a position posteriorly and resting against the muscular floor itself, in easy contact with them (Fig. 25, *I*, *C*—*E*, *S*, *L*); at the same time, are also free to move within the cavity in connection with respiration and the special functions in the organs; while they are retained in their relative positions by means of duplicatures of the lining membrane, forming the gastric, meso-colic and mesenteric ligaments. From this relation of the parts, it follows that the viscera are compelled to

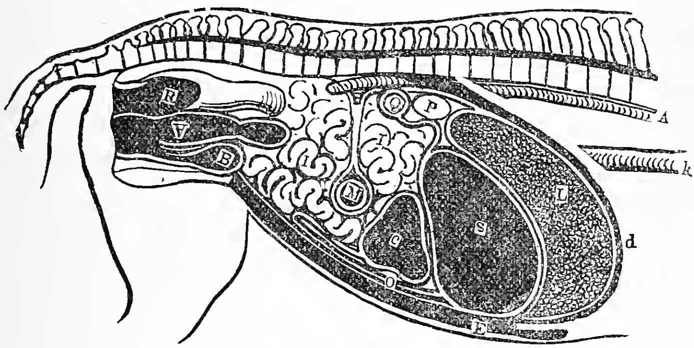


Fig. 25.—Diagrammatic Longitudinal Section of the Abdomen in the Horse, showing the position of the Viscera, and the relations they sustain to the lower abdominal walls, or floor of support. *E*, abdominal walls; *S*, stomach; *L*, liver; *O*, omentum; *C*, colon; *M*, mesentery; *I*, small intestines; *Q*, duodenum; *P*, pancreas; *B*, bladder; *V*, vagina; *R*, rectum; *d*, diaphragm; *k*, œsophagus; *A*, aorta.

respond to every movement in the muscular walls. It could not be otherwise, in the very nature of things. Thus, during inspiration, when the muscles expand, the viscera sink down, so to speak, with the walls; but when contraction sets in during expiration, they rise again with them, in this manner effecting a to-and-fro movement of the viscera in the chest-excavation during respiration for producing the rhythmical changes of pressure in the lungs; while the large apron-like duplicatures of the lining membrane forming the great omentum (*o*) intervening between them and the floor, facilitates the gliding movements and obviates friction, the secretions in the lining membrane serving also to lubricate the organs, thus reducing friction to a minimum, the mechanics being fundamentally the same as in the birds and reptiles. Now, then, in regard to the diaphragm. In addition to the great increase in size of the stomach and intestines, they are now *filled* and *distended* with air (Fig. 25, *S, C, M*), which tends to balloon them in the cavity, and but for this diaphragm for restraining and operating them in connection with respiration, would rise up in the chest-excavation and inhibit the action in the lungs, putting an end to life. Hence this circumstance.

At the same time, however, this calls for the phrenic nerves (Fig. 91, *F*), which are correlated with the other nerves in the medulla oblongata for operating the organ in connection with the muscular envelope and lungs, all the parts acting in harmonious concert as previously, in order to produce the changes of pressure in the alveoli. In fine, the old foundations are simply built upon and further extended for producing a larger amount of work commensurate with the force expended in the organism, while the principle in the mechanics remains unchanged and unchangeable, from the very nature of things. Thus, with inspiration the diaphragm contracts for pulling the viscera away from the lung-region, while the abdomen expands simultaneously and *pari passu* with this action, in order to make requisite room for descent of the diaphragm and lungs, which expand synchronously with the muscles in the abdomen, as before; while during expiration the action is reversed simply, the diaphragm expanding simultaneously and *pari passu* with contraction in the abdominal muscles and the lungs, in order to effect this action. In short, the old mechanics continues in operation as it ever did, while the diaphragm comes into the scheme as an adaptation to the changes effected in the stomach and intestines, for increasing the digestive and absorptive processes, and without which they never could have been made, leaving development at the stage in the birds. And let it not be imagined that the powerful muscles in the abdomen are made to yield to the force in the diaphragm, and are pulled into extension by this means, which cannot be thought of for a single moment even, the vast preponderance of the muscles, of itself alone, inhibiting this action; if, forsooth, such rude mechanics were at all admissible.

The large undulation, extending over the abdomen during inspiration, is produced by expansion in the muscles, together with contraction in the diaphragm for pushing the viscera along *pari passu* with this action for occupying the space thus made, in this manner creating the billow; while during expiration the action is reversed, the contraction which then sets in in the muscles of the abdomen causing the wave of reflux in the viscera, which return again into the chest, the diaphragm at the same time expanding *pari passu* with contraction in the walls, till at the end of a forced expiration most of the viscera are in the chest-excavation, leaving the abdomen less than one-half the size it had at the end of inspiration. Indeed, in an athlete this recession of the viscera in the chest may be made so complete by the energetic action of the muscles as to remove nearly all the lower coils of the mesentery, so as to bring the walls in actual contact with the lumbar vertebræ (Fig. 128), which are easily felt.

Of course, the diaphragm, with the lower chest-region, expands correspondingly in order to effect this action; otherwise impossible.* So, then, it is very readily perceived that the diaphragm is in perfect concert with the muscles in the abdomen; only that the action is reversed in them, the former contracting as the latter are expanding, and *vice versa*. The extensive action which this involves to the viscera is amply provided for by the long ligament in the mesentery (Fig. 25, *m*), which permits the loose coils of intestine to readily glide over each other for the purpose; at the same time, they are freely lubricated by the secretions in the membrane.

But as we shall have occasion to refer to this again, in connection with the functions in the abdomen, it need not detain us here, and we pass on to the special phenomena in respiration, taking them up as we go along.

The Action the Diaphragm Exerts upon the "Ribs."—The relations which the diaphragm sustains to the ribs, and the manner they are affected by its action, are in keeping with the comprehensiveness in animal mechanics and the

* But as life advances the cartilages become more and more ossified, while fat accumulates in the viscera; hence, this extreme action becomes more and more difficult.

wonderful utilitarian methods which everywhere obtain, Thus, while contraction in the diaphragm increases the longitudinal axis in the chest, it at the same time *compels* the ribs *to flare open upon the sides* for increasing the transverse axis simultaneously, so that the lungs may expand outward as well as downward for increasing the action in them correspondingly. And while it is true that the ribs expand in the absence of a diaphragm for effecting it, as is fully proven in birds and reptiles, nevertheless the converse is equally true, as I have fully demonstrated upon the dog and cat by denuding the chest of its muscles * (the animal under chloroform) without embarrassing respiration in the least, while the ribs continued to expand and contract in the usual way. In point of fact, the intercostal muscles share in the general muscular paresis which accompanies chloroform narcosis.† Moreover, "sex" would seem to exert no influence in this respect, the action in the chest and abdomen being as conspicuous in the female as in the male, there seeming to be no difference in them. And by thus eliminating the intercostal muscles, chloroform furnishes a crucial test of this action in the diaphragm and ribs. The explanation of the mechanics is sufficiently easy, notably: The diaphragm is attached to the *ends* of the ribs, being inserted in the cartilages (Fig. 26, 9), whence it is ballooned in the chest by the viscera (Fig. 27) so as to bring the muscular fibres in correspondence with the long axis in the ribs (*A, f, f*); hence, when contraction sets in during inspiration, the traction would necessarily be upon the *ends* of the costal bows, tending to bend and flare them open upon the sides like the ribs in an umbrella, while their resiliency would impart elastic action to expiration with relief in the traction force which this produces. The natural curvature of the ribs, being also slightly twisted upon the long axis,

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* In destroying the intercostal muscles, great care is necessary to prevent puncturing the pleuræ, which is extremely difficult.

† This circumstance I had seen strikingly illustrated after the removal of a malignant tumor of the chest, in which the intercostals were laid bare, and which flopped to and fro during respiration, being pushed in and out alternately by the changes in pressure within the chest, which continued to expand and contract in the usual way.

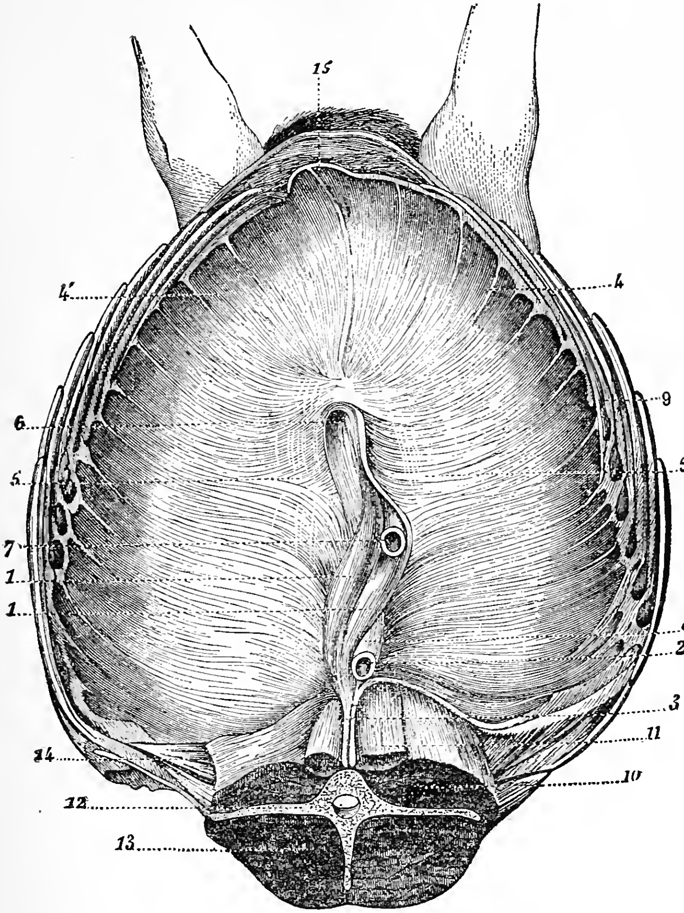

Fig. 26.—Showing the manner in which the diaphragm is attached to the cartilages of the inferior ribs, viewed from below.—Chauveau. 1, 1′, pillars of the diaphragm ; 2, left pillar ; 3, common tendon ; 4, tendinous attachments to the cartilages ; 4′, muscular attachments ; 5, attachments to control tendons ; 6, vena cava opening ; 7, œsophagus ; 8, aorta ; 10, psoas magnus ; 11, psoas parvus ; 12, transverse process of lumbar vertebra ; 13, superior or external lumbar muscles.

Diaphragm of the Horse ; Posterior Face.—1, 1′, the two portions of the right pillar ; 2, left pillar ; 3, tendons of the pillars ; 4, 4′, peripheral muscular portion ; 5, left leaflet of the aponeurotic portion ; 5, 5′, right leaflet of the same ; 6, posterior vena cava ; 7, œsophagus passing through the opening in the right pillar ; 8, posterior aorta between the two pillars ; 9, cartilaginous circle of the ribs ; 10, 11, section of the psoas muscle ; 12, section of a lumbar vertebra ; 13, section of the common mass ; 14, retractor muscle of the last rib ; 15, xiphoid appendage of the sternum.

must inevitably cause them to revolve in the long axis in inspiration, and thus flare them open upon the sides.

At the same time, the external intercostal muscles should increase the action in inspiration, while the internal, by acting in the opposite direction during expiration, should impart corresponding energy to the reverse action, so that the force in these muscles is still utilized in respiration, though not essential to it. But there is concert of action throughout, so that all act together; and which is readily accomplished by the correlation of the nerves in the respiratory centre, the intercostal nerves supplying the external parts, inclusive of the muscles in the abdomen; the phrenic and pneumogastric nerves the internal parts, whereby correspondence is produced during inspiration and expiration as in the previous stages in development. This action in the diaphragm and ribs would also explain another curious circumstance, notably the to-and-fro movement in the head and shoulders during respiration, or backward and forward, otherwise inexplicable. In other words, the head and shoulders are rocked to and fro by the action in the diaphragm and ribs during respiration, and the deeper the inspirations the more conspicuous it becomes. As we have said, the diaphragm is inserted into the *ends* of the ribs, and with the viscera against its breast in the chest-excavation with the spinal column as the point of resistance, it is manifest that, with contraction in the diaphragm, this would tend to push the spine backward during inspiration; but when relief comes during expiration, which reverses the action, the spine would return to its original position. Hence the oscillations in the head and shoulders during respiration. In the quadruped, this circumstance is seen in the sudden shooting forward of the whole body, produced by the occasional deep and energetic inspirations which the animals take, especially after rousing from slumber and during digestion; the whole body rocking forward upon the limbs under the energetic action in the diaphragm, exerted through the ribs and spinal column. It is deeply interesting. One other circumstance of deep import remains for mention in this connection, though we shall not do more than make a passing reference, as the matter pertains more particularly to another work.* Notably, by

* See "Gravitation and Development."

the action in the diaphragm the viscera are thrown against the *anterior* walls of the abdomen during inspiration, moving downward and backward in place of directly backward; the object being to avoid impact in the pelvic viscera, which would tend to force out the contents and produce strain in the organs, hence must be avoided. And by attaching the diaphragm to the lumbar vertebræ and the ribs in the manner as obtains,

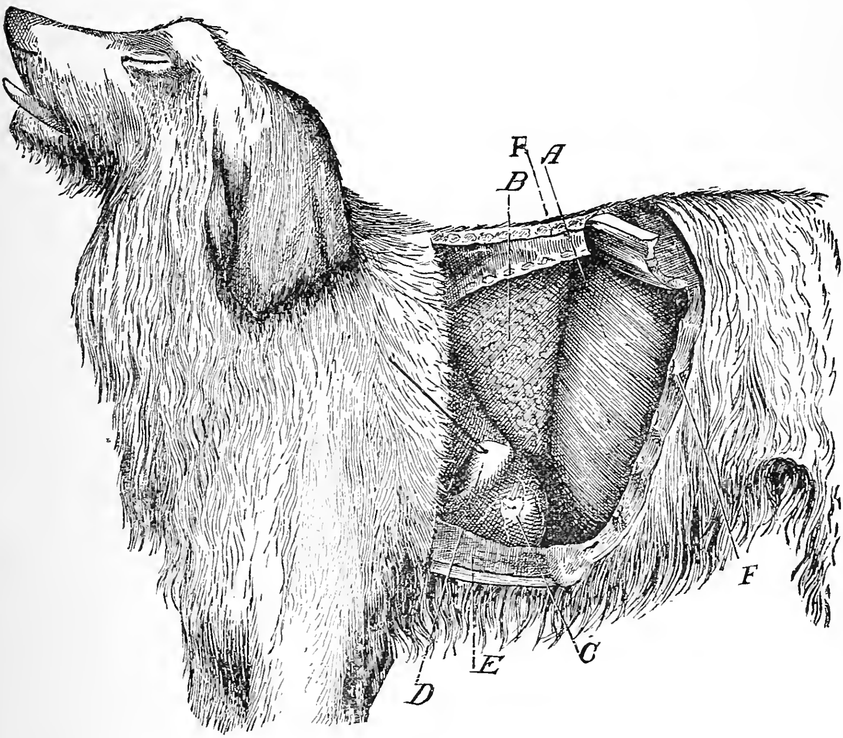

Fig. 27.—Section of the chest-walls, showing position of the diaphragm in the excavation and the relations it sustains to the lungs and ribs, the muscular fibres corresponding with the long axis in the ribs (*A*, *F*, *F*). *A*, diaphragm; *B*, lungs; *C*, heart; *D*, pericardium, reflected; *E*, sternum; *F*, ends of the ribs.

with the muscles acting in the long axis in the ribs, this action in the viscera is readily effected, so that impact in the pelvic viscera is entirely obviated, which, for reasons already given, must apply for every stage in development The depression which occurs in the epigastric region during inspiration is due to the bending in of the costal and ensiform cartilages produced by the traction in the diaphragm; but as life advances and they become more and more ossified, it is less and less conspicuous by reason of the rigidity this produces in the structures. Thus, these adjustments in the diaphragm are far-reaching.

Concerning the Action in the Lungs.—During inspiration the lungs expand as the diaphragm contracts, and simultaneously, expanding with a force sufficient to firmly approximate them to the diaphragm and costal surfaces, for obviating low pressure in these localities and producing this in the alveoli *only*, expanding outward and downward, following the diaphragm and *completely filling* the pleural cavities; while during expiration the action is reversed, the organs now contracting and moving upward and inward, the ribs *against* the *sides*, and the diaphragm with the viscera in the abdomen *pushing against* the *bases* for producing high pressure in the alveoli, while the air and blood flow into and out of these compartments simultaneously in order to equalize pressure, fluid equilibrium compelling them to do so, since both are in *direct* communication with these localities, each by means of a special system of canals in correspondence with the special requirements, the veins and capillaries being also very soft and compressible.

The reasons why this should be as stated are simply unanswerable, notably:

1. Did not the lungs expand *pari passu* with contraction in the diaphragm, the result would be to develop *low pressure in the pleural cavities*, caused by the pulling away of the diaphragm and ribs from the lungs, which would virtually convert them into a huge cupping apparatus for sucking the fluids into the pleural cavities, and thereby destroying life by producing fatal compression of the lungs, since pressure is transmitted through and through the body; and the fluids would inevitably flow into the low-pressure areas to equalize pressure. It could not be otherwise, in the very nature of things.

Furthermore, were the lungs passive, or as bags simply, *resistance would increase with the traction force upon* them;

hence, during inspiration, there should be *progressive* increase of suction-force in the pleuræ, caused by the lungs pulling one way and the diaphragm with the chest-walls the other; hence, the deeper the inspiration, the more effective it should be for aspirating the fluids into the cavities of the pleuræ.

In other words, a force which acts in *all* directions and upon *every* fluid without distinction cannot be made subservient to the convenience of a theory which would limit its action to a single fluid (atmosphere), and confine *this* within specific limits or to the lungs simply, and ignoring the blood altogether. Even in this case, however, it would be ineffectual, since the air immediately adjacent to the pleuræ in the air-vesicles should be *first* affected *before* the outside air could be aspirated, drawing it into the pleuræ. The action has been compared to the one taking place in a "bellows;" but the simile fails at an essential point, for there never was a bellows with a pair of lungs inside of it in which a *dual* circulation of air and blood is carried on. And though the law of pressure which applies is the same in both, it had not been followed to its logical results, else this unfortunate and hasty comparison, tending to retard physiological inquiry, would never have been made.

So, then, we conclude that this bellows-principle cannot possibly be the mode of respiration, but that the lungs perform an active rôle, and by expanding synchronously with expansion in the chest following the descent of the diaphragm and elevation of the ribs, the conditions obtain during inspiration for producing *simultaneous* afflux of air and blood in the alveoli for respiratory purposes, at once the object and purpose of the mechanism; since this would have the effect of producing high pressure in the pleuræ, with low pressure in the alveoli, making this the *culminating* point of the changes in pressure, which the scheme calls for. While during expiration, which answers to systole in the lungs, the high pressure which this produces in the alveoli causes the air and blood to flow out of these compartments simultaneously, the former by reflux action through the route of ingress, the latter into the left cardiac chambers and arterial system on its way to the cell-brood in the tissues, the objective point of the commerce, as before remarked; and the whole surface of the organs being closely embraced by the containing walls *closing tightly around them*, the ribs upon the sides, with the diaphragm and viscera pressing against their bases from below, must necessarily produce high pressure in the pleuræ, whereby the walls of the alveoli are well supported for obviating rupture during expiration. Hence, at *no* time is there low pressure in the pleuræ, the principle underlying the mechanics inhibiting it, as we very well know. In this manner, then, a balance is maintained for keeping the fluids in their channels, as the body is expanding and contracting regularly and rhythmically, like the diastoles and systoles in the heart, for pumping air and blood through the alveoli simultaneously for respiratory purposes, while *the demands of imperious law are fully satisfied.*

So much for the principle underlying the mechanics in respiration, which is plain enough.

2. Under this head are included a number of reasons appertaining to the special vital phenomena, anatomical and physiological, otherwise inexplicable, to which brief reference will be made. Indeed, *no* theory of respiration can possibly hold its ground which does *not* include, nor *can* include, the special phenomena in the structures and functions in the lungs, and which, of course, would include the nervous arrangements for coordinating the muscular envelope and blood-vascular system with them, in order to produce the rhythmical changes of pressure in the organs for compelling efflux of air and blood in the alveoli for respiratory purposes, at the same time keeping the fluids in their channels and maintaining a balance in the circulation. And in the absence of a fundamental principle upon which to base the mechanics, it were utterly impossible to do this, as a matter of course.

But by applying this law of pressure and the power of producing rapid rhythmical changes in pressure to the special circumstances in the structures and functions in the lungs, together with the principle for evolving force in the organism, and the whole is at once made intelligible. The special arrangements that obtain in the aveoli, the manner the walls are hooped in with elastic tissue fibres to the framework in the lungs, the disposition of the capillary plexuses upon the walls, the *residual air* for ballooning them so as to obviate friction, the special arrangements in the tracheal system for maintaining patency, so as to effect free ingress and egress to the air, together with the numerous muscles and nerves for operating them, the circumstance of *suspending* the lungs from the upper dorsal vertebræ so as to hang *free* in the pleural cavities, and *entirely disconnected from the ribs*, the purport of the pneumogastric and recurrent laryngeal nerves ; finally, the relations which the heart sustains to the lungs, together with the special arrangements in the nerves for coördinating the heart and blood-vascular system with respiration ; all these things are made intelligible ; otherwise are utterly inexplicable. A number of others could be readily added, but they will come up as we go along.

Concerning Adjustments in the Lungs.—Commencing with the external surface, the first thing to note is *the suspension of the lungs from the upper dorsal vertebræ*, and clear of all connection with the ribs, *so as to hang free in the cavities of the pleuræ.*

Of course, this fact is impossible of explanation upon any other hypothesis than that of free action in the organs, for which this condition is absolutely essential, enabling them to expand outward and downward during inspiration, and for contracting upward and inward, or toward their roots, during expiration, thereby bringing *all* the air-cells into active operation, those in the apices with those in the bases of the organs, since all perform *work* in respiration in proportion to the size of the capillary plexuses. But in the absence of this power of expanding and contracting in the cavities of the pleuræ, the apices could *not* be brought into action, the upper portions of the chest-cavity being comparatively immovable. There must be some easy, natural method for doing this other than obtains by reducing pressure at the sides and bases of the lungs, which would have the effect of aspirating *all* the air into these localities only, and leaving the apices perfectly useless, even admitting that the old principle for operating the lungs did apply, which by no means can be done. But the cells, by expanding *simultaneously*, would compel circulation of air to be uniform throughout the lungs, otherwise impossible.

Furthermore, this would explain the existence of the pleuræ, together with the copious secretions for lubricating the organs so as to obviate friction during the rhythmical expansions and contractions; otherwise inevitable. Then, again, it would explain the rapid *re*sorption of the pleuritic secretions in order to maintain a balance; and since they are rapidly poured out, some expeditious and efficacious means must obtain for compelling resorption to be in correspondence with secretion for maintaining a balance, otherwise impossible. And nothing could be more admirable than the arrangements that obtain in this respect For example, the lymph channels to these membranes open upon the pulmonic and diaphragmatic surfaces by means of numerous stomata, while a dual force applies for compelling them into the channels; and which is produced during inspiration by the low pressure in the lungs, with high pressure ure in the pleuræ, acting *simultaneously*, so that the best possible conditions obtain during inspiration for pumping the pleuritic secretions into the lymph channels; while during expiration, and the expansion in the diaphragm which this produces, throws open *its* lymph channels; at the same time high pressure is produced in the pleuræ by the viscera in the abdomen, which are compressed into the chest-cavity under the action of the powerful muscles in the walls, the chest also contracting. Thus, during both inspiration and expiration, a *pulling* and a *pushing* force combine for compelling rapid resorption of the pleuritic secretions; and since they are concerned in hæmatosis as well, being lymphoid, the necessity for such expeditious method for producing circulation in the sacs will at once appear obvious.

Of course, the same mechanics apply for removing the morbid collections resulting from pathological changes in the organs. But the action in the lungs may be impeded by adhesive inflammation, which is very common—indeed, is nearly always the case in chronic pleurisy; hence the occasion for early surgical interference in acute pleurisy accompanied by copious serous effusions, lest the bridles of lymph which are likely to form between the surfaces should become firmly organized and inhibit the action in the lungs. This action in the lungs would also explain the friction sounds in the early stage of acute pleurisy, from arrest of the normal secretions and the drying of the membranes which this produces, the to-and-fro movement in the lung as it expands and contracts against the costal pleura giving rise to the friction sounds, or the same precisely as obtains in the early stage of pericarditis, the rhythmical expansions and contractions in the heart causing the opposite surfaces of the pericardial membrane to rub against each other.

Last, but not least, it would account for the embarrassment to respiration which is produced by pleuritic adhesions, and why this should be *in proportion to the extent* of the adhesions, and *most* dangerous when occurring at the *bases* of the lungs or most active portions, as this would inhibit free action in the organs. But should the lungs be passive, as alleged, then the more completely they were under the control of the containing walls the more efficient they would be, as this would compel response to every movement in the latter for pumping the air into and out of the organs. On the contrary, however, it dreadfully interferes* with respiration, and these unfortunates breathe with difficulty; and when extensive at the bases of the lungs, they perish speedily by asphyxia.

It follows that the lungs must be free in the cavity of the pleuræ to admit of the rhythmical expansions and contractions in respiration, and are *not* "passive bags," to be "pulled open and closed by the action in the external walls," but that they perform an active rôle. But the argument does not end here, only fairly begins, for overwhelming evidence, a perfect avalanche, is coming. We now turn to the *mucous* surface.

Of course, the sole purpose of respiration is to bring the air and blood into *intimate* relation for effecting mutual interchange; consequently, the air must complete the *entire* journey to the alveoli in order to carry in oxygen and bear out the waste

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* In a case of acute pleurisy coming under my own observation, occurring in a young man, and suddenly terminating fatally, no other cause of death could be found save *recent* extensive adhesions at the *bases* of the lungs; most extensive in the right, but affecting large portions of the left pleura also; in both sides the diaphragm was adherent.

products (inclusive of the foreign matter carried into the organs by the air), and which must be as rapidly removed for maintaining the functions in the lungs. Hence, it is manifest that the "*tidal air*" does not go *half*-way to the lungs, then stop suddenly against the "*residual air*," as though this were an impediment and a barrier to further advance, to transact its business with the venous blood as best it can through this obstruction; at the same time to remove the waste products, since this would by no means effect the objects sought to be accomplished by the mechanics, and less than this would come short of the scheme in the circulation and make it impossible to carry on the functions in the lungs. Moreover, the very mechanical principle which is involved for pumping air into and out of the lungs must inevitably produce a current through the tracheal system and terminal air-cells, since they expand and contract regularly and rhythmically, synchronous with respiration. But we have now to mention a number of facts of a most pressing and urgent nature connected with the functions in the alveoli, which make it absolutely certain that there is such energetic circulation of air through the tracheal system and air-cells, namely: In the first place, carbonic acid, by reason of its weight, tends to accumulate in the alveoli; and did not some effective means obtain for promptly expelling it, would put an end to respiration very speedily by displacing the oxygen or preventing its ingress. The noxious exhalations which are poured out as waste products in the alveoli, and if not as rapidly removed, would inevitably lead to decomposition and infection of the body, since the animal matter which is contained in them, together with moisture and high temperature in contact with the atmosphere, must lead to rapid decomposition with septic poisoning. Hence, this would inhibit "stationary air" in the alveoli. In short, stationary air is *stagnant* air, and the functions in the lungs would not admit of this. And what a commentary this upon the universal appetite for fresh air—its delightful sensations, its exhilarating and revivifying effects; yet never permitting it to reach the alveoli at all. And were not the statement set up in print, to be read of all men, one would scarcely credit it; but *there* it stands, in hideous irony of the beneficence in Nature. But science can make progress only when the facts are fully and completely ascertained, and this great law of pressure underlying the organism itself never having been applied to the functions in the lungs methodically, the phenomena could not possibly be understood ; hence this monstrous statement, not to be believed henceforth and forever in this world of ours.

2. There must be arrangement for maintaining *cleanliness* in the tracheal system and air-cells by removal of the *foreign* matter, such as dust, smoke, etc., borne in upon the tidal air, and which, by the force of gravitation, tend to the alveolar floors, and, mixing with the secretions, would soon form a thick layer of mud upon the capillaries and so inhibit the functions in the lungs, producing asphyxia ; a danger which may be appreciated more readily after reading the statement by Prof. Tyndall,* "that respired air *toward the end of expiration is strained of all dust particles* in the lungs, *and is absolutely pure*," referring to that coming from the deeper portions, or *the last expired.* One may readily imagine, therefore, the amount of deposit which must take place in the lungs from this source, and which must be as rapidly removed. But to this must be added the secretions that are poured out upon the surface for lubricating it ; together with the products of inflammatory action—pneumonia, for example —in which the affected air-cells are literally filled up with exudation products and for the time obliterated. Hence, to be commensurate with this circumstance would require some comprehensive and effective means for expelling them and so relieving the air-cells.

Much stress is laid upon the cilia for maintaining cleanliness in the lungs; but independent of the fact that these delicate hairs are totally incapable of performing the amount of work which this involves, the statement would certainly not apply to the alveoli, the place of places where cleanliness should be maintained, since they fade out and disappear altogether in the bronchioles. And in this connection we are forced to notice a statement of German origin, which has gone the rounds and would seem to be credited, "that the exudation products in pneumonia are resorbed and eliminated

* Fragments of Science, p. 161. D. Appleton & Co , New York.

through the special emunctories," and which is equivalent to saying that the copious septic materials in the alveoli are emptied into the arterial system and sent through the length and breadth of the domain to infect the nervous centres, and form innumerable foci for inflammatory action ; or, in other words, that the road to recovery in pneumonia is by septicæmia, which is preposterous. *Ach, Gott!* It is too horrible. It will not do to think about. That Nature would do this thing! That she should sweep the festering alveolar collections into the blood-vessels in order to get rid of them, when they are virtually already out of the body, being upon the mucous surface, and for their complete expulsion, by a most short, direct and expeditious route, a most perfect mechanical arrangement obtains, is, to say the least, and putting it mildly, a most extraordinary statement. Perceiving this, therefore, we only mention the circumstance to show how urgent the necessity for a further extension of purely mechanical principles in the body in order to make the circumstances in the structures and functions of the organs intelligible. In fine, the collections are pumped out of the alveoli by the rhythmical expansions and contractions in the bronchial tubing during respiration, and which are much more energetic than in the alveoli. The tough fibrinous concretions are first detached from the underlying capillaries and more or less disintegrated by the purulent secretions which they provoke, when they are readily aspirated by the bronchial tubing and expelled thence by cough—a sudden and forced expiration for sweeping out the bronchial collections, upon the same principle precisely as obtains in sneezing for expelling matter irritating the Schneiderian membrane. It is easily understood. Thus, the collections when aspirated into the bronchial tubing by their energetic expansions during the inspiratory efforts, excites cough, which expels them ; the irritation they produce in the bronchial mucous membrane being propagated thence to the medulla oblongata for setting up this reflex action ; a circumstance which is also proven by exciting the bronchial mucous membrane artificially, when cough is readily produced. And it would also explain the short, energetic inspiration which *precedes* cough, since this would have the effect of aspirating the collections in the alveoli, while the sudden forced expiratory effort, which follows *immediately* after, should have the effect of expelling them from the body. The anatomical dispositions are very perfect; could not be better.

For example, the bronchi are *surrounded* by neighboring alveoli, which are not only in contact with the tubing, but are actually *incorporated* in the walls for compelling them to respond to the movements in the tubing during respiration (Fig. 2 , *f*, *a*, *b*). The effect of this arrangement is sufficiently obvious. Thus, when the bronchi expand during inspiration, they *push against* the neighboring alveoli; at the same time they develop a suction force within themselves for aspirating

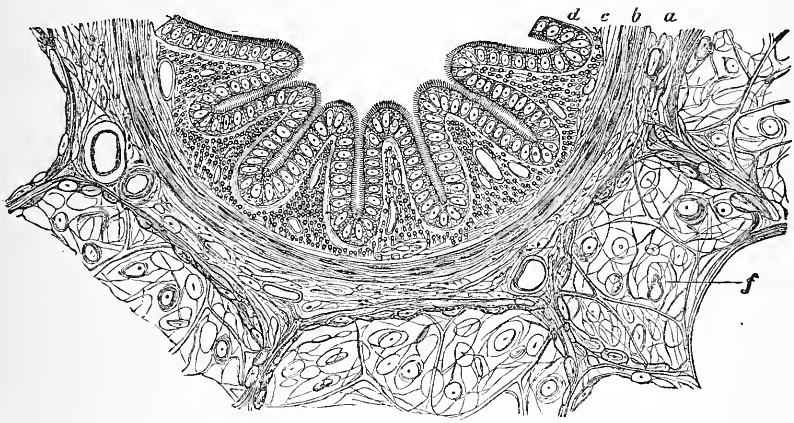

Fig. 28.—Portion of a transverse section of a pig's bronchial twig, .04 millim. in diameter, magnified $\frac{240}{1}$.—Schulze. *a*, outer fibrous layer; *b*, muscular layer; *c*, inner fibrous layer; *d*, epithelial layer; *f*, one of the neighboring alveoli.

the contents; hence a *pulling* and *pushing force* combine for expelling the alveolar collections during inspiration; while during expiration the sudden contraction which sets in, and the coincident narrowing this produces in the lumen of the tubes, increases the friction of the air against the membranes for compelling the secretions out of the body, which is finally accomplished by cough, in which the mucous surface is swept as with a broom by the out-rushing air, under the energetic action of the abdominal muscles and the pressure of the viscera against the bases of the lungs which this produces, the sides of the chest, of course, contracting simultaneously. And the more energetic this is made the more efficient it should be for expelling the collections. Nothing could be more perfect, and the adaptation of means to ends is marvelous in the extreme, the crowning point being its simplicity. But one thing calls for another. Thus, this power of expanding and contracting the bronchial tubing, produced by the muscles in the walls (*b*), calls for the *deep foldings* in the bronchial mucous membrane (*d*), which cannot expand and contract with the muscular walls; together with the *circular* arrangement of the folds which occurs around the longitudinal axis of the tubes, is in itself a forceful illustration of this principle in the mechanics. It also occurs in the intestines, bladder, etc., but is by no means so great, comparatively, as in the bronchial tubing; in all which the containing walls are composed of a basis of circular muscles and elastic tissue fibres, or such as obtains in the worms, and which has its explanation in the fact of a common organic law underlying animal life for regulating the movements of the fluids, and which calls for similar arrangements in the structures for compelling this circumstance, as has already been remarked. We must conclude that these extensive foldings in the bronchial mucous membrane are indicative of unusual powers of expansion and contraction in the bronchi and bronchioli. Thus we go along easily, naturally and without the slightest trouble in the investigations, the law itself being simple, while the anatomical adjustments are in accordance with the requirements.

Finally, nothing is more common than catarrhal affections of the bronchial mucous membrane, in which great quantities of mucus and muco-purulent secretions are poured out into the tubes and air-passages, and did not some effective means apply for expelling them, speedy asphyxia would be inevitable.

Indeed, there is very little doubt but that lobular pneumonia is produced in this way, the secretions being so abundant and tenacious in the affected bronchi as to resist the efforts at expulsion, and by inhibiting the ingress of air in the vesicles leads to enormous engorgement in the plexuses and copious effusions; but becoming more and more purulent, consequently less and less tenacious, are finally expelled in the manner referred to, and everything runs on as before.

To briefly summarize: Expansion in the bronchial system during inspiration is *sudden and energetic*, while that in the alveoli is *slow and gentle, lasting through the whole period of inspiration.* The effect would be to aspirate the atmosphere and the alveolar collections *simultaneously*, the fluids passing into the bronchial system from *both* directions; from *above* as well as from *below.* But the wave of expansion passing from the bronchial tubing over the alveoli, producing a slow and gentle action in the latter, causes the air to pass gently *over* the collections in the tubing to reach the alveoli, not sweeping them back again, the wide expansion in the lumen causing the air to pass over them with the least amount of friction; while the succeeding contraction during expiration would have the effect of impeding egress of the air, and in proportion increasing the friction against the mucous surface for compelling out the contents.

Thus, nothing could be more admirable for maintaining cleanliness in the alveoli and air passages than this beautiful device. Moreover, it will be seen from the nature of the mechanical adjustments which obtain, that by no possibility can there be any quiescent or stagnant air in the lungs in the normal condition of the organs; but, on the contrary, that it is maintained in incessant motion through the tubing, while the alveoli themselves are as so many little vortices, where nothing is at rest for a single moment even, the old air rushing out, carrying with it the waste products, and the fresh air rushing in, with its life-giving oxygen; thus fulfilling the conditions for energetic circulation of the commerce in and out of the lungs, for evolving the force expended in the organism. Then, again, the remarkable energy with which the blood in pulmonary hemorrhage is expelled from the lungs must be accounted for, together with the foreign substances, such as water, etc., that have accidentally fallen through the *rima glottidis;* the solid substances often catching here from presentation of the wrong diameter to the fissure, and so falling back again and again to the bronchial divisions. There is tremendous effort to expel them on the part of the tubing, often repeated, but, unfortunately, frequently requiring surgical procedure from the increase in bulk they speedily undergo by reason of the heat and moisture, as also from the spasmodic action they produce in the glottis from irritation.

But perhaps the most suggestive facts of the active rôle in the lungs are to be found in the anatomical dispositions, since these are as means to ends. Of course, the anatomy must be explained and reconciled with the physiological phenomena, as cause and effect, for work cannot be done in the absence of appropriate arrangements, and the adjustments that obtain in the lungs for special work are marvelous in their perfection and comprehensiveness. Beginning with the trachea:

In the first place, note the peculiarities that obtain in its several divisions, or the portions *external* to the lungs, and those *within* the lung-substance, notably the cartilages and the muscles. In the portion external to the lungs the cartilages are in the form of imperfect *rings* which open posteriorly and are filled in with muscles, while within the lung-substance they are thin plates disposed around the tubing, but leaving interspaces (Fig. 29, 2), while the muscles are *circular* and form a complete cylinder within them, and which continues to the very air-cells themselves though the cartilaginous plates gradually fade out and disappear in the smallest divisions. The effects of these arrangements are obvious. Thus, the strong cartilaginous rings in the trunk and primitive divisions of the trachea function as a framework of support to the organ against external force for maintaining patency, at the same time producing elastic movement during inspiration, thereby increasing suction force correspondingly for aspirating the lungs and maintaining cleanliness. Of course, the more energetic tracheal expansion is made, the more effective it should be in aspirating the collections, as must appear obvious. The cartilages being thick anteriorly, tapering posteriorly, leaving a shoulder for the muscular insertions (Figs. 34 and 35), could not otherwise than have this effect upon the tubing, nor could these anatomical dispositions be explained by any other theory of tracheal function; at any rate, it explains the phenomena.

The thin cartilaginous plates within the lungs maintain patency in the tubing during expiration, the firm compression of the lungs tending to destroy this; while during inspiration they oppose a firm surface to the surrounding alveoli for compelling the collections in the tubing and making the suction-action more effective on this account.

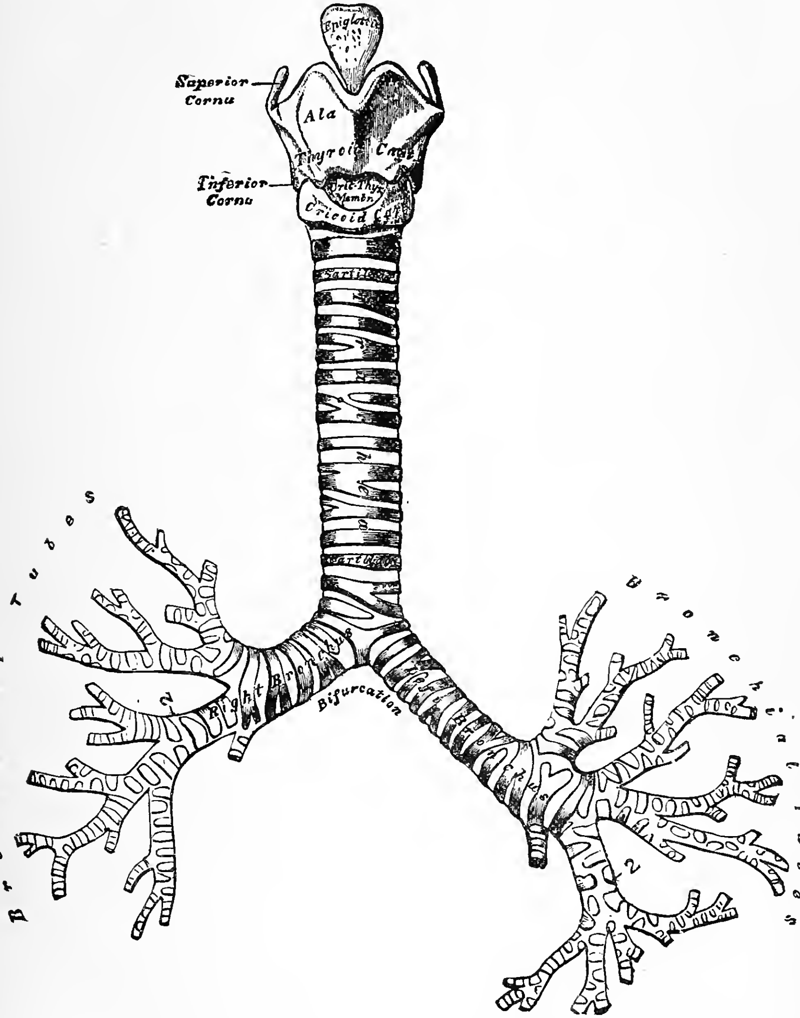

Fig. 29.—Front View of the Human Trachea and its Smaller Divisions.—Gray.

The *circular* arrangement in the muscles has plain import, the rhythmical expansions and contractions in the tubing calling for this : they simply elongate and contract, with inspiration and expiration, the wave of expansion extending from above downward to the air-cells, which are last affected, while the wave of contraction extends from below upward. In this way, an energetic circulation is produced through the tubing for respiratory purposes, and cleanliness is maintained. Of course, it also effects elongation and contraction in the lungs during inspiration and expiration, enabling them to expand outward and downward during inspiration, and to contract inward and upward during expiration, thus producing the up-

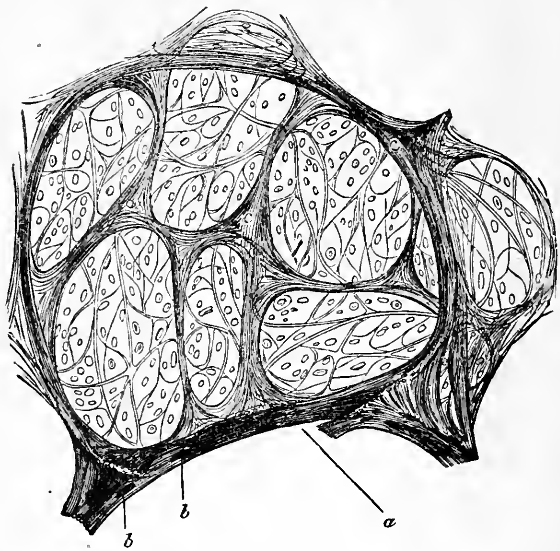

Fig. 30.—Section through a Lateral Infundibulum.—Schulze. From the lung of an adult human being, after it had been filled with and hardened in alcohol containing acetic acid. *a*, entrance from the alveolar passage into the infundibulum; the upper margin of the opening has been partially removed by the section, magnified $\frac{80}{1}$; *b*, *b*, nuclei of smooth muscular fibres, magnified $\frac{40}{1}$; *c*, *c*, framework of elastic fibres.

and-down action of the organs, or the to-and-fro movement in the long axis of the body, for which suspension by the roots from the spine so as to hang free in the pleural sacs, together with the copious secretions for lubricating them, is essential; therefore readily accounted for. Finally, external to this cylinder of muscles, we have a thick coat of elastic and connective tissue fibres (as obtains in arteries), in which the cartilages are imbedded, the latter, however, fading out and disappearing in the bronchioles; but not the elastic coat, which continues on to the terminal air-cells, forming the framework in which the cups are placed (Fig. 30, *c*), and casting around them the basket-like fibres for imparting strength and firmness, at the same time permitting them to expand and contract the same as the elastic coat of the arteries, with which

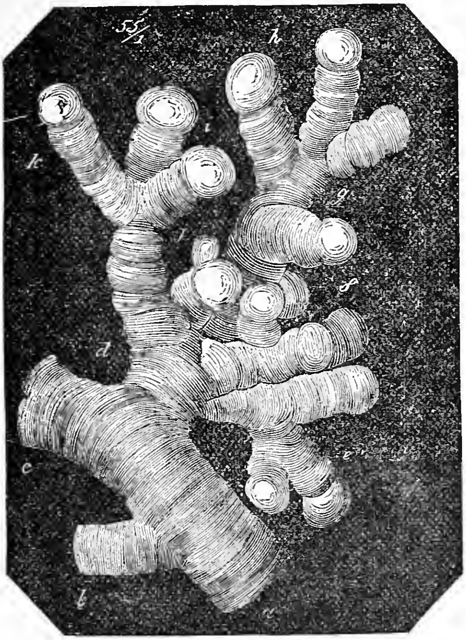

Fig. 31.—Mold of a Terminal Bronchus, and of a group of Air-cells, moderately distended by injection, from the human subject.—Robin. *a*, bronchiole; *b*, *c*, subdivisions; *d*, other sub-divisions, showing the different forms of the terminal groups of air-vesicles (*e*, *f*, *g*, *h*, *i*, *k*), and the relation of the bronchial tubing to them (referring to the *longitudinal* axis simply), magnified $\frac{55}{1}$. The rounded and knobbed appearance of the groups is due to the coalescence of the borders or margins of the air-cells around the central axis, which forms the air-passages and route of communication with the proximal bronchial tubing; the irregular and uneven appearance of which is due to distension from the injection and imperfect development of the connective and elastic tissues, and of the unstriped muscles which form the walls of the organs. (The preparation was made from an infant that survived its birth only a few days.)

it is homologous. And nothing could be more perfect than the beautiful adjustments that obtain in the lungs for producing the work connected with the respiratory processes. So, then, looking at the anatomical dispositions in the bronchial tubing and air-cells, the *circular* arrangement in the muscles and elastic coats, extending up to the very air-cells (Fig. 31), with the cartilages all *open* and arranged around the longitudinal axis throughout the whole system; the nerves for connecting them with respiration. Last, but not least, the suspension of the organs by the roots from the spine so as to hang free in the cavities of the pleuræ, together with the copious secretions for lubricating them for obviating friction; all regarded from the standpoint of the law of pressure. Can it be doubted for a single moment that they perform an active rôle in respiration and vocalization? Otherwise, all this were meaningless. The following diagram (Fig. 32) exhibits the general form of the lungs as they adapt themselves to the form of the pleural cavities, together with the relations the air-cells sustain to the tracheal system. It is easy to perceive how nervous force should cause them to respond to the actions taking place in the containing walls, so as to maintain them in close contact all the while during inspiration and expiration, expanding outward and downward during inspiration, contracting upward and inward during expiration—that for producing these movements the organs must be *free* in the cavities, and all the arrangements that obtain should be just as they are; while any pleuritic attachments should produce corresponding embarrassment to respiration, at the bases the worst, for this would trammel the great downward movement in the long axis of the body (vastly the more important), when extending up the sides inhibiting it, producing death. Finally, we would add the results of some physiological experiments made upon the lungs, which confirm this view of lung-action and establish incontrovertibly that the theory of a negative pressure in the pleuræ cannot possibly be correct.

Physiological Experiments Made upon the Lungs.—Notably, a large, lean dog (hound) was firmly held in the standing position by several assistants, and, electing the interspace between the sixth and seventh ribs, a short silver tube, bent at right angles (Fig. 33), was passed into the pleural cavities—one upon either side at the most external portion of the chest. They were one-fourth inch in calibre and one and three-quarter inches in length, with a flange and openings for securing them to the sides of the wounds; while they were bent to deflect them away from the lungs, at the same time it made it more difficult for the animal to extricate them. The immediate effects of the operation not a little surprised me, though I had previously discounted them.

In place of *at once* falling down in a state of asphyxia, the animal continued in the standing position, but taking long and deep inspirations, swelling himself out to a prodigious size, then as slowly contracting the chest again; doing this

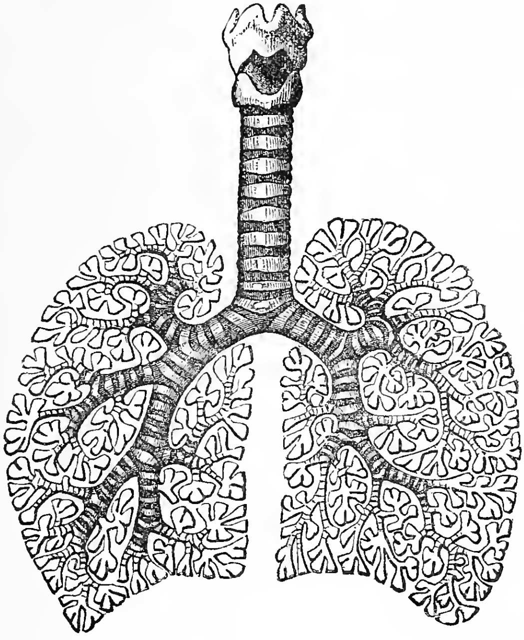

Fig. 32.—Tracheal System and Terminal Air-Cells, in diagram.—Dalton.

from seven to eight times per minute, the whole performance bearing a very striking resemblance to what takes place after section of the pneumogastric nerves. But when liberated, he *ran round and round the room* as though seeking for means of escape, frequently stopping suddenly upon the haunches to bite at the tubes, first at one side, then at the other, evidently in much misery; then as suddenly starting up again to take a run of the room, but never going far, however, without making one of these halts for relieving himself of the instruments. I had been watching him thus for over twenty minutes, when I was called away upon urgent business, my friends going with me, and when I returned, which was fully three hours later, being unavoidably detained, I found the poor fellow unconscious, lying at full length upon his left side, and breathing heavily, the respirations being thirteen per minute, the air passing into and out of the right tube with a loud, whistling sound; the left, of course, was obstructed. First one, then the other tube was now removed, and the wounds hermetically sealed by twisted suture ; and placing a basin of water near him, he was left for the night, I had thought in a dying condition. But the following morning, however, upon opening the door, to my infinite surprise, he dashed by me

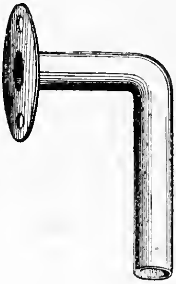

Fig. 33.

down the stairway with the greatest impetuosity, and, the hall door being open, he escaped to the street, where I saw the last of him as he turned the opposite corner. He certainly lost no time in getting away, not knowing the kindly feelings and intentions he had inspired, and though I made diligent search, keeping my eye upon the pound and the Health Office as well,* I never had the pleasure of seeing him again, so that he scarcely could have died from the wounds, and his recovery may be considered as pretty certain. Nor did I deem it necessary to repeat the operation, since the facts established by it prove incontrovertibly that the lungs are active organs in respiration, and not mere "passive bags," to be "operated by the chest-walls and diaphragm ;" other-

* This occurred at Washington, D. C., July 12, 1878.

wise death by asphyxia should have been produced the *instant* the pleuræ had been thrown open for free ingress of air. Neither could the rapid absorption of the air for producing recovery be explained. It is obvious, therefore, that this cannot possibly be the mode of respiration, but, on the contrary, that the lungs *expand and contract* regularly and rhythmically synchronous with the action in the chest-walls during respiration.

Furthermore, this would explain the cases of recovery from severe gunshot wounds in the chest, in which the ball had traversed both lungs, coming out upon the opposite side and leaving the pleuræ open for the time.* It would, moreover, show the utility of speedily closing these wounds for excluding the air and permitting the work of repair and restoration to proceed without interruption. Save from actual hemorrhage, they never perish outright from the wounds, but from the nutritive changes which are superinduced by them, pleuritic effusions, pneumonia, pyæmia, etc., though respiration may be greatly embarrassed, especially if much air and blood are present in the pleuræ, compressing the lungs and in proportion impeding their action. But the immediate danger passed from this source, absorption becomes more and more energetic from increase of action in the lungs with the removal of the contents in the pleuræ, as this admits of corresponding expansion in the lungs. The following experiment will show how very rapidly air is absorbed from the cavity of the pleura in the normal condition of the lungs, notably:

A medium-sized dog was placed under chloroform and air forcibly injected into the right pleural cavity through the sixth intercostal space, by means of an air-pump and canula, until no more could be introduced without dangerous violence, when the instrument was removed and the wound hermetically sealed by twisted suture, the animal recovering consciousness within a few minutes. The immediate effect of the operation was to greatly hurry respiration, the animal gasping for breath, the mouth partially open and the tongue protruding, the parts discolored from venous stasis in the systemic capillaries, and the eyes more prominent from distension of the intra-orbital veins,

* Cases of this kind frequently occurred during our great Civil War.

with a look of distress and anxiety in them painful to witness. He was very restless, going but a few feet at a time, from inability to maintain the erect posture, continually rising up and lying down, his whole attention seeming to be concentrated upon respiration, which was voluntary. Time, 3 P. M. At 6 P. M. he was lying down, but got up immediately when I entered the room, and began to move about, but evidently was not in as much distress as at first, while all the symptoms had improved. During my absence he had drank considerable water. At 9 A. M. the following morning he was bright and active, and to all appearances in a normal condition, apparently fully recovered, as there was not the slightest embarrassment to respiration. Thus, within the space of less than eighteen hours from the time the air had been injected into the pleuræ, it was absorbed by the lungs—*i. e.*, compelled through the alveolar membranes by means of high pressure in the pleuræ produced by the air, but increased by the expansile action in the lungs. In other words, expansion in the lungs during inspiration by increasing pressure in the pleuræ, at the same time diminishing it in the alveoli (which is inevitable, from the very nature of things), acts as a *pushing* and a *pulling* force combined upon the pleural air, and, reaching the mucous surface by this means, is finally expelled from the body with the tidal air, which is the shortest and most expeditious route. Hence, it is not difficult to account for the rapid absorption of air in the pleuræ, upon the basis of the organic laws controlling the movements of the fluids, and which are being incessantly invoked in the measure of the physiological requirements, as before remarked.

On the other hand, did a negative pressure obtain in the pleuræ, as alleged, all this were utterly inexplicable. Not rapid absorption in the pleuræ only, but the entire mechanics for circulating air and blood in the lungs as well, since it all is based upon pressure and fluid equilibrium, which is being incessantly invoked by rhythmical changes in pressure. It were proper to pause here a moment, perhaps, to comment upon this theory of "a negative pressure in the pleuræ"—how it came to be so widely adopted, considering the care and discrimination exercised by physiologists—before proceeding further. In the first place, some explanation is better than none, and the bellows principle once admitted, ran on wheels, seemingly able to take care of itself, the object being to get air in the lungs simply ; but followed to its logical results, the simile is seen to be false, since it should apply to the cavities in the pleuræ as well as the alveoli ; moreover, it should apply to the blood as well as the air, pressure being transmitted through the body, and which was overlooked, or, at least, not critically examined, owing to the absence of a fundamental principle upon which to base the entire mechanics of circulation, as this would have shown the necessity for connecting circulation with respiration, which would at once have laid bare the illusion ; and thus having no sure guide, it is inevitable that error should have crept in, not here only, but everywhere else in the organism—error after error—literally leaving nothing explained. Then, again, special circumstances tended to confirm and rivet the error, making it apparently incontrovertible. Notably, collapse of the lungs when the chest is opened, and as though they had been previously distended by the air as a balloon, but which is false in theory, and false in fact. The first, for the reason that a negative pressure in the pleuræ (upon which the theory is based) would inevitably suck the animal fluids into the pleuræ, as well as air into the lungs ; hence, cannot possibly be correct, as has been already fully shown.

The second, for the reason that collapse of the lungs does *not* take place *after rigor mortis* when the chest is opened, the lungs maintaining their size and shape, and which is absolute proof that collapse is *not* due to elastic force from previous distension of the lungs, but to a vital action produced by the *stimulus* in the air, brought suddenly in contact with them, for elastic force is *unimpaired* by *rigor mortis*. And being produced by *vital action*, of course it grows less and less till *rigor mortis*, which *puts an end to life ;* otherwise is inexplicable.

And where is this negative pressure in birds and reptiles for distending *their* lungs, having no diaphragm for effecting it ? And in the frogs, which have neither ribs nor diaphragm, nevertheless can expand their lungs, *even in the absence of a* *throat-apparatus for assisting it?* It will not do at all. The principle is wrong.

Then, again, consider the strain to the lungs which is involved in this theory of a vacuum in the pleuræ for effecting distension—strained open through all the expanse in the chest for filling out the cavity, with yet more strain added to this with each inspiration and every degree of it, to last throughout all of life, from the first inspiratory act at birth to the last expiratory at death—and in all candor it must be confessed the lungs would be put upon a "rack" the most infernal that human ingenuity could devise or living structure endure; but done all unconsciously. It will not do to think about—*Ach Gott!*—not for a moment even. Curing pneumonia by inducing septicæmia is bad enough, but this is worse.

The explanation is easy. Thus, during intra-uterine life the lungs are molded to the cavity, the incurvated diaphragm, as well as the sides, taking the shape of the excavation, broad and excavated at the base to fit the convexity in the diaphragm, and tapering up to the conical apices, fitting the cavity out and out; and at birth the organs expand with the chest, the diaphragm at the same time contracting, all the parts acting simultaneously under nervous force propagated through the medulla oblongata by means of sensory impressions in the skin; while they grow *pari passu* with the walls and the increase in size of the cavity; and expanding and contracting with these, strain is made impossible. But when the chest is invaded and air admitted into the cavity, this stimulus, acting on the sensory surface, produces the energetic and powerful contraction which condenses the organs and draws them out of shape and out of all proportion to the cavity which they occupy; and which only proves the contractile energy in the organs, but not that they are distended by the air. Nor is it the number of the nerves in the pleural surface which produces the action, but the fact that the organs themselves are sensory, the same circumstance being seen even in plants, but is especially noticeable in sea anemones, which contract the fronds energetically the instant they are touched, then expanding them again; this in the entire absence of nerves for producing the actions.

But you cannot make the lungs expand! No! No more can you make the leech expand; on the contrary, he contracts, and contracts the more energetically the greater the irritation; nevertheless, he expands himself readily enough upon occasion; notably when sucking, swelling *himself* out to a number of times the size in the empty condition (Figs. 15 and 17). And he must do so in order to make room for the blood; so, likewise, may the lungs expand of themselves during inspiration; nay, must do so, in order to make corresponding room for the air and blood which flow into them, the principle being the same in both, precisely; while the fluids flow into the interior in conformity with the organic law underlying both alike. The organ, or the animal; what matters it?—the same law underlying all of it. And, irrespective of the anatomical and physiological facts referred to, which make it absolutely certain that the lungs expand and contract regularly and rhythmically synchronous with the action in the containing walls, we have the imperious requirements in an inflexible law compelling them to do so.

In conclusion: The curious circumstance, or the flapping in and out of the relaxed intercostal muscles in the case referred to produced by chloroform narcosis was not due to changes of pressure in the pleural cavity, but to changes of pressure *within* the lungs themselves, the lung-tissue pushing them out during expiration when the organs are tightly compressed; while they were pushed in during inspiration from the inability of the lungs to sustain the weight in the atmosphere which this invokes, being able to sustain only a portion of it, and sufficient only to make pressure in the pleuræ greater than in the alveoli, which the scheme calls for. It need not be great, but the lungs *must* expand in order to produce it. Fifteen pounds per inch is too much for the lungs, but since several ounces only is necessary, the air flowing in at the same time through the trachea for assisting it *pari passu* with expansion, the action is readily effected.

Concerning the Action in the Trachea.—With a view of determining the energy in the trachea, I was led to make the following physiological experiments upon the organ:

As soon as a bullock had been dispatched at the slaughterhouse, but before life had become extinct, I made the following section of the trachea (Fig. 34), which shows the condition *before* contraction sets in, which occurs some minutes later, from 10 to 15 only, or long before it invades the other structures, and which is also suggestive, since it would indicate unusual energy in the organ. It will be seen that the organ is circular, being nearly perfectly round. But when fully con-

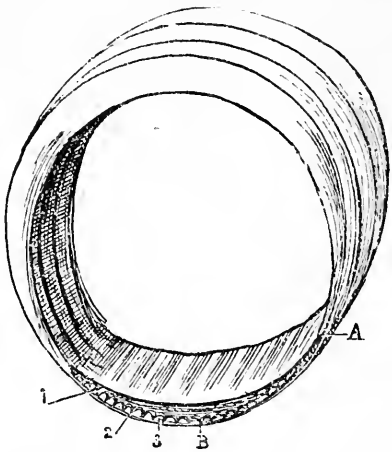

Fig. 34.—A Transverse Section of a Bullock's Trachea, made *immediately* after death, and before contraction had set in. *A*, shoulder of the cartilages where the transverse muscles have insertion ; *B*, extension of the thin cartilaginous plates to near the mesial line (3) ; 1, mucous membrane ; 2, transverse muscles ; 3, longitudinal muscles.

tracted, it presents the following appearance (Fig. 35), which will give some idea of the energy in the organ.* The contraction is enormous, reducing the lumen nearly one-half, while the thin terminal plates forming the posterior portions of the cartilaginous rings (*A*, *B*) are pulled forcibly in contact—about a half-inch space separating them (Fig 34, 3, *B*), and are bent upon themselves by the action in the muscles, which pull away from the plates and put the loose connective tissue (Fig. 35, *C*) upon the stretch. It is proper to remark, that at the point where the muscles have insertion into the cartilaginous rings there is an offset or shoulder, from which the thin cartilaginous plates are extended.

* As these cuts were copied from a photograph, they may be taken to be pretty accurate.

Now, then, the point we wish to make is, that this contraction which sets in after death describes the arc of movement during life, for which the anatomical dispositions in the parts are the appropriate adjustments, and which is so obvious that it needs no argumentation.

The progressive increase of the cartilaginous substance in the anterior portions of the rings for increasing their elastic force should make expansion very energetic for aspirating the alveoli, while the degree of contraction in the lumen produced by the muscles would show the force in the organ for expelling the air. All of which is sufficiently manifest.

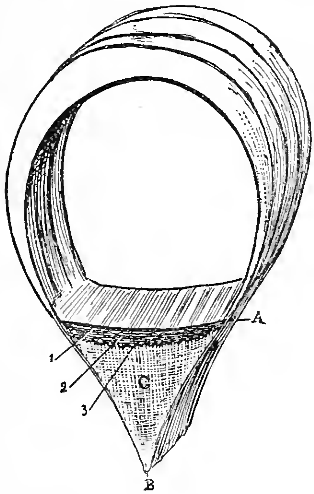

Fig. 35.—A transverse section of the same, made a few minutes after death, showing the amount of contraction in the cartilages produced by the action in the muscles. *A*, shoulder of the cartilages; *B*, the thin cartilaginous plates pulled together and bent upon themselves; *C*, loose connective tissue fibres; 1, mucous membrane; 2, transverse muscles; 3, longitudinal muscles.

But this, again, brings up the nervous apparatus for coördinating the structure with respiration and vocalization, and which brings out in clear relief the beautiful adjustments that obtain in this respect, otherwise inexplicable. Notably the number of the nerves to the bronchial tubing sent off from the pneumogastrics (Fig. 36, 12, 13) for coördinating the action with respiration and vocalization; together with the *devious* course of the recurrent laryngeal nerves, which first descend into the chest to connect with the lungs (9, 9), ascending thence *upon the sides of the trachea* to the vocal cords, for coördinating them with the action in the lungs and trachea. As the principle is the same in both, we need only take up the action in vocalization.

Concerning the Action in Vocalization.—Of course, the principle in vocalization is the same as obtains in an Æolian harp; notably the sounds are produced by rapid vibrations in the vocal cords from the rush of air against them, only that in the case of the vocal cords tension is constantly changing for producing the variety of sound characteristic of them, and which is effected by means of nervous force acting upon the structures; while this in turn is determined by the force in the outgoing air, the two being always in correspondence in the normal condition of the organs. This being true, it follows that in order to produce the vibrations in the cords the lungs and trachea would *first* have to be contracted for forcing out the air, the vibrations depending upon this; hence, the fact that nervous force should run this circle in the chest *before* connecting with the vocal cords; otherwise, it would be putting the cart before the horse. In other words, the vocal cords being *an attachment* to the lungs, they must be *directly* connected with them by nervous force for producing correspondence in action, the one depending upon the other.

And it makes no difference how long the neck may be—*e. g.*, the giraffe—the same necessity exists for this nervous connection between the parts, as must appear obvious. Finally, for producing the rapid vibrations in the cords, it calls for quick, energetic action in the trachea for driving the air forcibly through them, and which the larger movements and the slower action in the lungs are not equal to, requiring the swifter movements in this fine adjustment for producing them; moreover, the force should be *directly* applied upon the air itself, for which the special anatomical dispositions in the trachea are the appropriate adjustments, making it easy and natural. So, then, we can readily understand why the recurrent laryngeal nerves should thus connect the trachea with the vocal cords, since this is necessary for producing correspondence;

and as the medulla oblongata is the common centre of nervous force, the whole performs as a single organ only for pro-

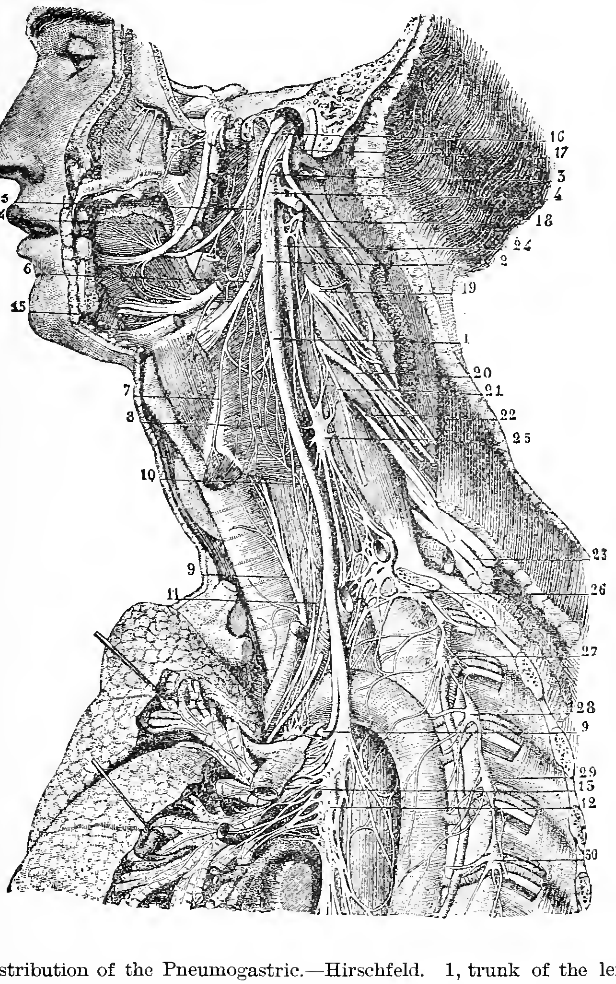

Fig. 36.—Distribution of the Pneumogastric.—Hirschfeld. 1, trunk of the left pneumogastric; 2, ganglion of the trunk; 3, anastomosis with the spinal accessory; 4, anastomosis with the sublingual; 5, pharyngeal branch (the auricular branch is not shown in the figure: 6, superior laryngeal branch; 7, external laryngeal nerve; 8, laryngeal plexus; 9, 9, inferior laryngeal branch; 10, cervical cardiac branch; 11, thoracic cardiac branch; 12, 13, pulmonary branches; 14, lingual branch of the fifth; 15, lower portion of the sublingual; 16, glosso-pharyngeal; 17, spinal accessory; 18, 19, 20, spinal nerves; 21, phrenic nerve; 22, 23, spinal nerves; 24, 25, 26, 27, 28, 29, 30, sympathetic ganglia.

ducing the sounds in vocal resonance, inclusive, of course, of the muscles in the abdomen and the walls of the chest. Furthermore, that the trachea does perform an active rôle in vocalization has forcible illustration in birds—notably, insessorial birds (the greatest songsters) possess five pairs of muscles for connecting the bronchi with the lower larynx, in which the vocal cords are placed, and are so disposed as to influence both the length and the diameter of the tubes ; while the number diminishes with the power of song in other birds, the Natatores possessing but two, Rasores and Grallatores one only ; while in the king of the vultures and the condor the vocal muscles are absent. Then, again, in Chelonia, which have neither diaphragm nor ribs, and cannot contract the houselike body, we have a special arrangement in the muscles for compressing the lungs, the so-called diaphragm (Figs. 172, 42) connecting with this action in the trachea, by means of which they are enabled to produce loud vocal resonance.

But man possesses the most extensive provisions for producing the energetic action here referred to, since the cartilaginous interspaces for increasing the arc of movement are widest in him (Fig. 38, 3) while the muscles are in correspondence, and undoubtedly brought about as adaptive changes for producing the variety of oral sounds characteristic of him, as speech calls for constant exercise of the parts. It will thus be seen that everything is in correspondence with the physiological requirements, while the anatomy falls readily into line as means to ends, and leaving no outstanding quantity refusing absorption, furnishing absolute proof in itself of the correctness of the premises.

CHAPTER VI.

THE MECHANICS FOR CIRCULATING BLOOD IN THE LUNGS, AND THE ACTION OF THE HEART AND ARTERIAL SYSTEM IN CONNECTION THEREWITH.

Mechanics for Circulating Blood in the Alveoli—Anatomical Dispositions in the Walls of the Alveoli for Effecting it, or for Compelling Circulation of Blood in the Plexuses to be in Correspondence with the Circulation of Air in the Alveoli—Extent of the Alveolar Plexuses and the Manner They are Affected by Inspiration and Expiration—Functions of *Residual-Air* in this Connection—An Elastic Cushion for Transmitting the Force in the Lungs and the Muscular Envelope Upon the Plexuses for Compelling the Blood to be in Correspondence with the Circulation of Air in the Alveolar Chambers—Manner of Maintaining a Balance in the *Dual* Circulations in the Alveoli—Relations which the Heart Sustains to the Pulmonic Circulation—Mechanical Principle in the Heart Itself—Anatomical Dispositions in the Right Side Adjustments with the Functions in the Lungs—Ditto, Left Side—Nerves for Effecting Coördination with the Lungs—Action in the Arterial System Synchronous with Respiration—Nerves for Effecting it—Physiological Problem Connected with the *Curves* in Blood-Pressure Tracings and the *Curves* in Intra-thoracic Pressure—Traube's Curves—Physiological Experiments Proving the Existence of Rhythmical Expansions and Contractions in the Arterial System Synchronous with the Actions in the Heart and Lungs.

In order to see through the marvelous clockwork in respiration and circulation, two facts should be kept uppermost in the mind, not to be lost sight of for a single moment even, namely:

1. That respiration is the means for evolving *force* in the organism, for which purpose streams of air and blood are passed *simultaneously* through the alveoli by means of rapid rhythmical changes in pressure and a comprehensive tubular system appropriate to each communicating with the alveoli; the one flowing out by reflux action through the route of ingress, the other into the left side of the heart and arterial system on its way to the cell-brood.

2. That by reason of *inertia*, additional force is needed in the blood for maintaining it in correspondence with the circulation of air in the alveoli, or a measure of blood for a measure of air, a balance being maintained between them; hence the

force-pump in the heart and the intimate relations it sustains to the lungs, together with the innumerable muscles in the vessels, and why the blood-vascular system as a whole is set to respiration, or as the minute-hand to the hour-hand, by means of the nerves correlated in the medulla oblongata, which functions as the solar centre of nervous force for the organism, coördinating the whole mechanics with respiration, to the end that the blood and air may be pumped through the lungs for generating force in the measure of the requirements and a balance be maintained in the organism; otherwise impossible. From that standpoint—and there is none other—the wholefield is readily overlooked and everything made plain and easily understood.

The mechanics for circulating air in the alveoli have already been considered, and it remains to show how the blood is maintained in correspondence. The first thing in this connection are the anatomical dispositions in the alveoli, as means to ends, for compelling afflux and efflux in the plexuses with inspiration and expiration simultaneously with the air in the chambers; proceeding thence to the phenomena in the heart and the vessels for still further increasing the action, bringing it up to the physiological requirements. The arrangements which obtain in the alveoli for compelling circulation in the plexuses, with afflux and efflux of air in the chambers, are most comprehensive, at the same time extremely simple, notably: 1. The telangiectatic plexuses project *into the cavities of the alveoli* (Fig. 37), which at once secures large exposure of the capillary surface to the action of the air, for effecting rapid interchange of the gases. 2. The plexuses are *incorporated with* the alveolar walls, a layer extending over them; and which not only secures them firmly in position, but compels them to respond to the action in the walls, so that when the walls expand for sucking in the air during inspiration, the vessels *must* expand simultaneously, or widen and elongate at the same time for sucking in the blood; while during contraction in the alveoli for forcing out the air in expiration, the capillaries are similarly affected, the lumen being contracted, as well as the longitudinal axis, for forcing out the blood. Thus, the two are necessarily in concert, the air and blood, in consequence, rushing into and out of the chambers simultaneously; the one by reflux action through the route of ingress, the other into the left chambers of the heart and arterial system, as before remarked. It could not be otherwise, in the very nature of things. The plexuses are not rudely *stretched*, then—let nothing more be said about *stretching* capillaries, for they are not intended to be stretched—but, on the contrary, they expand and elongate with alveolar expansion, and reverse the action during alveolar contraction, with no strain whatever upon them during these movements. The capillaries and walls of the alveoli, being composed of the same material or protoplasmic substance, are alike capable of both these actions. But we have now to no-

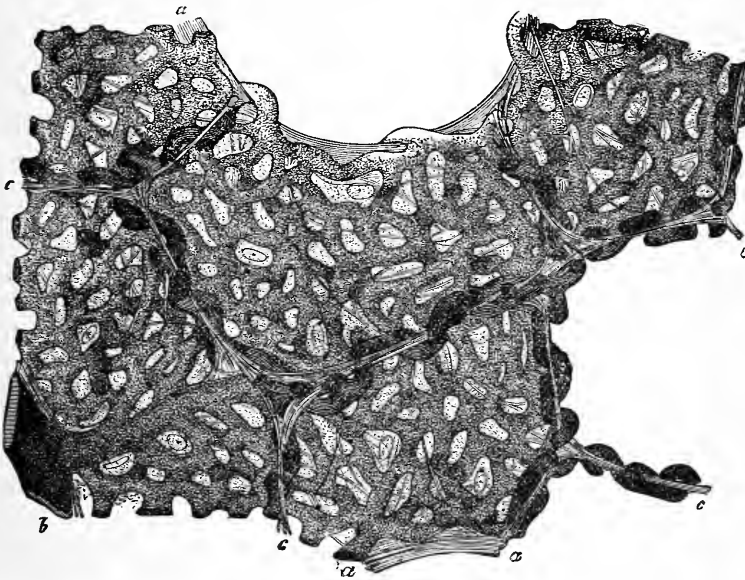

Fig. 37.—Section of the Alveolar Parenchyma of a Human Lung, injected through the Arteria Pulmonalis.—Schulze. *a a*, Free alveolar margins; *b*, small arterial branch; *c c*, alveolar walls seen in transverse section.

tice another important factor in the mechanics for assisting the capillary circulation, notably the action in *residual air*, which it would be difficult to overestimate, since it is by means of this elastic air-cushion in the alveolar chambers that the force in the muscular envelope is *transmitted upon the plexuses* during respiration for producing the requisite changes in pressure upon the blood itself for compelling afflux and efflux in inspiration and expiration, the same as in the air itself, at the same time that it obviates friction to the vessels; otherwise inevitable. Thus, during inspiration the elastic cushion expands with the reduction in pressure which this produces, thereby facilitating the expansile action in the walls, at the same time that it invites air and blood into the locality to equalize pressure, each flowing in through its respective channels; while during expiration the cushion is firmly compressed against the plexuses for compelling their contents into the left side of the heart, an equivalent of air at the same time escaping through the air-passages by reflux action, but which the simultaneous contraction in the trachea tends to retard or regulate so as to maintain a balance in this respect. In other words, the mechanical principle in the alveoli is the same that obtains in a pump with an air-chamber, only that in the present instance the chamber *leaks*, as it were, letting out some of the air when a given degree of pressure is reached. But, then, considering the enormous surface involved in the alveolar floors (estimated by Leiberkühn at 1,500 square feet), due allowance is made for this leakage, but which is absolutely necessary for maintaining a current of air into and out of the compartments, the same as the blood, the object being to bring *fresh* air and *venous* blood into intimate relation for mutual interchange, as before remarked. Finally, by reason of the mechanical adjustments that obtain in the lungs and chest-walls, a limit is set to inspiration and expiration, in order that only a given amount of air and blood can be taken in or given out at a time, so that at the end of the most forced expiration a large amount of *residual air* still remains in the lungs, which prevents collapse in the walls and rude contact of opposing surfaces; otherwise inevitable. Hence, it is easy to perceive the enormous rôle residual air performs in respiration. And nothing is to be more admired than the comprehensive arrangements that obtain in the lungs for producing simultaneous currents of air and blood through the alveoli and maintaining correspondence; but a common law underlying it all enables this to be done. And by means of the cardiac force-pump and the innumerable muscles in the vascular system, inclusive of the nervous combinations in the medulla oblongata for coördinating them with respiration, inertia in the blood is overcome and correspondence readily produced between the blood and air in the alveoli, while the pumping movements extend from centre to circumference of the body and from the lungs to every tissue territory, the whole being intimately connected with respiration by means of the correlation of the nerves in the respiratory centre.

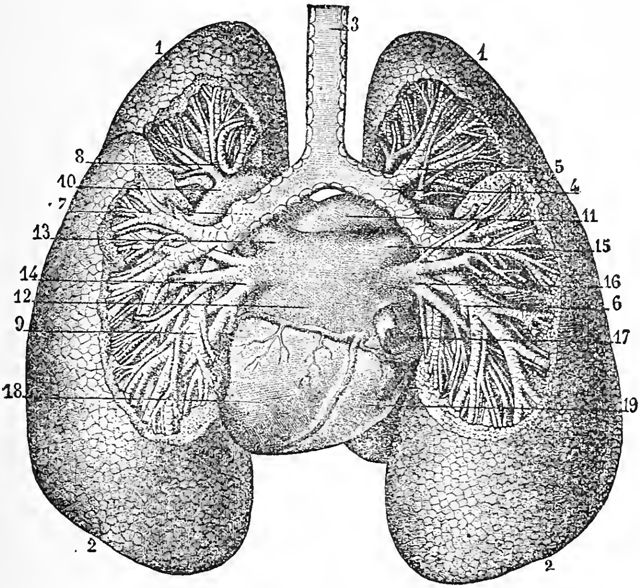

Fig. 38.—Bronchi and Lungs, Posterior View.—Sappey. 1, 1, summit of the lungs; 2, 2, base of the lungs; 3, trachea; 4, right bronchus; 5, division to the upper lobe of the lung; 6, division to the lower lobe; 7, left bronchus; 8, division to the upper lobe; 9, division to the lower lobe; 10, left branch of the pulmonary artery; 11, right branch; 12, left auricle of the heart; 13, left superior pulmonary vein; 14, left inferior pulmonary vein; 15, right snperior pulmonary vein; 16, right inferior pulmonary vein; 17, inferior vena cava; 18, left ventricle of the heart; 19, right ventricle.

In this manner, then, a dual circulation of air and blood is produced through the lungs for respiratory purposes, the waste products flowing out with the tidal air for redistribution, while the oxygenated blood passes into the left cardiac chamber and arterial system on its way to the cell-brood, as before remarked. The four wide, short pulmonary veins (Figs. 38, 13, 14, 15, 16) give it ready egress by a short and direct route to the auricle and ventricle. This would account for the size of the left auricular and ventricular chambers, the amount of blood passing out of the lungs during expiration from the production of high pressure in the alveoli compelling this circumstance.

Concerning the Action in the Heart.—The intimate relation which the heart sustains to the lungs has its explanation in the fact that the organ, like the lungs, relates to oxygenation for evolving force in the organism, and since oxygen is imported through the blood sent into the lungs, it is manifest, for increasing the action, that circulation in the organs would have to be increased correspondingly—both the air and the blood; but the latter possessing greater inertia, it calls for a force-pump for effecting correspondence between them; hence the force-pump in the heart and the intimate relations it sustains to the lungs, inclusive of the nerves for effecting coördination or for increasing the diastoles and systoles with the exigencies in the functions in the lungs, which the scheme calls for. The relations it sustains to the systemic circulation will come in presently. But the first thing to be disposed of concerns the mechanical principle in the heart itself. This also is easily determined by the law of pressure underlying the organism. Thus, a force-pump, as the heart is, involves two elements—a *suction* and a *lifting* force, acting alternately—the one involving the other. The former is represented by the cardiac diastole, for aspirating the blood; the latter. by the systole, for compelling it out again, in order to produce a current; while the speed of the current thus produced is dependent upon the energy and rapidity of the diastoles and systoles, the former taking precedence of the latter.

In short, the blood would *first* have to be gotten into the chambers *before* it could be forced out again by the systole, in this manner producing a stream through the organ. Furthermore, that diastole produces suction-force is fully proven by the fact that pressure in the heart falls *below* atmospheric pressure during this time, while systole, of course, is greatly in excess. For example, in the dog the minimum pressure in the left ventricle varies from —52 to —20 mm. (mercury), while the maximum pressure is about 140 mm. In the right ventricle the minimum fell to —17, while the maximum rose to 60 mm. And that this reduction in intra-cardiac pressure is not due to any mechanical action in the chest was demonstrated by opening the chest when a pressure as low as —24 mm. was obtained in the left ventricle. [Goltz and Gaule, Pflüger's Archiv., xvii. (1875), p. 100]. This suction-action in the heart would account for the danger from opening the veins in the neck during surgical procedures undertaken in that locality, without proper precautions for preventing the entrance of air into the veins under the suction-action in the heart, producing instant death by preventing afflux and efflux of the blood, the air itself filling the heart, which cannot get rid of it, and so causing death. It is thus seen that the heart performs work in diastole as well as systole, reduction in pressure compelling this circumstance; while during systole, when the action is reversed, more work is performed for producing lifting force, the one necessarily involving the other, in order to produce a stream through the organ, as before remarked. So, then, the same principle precisely applies for the heart as for the lungs, the fluids flowing into and out of the chambers by reason of rhythmical changes in pressure *within* itself, produced by means of the rhythmical expansions and contractions taking place in its walls; only, that the action is confined to the blood itself, for reasons already given. Far be from us the wish to underestimate the *work* performed by the heart in the circulation, but its importance cannot be overestimated, since without it evolution would undoubtedly have arrest at the stage in the worms, for neither could correspondence be produced between the circulation of blood and air in the alveoli, nor the high pressure in the arterial system for increasing the capillary circulation. But we would not anticipate. We will now take up the special anatomy in the organ in corroboration of the view herein set forth.

Concerning the Anatomical Dispositions in the Right Side of the Heart as Adjustments with the Functions in the Lungs.

A most notable circumstance in the right side of the heart, as adjustment to the functions in the lungs, is the *size* of the ostia, which are very much larger than in the left side of the organ; the auriculo-ventricular opening especially, but the pulmonary as well, which is considerable larger than the aortic, while the pulmonary artery itself is larger than the aorta.*

Another circumstance of deep import is the *insufficiency* of the tricuspid valves, the provision for reflux in the venous system as a safety-valve for the ventricle during excessive action in the lungs—*e. g.*, blowing upon wind-instruments, carrying whole notes, etc., when the blood tends to accumulate in the right side, by reason of the high pressure which prevails in the alveoli during this time; and were not some safety-valve thus provided, the ventricle must evidently be *choked*, bringing life to a sudden termination by arresting the action in the left side; hence this circumstance. Of course, some blood passes from the right side of the heart through the lungs during expiration, but is not sufficient for relieving it, as is fully proven by the rapid venous suffusion of the skin, which accompanies expiration when unduly prolonged from venous stasis in the systemic capillaries, the blood damming back from the heart to the tissue-territories. Indeed, partial damming of the blood at the right side of the heart is observable in ordinary respiration by watching the veins in the neck in thin, old people; but, better still, when laid bare in an animal by removal of the skin, swelling up and becoming prominent during expiration, and then as suddenly shrinking during inspiration, producing the so-called *pulsus venosus.* Hence, there can be no doubt whatever of the fact that the heart of itself is incapable of maintaining the normal current of the blood through the lungs, the rapid accumulations in the right side and venous system during expiration proving incontrovertibly that it falls short of doing this. So, then, this safety-valve in the right ventricle is absolutely necessary for conserving life. In death from asphyxia, the right chambers are full almost to bursting, the enormous accumu-

* According to Mr. Peacok (Pathological Transactions, Vol. VI., p. 119), the mean circumference of the right auriculo-ventricular opening is 54.4 lines ($4\frac{20}{24}$ inches), while the left is but 44.3 lines ($3\frac{22}{24}$ inches), a difference of nearly one inch in favor of the venous ostium; while the pulmonary and aortic openings are respectively 40 and 35.5 lines, or $3\frac{13}{24}$ and $3\frac{4}{24}$ inches, a difference of nearly one-half inch in favor of the pulmonary opening.

lations in the venous system preventing the heart from relieving itself of the blood. It is needless to add that this could not occur had the heart the power to compel the blood through the lungs independent of the pumping action in the latter during respiration. The great size of the venous ostia facilitates afflux in the lungs during inspiration, under the suction-force which this produces, while the heart greatly expedites it, contracting more rapidly during this time for increasing its action upon the blood, whereby time is gained for effecting interchange of the gases; while during expiration the great size of the pulmonary artery, with the semilunar valves at the root, admits of an amount of blood being *stored* in the interval, to be rushed instantaneously into the plexuses the moment inspiration sets in, the low pressure in the alveoli at once inviting it; at the same time, pressure in the artery is maintained by the ventricle for compelling some of the blood through the plexuses to the left side of the heart, which acts in concert with it by means of the diastoles, for continuing the current; the blood tending to accumulate in the alveoli by reason of low pressure. In short, the *size* of the *venous* ostia and pulmonary artery, the reduced size of the chambers, together with the imperfection in the tricuspid valves, all have their explanation as adaptive changes to the functions in the lungs, inclusive of the increased action in the heart during inspiration, together with the reduced action or fall in frequency of the rhythms, which takes place during expiration, to be considered presently in connection with the action in the arterial system. We now pass to the left side of the heart.

Concerning the Anatomical Dispositions in the Left Side of the Heart as Adjustments with the Functions in the Lungs and Arterial System.

The first thing to note in the anatomical dispositions in the left side of the heart is the *size* of the chambers, both auricle and ventricle being considerably larger than in the right, while the walls of the ventricle are also thicker (Fig. 33, *vg.*, *vd.*); and as this is the rule, it must relate, of course, to special functions in the organ for which they are the relative adjustments. The explanation is easy:

From the very nature of the mechanics in respiration, it follows that during expiration and the production of high pressure in the alveoli a large outpour of blood must occur in the plexuses, the four wide, short pulmonary veins (Fig. 39, 13, 14, 15, 16) giving it ready egress; hence the great relative size of the chambers which function as receiving reservoirs, But Nature is *utilitarian* to the last degree, here as elsewhere. Thus, the number of the muscles in the left ventricle, together with the augmented capacity of the chamber, increases its *suction* and *lifting* force correspondingly for aspirating the plexuses and pumping the blood into the arterial system for producing the high pressure in the

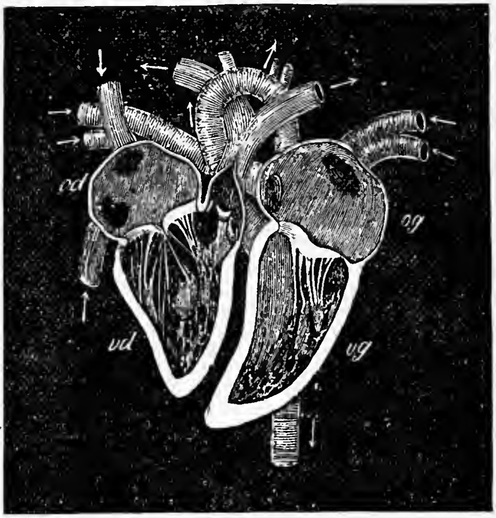

Fig. 39.—Diagram of the Four Cavities of the Heart.—Bernard. *od*, right auricle; *vd*, right ventricle; *og*, left auricle; *vg*, left ventricle. The arrows indicate the course of the blood.

latter, the importance of which it would be difficult to overestimate.

Then, again, during inspiration, when blood tends to accumulate in the plexuses from low pressure in the alveoli, it serves for continuing the stream, acting as a strong suction-force upon it. Last, but not least, during expiration, when blood tends to accumulate in the right side of the heart from high pressure in the alveoli, the augmented energy it gives to the outpour acts as a *pulling-force* upon the venous blood for maintaining a current through the lungs. Hence, everything works together for the common good. But, unlike what obtains in the right side, the auriculo-ventricular opening is a *closed* door during systole, the mitral valves fitting closely together, for the alveolar plexuses must be protected at all hazards—life's portal, as it were—and reflux would pull down the very pillars of the temple but for this circumstance, for everything rests upon respiration. When reflux does occur, however, as the result of pathological changes in the valves, the insufficiency in the tricuspids should act beneficially by increasing reflux in the right ventricle; but it would involve strain to the alveolar capillaries and inhibit due oxygenation of the blood, upon which the activities depend, and leading sooner or later to a fatal result by inducing pulmonary hemorrhage and œdema of the lungs. It is needless to extend the matter.

Concerning the Nerves to the Heart and Vessels for Coordinating them with the Lungs.—From what has preceded, it follows that there must be special nerves to the heart and vessels for coördinating them with the lungs, nerves for producing diastole and systole and regulating the rhythms, so as to meet the special requirements in lung-function, or the exigencies in its circulation. Thus, in the heart we have the "inhibitor," so-called, and "accelerator" nerves; the former being a *dilator*, the latter a *contractor* nerve for the heart, while both connect with the respiratory centre, whereby the actions are readily coördinated with respiration or inspiration and expiration. The principle involved in the mechanics is the one of reflex action. Thus, during inspiration the traction upon the nervous filaments, which is produced by expansion in the alveoli and tracheal system irritates the "contractor" nerve ("accelerator"), while the compression of the filaments during expiration excites reflex action in the "dilator" nerve ("inhibitor"), so that the rapidity of the rhythms is determined by the depth of inspiration, while the slowing of the same (which is due to prolonging of the diastoles), by the energy of expiration. In this manner the action in the *force-pump* is regulated by the exigencies in the alveolar circulation for maintaining a current through the plexuses during inspiration and expiration ; otherwise, there would be undue accumulation of the blood in the plexuses during inspiration from the low pressure this produces in the alveoli, and undue accumulation in the right side of the heart during expiration, from the high pressure which this produces in the alveoli ; hence the altered rhythms in the heart during these periods, together with the nervous arrangements for effecting them. That this is the principle in the mechanics, there is little room for doubt, since it corresponds with the *ebb* and *flow* of blood in the lungs with respiration, which it tends to regulate, so as to maintain a current through the lunge *as nearly uniform as possible*, though it does not succeed altogether ; more blood flowing out of the plexuses during expiration than inspiration. Furthermore, it accords with the results of physiological experiments made upon the nerves. For example, irritation of the "accelerator" nerve increases the rhythms, by shortening the diastoles, while irritation of the "inhibitor" slows them, by prolonging the diastoles, and when excessive arrests them altogether, the heart *in extreme diastole.* Then, again, in artificial respiration the injection of air into the lungs *increases the systole*, the air, of course, distending them, and so pulling upon the nervous filaments, as in inspiration. On the other hand, during forcible efforts to expire with the nose and mouth occluded so as to inhibit escape of the air, and thus produce unusual pressure upon the nervous filaments, suspends the systole, by prolonging the diastole, causing the heart to intermit ; is *not free of danger, however*, and should be practiced cautiously.

Finally, we have the phenomena in the tracings of blood-pressure as further corroborative proof of this principle in the hæmal mechanics, since the elements in the blood-pressure curve correspond with the physiological requirements in the lungs, as announced by the curve of intra-thoracic pressure. The following diagram, by the eminent physiologist at Cambridge, presents the matter forcibly (Fig. 40). It represents *two* tracings made from a dog, taken at the same time. One, *a*, being the ordinary blood-pressure curve from the carotid, and the other, *b*, representing the condition of the intra-thoracic pressure as obtained by carefully bringing a manometer into connection with the pleural cavity. It contains a number of elements, but all are readily explained.

1. We have the large undulations in arterial pressure synchronous with respiration (2, 2).

2. The small undulations that are superposed upon the larger, and indent the surface not unlike the teeth in a saw, only they are not so regular, and which are produced by the actions in the heart and arteries.

3. The difference in the rhythms upon the *opposite* sides of the large undulations (3, 4), corresponding with inspiration and expiration, only that they *encroach upon one another;* the rapid rhythms running into the expiratory period (3, *e*), and the slow into the inspiratory (4, *l*, *i*). Finally, we have the maximum of blood pressure corresponding with the maximum of intra-thoracic pressure (2, 1). Here we must anticipate a little, in order to make the matter fully intelligible. The grand point to be kept uppermost in the mind—not to be lost sight of for a single moment even—is to bring the *venous* blood into the alveoli *simultaneously* with the air and maintain them in correspondence, to the end that *fresh* air and *venous* blood may be kept in close proximity for effecting mutual interchange, upon which everything rests, as before remarked.

Well, in order to do this, the blood-vascular system, inclusive of the heart, is set to respiration for maintaining correspondence between the circulation of blood and air in the alveoli, by means of the vaso-motor centre.

Now, then, during inspiration the arterial system *contracts* for *pushing* the venous blood toward the chest-cavity, thereby greatly assisting the aspiratory force in the lungs for speeding the blood into the plexuses. Hence, the rise in arterial pressure during inspiration, together with the increased rhythms in the heart and vessels, as indicated in the tracings (Fig. 40, 3); which is plain enough, the increased action in the heart, the rise in arterial pressure, and the fall in intra-thoracic pressure. But during expiration and the development of high pressure in the alveoli, which this produces, the arterial system *expands* for receiving the blood which pours into it during this time from the plexuses, thereby reducing resistance to the inpour of blood from the heart and obviating strain to the organ, since *room* must be made for the blood; hence the fall in arterial tension, which continues on into the earlier portions of inspiration (*e. i.*, 2, 4, 5). In this manner, then, the large undulations in arterial pressure synchronous with respiration (2, 2) are formed, two of them presenting in the tracings.

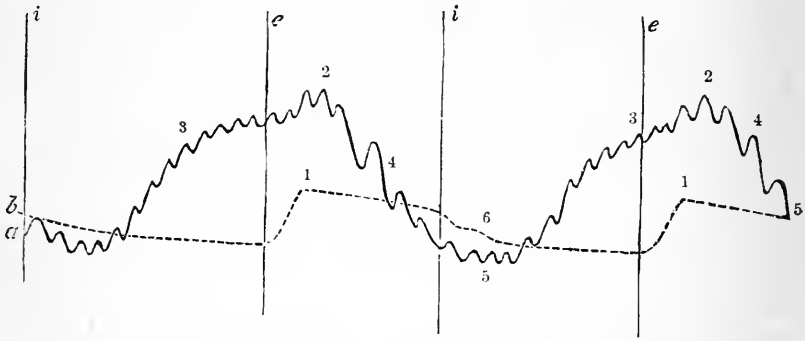

Fig. 40.—Comparison of Blood-Pressure Curve, with Curve of Intra-Thoracic Pressure. To be read from left to right. The figures are added.—Foster. *a*, blood-pressure curve, with its respiratory undulations, the slower beats on the descent being very marked; *b*, curve of intra-thoracic pressure obtained by connecting one limb of a manometer with the pleural cavity. Inspiration begins at *i*, expiration at *e*. The intra-thoracic pressure rises very rapidly after the cessation of the inspiratory effort, and then slowly falls as the air issues from the chest; at the beginning of the inspiratory effort the fall becomes more rapid.

But while this action is going on in the arterial system, the rhythms in the heart and arteries are altered correspondingly, being increased in frequency during inspiration (3, *i*, *e*) by hurrying the systoles and shortening the diastoles, the one involving the other, the object being to increase afflux in the plexuses, so that time may be gained for effecting interchange before the succeeding expiration shall have forced it out of the plexuses into the left side of the heart and arterial system; while during expiration the systoles are slowed by prolonging the diastoles (2, 4, *e*, *i*), the object being to expedite the flow into the left side of the heart and arterial system, at the same time that it acts as a pulling force upon the blood in the lungs and the right side of the heart, where it tends to accumulate by reason of the high pressure in the alveoli during this time; but the prolonged diastoles in the left ventricle tend to pull it on again and thus complete the circuit in the lungs, the right side at the same time assisting it by increasing pressure upon the opposite side, while the whole arterial system expands in order to make room for the blood thus surging into it during expiration. Hence the rise and fall in arterial pressure, corresponding with inspiration and expiration, together with the rise and fall in the cardio-arterial rhythms superposed upon the large undulations answering to the action in the heart and arteries. By increasing diastole, you increase suction-force correspondingly, at the same time it reduces the rhythms. The discrepancies in the curves of blood-pressure and the curves of intra-thoracic pressure are easily explained: thus the rise in arterial pressure during the early periods of expiration (2, 1) is due to the sudden damming in the right side of the heart and venous system, which prevents due escape of blood through the capillary system, and so tending to increase pressure in the arteries; but the sudden expansion which now sets in in the arterial system produces the sudden fall in pressure (2, 4), as indicated by these tracings, and which continues on into the earlier periods of inspiration (5, 6, *i*), where arterial contraction again sets in, which pushes up the blood column again, as before. The swell in intra-thoracic pressure in the early stage of expiration (1) is due to reversal of inspiration by expiration and the sudden checking of the ingoing stream which this produces, after which the stream is uniform; consequently, the tracing is a straight line till inspiration is reached, when another wave occurs (*i*, 6) indicating the fall in intra-thoracic pressure. Thus, all the phenomena in the tracings are explained or accounted for, the whole being based upon rhythmical changes in pressure extending over the entire mechanics in respiration and circulation; at the same time, it is evident that Nature nurses the blood apparently with the greatest care. Nay, more than this; the arteries not only expand and contract synchronous with respiration, but with the action in the heart as well; which we will come to presently, placing the matter beyond the shadow of a doubt or the possibility of mistake.

Finally, that there are such nervous combinations in the medulla oblongata for producing the rhythmical contractions and expansions in the arterial system synchronous with respiration, is fully proven by the fact of *their continuance after respiration is suspended*, "producing the so-called Traube's curves (Fig. 41, 2, 3), very similar to the previous ones, except that their curves are larger and of a more sweeping character." Indeed, the distinguished author fully concedes the circumstance in the following forcible language:* "These new undulations, since they appear in the absence of all thoracic or pulmonary movements, passive or active, and are witnessed even when both vagi are cut, must be of vaso-motorial origin; the rhythmic rise must be due to a rhythmic constriction of the small arteries due to a rhythmic discharge from the vaso-motor centres, and especially from the medullary vaso-motor centre, since the undulations are far less marked when the spinal cord is divided. They are maintained as long as the blood-pressure continues to rise. With the increasing venosity of the blood, however, both the vaso-motor centre and the heart become exhausted; the undulations disappear and the blood-pressure rapidly sinks. We have, then, experimental evidence that, in the entire absence of all mechanical causes, undulations of blood-pressure, of direct nervous origin, closely simulating those accompanying natural respiration, may be brought about whenever the blood becomes sufficiently venous. It is difficult to imagine why the vaso-motor centre should exhibit the rhythmic activity shown in Traube's curves, and why that rhythm should simulate the respiratory rhythm, unless the vaso-motor centre *had been previously accustomed to a rhythmic activity synchronous with the rhythmic activity of the respiratory centre*." Italics are added

It is needless to extend the matter, for we have seen that the law in the circulation and continuity in force alike call for this nervous combination in the medulla oblongata for making respiration and circulation a connected movement, in order to maintain a balance between supply and demand in the cell-

* Text Book of Physiology, pp. 385, 386.

brood, at once the object of all this arrangement, and that it could not be done *in any other way.* But it is well to note, however, the physiological adjustment which obtains respecting it, for the *venous* blood itself, is the stimulus for increasing the action in the respiratory and vaso-motor centres, whereby venosity in the blood is rapidly reduced and the balance once more restored when disturbed by defective respira-

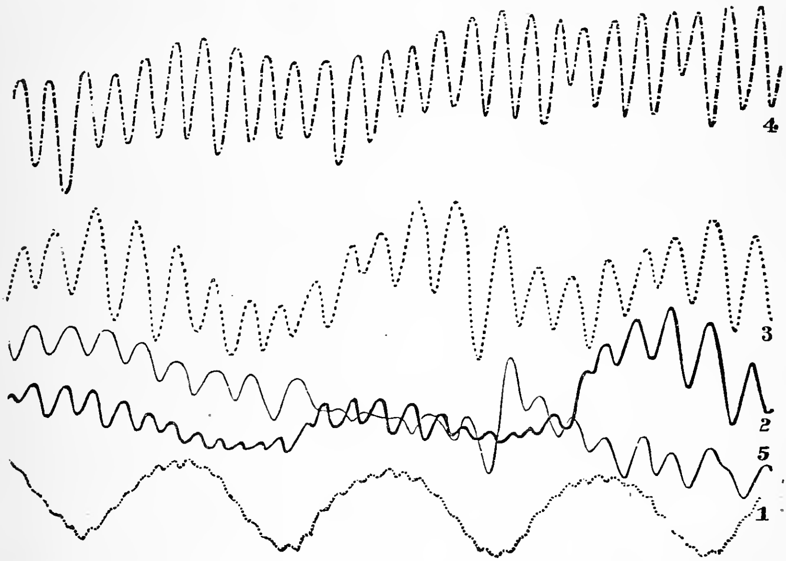

Fig. 41.—Traube's Curves. To be read from left to right.—Foster. The curves 1, 2, 3, 4, 5 were taken at intervals, and all form part of one experiment. Each curve is placed in its proper position relative to the base line, which, to save space, is omitted. During 1, artificial respiration was kept up, the undulations visible are therefore not due to the mechanical action of the chest. When the artificial respiration was suspended these undulations for a while disappeared, and the blood-pressure rose steadily while the heart-beats became slower. Soon, as shown in curve 2, the undulations reappeared. A little later, the blood-pressure was still rising, the heart-beats still slower, but the undulations still obvious (curve 3). Still later (curve 4), the pressure was still higher, but the heart-beats were quicker, and the undulations flatter. The pressure then began to fall rapidly (curve 5), and continued to fall until some time after artificial respiration was resumed.

tion. The pumping actions in the lungs, heart and vessels are all increased correspondingly with venosity in the blood, while the demand for *fresh* air for restoring the balance becomes more and more imperious. In this manner, then, the mechanics in respiration is self-adjusting.

CHAPTER VII.

AUTOMATISM IN THE VESSELS, AS WELL AS IN THE HEART.

Principle in Cardio-Arterial Movement—The Arterial System Expands as the Heart Contracts, and *Vice Versa*—Mode of Proving this Action in the Vessels—Evidence in Arterial Tracings—Arterial Tracings Contrasted with the Artificial Tracings, Produced by the Apparatus of Marey, Showing Essential Points of Difference, and Proving Incontrovertibly Automatism in the Vessels—The Variations in Blood-Pressure Tracings Corroborative of this Action in the Vessels, Confirming the Deductions from Arterial Tracings—*All* the Elements in Arterial Tracings and the Tracings which are Produced by Variations in Blood-Pressure Harmonize—The Facts in Development Confirmatory of Automatism in the Vessels—Regular Rhythmical Expansions and Contractions Taking Place in the Vessels of the Worms *in the Entire Absence of a Heart* for Producing Them, the Vessels Expanding and Contracting Themselves—The Pulsations in the Umbilical Cord *not* Synchronous with the Action in the Fœtal or Maternal Heart; Moreover, Pulsates even *after* Connection is Severed—The Pulsations in the Ears of a Rabbit and in the Wings of a Bat *not* Synchronous with the Action in the Heart, Showing Independent Action in the Vessels—The Special Anatomy in the Vessels Fundamentally the Same as in the Heart—Progressive Increase of the Muscles in the Arterial System from the Heart to the Tissue-Territories—Function of the Strong Elastic Coat—How High Pressure is Produced, and the Occasion for it—How Reflux in the Capillaries is Obviated—Mode of Increasing and Diminishing the Local Actions, and for Coördinating the Vessels with Respiration and the Action in the Heart.

The arteries perform a much higher rôle in the mechanics of circulation than as conduits simply, expanding and contracting upon their contents for increasing circulation, the same as the heart, the principle being the same Furthermore, the actions alternate, the vessels expanding as the ventricle is contracting, and *vice versa*, the same applying for both sides of the heart. The following are the reasons upon which this statement is based: (*a*) By the arteries expanding synchronously with contraction in the ventricles, it would have the effect of *reducing* resistance to the *in*-pour of blood from the ventricles, and in proportion obviating strain to the heart and rude force to the blood itself, the blood corpuscles especially being too delicate to withstand it. (*b*) It would explain numerous phenomena anatomical and physiological, appertaining to the vessels; otherwise inexplicable. (*c*) Last, but not least, this automatism in the vessels corresponds with the facts in development, notably the existence of independent pulsations in the vessels *in the entire absence of a heart for producing them*, the vessels expanding and contracting themselves.

For the sake of simplicity, we begin with the arterial tracings as indicative of automatism in the vessels, and the manner they are coördinated with the heart and with respiration; proceeding thence to the special anatomy in the organs as means to ends, or the provisions for special work performed by the vessels; and concluding with the facts in development, for all these circumstances should be reconciled and explained, thereby proving the correctness of the premises. If a given theory of the animal circulation cannot account for these circumstances, it is proof in itself that it is false and unreliable, not to be depended upon for a single moment even.

Concerning the Phenomena in Arterial Tracings.—There are three *elements* in arterial tracings: or, diastole, systole and the *wave* of dicrotism. The first corresponds with the straight perpendicular line (Fig. 42, *b*, *c*), which occurs during systole in the left ventricle, the vessel expanding against the button of the sphygmographic lever, and so producing this straight perpendicular line in the tracing. The second, or oblique crooked line, *c*, *d*, which joins the first at an *acute* angle, corresponds with systole in the vessels, in which the button of the sphygmographic lever falls, producing this tracing; while the *crook* itself is the *wave* of dicrotism passing along the vessels during systole.

Thus, there are three elements in the tracings of arterial action. According to received opinion, however, this action in the arteries is believed to be produced by the action in the heart, but it cannot be sustained, the facts in the case inhibiting it. Indeed, the very efforts that are made to sustain this view end by furnishing the most indisputable evidence of its utter fallacy.

For example, Professor Marey, under the impression "that the heart is the force in the circulation, and produces the action in the pulse," had constructed an apparatus for reproducing this action artificially in elastic tubing, but which is no more like the action taking place in the arteries than day is to night. And how such an impression could have been produced or have gotten abroad is explicable only upon the circumstance of prejudice, or the mental bias produced by the teachings of tradition, and which seizes upon every fact that apparently sustains it, shadowy and unreal however that may be, and this, too, in the acutest intellect; for stronger evidence of automatism in the vessels than that very experiment affords, it would be difficult to find, as I shall now proceed to show. Fortunately, however, much evidence of a totally different kind, not open to controversy, being visible to the unassisted eye, is ready to our hand.

But concerning this experiment. Briefly summarized, it consists as follows: The bulb of a gum elastic syringe (Fig. 43, *B*) is taken to represent the left cardiac ventricle, the same, of

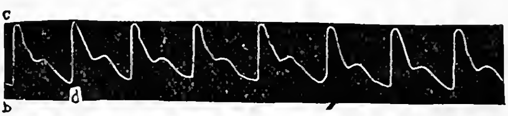

Fig. 42.—Arterial Tracings. *b*, *c*, answers to diastole; *c*, *d*, to systole, in the vessels.

course, applying for the right, with valves for obviating reflux: the tubing upon the left, with the end in the basin of water, the pulmonary veins and the blood in the alveolar plexuses, that upon the right—arranged in three coils upon an upright piece holding as many sphygmographs (*l*, *l*, *l*), to which they are adjusted for registering the actions taking place in them, and which are duly recorded upon a paper of a revolving cylinder (*C*)—the arterial system, which is supposed to be discharging into the capillary system, in which the vessels terminate (*V*). Thus constituted, the bulb is now rhythmically compressed by the hand in imitation of the action in the left cardiac ventricle. Pardon us! But, indeed, we are brought to a standstill, unless you freely allow considerable suction-action in the heart for compelling the blood into itself in imitation of the bulb and the water, else the comparison is false. Pumps may differ, but the principle *never* changes, and this it would be well to bear in mind—not to be lost sight of for a single moment, else all is chaos in this mechanics. Well, the result of the three tracings thus produced is to be seen in the three *undulating* lines (Fig. 44, 1, 2, 3). In the lowest tracing—the one nearest the bulb of the syringe (1)—the undulations are greatest, while in the uppermost tracing (3) they are smallest and upon

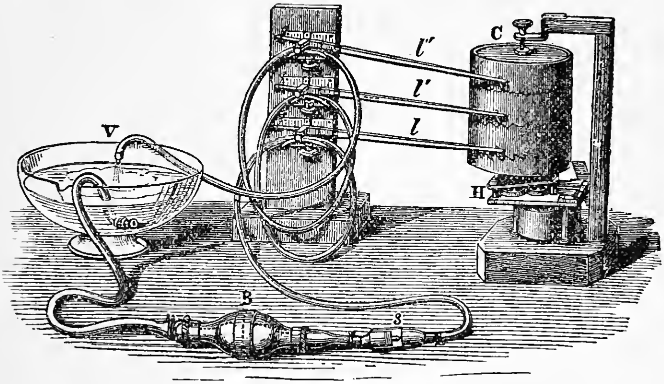

Fig. 43.—Marey.

the point of extinction. Now, then, where is the correspondence spoken of as subsisting between the tracings produced by this artificial scheme and the tracings which are produced by the action in the arteries? For the life of me, I cannot perceive where it comes in. No, not at *any* place whatever can it be seen in any one of these tracings. For example,

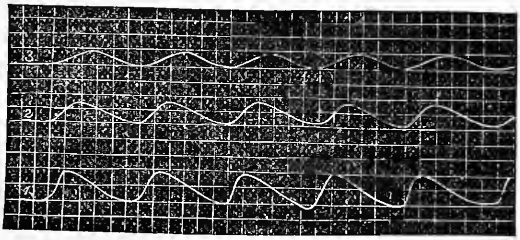

Fig. 44.—Marey.

take that first ascending line in the tracing nearest the bulb, where the undulations are largest, and where impact of the liquid against the walls of the tubing is greatest, and compare *it* with this first *perpendicular* line in the arterial tracings, which corresponds with arterial diastole (Fig. 42, *b*, *c*): The former is *not* perpendicular at all, the nearest approach approximating 70 or 75 degrees only, while *it rapidly tumbles down*, in the third tracing being upon the point of extinction ; whereas, in the case of the arterial tracings this line *is* perpendicular, and *remains to the end* perpendicular, even to the very capillaries themselves (Fig. 51, *V*). Thus, *two* objections which are fatal to this argument are at once made apparent. The reason the large undulations in the first tracing so rapidly tumble down in the low, flat forms in the third tracing is easily understood, notably : With every impact of the waves against the tubing they part with some of the initial force, and in consequence they rapidly become less and less until the point of extinction is reached They must do so in the very nature of things. But in the arterial tracings the matter is quite different. Here the line answering to the initial force *is perpendicular at the start*, and there is *no falling away from this anywhere*, but it is fully maintained *throughout the limits in the arterial system.* Nor does it differ in the smallest arterioles from that which occurs in the aorta itself. And how otherwise account for *this* circumstance, but that the force in the wave sent out by the ventricle is *supplemented by the force inherent in the walls of the arteries* themselves ? In other words, that the vessels, in place of *withdrawing* force *from* the waves, and thereby crushing them, as in example of the artificial scheme, *expand of their own accord in concert with the waves from the heart ;* and by thus producing a *vis a fronte*, the blood flows with augmented speed through the vessels, with the least possible friction upon it, since resistance is reduced to a minimum. Indeed a suction force is added. And this force, being inherent in the vessels, should be *coextensive* with the arterial system ; hence the maintenance of the type-tracings throughout the limits in the arterial system ; together with the *energy* in the arterial pulsations, which is the product of this *dual* force in the vessels, produced by the heart and the vessels themselves. Their strike is like a hammer against the finger-tips. while the *perpendicular* line which this produces in the tracings will give some idea of the energy in this expansile action.

In reference to that second line (Fig. 42, *c*, *d*), in the arterial rhythm which answers to systole in the vessels, and in which the dicrotic wave presents: Where is resemblance to be found between *this* and the corresponding portion of the tracings in the artificial scheme? *Not* to be found, either! No. not the faintest trace in *any* of the tracings of the dicrotic wave which is superposed upon it, producing the small wave or undulation in this line. Nor can it be produced artificially, since it involves *independent* or automatic action in the *vessels themselves*. And in the *absence* of the cardinal circumstances in arterial movement, one may not speak of correspondence at all. Hence we must conclude that *that* artificial scheme which is based upon *vis a tergo* simply, does *not* represent the principle in cardo-arterial action which combines *vis a fronte* with *vis a tergo*, acting *simultaneously* and which accords with the special phenomena in the tracings, the phenomena in the heart and arteries, anatomical and physiological, and satisfies the physiological requirements in the blood itself, and the blood-supply to the organs. What amount of force Professor Marey applied to the bulb in imitation of the cardiac systole, we are not prepared to say, but if he used the force in his hand he certainly put as much force upon this artificial circulation as exists in the left cardiac ventricle, since in actual weight and number of the muscles, the flexors in the forearm and hand far exceed the muscles in the left ventricle.

But notwithstanding this, the *perpendicular* line is not produced, while the high undulations in the early portions of the tubing rapidly tumble down into the low, flat forms preceding final extinction; as already remarked, cannot produce either of the lines. That ends the matter.

We now proceed to other evidence of *automatism* in the vessels, founded upon sphygmographic tracings also.

The Variations in Blood-Pressure Indicative of Automatism in the Vessels.—In the case of the arterial tracings, the actions in the vessels are *directly* reported through the sphygmograph; whereas, in the case of the variations in blood-pressure, the actions are communicated to the sphygmograph through the *oscillations* taking place in the blood itself, and communicated through a hæmadynamometer to the lever of the sphygmograph, thereby furnishing, as it were, the *reverse* side of the matter.

Let us see, then, how it is here, for this is important evidence.

We begin with *permanent* high pressure in the arteries or zero, which answers to the horizontal line in the tracings (Fig. 45), while the waves (*a*, *c*) represent the oscillations which occur in it; the large waves (*a*, *a*) corresponding with the action in the heart, the small ones (*c*, *c*) answering to dicrotism. The great *rise* in pressure, as indicated by the perpendicular line upon the *left* side of the large waves, is produced by the systole in the vessels; while the *fall* in pressure, indicated by the perpendicular line upon the *right* side of the waves (*a*, *b*), is the result of *expansion* or diastole, the blood column, in consequence. falling down in the tube to which the lever of the sphygmograph is adjusted, and so registering the action. But the circumstance to which special attention is directed is, that this sudden fall in pressure exceeds or goes *beyond* zero, coming considerably *below* the horizontal line (Fig. 45, *b*). And since this occurs synchronously with the systole in the heart, is it not absolute proof of expansion in the arterial system during this time? Of course, the *sudden* fall in pressure *must* be due to expansion in the vessels and the loss of support to the blood-column which this occasions, causing it to fall in the instrument correspondingly; since it could not be accounted for in any other way. Hence, the more the arterial expansion, the greater will be the fall in the blood column, as must appear obvious. During this fall in pressure, however, the heart *empties itself into the arterial system;* hence strain is obviated, and friction to the blood is reduced to a minimum, the importance of which it would be difficult to overestimate.

In fine, the cardiac systole *disappears, and is swallowed up* by the greater movement taking place in the arterial system itself, in which it is merged, as *indicated by the perpendicular line* in the arterial tracings *corresponding with expansion* in the vessels (Fig. 42, *b*, *c*).

There are, then, rhythmical expansions and contractions in the arterial system synchronous with the action in the heart.

the one *alternating* with the other. In other words, there is complete rhythm in *both*—in the arteries as well as in the heart. The fact must be borne in mind, also, that *only one-half* of the cardiac rhythm, or the systole simply, *can* produce *any* effect in the arteries, since the ventricular diastole *can* accomplish nothing with the semi-lunar valves *closed*, for obviating reflux in the ventricle, as is the case in diastole. Now, then. by the monistic theory of the circulation, or a *vis a tergo* simply, how is it possible to explain the phenomena in these tracings? The thing is utterly impossible.

A moment's reflection will make this obvious. For example: How can the cardiac systole produce the *sudden fall* in pressure *below* zero (Fig. 45, *a*, *b*)? If the *rise* in pressure (*a*, *a*) is to be explained by the inrush of blood from the ventricle, how, then, is this opposite movement, or *fall* in pressure, to be

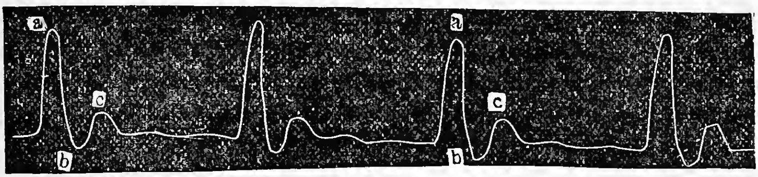

Fig. 45.—The Variations in Blood-Pressure in the Carotid of a Horse.—Marey. The horizontal line between the undulations represents the *permanent* high pressure in the arterial system, or zero of pressure in the arteries, while the undulations represent the variations. *a*, *a*, the *rise* in pressure produced by *systole* in the *vessels*, and which corresponds with diastole in the heart; *a*, *b*, the fall in pressure which answers to *diastole* in the vessels, and corresponds with systole in the heart; *c*, the dicrotic wave.

accounted for? Surely not by "resiliency in the vessels," so called, for *this* should produce still higher pressure from the contraction it would occasion in the vessels, though the term itself is inapplicable to vital action. At any rate, it should have directly the opposite effect to that ascribed—increasing, in place of decreasing, blood-pressure.

Then, again, how is it possible to produce the *fall* in pressure by closing the semi-lunar valves simply, as occurs at the end of systole? Since the blood is *still* in the arteries; and allowing for an amount passing out at the distal end in the capillaries, the contraction or "resiliency" would more than make up for the loss in pressure this tends to produce, reflux being obviated by the closing of the valves. At any rate, the fall in pressure should be gradual, whereas it is *sudden*, *abrupt* and *extreme*, sending it *below* zero (Fig. 45 *a*, *b*), the line of permanent pressure ; hence, there must be arterial expansion in order to effect it, and that would very readily account for it ; otherwise is inexplicable.

This circumstance, then, is sufficient to show that the action in the heart would not of itself account for the phenomena in the blood-pressure tracings ; and taken in connection with the facts already developed in the arterial tracings, namely, that it cannot produce the *perpendicular* line answering to arterial diastole (Fig. 42, *b*, *c*), nor the *crooked* oblique line (*c*, *d*) answering to systole, amounts to actual demonstration of automatism in the vessels themselves, by means of which only could the phenomena be produced, inclusive, of course, of the action in the heart, with which the vessels are coördinated. One other circumstance, however, remains for mention in this connection, showing the correspondence subsisting between the tracings which are produced by the oscillations in blood-pressure and arterial tracings, notably the *wave* of dicrotism. For example, dicrotism occurs in the oblique line answering to systole in the vessels (Fig. 42, *c*, *d*) ; in other words, is produced during systole, and which corresponds with the wave of dicrotism, which is produced during the *rise* in blood-pressure (Fig. 45, *b*, *c*), which is also the result of systole in the vessels, showing conclusively that *they are expressions of the same thing.* Thus, *all* the characteristic elements in the arterial tracings are reproduced in the tracings of blood-pressure, the oscillations in which correspond with the rhythmical expansions and contractions taking place in the vessels which alternate with the actions in the heart, inclusive, of course, of the movements synchronous with respiration. In fine, the *mean* pressure in the vessels is produced by the action in the heart, but the oscillations in pressure are mainly produced by the vessels themselves, which have adjustment with the heart and with the lungs, expanding and contracting upon their contents to meet the special emergencies in the functions in these organs ; while the rich nervous plexuses which emboss the vessels connecting them with the cardiac and respiratory centres serve for coördinating and unifying the actions throughout, at the same time also serving to produce the local actions in response to special stimulus. Hence the existence of this enormous web of nerves.

But to this must be added the evidence which is furnished in the tracings produced by *changes in volume* (Fig. 51), in which entire organs, inclusive of the whole soft tissues in the body, expand and contract regularly and rhythmically synchronous with the actions in the heart and in the lungs. And to say that this also is produced by the action in the heart is perfectly absurd.

Some idea of the *force* in the arterial pulsations may be had by watching the to-and-fro movements in the foot when the legs are crossed at the knees in the sitting posture, the foot of the upper limb riding up and down with every rhythm in the vessels. To say that the heart produces this action also, is utterly incredible. Moreover, this action may be seen in another form in the fierce pulsations which occur in the local vessels in inflammatory processes, though the heart may be beating as usual, and which in itself is ample proof of automatism in the vessels; otherwise is inexplicable. The pulsations which occur in the ears of a rabbit and wings of a bat are *not* synchronous with the action in the heart, thereby showing conclusively independent action in the vessels themselves, furnishing incontrovertible proof of this circumstance.

Concluding this class of evidence, we may mention the pulsations occurring in the *umbilical cord*, which are *not* synchronous with either the maternal or fœtal heart, moreover occur *after connection is severed*, and which furnishes absolute proof in itself of automatism in the vessels. Last, but not least by any means, are the facts in development, showing how a complex circulation is carried on, with regular rhythmical expansions and contractions taking place in the vessels, *in the entire absence of a heart for producing them;* notably in worms. The point we wish to make in this connection is, that the animal circulation is at *first* carried on by the vessels only (inclusive, of course, of the actions in the walls of the body and the molecular movements), and that the heart comes into the vascular system with progress in development for increasing circulation simply; being itself a differentiation in the vessels for this purpose only, and *not* to displace or substitute the action in the vessels, which can by no means be done, the local actions themselves inhibiting it, the question being one of *increasing* force in the circulation simply; and which is done not by the differentiation of this central force-pump only, but *also by innumerable muscles and nerves to the vessels themselves;* the two being always in correspondence, the vessels developing as the heart is being developed, and growing *pari passu* with each other. And which holds true in embryogeny as well, the nutritive processes building up the vessels contemporaneously with the heart, the two going on together. Moreover, they are fundamentally the same in structure, consisting of an inner, a middle and an external layer; or a serous, muscular and elastic or fibrous tunic (which in the heart is converted into a pericardial membrane), thereby enabling them to expand and contract the same as the heart, which the functions call for. In further proof of this automatism in the vessels, we might mention also the pulsations occurring in the post-caval, axillary and iliac veins in *Batrachia*, which are *not* synchronous with the action in the heart; also the action in the lymph-hearts, which are *not* synchronous with the pulsations in the heart; nay, not even with one another, each seemingly possessing an independent action So, then, this matter of automatism in the vessels rests upon incontrovertible evidence, anatomical and physiological; in fact, everything is in accord with this circumstance, the law in the circulation also compelling it.

But the matter is not yet fully summed up; turn we to the special anatomy in the organs, to see how this accords with the other phenomena, or, as means to ends, for producing the work involved in the tracings, the rhythmical expansions and contractions in the walls of the vessels indicated by them.

Descriptive Anatomy.—1. The arteries are very muscular organs, the small arteries nearly all muscles (Fig. 46).*

* The dark lines show the longitudinal muscles.

If the vessels are conduits simply, what then is the office of these numerous muscles, seeing that muscles and nerves (so many nerves, too, to the vessels) are physiological adjustments for performing work; whether it relates to circulation or the voluntary movements it is all the same, force being pro-

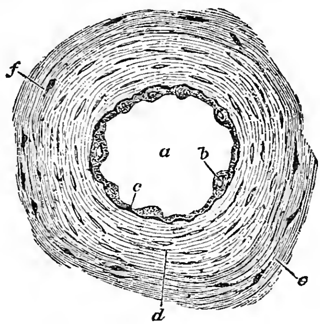

Fig. 46.—Transverse Section of an Artery from a Vertical Section of the Skin of a Guinea Pig.—Klein. *a*, lumen of the vessel; *b*, endothelium seen in profile; *c*, intima; *d*, circular muscles; *e*, adventitia; *f*, cellular elements of adventitia. (Oc. 3; obj. 7.)

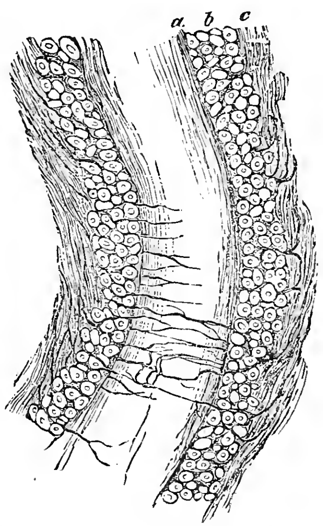

Fig. 47.—Longitudinal Section of a Branch of the Pulmonary Artery, from the Lung of a Guinea Pig.—Klein. *a*, intima; *b*, circular muscular fibres cut across; *c*, adventitia. (Oc. 3; obj. 7.)

duced by this means, while the energy is determined by the numbers of the muscles and nerves?

2. Why should the muscles in the vessels be nearly all circular, extending round the vessel? (Fig. 47, *b*.) And since muscles elongate and shorten, or expand and contract when in action, would not this necessarily expand and contract the lumen correspondingly, thereby producing the rhythmical changes of pressure upon the blood for speeding it through the channels in the manner as alleged, the vessels being coördinated with the heart and the lungs by means of the nerves, which emboss them? It could not be otherwise, in the very nature of things, seeing that the muscles expand and contract, and this cannot be doubted for a single moment even. In short, the arrangement of the muscles in the vessels is the same as in the dermo-muscular tube in the leech, which expands enormously (Fig. 17), only that the longitudinal muscles are more numerous for effecting elongation and contraction of the body, for which it possesses great powers; whereas, in the vessels, the object is to effect expansion and contraction of the lumen for producing the changes of pressure upon the blood; while the less numerous longitudinal muscles enable a degree of shortening and elongation as well, producing the so-called locomotion in the vessels (Fig. 48), the effect of elongation simultaneously with lateral expansion, together with the subsequent contraction which sets in, also accounting for the retraction of the vessel within the sheath after division, as occurs in amputations, for example.

The movements connected with the systemic circulation would include the actions for producing a norm in arterial pressure, the rhythmical changes in pressure with inspiration and expiration, finally with the actions in the heart itself, the vessels expanding during the systole and contracting during diastole. But, in addition to this, the local vessels expand and contract for increasing and diminishing the lumen, in response to special stimulus in the organs, whereby the local circulation is increased or decreased correspondingly, a matter determined by the local ganglia or mind centres, which, as a rule, are located at the points where the branches are given off from the main stem. And the whole being connected with the medulla oblongata by means of the vaso-motor centre, coördination with respiration and the action in the heart is readily effected; at the same time a norm in pressure is maintained. Thus, these *two* important anatomical facts in the muscles and nerves to the vessels have easy and natural explanation.

3. Last, but not least, we have to mention *the progressive increase in the numbers of the muscles in the arterial system from the heart to the tissue-territory* (Fig. 49). How is this circumstance to be accounted for?

According to present theory, which makes the heart the

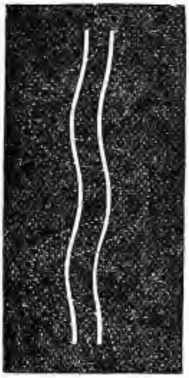

Fig. 48.—Elongation and Curvature of an Artery in Pulsation.—Dalton.

force in the circulation, this arrangement of the muscles is totally inexplicable, since the effect would be to place obstruction in the roadway of the blood, and hinder in place of assisting the action in the heart; and, considering the number of the muscles, it must necessarily involve prodigious strain to the heart itself for overcoming the resistance, admitting, for the sake of the argument, it were capable of doing this, which can by no means be done. The vessels being always full, arterial pressure only varying, it follows that in order to compel more blood into the vessels, this force would have to be overcome by the heart, which is utterly impossible. Then, again, conservation of force, and of the very blood itself, would inhibit such rude mechanics, ignoring altogether strain to the heart, which, for obvious reasons, cannot be done. And not these only, but the sudden force and energy in the very *leap* of the pulse would alike have to be explained by cardiac action. Last, but not least, the danger to the blood itself should it be used as a wedge, so to speak, to be driven into the vessels by the sledge-hammer strokes of a central cardiac engine for forcing them open. Either the delicate blood-corpuscles would go to pieces in the midst of this rude force, else the aorta itself would burst, admitting the heart were capable of performing the work assigned it, and that the vast numbers of circular muscles and elastic tissue-fibres could be pulled into forcible extension by this means. It is coarse and brutal to the last degree, and extremely primitive. But the hæmal mechanics is of a much higher order, nursing the blood and conserving the heart and vessels by reducing friction and resistance to a minimum, and which is done by dividing the force for effecting circulation into a *vis a fronte* and a *vis a tergo*, acting in concert and *simultaneously*, or a *pulling* and a *pushing* force combined; the former produced by the arterial diastole, the latter by the cardiac systole, working together harmoniously and in conformity with the law underlying the organism, the blood flowing relatively from high to low pressure.

And with the *bases* of the arterial pyramids in the tissues and the *apices at the heart* (Fig. 49), this action in the vessels would inevitably have *that* effect upon the blood during the cardiac systole. And since the pressure in the ventricle during systole amounts only to about 6 oz. (mercury), while that in the arteries falls *below* this, it follows that during arterial diastole the blood would flow from high to low pressure, pressure falling from the heart to the tissue-territories where expansion is greatest, being the widest portions of the pyramids (Fig. 42, *L*, *L*); and by thus sucking the blood, relieving work at the heart in proportion; while the nervous plexuses embossing the heart and the vessels serve for coördinating the actions, as before remarked. And in regard to these nerves, too, what possible explanation can be found in this old theory for their presence also, any more than for the muscles? None whatever, save to produce contraction in the vessels, which should hinder in place of assisting the action in the heart. But they "relax" the vessels also! Ah! that concedes the matter fully, and no more need be said, for relaxation means expansion; and the two being coördinated in the functions produce the phenomena in the tracings. And since expansion

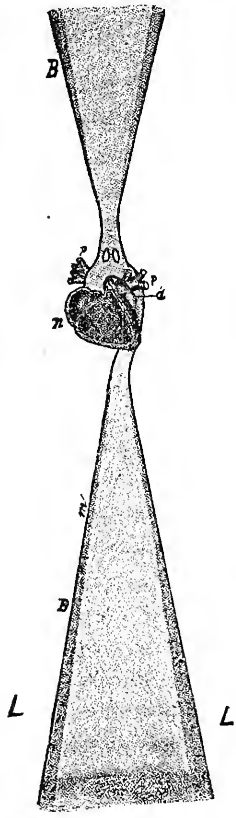

Fig. 49.—An Ideal Diagram of the Arterial System, showing *progressive increase* of the muscles from the heart to the tissue territory. *L*, *L*, upper and lower arterial pyramids; *a*, *left* ventricle and auricle; *p*, *p*, right and left pulmonary veins as they debouch in the auricle; *n*, longitudinal section of right auricle and ventricle, showing inter-ventricular and auricular septum; *B*, *B*, walls of the vessels, representing the *progressive increase* of the muscles from the heart to the tissue territory.

and contraction are correlated forces in Nature, the whole mechanics in the animal circulation is at once laid bare under the white light which is furnished in the law underlying the organism. But should the arteries expand, would not this produce reflux in the capillaries and venous system? No; it would not produce reflux in the capillaries and venous system, for the following unanswerable reasons inhibiting it, notably: 1. Pressure in the arteries—thanks (!) to the force in the heart—is *ever* higher than in the capillaries and venous system; hence reflux in the latter is made impossible. 2. Expansion in the vessels is *from* the heart to the tissue-territories, while the blood keeps pace with it, flowing into the vessels as rapidly as expansion is effected; and even in excess of this, transmitting some of the force in the heart to the walls during the systole, thus producing an increase of pressure during this time, which is still further augmented by the systole in the vessels, which sets in at the end of the cardiac systole, the one running into the other, the same as in the respiratory rhythms, with which the vessels are coördinated, as in the heart, the principle being the same; while reflux in the arteries is obviated by the valves at the root of the aorta and pulmonary arteries, so that reflux in the arterial, capillary or venous systems cannot possibly occur; the only thing being venous stasis in the systemic capillaries from damming of the blood at the right side of the heart by obstructing circulation in the lungs, the venous system filling back to the capillaries. And so far as the argument is concerned, we might safely rest the case here, were it not incumbent upon us to carry the matter further by explaining *all* the phenomena, anatomical and physiological, appertaining to the vessels; and this a true theory of the circulation should be capable of doing, else it is *not* the true theory, but a false. And by applying this crucial test to the Harveian, its utter fallacy will at once be seen, for it would leave all these matters unexplained and inexplicable; and the beautiful adjustments that obtain in the vessels and in the heart for producing work in the circulation would be perfectly meaningless. But by the true theory it is all brought out fully and elucidated so that everything is seen to be just as it should be to meet the requirements in the functions and the ends sought to be accomplished, while the enormous resources in Nature and her matchless handiwork receive additional emphasis, inspiring a feeling of awe and reverence in the mind unspeakable!

Proceeding with the anatomy, we come next to the thick elastic coat in the vessels The animal circulation being *based* upon pressure, for *increasing pressure in the arteries* it calls for this thick elastic coat for producing it, otherwise it were impossible to effect it (as is seen in the case of the veins), the vessels giving way under it; and which would also explain the circumstance of the relative thickness of the elastic coat in the aorta, together with its *progressive increase* as the heart is approached, where pressure is greatest, the artery at this point being *nearly all* elastic fibres. For maintaining high pressure in the arteries, then, is the explanation of this strong elastic coat in the vessels, the whole matter relating to pressure; while the high pressure which is produced in the arteries by the action in the ventricles serves for increasing the capillary circulation, at the same time that it functions as the *vis a tergo* to the venous system for compelling this blood more rapidly toward the lungs, the arteries contracting and expanding synchronous with respiration for increasing the action, and for compelling the blood more rapidly through the lungs during inspiration and expiration, as before remarked.

Concerning the Local Actions.—Finally, we come to the local actions in the vessels in connection with the multitudinous functions in the body, and which vary from moment to moment, so that perfect uniformity in the circulation nowhere obtains, and is utterly impossible. Now, then, for producing these actions, it calls for automatism in the vessels in order to enable them to respond to stimulus so as to increase or decrease the circulation, as the case may be. And in the midst of this overwhelming avalanche of facts, what is to become of that old monistic theory of cardiac action only?—it is utterly lost, swallowed up, disappearing from sight in the midst of the myriad phenomena.

It need not detain us; one or two illustrative cases will serve. Thus, when food is passing into the stomach its presence produces enormous afflux of arterial blood in the organ, the vast capillary network in the gastric mucous membrane (Figs. 64, 65) springing open at once, for compelling blood into the parts in the measure of the physiological requirements in the glandular structures and for increasing absorption, at the same time the biliary and pancreatic secretions are increased correspondingly, which is done by springing open the vascular feeders in the separate arteries of the cœliac axis, while this in turn has regulation by the amount of food ingested, diminishing with the gradual absorption and removal of the gastric contents. And each organ, by having a separate feeder (Fig. 110), controlled by the local nerves and ganglia (Fig. 109), is thus enabled to command all the blood that is needed for effecting the functional processes without interfering with the general circulation, which must not be done. Nay, more than this, each group of cells is enabled, by the separate branches given off by the common feeder to the organ, to command the blood they need in the special exigencies arising in the local actions, so that the organ as a whole and in its several parts may command the blood-supply in the measure of the requirements. And so, likewise, down the whole intestinal canal, each and every portion, by means of the separate feeders to them represented in the trunks and numerous branches of the superior and inferior mesenteric arteries (Figs. 111, 112), may command, by means of the special nerves and ganglia, the amount of blood they need *without interfering with any other portion*, so that perfect independence of action is maintained. Well, while all this is going on in digestion, the heart beats as usual, and as though there were no such thing as digestive processes, and all the multitudinous arrangements for expediting and controlling the flow of blood into the organs: moreover, is utterly incapable of effecting the actions, requiring automatism in the vessels themselves in order to accomplish it. But the heart, by maintaining pressure in the arterial system, which tends to fall by reason of these depletions, does subserve important uses, the vaso-motor system also contributing by contracting them in proportion, and thus maintaining pressure, which is essential for increasing the local actions by causing instantaneous flow into the capillaries the moment they expand, at the same time maintaining the other actions in the body which the scheme calls for.

Take another case—the kidneys, for example. Upon occasion an enormous flow of urine takes place. Well, since this is drawn directly from the blood through the secretory actions in the organs, it follows that there must be an increased supply of blood in the parts in order to effect it. And how is it possible to command this increased supply of blood save by springing open the renal vessels correspondingly? It all comes from the blood, and there must be increase of this in the organs for producing it, the amount being determined by lumen of the vessels, which the local nervous ganglia regulate by means of the nerves extending over and literally embossing them (Fig. 109, 9, *G*). At the same time, the vessels, arteries and veins are very muscular. And there is no nervous plexus in the body richer in nerves and nervous ganglia than the renal, save the solar plexus itself, the solar centre of the intestinal mechanics,

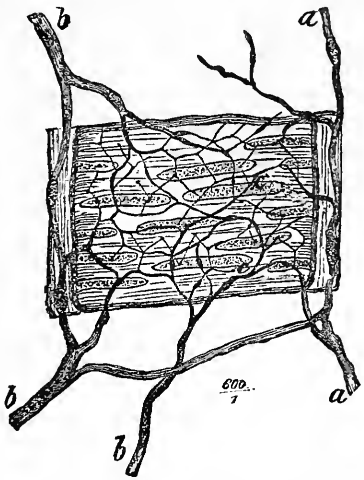

Fig. 50.—Ramification of Nerves and Termination in the Muscular Tunic of a Small Artery of a Frog.—Arnold.

of which it forms a part, being immediately contiguous to it (Fig. 109, *G*); thereby showing the relative importance of the renal functions for maintaining a balance in the organism through the excretory functions in these organs. But in the absence of the power to expand and contract the vessels, all this would be meaningless. As it is, everything is in correspondence for promoting the ends in view.

Nervous Supply to the Vessels.—Finally, we come to the nervous supply to the vessels, with the mode of termination in the sarcous elements for effecting the actions spoken of. According to the exhaustive researches of Arnold, the nervous twigs in unstriped muscles consist partly of medullated and partly of non-medullated fibres, in varying proportions, penetrating to the nucleus of the muscle cell in the form of a fine terminal filament, and ending probably in the nucleolus. Externally, in the connective-tissue covering the muscle, these nerves are arranged in the form of a wide-meshed network, in which, as Beale has pointed out, *ganglion cells* are to be found at certain points *in the muscles of the vascular system* (Frey). To this the name "ground plexus" has been given. From this are given off the nerves which penetrate between the layers of muscles to form the "intermediate network" (Fig. 50), which lies immediately upon or between the muscular layers ; while from this again a series of fibres are given off which penetrate between the muscle fibres to form a new network, "intra-muscular," surrounding the muscle cells, from which dark straight fibres of extreme fineness penetrate into the cells, and, advancing to the nucleus, terminate in the nucleolus (Frankenhäuser). The number of terminal filaments which enter any one muscle cell corresponds with the number of granules occurring in the nucleus (Frey). According to Arnold, these fibrillæ leave the nucleoli again in the opposite direction, and after having traversed the nucleus and body of the cell, unite once more with the intra-muscular network. Finally, a set of pale fibres proceed *directly* from the "ground plexus" to the muscle cells, forming a direct connection between them. Now, then, what can be the purpose of the ganglion cells in the "ground plexus" and the intricate nervous arrangements which obtain in arterial muscles for producing molecular action in the cells other than to effect the actions spoken of? Seeing also that an intimate connection subsists between them and the plexuses embossing the vessels, connecting them with the central nervous system. It is needless to extend the matter.

This brings us to the remaining *element* in the arterial tracings, notably, *dicrotism;* but that will require a chapter to itself, involving the action in the capillaries in connection with respiration in the tissues.

CHAPTER VIII.

RESPIRATION IN THE TISSUES AND THE ACTION OF THE CAPILLARIES IN CONNECTION THEREWITH.

Two Respiratory Movements Going on at the Same Time in the Body, one in the Lungs, the other in the Tissues—The Force for Producing the Movements Propagated from the Medulla Oblongata and Respiratory Centre—The Composite Character in Arterial Tracings Readily Explained—Rhythmical Expansions and Contractions in the Tissues Synchronous with the Actions in the Lungs, Heart, Arteries and Capillaries—The *Waves Superposed* Upon One Another in the Order Named, or the Cardo-Arterial Upon the Respiratory, and the Capillary or Dicrotic Waves Upon the Cardo-Arterial—Capillary Action the Source of Dicrotism—Mode of Demonstrating this Circumstance—The Action in the Capillaries Producing a Current *Into* and *Out* of the Tissue-Interstices—Relations of the Cell-Brood to this Circulation—Nervous Apparatus for Connecting Them with the Capillaries and Central Nervous System for Increasing and Diminishing the Local Circulation, with the Exigencies in the Functions—Mechanics in Blushing—Explanation for Arrest of Arterial Pulsations Upon the Distal Side in Aneurisms—Action in the Venous System—Functions of the Muscles and Nerves in Veins—The Relations they Sustain to Respiration—Explanation for the Great Volume of Venous Blood and the Slowness in this Circulation—Also for the Motion in the Brain Synchronous with Respiration.

Finally, in order to fully interpret the phenomena in *arterial* tracings, it will be necessary to consider them in connection with the capillary circulation and the respiration in the tissues.

In, short, there are *two* respiratory movements going on at the same time in the body: One in the lungs, the other in the tissues, and which answer to the two poles in the floral circulation; while the heart and vessels function as a *carrier* between them, expanding and contracting upon the fluids for increasing circulation in the two poles, while the *force* for compelling these actions is transmitted *over* the vessels from the central nervous system by means of the nervous plexuses which emboss them. The result is the production of the composite character in the arterial tracings, or the existence of respiratory, cardo-arterial and dicrotic *waves;* and which are *superposed* one upon the other in the order named, or the respiratory by the cardo-arterial, and the latter by the capillary or dicrotic waves, which represent the respiratory action taking place in the tissues. It is all plain enough and readily understood, the actions being simply *throbbed* over the vessels as the common carrier between the two poles of the circulation from the medulla oblongata, in which the nerves converge for coördinating and unifying the actions throughout, which the scheme calls for.

This being the case, of course there should be a means of proving and demonstrating the fact by showing the following circumstances:

First, That the respiratory *waves*, or the waves produced by respiration in the lungs, *reach* and *pervade* the tissue-territory.

Second, That the cardo-arterial *waves*, or pulsations, *reach* and *pervade* the tissue-territory.

Third, That *dicrotism*, so-called, is the *capillary* movement *superposed* upon the cardo-arterial.

Thanks (!) to the distinguished physiologist and experimentalist at Paris, we find the evidence ready to our hand: It consists in inclosing the hand in a glass jar filled with water, made air-tight over the top, and so constructed as to cause the oscillations it produces in the water to be transmitted to the lever of a sphygmograph for registering the result (Fig. 51).* It produces the following tracings (Fig. 52, *V*): †

In the same cut the tracings are contrasted with the tracings produced by the arteries (*C*), but for a different purpose from the present, the author being under the impression that they are produced by the action in the heart, alleging the same for the arterial tracings, making this organ *the force* in the circulation, which cannot be thought of for a single moment, for the reasons already given.

We will begin with respiration, as this is the basis, so to speak, of animal life, being the pumping action for compelling the commerce in the organism with which the vascular system connects for distributing it through the tissues, as before re-

* La Méthode Graphique dans les Sciences Experimentales, et Principalement en Physiologie et en Médecine. Par E. J. Marey, Professeur au Collége de France, Membre de l'Académie de Médecine. Fig. 327.

† Ibid. Fig. 328.

marked. Now, then, we have this great movement, which pervades the entire organism from centre to circumference,

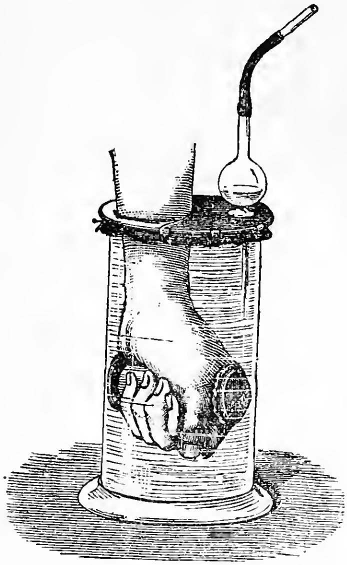

Fig. 51.—Apparatus for Inscribing the Changes of Volume in the Hand. The membrane which traverses the fluid is rendered immovable by a metallic plate; while the oscillations which are produced in the water are transmitted through the bulb and vertical tube to the lever of the sphygmograph by means of air.—Marey.

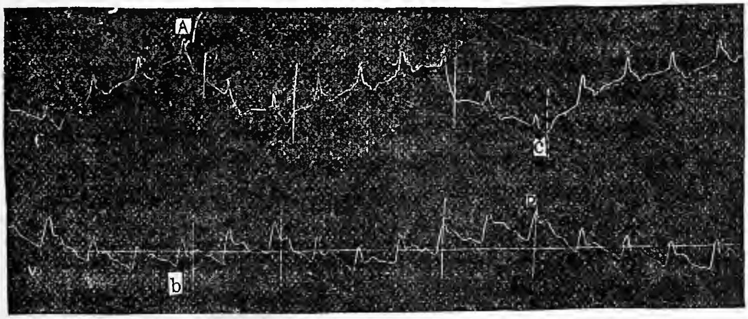

Fig. 52.—Sphygmographic Tracings, showing the undulations in the vessels and tissues synchronous with respiration. *C*, respiratory rhythms in the arteries; *A*, crest of a wave; *C*, trough of a wave. *V*, respiratory rhythms in the tissues, smaller, but very apparent; *b*, trough of a respiratory wave in the tissues, corresponding with the crest (*A*) to the respiratory wave in the arteries, which arrives later; *D*, crest of a respiratory wave in the tissues, which corresponds with the trough (*C*) of the respiratory wave in the arteries which had passed into the tissues.

registered in the arterial tracings in the *large undulations* which occur in it (Fig. 52, *C*, *A*). Two and one-half such waves occur in the tracings, the one at the right-hand side of the figure being cut off. And the same circumstance also presents in the tissue tracings (*V*), only that they are *smaller* and arrive *later*, having to pass over the arteries in order to reach the tissues, the nerves lying upon the walls of the vessels. As a result of this circumstance, therefore, the *crest* (*A*) of the respiratory waves in the arteries corresponds with the *trough* (*b*) of the respiratory waves in the tissues, and *vice versa* (*C*, *D*). In other words, the *same* number of respiratory actions occur in the tissues as in the arteries to the very fractional portions of the waves, and nothing could be more conclusive of respiratory action in the tissues than this very circumstance. Prof. Marey, however, conceiving it to be due to the action in the heart, has drawn perpendicular lines at certain points through the upper and lower tracings, in order to show correspondence, as he thinks, *between the action in the heart and the changes of volume in the hand*, as cause and effect. But we fail to perceive it in this light, for the reasons already given. It is not so simple as this, but highly complex, the result of several actions blended together. It will not answer at all.

What is to be done with the correspondence between the large undulations—the two whole and the fractional portions of the respiratory waves—which occur in *both* tracings, since there is *exact* correspondence; only they are smaller in the tissues, as a matter of course, and arrive later, which is also a matter of course. Then there are sixteen smaller waves, which are superposed upon the larger, indenting them like the teeth in a saw, which answer to the action in the heart and arteries. the same number precisely occurring in both tracings, so that correspondence here is also complete—impossible to make it more so. Well, what is to be done with this correspondence? as it all must be explained and satisfactorily accounted for; else the theory is false. These smaller undulations occur all along the surface of the respiratory waves, at the crest (*A*), at the sides, and in the very trough (*C*) itself, in regular order and succession; the same applying for *both* tracings. Then, again, there are *four* of these to each of the billows, which correspond with the relative frequency of the respiratory and cardiac rhythms, showing conclusively that the one is respiratory, the other cardiac, or, rather, cardo-arterial, being produced by the united actions of the heart and arteries. The action in the heart, forsooth! There is more here than is explicable by the action in the heart. It cannot produce the respiratory undulations in the arteries, and why should it produce the corresponding undulations in the tissues? It follows that the respiratory waves, as well as the waves produced by cardo-arterial movement, pervade the tissues, the latter being superposed, so to speak, upon the former, giving rise to the serrated appearance in the respiratory waves. But we have *still smaller* waves, which in turn are superposed upon the arterial, producing the appearance known as dicrotism, and indenting these as the arterial the respiratory, and which also present in *both* the tracings, but *are more distinct* in the lower (*V*); and which, also, must be accounted for with the others.

Concerning Dicrotism.—The very fact that dicrotism is more pronounced in the tissue tracings (Fig. 52, *v*) is of itself suggestive of capillary action as its source, and that it is actually produced by the action in the capillaries is also easily proven by simply *arresting* the action in these vessels when dicrotism *promptly* disappears, but *re*-appearing again with restoration of capillary action, at once showing the relations they sustain to each other. This object is attained by *distending* the vessels with venous blood, and so preventing their action; while the action is reëstablished again by relieving them of the blood. Thus, with the hand in the registering apparatus as previously (Fig. 51), a constricting band was placed above the elbow sufficient to arrest the venous blood only, and after waiting a short interval for the blood to accumulate in the hand, was again relaxed. When suddenly and forcibly applied and as suddenly relaxed, it produced the upper tracing (Fig. 53);* when slowly applied and slowly relaxed, the lower.

* (*Ibid*, Fig. 330.) It is proper to remark, in this connection, that Professor Marey did not have the present purpose in his mind when he made this experiment, but we thank him all the same for the important contribution to science.

It will be seen by the upper tracing that when the venous blood is entirely arrested, dicrotism promptly disappears; nevertheless, the arterial movements corresponding with the action in the heart are well pronounced, dicrotism *only* disappearing; doing so almost at once after the veins are constricted. And this shows that it is due to the choking of the capillaries by the damming of venous blood in them, preventing their action. At least, this would account for the circumstance. This is also corroborated by the second tracing, in which the blood was not entirely arrested, but nearly so toward the middle or summit of the tracing, where dicrotism disappears momentarily only, showing some action still left in the capillaries. In other words, the rhythms in the large vessels continue and are well pronounced, but dicrotism disappears. The sudden, almost perpendicular, fall in the upper curve, which was due to the energetic contraction in the capillaries and veins, produced by the venosity of the blood, which acts as a stimulus, will give some idea of the force in these vessels, which should not be lost sight of in the mechanics of circulation, at once showing that the force is available in the circulation by coördinating the capillaries and veins with respiration, as does actually occur; moreover, is fully proven by the tissue-tracings (Fig. 52, *V*). In other words, the same principle precisely obtains for increasing circulation in the capillaries and veins as in the lungs, heart and arteries—namely, by rhythmical changes in pressure; while the force is propagated from the medulla oblongata by means of the nerves, connecting them with the respiratory centre (Fig. 54),* the same as in the other cases; since this is necessary for producing continuity in force for maintaining an uninterrupted current of the blood in the round of the circulation, in the measure of the physiological requirements, otherwise impossible. It is plain enough.

The damming of the venous blood in the capillaries by distending them must inevitably choke the pumping action, the blood being unable to escape by reason of the ligature, while the energy with which they contract to force out the blood is seen in the sudden fall of the upper curve the moment the ligature is relaxed.

* Handbook for the Physiological Laboratory, plate xxxvi. Burdon-Sanderson, etc.

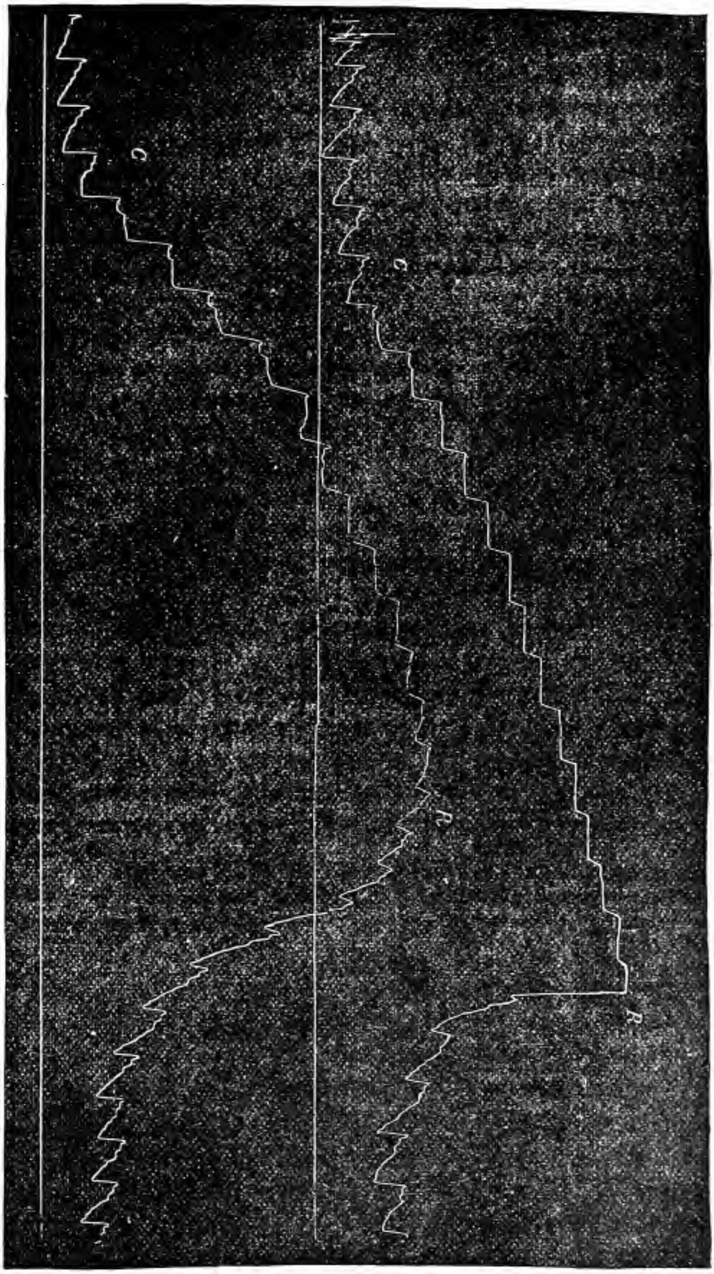

Fig. 53.—Showing that *dicrotism* is arrested by arresting the flow of blood in the capillaries, and so preventing their action. In the upper tracing the flow is entirely arrested; in the lower, it is not complete, for the reason that the flow in the capillaries is not entirely arrested.

When gradually relaxed, the escape of blood is, of course, in correspondence; hence the difference in the curves of the two tracings. It is not produced by the force in the heart, as the eminent Frenchman conceives; but the force is upon the ground where the work is done, and in the very walls of the vessels themselves, which regulate their own circulation. The heart is too far removed for this work, were not the principle itself wrong. The pith of the whole matter being

Fig. 54.—Horizontal Section of Tongue of Frog Treated with Chloride of Gold, showing the distribution of non-medullated nerve fibres to a capillary blood-vessel. *a*, capillary vessel; *b*, coarse non-medullated nerve fibres; *c* and *d*, fine non-medullated nerve fibres forming a plexus which surrounds the vessel like a sheath; *d*, non-medullated nerve fibres in the wall of the vessel. (Oc., 3; obj., 8.)—Klein.

that the tissues respire for maintaining the life that is in them and for increasing their activities, and they must connect with the respiratory centre and the action in the lungs in order to command the oxygen that is needed for increasing metabolism in the measure of the requirements, respiration in consequence readily rising and falling with the swell in the activities. And the force for effecting this action in the capillaries being propagated over the vascular lines from the medulla oblongata would easily account for dicrotism in the heart and arterial system; and why this should be more pronounced with the increase of venosity in the blood, for this makes the demands in the cell-brood more imperious, at the same time it acts as a stimulus to the nervous centres. It would not do, then, to have this important link in the vascular chain neglected, as it would involve failure to all the rest. In fine, the large undulations which answer to the pumping action in the lungs are let down, as it were, in stages till it meets the finer actions in the capillaries, and so passing on into the venous system, while the whole is intimately connected by means of the nerves extending over them for producing an uninterrupted flow of blood between the lungs and cell-brood (the two poles in the circulation), the cells respiring through the lungs, as it were, by means of the arteries and veins which bring in the oxygen and carry out carbonic acid, or upon the same principle precisely as obtains in the embryo, which breathes through the placenta by means of the umbilical arteries and vein, only that in the latter there is still greater removal from the environment or source of supplies. Still, the principle is the same in both, and the mechanics must connect through and through in order to accomplish it. It would require that all the parts should be coördinated in the vascular chain in order to produce and unify the universal pumping actions for increasing circulation commensurate with the physiological requirements, and dicrotism must take its place in the march of the phenomena, at the same time it shows the interdependence subsisting between them and the common relation they sustain to the law underlying the organism, the whole performing in harmonious concert under action of the nervous forces radiating from the solar centre of the organism. So, then, we can readily understand why the capillary or dicrotic waves should announce themselves in the tissue tracings, appearing and disappearing with the relaxing and tightening of the ligature which relieves or chokes the capillaries, as the case may be. In this manner, then, that vexed problem in experimental physiology has easy and natural solution, dicrotism falling into line at the proper time and place with the other phenomena, leaving nothing to explain, which a true theory of the circulation would naturally do.

Another Mode of Proving Capillary Action.—Another mode, the very opposite of this, obtains for proving the action in the capillaries as a potential and independent factor in the circulation, without which neither the systemic nor local circulation could be made commensurate with the physiological requirements, and animal life would have arrest at the flora. It consists in arresting the flow of blood in the main arterial trunk or feeder for the limb, but leaving the veins open; and by thus cutting off the force in the left ventricle, to throw the burden of the tissue circulation upon the local vessels themselves, which should give us some idea of the force in the local vessels for compelling circulation. The same instrument answers for making the tissue tracings as in the preceding, there being no other way of doing it, while the evidence it furnishes is equally conclusive. Of course, compressing the main artery to the limb at once puts an end to *all* the elements of rhythmic movement in the tracings, the cardo-arterial with the rest (Fig. 55, *C*, *C'*), the uninterrupted flow of blood in the vessels being essential for their development. The point we wish to make, however, is that the hand *immediately shrinks in volume*, which the lever promptly registers in the low depression (*C*, *C'*) in the curve of the tissue tracings, and this is produced by contraction in the vessels, driving the blood toward the heart and lungs; and which proves incontrovertibly an independent action in the vessels themselves. So, then, the force to the tissue circulation is not in the heart, which simply assists it, the main force being actually upon the ground where the work is done, in the walls of the vessels themselves, which regulate their own circulation, and must do so in order to maintain autonomy in the tissues, which is essential to existence.

The sudden, perpendicular leap made in the tissue tracings (*c'*) when arterial compression is relieved, is the product of the combined action in the vessels, aided, of course, by the pressure in the arterial system, compelling the blood into the vessels with the energy of expansile action; and which soon restores the normal rhythm in the vessels and the volume of the hand, indicated by the rise in the curve of the tissue tracings, sending it above the horizontal line, and the reappear-

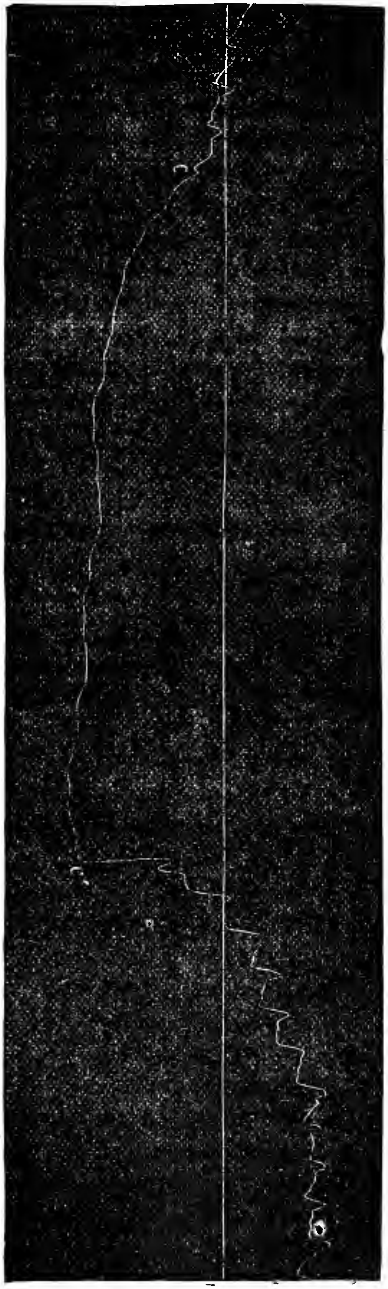

Fig. 55.—Showing the force in the capillaries and veins for compelling circulation *after* the flow is arrested in the arteries, and the force in the left ventricle *eliminated*. The horizontal line indicates the normal volume of the hand as registered by the lever of the sphygmograph, the depression in curve of the tissue tracings (*C*, *C'*), the amount of shrinkage in the hand produced by the action in the vessels, which contract and drive the blood toward the chest; the arterial arrest by (*C*); the renewal by (*C'*).

ance of dicrotism and arterial movement. And that it is produced by the action in the vessels in the manner as stated is fully proven by the straight, perpendicular line (c'), which answers to diastole in the vessels, and which we have seen the heart, of itself, is utterly incapable of producing unassisted by the action in the vessels, requiring expansile action in the vessels themselves in order to effect it. At the same time, the over-distension which this produces in the capillaries, the blood rushing into them from the pressure in the arterial system, tends momentarily to choke the action; hence, the small and imperfect rhythms immediately succeeding the diastole. Furthermore, we know that contraction must possess its equivalent in expansion, so that the previous contraction in the vessels must have its representation in this expansile effort, the one involving the other, expansion and contraction being correlated forces. Moreover, we have the same circumstance illustrated in blushing, in which there had been no previous contraction from anæmia, the vessels suddenly expanding under the nervous force pouring into them from the central nervous system, the blood rushing into them instantaneously under the pressure in the arterial system, producing the characteristic coloring of the skin, followed promptly by energetic contraction, producing the succeeding blanching of the parts from the anæmia this produces. So, then, there can be no doubt whatever of an independent action in the capillaries; otherwise, these actions would be meaningless. Finally, we have to note the low, flat, faint undulations, which answer to the rhythm in the arteries, still remaining in the tissue tracings, notwithstanding the occlusion of the brachial artery above the elbow, and which marks the effort in the vessels to perform the normal functions inherent in them. But in the absence of the blood for filling them *pari passu* with expansion, as in the case of the air when excluded from the lungs, of course they cannot expand, showing the effort to do so only in these indistinct and faint undulations. But this also subserves important uses by promoting the collateral circulation in the anastomosing vessels, producing a suction-force upon the blood, the connecting capillaries expanding under the nervous force pouring into them, and the pressure in the arterial system, which rapidly restores the normal circulation—the one, the *vis a fronte,* the other, the *vis a tergo,* acting simultaneously. In fine, it is the tremendous effort which the tissues make to respire when the supplies are cut off, threatening asphyxia, and in which everything is brought to bear for expanding and filling the vessels with arterial blood.

Of course, any circumstance which should prevent the flow of blood through the arteries would also be reflected in the tissue tracings, since this would inhibit afflux of blood, which is essential for filling the vessels *pari passu* with expansion, in order to effect expansion ; otherwise impossible. In other words, the capillaries cannot expand unless the blood flows into them simultaneously, since it would require prodigious force to effect it in the absence of the blood, involving the production of a vacuum throughout the whole affected capillary territory, and which the capillaries are by no means capable of ; hence, in this condition they contract till the lumen is entirely closed (if the interruption is complete), and the parts are blanched. But with the blood flowing into them all the while, as in the normal condition, there is no difficulty in effecting expansion, while the high pressure in the arterial system in warm-blooded animals enables it to be made very energetic, and which the exigencies in the functions call for, in order to make it commensurate with the force expended in them. This necessity for producing afflux of the fluids in the organs simultaneous with expansion, has forcible illustration in the lungs, for with the force in the chest-walls, diaphragm, and muscles in the abdomen, inclusive of the action in the lungs themselves, it would be utterly impossible to effect expansion in the absence of the air ; which one may readily prove upon himself by closing the nose and mouth and then attempting to inspire. He cannot expand his lungs, putting his force upon it and bringing everything to bear. But how easily it is done with removal of the obstruction, the air flowing into the organs *pari passu* with expansion for filling the room this effects in the alveoli, pressing against the walls, and in this manner aiding expansion. So, likewise, in the capillaries we have the blood flowing into them *pari passu* with expansion for occupying the room thus made, pressing against the walls, thereby aiding expansion, the principle being the same precisely as obtains in the lungs.

Multiple Dicrotism.—This brings us to the remaining difficulty in the tissue tracings, notably multiple dicrotism. As we have seen, the systemic pumping-action in the lungs is let down in stages to the tissue territory, which should give us but one dicrotic wave for all the vessels, inclusive of the heart; whereas, in the capillary tracings we have sometimes two, and occasionally as many as three or even four present (Fig. 53), and which is undoubtedly due to interference on the part of the local functions and the action in the cells. And when so many dicrotic waves appear, we know there is something wrong in the tissues, or the cells are not duly supplied, and the circumstance is announced in this manner. In the case before us, in which the capillaries are choked with venous blood, therefore cannot act, dicrotism disappears; while in the opposite condition of anæmia, produced by an application of ice to the inner side of the arm, or along the course of the brachial artery, for effecting contraction in the vessel, thereby to diminish the flow of blood in the tissues below the normal amount, accentuates dicrotism (Fig. 56),* at once showing that its origin is in the capillary vessels, and due to the diminished supplies in the cell-brood. In other words, the cell-brood is suffering, and this is the only means for increasing circulation. The action on the artery irons out the respiratory wave, but it does not stop dicrotism, for *that* is the voice of the cell-brood, the *vox populi, that will not down.*

Explain the phenomena in the tissue tracings by the action in the heart! No, *Monsieur!* You might as well have attempted to explain the force in this vast republic by the powers of the Chief Magistrate, who is only a servant of the people, and in which every individual is an independent integer, performing work so as to sustain himself, if it be not further than to eat and sleep, to rise up and lie down again, and attend to the calls of nature—all the same, they are his own acts and essen-

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* Ib., Fig. 329, produced in the same manner as the preceding, while the *fall* in the line of tracings indicates the amount of shrinkage in the hand.

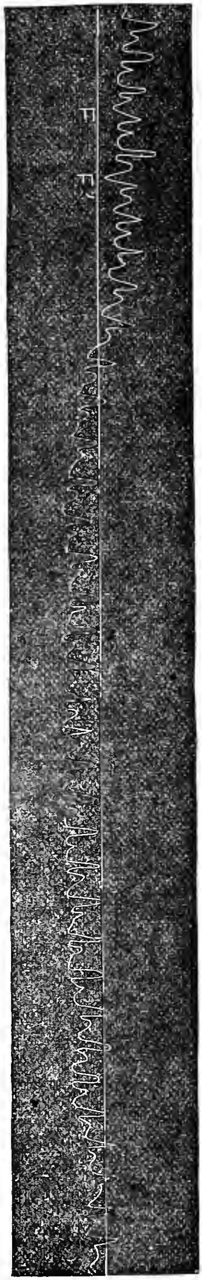

Fig. 56.—Showing how dicrotism in the local vessels is accentuated by anæmia, produced by the application of ice over the brachial artery, causing contraction in the vessel and reduction of the normal supply. *F*, *F'*, the interval of time (4 seconds) before any change set in in the artery.

tial to him; at the same time, his force is joined with the body politic through coördination of the multitudinous parts in the common federal centre for the autonomy; so that the whole performs as though but a single individual only, while separate and independent action obtains all along the line down to the individual integers, however insignificant they may be. So, likewise, in the autonomy in the body itself, of which the other is reflex (for a stream cannot rise higher than its source), every individual cell is an integer, performing work relating to its own existence and the public weal, while all the multitudinous parts are coördinated by means of the correlation of the nerves and nervous centres in the medulla oblongata, the federal centre of nervous force for the organism, while separate and independent action throughout is a *sine qua non* to existence: in the one not more than in the other. It follows that the cells and tissues *must control their own circulation* in order to make it commensurate with the physiological requirements and sustain existence. And had the heart fifty times the force it has, it would not serve the purpose of the circulation, for the principle itself is wrong. The theory of Harvey is well enough under limitations, though it was a splendid service he rendered to science in rounding the circulation through the arteries and veins, sending it out of the left side through the arteries and returning to the right through the veins. But then, Harvey knew nothing of the tissue-circulation, nor of the vast cell-colonies upon its banks, and the individualism in the tissues; nor of the vast lymphatic circulation, which is slower than the other, connecting with the nutritive processes, embracing the tissue-interstices and the cells, and emptying into the venous system at the root of the neck; nor of the special anatomy in the vessels as the relative anatomical dispositions for producing work in the circulation, inclusive of the vaso-motor system of nerves for coördinating them with respiration, all of which were subsequent revelations effected at the cost of enormous labors by devoted, self-denying and independent workers in the field. Last, but not least, he knew nothing of this law of pressure underlying the organism and forming the basis of the entire mechanics in the body, for Torricelli had not yet announced atmospheric pressure, coming out some years after (1645), while Harvey announced his theory in 1627, or nearly twenty years previously. He was correct about the blood-circuit, but wrong about the force being in the heart, which cannot possibly be true. But had it been otherwise, he could not have worked out the problem in the absence of the painstaking anatomical and microscopical researches, inclusive of the physiological experiments made upon the nerves, blood-vessels, etc., which were essential for showing the relations they sustain to each other and their relevancy in the vital phenomena of which respiration is the typical movement A blast from John Hunter, "its heart is all over its body,"* however, had sounded the alarm all along the line, and the matter of the final overthrow was only a question of time, for truth only can meet and endure the assaults of science. It is a contravention of the law underlying the organism, therefore is false. But we would say of these beautiful experiments, that we would not do without them if we could, and we could not do without them if we would

Circulation in the Tissue-Interstices and the Relations which this Sustains to the Capillaries and Cell-Brood.—For illustrating circulation in the tissue-interstices, and for impressing it upon the mind, we have prepared the following illustrative diagram of the soft tissues (Fig. 57). It represents four capillary vessels, with the intervening tissues (2), formed of cells and interstices, sufficient for the purpose of illustration. Now, then, should the capillaries (1, 1, 1, 1) contract for increasing pressure upon the blood, it would have the effect of increasing the *distances between* them, thereby *reducing* pressure *in* the interstices in proportion, and which should cause the liquor sanguinis to escape through the stomata into the interstices, which would be from high to low pressure. But during expansion the opposite should take place, since this would have the effect of *diminishing* the distances between the capillary walls, thereby increasing pressure in the interstices in proportion, at the same time developing low pressure within themselves ; hence, the fluids should flow into the vessels again from the interstices, being from

* This remark was evoked by the fruitless search for the heart of a fly.

high to low pressure, in conformity with universal law. In other words, the fluids should flow into and out of the interstices from the capillaries during their rhythmical contractions and expansions, for the same reason precisely that they flow into and out of the lungs, pressure alike applying to it all. The blood corpuscles being too large to pass the stomata, pass on, of course, into the venous system, but yielding up their oxygen, which very probably passes with the liquor sanguinis through the stomata to the cell-brood, as this would greatly facilitate the passage through the membrane. In this manner, then, the nutritive and force-producing elements are pumped into and out of the interstices for the due supply of the cell-brood; and which is readily increased or dimin-

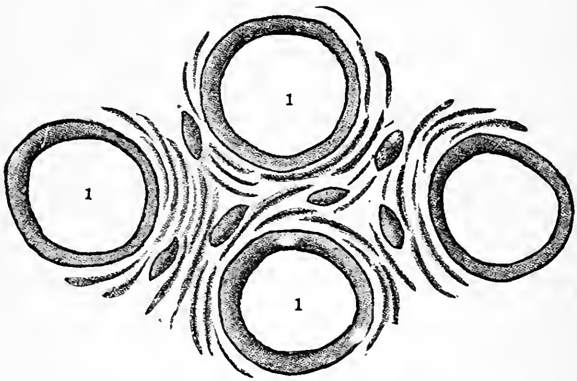

Fig. 57.—An Ideal Diagram of the Tissue-Circulation, showing the relations which the capillaries sustain to the tissues. 1, 1, 1, lumen of capillary vessels.

ished upon occasion in correspondence with the exigencies in the functions, thus giving them complete control of their own supplies, which the scheme calls for; otherwise it must inevitably fail, the sole purpose in all the vascular arrangements being the due supply of the cell-brood or workmen in the tissues through whose instrumentality all the phenomena are evolved; and failing at one point, the vascular chain would be broken, since it all rests upon this power of producing rapid rhythmical changes in pressure for increasing circulation commensurate with the physiological requirements, no other means applying for the purpose. Thus it is manifest, for feeding the cell-brood and removing waste products, that it calls for rhythmical expansions and contractions in the capillaries, in the arteries, in the heart, and in the lungs, for producing an uninterrupted flow of the fluids between the cell-brood and environment, whence all the supplies are derived, and into which the waste products are returned, the whole forming a connected movement in the very nature of things, since in no other way could a balance be maintained. Moreover, it is reduced to actual demonstration in the tissue tracings (Fig. 52, *V*) that the tissues do expand and contract regularly and rhythmically synchronous with respiration and the action in the heart, arteries and capillaries, as indicated by the respiratory, cardo-arterial and capillary waves which are superposed upon each other in the order named, as before remarked, thus completing the argument by accounting for *all* the phenomena in the tissue tracings; together with the special anatomy in the organs, inclusive of the enormous web of nerves for coördinating them with respiration; otherwise utterly inexplicable. While all the phenomena, anatomical and physiological, fall readily into line in regular order and succession as appropriate adjustments with the fundamental law underlying the organism, which is thus being incessantly invoked in the measure of the requirements, and which is indicated by the pumping actions taking place in the lungs and organs of circulation, the whole rising and falling with the swell in the activities.

The following illustrations (Figs. 58, 59) will give some idea of the nervous lines connecting the capillaries with the cell-brood, enabling them to expand and contract the vessels, inclusive of the arterial feeders for increasing and diminishing the blood supply in correspondence with the exigencies in the functions, and which could not be effected in any other way, as they are constantly changing; hence, the vessels must be subject to the mandates in the cell-brood. All of which is plain enough.

This force in the cell-brood for compelling supplies into the body to themselves through the action of the rhythmic centre, is seen in the increase of respiration and the action in the heart and arteries with the swell in the activities, rising and falling with these, the two being in correspondence; for in no other way could it be effected. Moreover, the influence which the tissues exercise over circulation and respiration in abnormal conditions, so as to produce fever, notably traumatism and inflammatory processes brought about by any means, is further proof of the intimate connection subsisting between them. Finally, the accentuation of dicrotism in the cardiac and arterial tracings by anæmia, superinduced by any cause, whether by recurrent hemorrhages or exhausting fevers—*e. g.*, typhoid fever, in which the supplies are defective—affords eloquent proof of the power of the cell-brood for compelling the rhythmic centre to respond. One more reference, and we shall

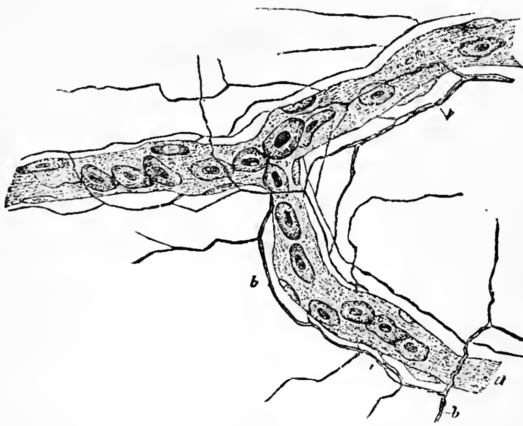

Fig. 58.—Horizontal Preparation of Nictitating Membrane of Frog in Chloride of Gold, showing the distribution of non-medullated nerve fibres to, *a*, capillary blood-vessels. *b*. Coarse non-medullated nerve fibres giving off fine branches *c*, which form a plexus around the vessel. (Oc., 3; obj., 8.)—Klein.

have finished; notably: It is a well-known fact that *any* circumstance which should suddenly reduce arterial pressure would accentuate dicrotism, bringing it out more conspicuously in *all* of the tracings. Now, then, as arterial pressure increases circulation in the tissues, it follows that any reduction of pressure would call for corresponding compensation, in order to maintain circulation in the tissues up to the norm, and which can only be done by increasing the rhythmical expansions and contractions in the vessels, and hurrying respiration; hence the quick respiration in these cases and the accentuation of dicrotism, which are undoubtedly produced through the rhythmic centre and reflex action propagated from the cell-brood.

Concerning the Arrest of Pulsation on the Distal Side of Aneurismal Tumors.—Since the central nervous system operates the movements in the vessels, the force being propagated

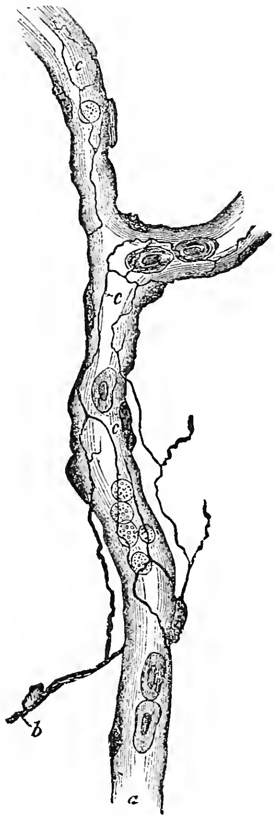

Fig. 59.—Mesentery of Frog prepared in Chloride of Gold, showing the distribution of non-medullated nerve fibres to a capillary blood-vessel, *a*. *b*, A coarse non-medullated nerve fibre giving off finer branches, which form a plexus around the capillary. Some of these finer fibres belong to the wall of the vessel. (Oc., 4 ; obj., 8.)—Klein.

from the medulla oblongata, or the same as in the voluntary movements with which the vessels are coördinated, this would explain the arrest of pulsation in the vessels on the distal side of aneurisms, which distends the nervous plexuses, and by putting them upon the stretch would inhibit the passage of the currents, while the force in the heart is absorbed in the aneurismal expansions, thus taking off nervous and cardiac force at one and the same time; hence, the cessation of the pulsations. Furthermore, we have seen that the force in the ventricular systole is needed for producing a degree of pressure in the vessels, in order to enable them to expand, and to produce the energy involved in the pulse. So that should the nervous currents continue as before, the pulsations could not be produced. Still, there is some action in the vessels and tissues, and circulation is sufficient for maintaining life in the affected structures, the force in the aneurism itself not being lost, while the polar forces continue in action. In respect to the fall in arterial tension, this, of course, is an effort of Nature to promote recovery by reducing pressure in the aneurism, thereby to lessen the tension so as to diminish the danger of rupture. At any rate, it has this effect, and it cannot be accidental, for there is method in it.

Concerning the Cardiac Tracings.—The exceptional conditions which obtain in the heart tend to misdirection with respect to the true import of cardiac movement as registered by the sphygmograph. 1. Thus, being in a manner suspended by the vascular rootlets, notably the pulmonary and aortic arteries, resting lightly against the diaphragm in man, and the sternum in quadrupeds, the systole causes it to bound against the chest from the sudden action it produces in the vessels, which expand and elongate, *thereby throwing it forcibly against the walls*, producing the perpendicular line in the tracing, answering to diastole in the vessels; while during diastole the contraction which this produces in the vessels pulls the organ from the chest again, and so lets down the lever of the sphygmograph, producing the oblique line in the tracings, which answers to systole in the vessels. Furthermore, by reason of this to-and-fro motion produced in the heart, the lever is incapable of following it throughout the whole movement, the heart being pulled away from it. 2. Contraction in the heart is from the apex to the base, which shortens and thickens the organ, in consequence pushing up the lever of the sphygmograph, thereby indicating increase of size in the organ, whereas the organ is actually diminished in size to the extent of the blood discharged from it during this time; hence, is deceptive; while during the expansion or diastole the organ elongates, in this way letting down the lever again, thereby indicating decrease of size, whereas the size of the heart is actually increased to the extent of the blood it contains during this time; hence, this is also deceptive. What is desired in the tracings is to get the actual increase and decrease of volume during diastole and systole, which should give us tracings similar to what obtains in the arteries, where no such difficulties exist, and which the lever truly registers, following the whole movement in the vessels. And in order to get them in the heart, the instrument would have to be applied directly to the organ, as must appear obvious. Thus it is seen the tracings are deceptive. In point of fact, there are four movements taking place in the heart, two corresponding to diastole and systole, and two embraced in the to-and-fro movement corresponding with impact and recession from the chest.

The Venous System.—The arrangements which obtain in the venous system are also easily explained. It embraces a number of circumstances. In the first place, it is about four times the size of the arterial; hence, did not some arrangement obtain for regulating the capacity by altering the lumen of the vessels, the low pressure which prevails here, together with the high pressure in the arterial system, would soon empty all the blood into the venous, bringing life to a sudden termination. Hence, the numbers of the muscles and nerves in the veins for effecting this circumstance, while the valves sustain the venous column against gravitation and obviate reflux. 2. This increased capacity in the venous system would explain the slowness of the respiratory rhythm, and the speed in the cardo-arterial, being as 4 to 1 of the former, the object of respiration being to bring the venous blood into the alveoli for effecting oxygenation, the heart and arteries serving to transfer it thence to the cell-brood for evolving force in the organism, while the relative rate in the rhythms is necessary for maintaining a balance between the venous and arterial systems. Hence, the nervous connections subsisting between the veins and the vaso-motor and respiratory centres for regulating the venous system with respiration, for in no other way could a balance be maintained. In fine, respiration, assisted by the action in the heart and arteries, pumps the blood out of the great venous reservoir into the alveolar plexuses in the measure of the requirements, while for facilitating the action the walls of the reservoir itself contract and expand regularly and rhythmically, synchronous with respiration. This would explain the number of the muscles in the veins, together with the circular arrangement of the muscles in the walls, or the same as obtains in the arteries, minus the thick elastic coat for producing the high pressure in the latter, which is not called for in the venous system, where pressure is low in order to give the requisite time for effecting the oxygenating and nutritive processes in the tissues, and for effecting the interchanges in the lungs, which call for a slow circulation, in order to accomplish them. Finally, the venous system being harnessed to respiration, with the arterial for producing an uninterrupted flow of blood through the circuit, it is manifest the balance is struck in the lungs for producing correspondence between the circulation of blood and air in the alveoli, otherwise impossible. In this manner, then, the blood is compelled from the centre to the periphery of the body, or from the lungs to the tis ue-territories through the heart and arteries, thence back again through the veins to the lungs for completing the circuit, rocked in the arms of nervous force, gently and tenderly nursed through the work. Before leaving this portion of the subject, it were not amiss to refer to an interesting phenomenon connected with the brain and venous system; notably the oscillations which occur in the brain synchronous with respiration, rising up during expiration (as seen through an opening in the skull), and sinking down again during inspiration.

The explanation of this circumstance is furnished in *the alternate filling and emptying of the great venous sinuses at the base of the brain*, and which is due to the mechanics in respiration. For example, during expiration there is retardation of the blood in the sinuses, produced by arrest of suction-force in the chest, save in the heart only, which is not sufficient for maintaining an uninterrupted flow of blood in the sinuses —indeed, nowhere else in the venous system, as is fully proven by the rapid accumulations of blood during prolonged expiration, in which the whole body-surface becomes suffused with venous discoloration from venous stasis in the systemic capillaries; in consequence, they become distended, lifting the brain in proportion, causing it to *present* at the opening in the skull; but when inspiration sets in, the great increase of suction-force this produces in the chest causes sudden efflux in the sinuses; in consequence, this soft vascular cushion collapses and as *suddenly lets down* the brain again.

In other words, the matter resolves itself into one of hydraulic pressure simply, the brain riding up and down upon this hæmal cushion underlying it with the oscillations of pressure in the lungs and venous system. And that it is the correct explanation of the phenomenon, is proven by the fact that the motion does not occur when the sinuses are laid open, in itself furnishing eloquent proof to the damming of the blood in the venous system during expiration, showing that the heart is not equal to maintaining circulation in the lungs, but a helpmate for assisting it only.

During sleep, therefore, in which respiration falls in frequency, the oscillations are greatest, as a matter of course. But then, again, this subserves important functions, since the plethora of the capillaries and the slowing of circulation which takes place in sleep conduces to rapid nutrition, since it favors crystallization, which requires a slow circulation. But it is all in correspondence; thus, with diminished respiration there is diminished action in the heart and arteries, in correspondence with this circumstance, for maintaining a balance in the arterial and venous systems. with a slow circulation for promoting the nutritive processes; while with revival of consciousness and the activities, a *simultaneous* increase occurs in correspondence with this circumstance for evolving the force expended in the organism, *extending through the entire mechanics* in wondrous order and harmony, considering the complexity which exists, which, of course, is effected by means of nervous force propagated from the medulla oblongata, the solar centre of the organism. But when considered in the light of this common law underlying it, it is readily perceived why there should be such precision and harmony pervading it, and why similar arrangements should obtain in all the animals, commensurate with the stage in development; and when one reflects over the circumstance that *everything is regulated by law*, it is passing strange that this fact had not been applied to the animal circulation.

Turn we now to the portal circulation and the mechanics in the abdomen for further corroborative evidence of this fundamental law underlying the organism, with which everything must have adjustment, as has already been remarked.

CHAPTER IX.

THE PORTAL CIRCULATION AND THE MECHANICS IN THE ABDOMEN.

The Intestines of Mammalia Filled and Distended with Air for Increasing the Digestive and Absorptive Processes, Serving the Purpose of an *Elastic Cushion* for Transmitting the Force in the Gut upon the Food for the Purpose—The Action not Unlike that which Obtains in a Churn—Necessity for a Diaphragm—Existence of High Pressure in the General Cavity of the Abdomen Produced by the Air in the Intestines for Increasing the Portal Circulation so as to Maintain this in Correspondence with the Absorptive Processes—Principle of Coördination Applied to the Stomach and Walls of the Abdomen for Effecting Ingestion and Office of the Pneumogastric and Phrenic Nerves in Connection Therewith—Why the Animal *Rises* when Eating and Drinking—Why Respiration is Suspended During Deglutition or After the Aliment has Passed the Glottis, and the Danger of Intrusion in the Air-Passages is Over—The Action in the Stomach and the Physiological Anatomy in the Organ—The Rôle in the Air-Cus ion in Connection Therewith—Similar Survey of the Intestines—The Rapid Absorption of Fat, Alcohol and Other Non-Dialyzable Substances Easily Explained—The Fine Adjustments in the *Muscularis Mucosæ* and the Mode of Coördinating Them with the Muscles in the Walls for Making Absorption Very Effective—No Difficulty in Absorption.

Having passed in rapid review the phenomena, anatomical and physiological, appertaining to the systemic circulation, and their relevancy to the law underlying the organism, fully shown and established by indisputable evidence, we are now prepared to take up the portal circulation and the mechanics in the abdomen for compelling the digestive and absorptive processes to be commensurate with the physiological requirements, so as to maintain a balance in the organism; otherwise impossible. The adjustments which obtain in this respect are beautiful to look upon, and passing all belief, could they not be inspected with one's own eyes. But there they are, true enough, and open to inspection And taken all in all, the number and diversity of the adjustments, the charming manner of the workmanship, and the mechanics in the abdomen exceed anything in the domain. The finest adjustments come in with the nervous apparatus for effecting the multitudinous actions in the organs, and for coördinating them with respiration, the whole being intimately interwoven with the systemic mechanics and blending thoroughly with this. We shall not dwell longer than necessary, passing over the structures rapidly.

Antecedent to the mammalia, the intestines remain small and contracted, the walls comparatively thick, and the cavity filled with liquid contents (Fig. 60); but with the mammalian stage in development the organs are widely expanded, the walls comparatively thin, while the cavity is filled and distended with air, the liquid contents at the bottom and around the sides of the tube (Fig. 61, 1, 2). Accidental! No; of course not! Nature does not deal in accidents; her arrangements are all methodical, being based upon law, here as elsewhere.

Besides, accidents would not be confined to *one* class of animals only, all the rest escaping. And if you mean that the air in the intestines of mammalia is the result of fermentative changes in the food, or to decomposition, you are entirely wrong; the animals, moreover, live on the same kind of food as all the others, namely, vegetable and animal food—some one kind only, others both kinds; so that in no sense can there be any excuse for such opinion, and it is totally unscientific.

Briefly, the explanation for this phenomenon is as follows:

1. It affects a great increase in the mucous surface, thereby increasing the digestive and absorptive processes correspondingly, and which is necessary for evolving the force which is expended in them and for maintaining a balance in the organism otherwise impossible.

2. By means of this air in the intestines, the force in the *walls* of the organs is applied to the aliment for compelling absorption to be commensurate with the physiological requirements; at the same time it increases the digestive processes correspondingly, by the free movement it effects in the food, bringing it into rapid contact with the secretions that are poured out upon the mucous surface, and which is produced by the action of the nerves and muscles in the walls of the organs from sensory impressions in the

mucous membrane produced by the food. In short, the mechanical principle is the same as obtains in the case of *residual air* in the lungs, for compelling circulation of the blood to be in correspondence with the circulation of air in the alveoli; only the air-chamber does not *leak*, as in the former case, the air being *all* retained, while the force in the gut is available for compressing the elastic cushion against the aliment for

A

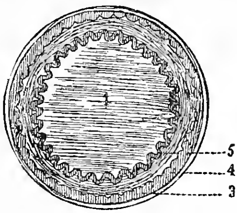

Fig. 60.—A Diagrammatic Transverse Section of the Intestines in Aves, Reptilia, Pisces, etc., showing the relative difference in the size of the lumen with Mammalia, together with the circumstance that the organs are filled with *liquid* contents, simply.

B

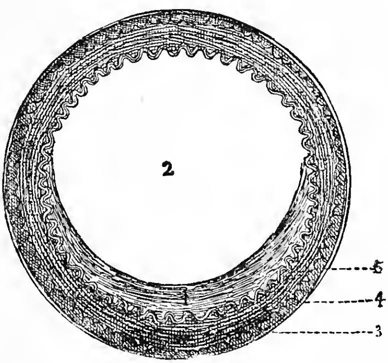

Fig. 61.—A Diagrammatic Transverse Section of the Intestines in Mammalia, showing the great increase in the lumen of the organ and the large amount of air it contains. 1, liquid contents at the *bottom* and *diffused around the sides;* 2, air-cushion; 3, peritoneum, longitudinal muscles adjacent; 4, circular muscles; 5, mucous membrane.

compelling absorption and digestion to be in correspondence with the physiological requirements; otherwise impossible. Moreover, it affords a ready explanation of the special anatomy in the organs as means to ends, otherwise inexplicable; notably, the arrangements in the muscles and nerves for effecting the changes of pressure in the contents in the gut, which we will come to further on. Finally, this would account for the rapid evolution of gas in morbid conditions of the organs; *e. g.*, dyspepsia, colic, hysteria, in the entire absence of food-changes, such as are involved in decomposition or fermentation, the food acting only as an irritant, and thereby disturbing the balance in the secretory processes in the organs, and thus causing the evolution of gas in abnormal proportions.

3. Last, but not least, by means of the air in the intestines, the increase of pressure is produced *within the general cavity of the abdomen* for producing correspondence between the portal circulation and the absorptive processes in the intestines, the force in the walls of the abdomen being available for the purpose of increasing the pressure which occurs during respiration, especially during inspiration, when the diaphragm descends; a circumstance which it would be difficult to overestimate, being necessary for maintaining a balance in the circulation. But, before proceeding farther, it were well to demonstrate this circumstance, that it may rest upon something better than mere assertion. For this purpose, a dog was chosen, and, placing it under chloroform, I made use of an abdominal sound (Fig. 62),* improvised for the purpose, by means of which I ascertained the following facts:

1. The existence of high pressure in the general cavity of the abdomen, produced by the gas in the intestines. 2. That pressure is increased during inspiration, leaping up the instant it sets in, and continuing higher than the norm through the whole period. That pressure is lower during expiration than inspiration, expansion in the diaphragm being so very rapid as to prevent any diminution in the abdominal area by the contraction of the muscles in the abdomen, otherwise inevitable, and there can be no doubt that it is a normal physio-

* The instrument was made as follows: The end of a glass pipette was passed into a small metallic bulb perforated with holes, over which was drawn a gum-elastic bag and firmly secured by means of turns of waxed thread. The instrument is then filled with water till it mounts half-way up the stem and tightly corked to prevent escape when being passed into the cavity of the abdomen.

When the water is poured into the open end of the stem it distends the gum bag, while the bulb prevents it all from being driven out under pressure. It is a rude device, but answers the purpose very well.

logical condition to meet the special requirements in the portal circulation; the obvious purpose being to obviate strain to the heart and venæ cavæ by reason of the damming of the blood in the right side during expiration, as has already

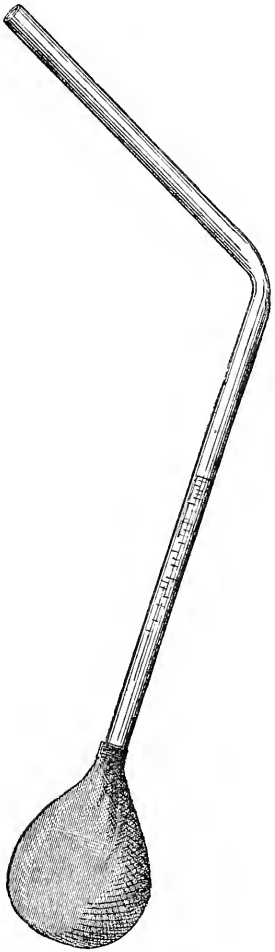

Fig. 62.—Abdominal Sound.

been demonstrated. I had no means of ascertaining it in millimeters, but the intra-abdominal pressure is very considerable. Thus, when the sound was first introduced through an opening in the linea alba, immediately above the umbilicus, and the cork withdrawn from the stem so as to permit the water to escape, it spurted out with great force against the opposite wall some eight feet distant, and would have gone farther, striking it some feet from the ground.

It rose and fell with inspiration and expiration, and had there been sufficient water in the instrument, would have issued *per saltam* with respiration, the same as arterial blood with the rhythms in the heart and arteries, showing the great pressure in the abdomen and the inevitable effect it must have upon the venous system in the abdomen. I do not mean that the pressure is as great as in the arterial system, but that there is considerable pressure in the abdomen, which oscillates with respiration, but highest during inspiration. After the first jet, other smaller jets followed synchronous with inspiration, till at last the quantity of water was so reduced that it simply rose and fell in the instrument, shooting up the stem during inspiration, then falling back out of sight again during expiration into the bulb of the instrument, the delicate india-rubber bag allowing it to do so. And it thus continued to oscillate all the while, no matter where the bulb was shifted, up or down, in the pelvis as well as elsewhere, but always greatest in the region of the diaphragm and stomach. Furthermore, the pressure is higher in a *fat* than in a *lean* dog, showing conclusively that there is greater difficulty in carrying on the portal circulation in the former condition, since the accumulation of fat in the viscera tends to embarrass respiration, thereby choking the portal vessels; hence this circumstance. Fat animals are always windy, the gas frequently escaping by the anus from the pressure in the abdomen The explanation of the mechanics is obvious enough. The gas acts as a lever under the force of the muscles in the abdomen, and in the walls of the intestines for overcoming inertia in the venous blood, in this manner lifting it up to the chest-cavity and lungs, inclusive, of course, of the liquid aliment with the portal blood, the whole forming a connected movement, and it must do so in the very nature of things. It is all very beautiful, while nothing could be more simple: air upon the one hand, muscular force upon the other, the blood with the nutritive and force-producing elements in the intestines sandwiched between them, with the nervous force in the medulla oblongata for operating the mechanics and co-ordinating it with respiration. *Mirabile!*

The pressure in the abdomen would account for the elevation of the diaphragm in the chest-excavation, as has already been shown (Fig. 27). It is higher after death by reason of the contraction in the lungs, forcing out a larger amount of residual air than during life, while the viscera in the abdomen are compelled into the excavation in order to equalize pressure ; hence this circumstance.

And it would also account for the tendency in the viscera to escape through the natural and artificial openings from wounds in the abdomen, and which is increased during inspiration,* loops of intestine and portions of omentum fairly leaping through the openings the instant they are made, from the high pressure in the abdomen. It takes considerable force to cause the viscera to burst through the openings in this manner. Last, but not least, when the *diaphragm* is ruptured or incised (as has occasionally occurred), the viscera rush through the opening into the pleura and, compressing the lungs, extinguish life. In conclusion: That there is high pressure *within* the intestinal cavity itself also admits of easy demonstration by simply puncturing the gut, when the gases escape with audible noise, the walls at the same time collapsing, showing conclusively that they had been distended by the gases. Moreover, it would explain the rotund appearance, not to be accounted for by any other hypothesis, the walls being thus ballooned by the air.

We are now prepared to take up the mechanics in the intestinal canal. As we live by breathing and eating, the first thing to note is the adjustment that obtains between eating and breathing, an important adjustment obtaining in this respect. Thus, when the animal desires to take food (solids or liquids, it matters not), *it rises to its feet* (man to the sitting posture) in order to do so. Second, that *during deglutition, respiration is suspended.* The explanation of the phenomena is sufficiently easy.

* A very notable example in the experience of obstetricians is the gush of blood which precedes the outcry of the parturient woman, and which is produced by inspiration.

It *rises* up in order to reduce pressure and facilitate expansion in the abdomen, which are essential for introducing the food into the cavity, doing so instinctively, but first compelled to it. At the same time, gravitation is also brought to bear for facilitating expansion, acting also upon the food; whereas in the recumbent posture it acts adversely by increasing pressure in the abdomen, from the weight in the body compressing the abdomen against the ground, thereby inhibiting expansion; a circumstance which is also easily demonstrated by lying upon the abdomen, then making an attempt to swallow liquid or solid food. It cannot be done but to the most limited extent; and if the abdomen be at all pendulous, it will be utterly impossible to get down any whatever. This, then, is the explanation for the rising up to eat and drink.

2d. The suspension of respiration has its explanation in the circumstance that the diaphragm *must* be *relaxed* (expanded) in order to reduce pressure in the abdomen and relieve the muscular constriction around the œsophageal opening in the diaphragm, which *constricts the tube during inspiration.* Hence, there must be *no* inspiratiory effort during deglutition.

It is the common impression, however, that "suspension of respiration during deglutition is designed to obviate intrusion of the food into the air-passages;" but while this important end is also attained, it is not the controlling principle in the mechanics, as is fully proven by the fact of its continuance *after* the food has passed the glottis and when all danger from intrusion is over, not pausing till the bolus *has traversed the entire distance in the gullet and been safely lodged within the stomachal cavity.* And the glottis, being at the very commencement of the gullet, is *quickly* passed, from the energetic action of the muscles of the pharynx, which are of the *striated* variety for *compelling rapid action*, the evident purpose being to *rush it* by the glottis, while it is the *distance*, together with the *slower* movements in the gullet, that *consumes the time.* Nor is the temporary arrest of the bolus in the gullet from mechanical causes, with resumption of respiration *before* the act is completed, an infraction of this important principle, since for the *final consummation* it still requires *the suspension of respiration*, and as though there had been no stoppage whatever, in order to *relax* the *œsophageal opening*, or pillars, in the diaphragm, at the same time reducing intra-abdominal pressure, the whole diaphragm, together with the muscles in the abdomen, expanding, which is accomplished by means of the reflex actions set up through the pneumogastric nerves from sensory impressions in the mucous surface.

Thus, deglutition is seen to be far-reaching, a movement, in short, extending from centre to circumference of the body, and involving the most extensive adjustments for effecting it, while the mechanical principle underlying it is the one of pressure, and the power of producing rapid rhythmical changes in pressure. In the quadruped, when drinking from the ground, the liquid has to *ascend* the tube ; hence, it involves a greater expenditure of force on the part of the gullet than in man, who lifts it to his lips, thereby gains the force in gravitation. But the juggler, drinking while standing upon his head, reverts to the old mechanics, and while he is able to accomplish the feat, he, at the same time, finds it much more difficult than the natural way, or by lifting it to his lips with a cup, with the body in an upright position, or with the head up. But it is quite as easy to effect expansion in the stomach and abdomen as in the normal position. The popular interest it excites is amusing. The idiots! The act of deglutition, however, is somewhat complex. Briefly, when the food has been duly insalivated and all is ready, the mouth-cavity contracts upon its contents, the tongue being forced up against the hard palate from before backward by the action of the hyo-glossal, stylo-glossal, and palato-glossal muscles, strongly arching the organ upon itself so as to throw the convex surface against the surface of the hard palate, and pulling it from before backward; at the same time, the larynx is firmly approximated against the base of the tongue by the action of the genio-hyoïdei, thyro-hyoïdei, mylo-hyoïdei, and the anterior bellies of the digastric muscles, the effect being to close the glottis and effectually prevent intrusion of the food into the air-passages, the base of the tongue also arching over it. At the same time this is going on, however, changes are taking place in the back of the mouth and pharynx for accelerating the passage of the bolus, notably as the root of the tongue approaches the velum palati and fauces—previously tightly closed; these *expand*, the velum being drawn upward and backward, and opposed to the posterior wall of the pharynx by means of the pharyngo-palati, and the levator and circumflexus palati for obviating intrusion in the nasal passages, and with the pharynx at the same time widely expanding for sucking the food. The elevation of the larynx must have this effect, not to mention the special action in the muscles; the bolus readily passes into the excavation, which closes *at once* upon it; thence, by a series of rhythmical expansions and contractions, is compelled through the tube to the stomach. And the pharyngeal muscles being *striated*, this secures energetic action in the pharynx for rushing it out of the dangerous locality, as before remarked. Otherwise, this differentiation of the muscles in the gullet is inexplicable. As soon as the food reaches the pharynx, the reflex actions are at once set up, nor pause till the bolus has reached the stomach. The sensory fibres, which lead to the reflex movements in the gullet, are contained in the palative branches of the fifth, and in the pharyngeal branch of the pneumogastrics, and the centre for their movements is in the olivary bodies in the medulla oblongata (Schröder *v. d.* Kolk). That the progressive contractions and expansions which occur in the œsophagus during deglutition do not depend upon the stimulation of the advancing bolus, but are the result of a central coördination, is evident from the fact that the wave travels over ligatures or even excised portions of the œsophagus (Mosso). One other thing in this connection: When the mouth is closed it has a negative pressure corresponding to 2 to 4 millimeters of mercury (Mezzer). In this manner, then, atmospheric pressure would serve for supporting the maxilla and tongue, while for increasing it, for producing the suction-action in the cavity during nursing and drinking, the lips close around the mamma or open in the fluid; at the same time, the cavity is expanded by expanding the buccinator muscles and depressing the tongue, the fluids flowing in till expansion ceases, when the cavity contracts firmly upon it for compelling it into the pharynx, etc., etc. First and foremost, however, we must keep conspicuously in the foreground the principle of coordination as it relates to the internal and external parts, together with the nervous combinations in the medulla oblongata for compelling simultaneous action in them, since this is essential to the mechanics and the performance of the functions in the abdomen.

As before remarked (p. 60, Fig. 16, 2, 3), the *waves* of expansion in deglutition are not lost, but are added up in the general expansion which takes places in the stomach and the cavity of the abdomen, all the parts expanding *pari passu* with the ingestion of food; otherwise, it were utterly impossible to introduce the food, since the progressive increase in pressure this should occasion in the stomach and abdomen would inevitably produce regurgitation. The extension of the pneumogastric trunks to the stomach, which they literally envelop with nervous filaments, and the correlation of these nerves with the nerves to the muscles in the abdomen, notably the intercostals and phrenic nerves, has its explanation in this circumstance; for in no other way could correspondence be produced for maintaining a balance in pressure in the stomach and abdomen, since the stomach is separated from the walls by the differentiation of a peritoneal cavity.

Furthermore, that the abdomen does actually expand *pari passu* with ingestion is matter of easy demonstration by taking the dimensions *before* and *after* a meal, when it may be at once seen that expansion is in correspondence with the amount of ingesta. That ends the matter *there*. Now, then, it will scarcely be contended that deglutition—that is, the action in the gullet—can force open the stomach in order to produce the increase in the size of the organ when thus distended with food, the powerful muscles in the abdomen inhibiting this circumstance, not to mention the strain it would involve to the stomach. It sends a spasm through the chest. *Gott in Himmel!* Give it the go-by instantly; it would choke the life out of you. And do not think of forcing open the stomach and abdomen by *any* means whatever, but rather permit them to expand of their own option under the stimulus of the food and the reflex actions this excites in the medulla oblongata from the sensory impressions it produces in the mucous surface, or the same as obtains in the lower animals.

You cannot improve the mechanics, founded as it is in the organic laws, therefore wonderfully perfect and harmonious in all the movements.

In short, the effort to explain this beautiful mechanism in the absence of the fundamental principle underlying it, is as futile as the attempt to *sit* upon nothing. Food requires room to be made for it, and you must permit the stomach and abdomen to expand *pari passu* with the ingoing of the ingesta in order to make this room; otherwise, the food could never be introduced and animal life would be impossible. All is

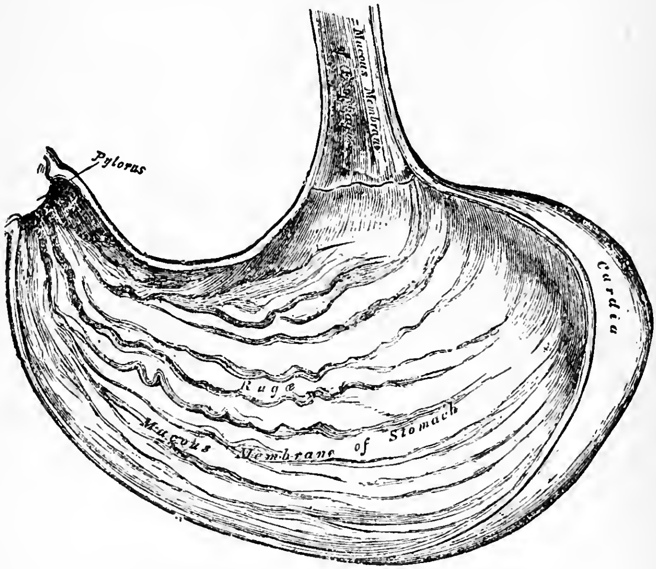

Fig. 63.—A Longitudinal Section of the Human Stomach, showing the *folds* in the mucous membrane.—Gray.

chaos in the absence of this law and what it involves. It is needless to extend the matter.

Concerning the Action in the Stomach.—Coming to the stomach, the first thing to engage attention is the anatomical dispositions in the mucous membrane, which contains the organs of secretion and absorption. In the empty or contracted condition of the stomach, the mucuous membrane is thrown into a series of longitudinal folds (Fig. 63), the loose areolar tissue connecting it with the adjacent circular muscles, which form a continuous cylinder through the whole length of the intestinal canal, admitting of this action in the mucous membrane, or, rather, compelling it, since it does not possess the same powers in expansion and contraction as the muscles; hence, when the organ becomes greatly contracted, as in the empty condition, this folding in the mucous lining occurs, while in the expanded condition, produced by inges-

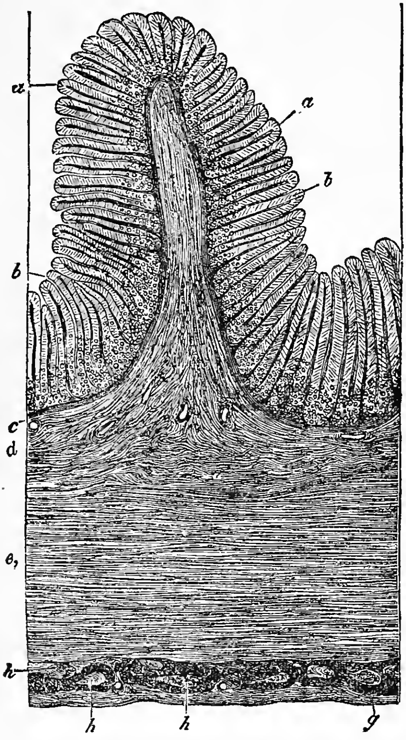

Fig. 64.—A Transverse Section through the Fundas of the Stomach in a Child.—Verson. *a*, *a*, cylindrical epithelium ; *b*, *b*, peptic tubes ; c, muscalaris mucosæ ; *d*, submucous tissue ; *e*, circular muscular layer ; *g*, peritoneum ; *h*, ganglia of Auerbach.

tion, they again apply themselves accurately to the muscles, causing the gland-tubes to stand erect and facilitating circulation and secretion correspondingly. The following beautiful cut, by a distinguished German microscopist, will serve for impressing the matter (Fig. 64). The great relative thickness of the circular muscles (*e*) is a conspicuous circumstance, while the loose areolar tissue is drawn into forcible extension by the folds in the mucous membrane. Of course, the secretions for dissolving the food should be compelled out of the tubes as fast as they are formed ; and looking to the secretory processes in these organs, then, it is readily perceived how this is materially assisted by the action in the circular muscles for compelling the contents in the cavity ; at the same time, additional force is put upon it by means of the finer adjustments that obtain in the *muscalaris mucosæ.*

Briefly, they are as follows: The peptic and mucous glands occupy a perpendicular position in the *mucosa*, the closed end resting against the circular muscles, with the loose connective tissue and *muscalaris mucosæ* between, in intimate relation with them, the open end at the free surface. The result of this arrangement is that, when the stomach contracts upon its contents (inclusive of the air it contains for increasing the action) it compresses them firmly against the mucous surface, tending to flatten this more and more, and so compelling the secretions into the stomachal cavity, constringing the glands and *milking* them, as it were, into the food to be dissolved. And being sandwiched, so to speak, between the muscles and the food, the open ends communicating with the latter, this action in the muscles could not otherwise than have that effect upon the glands. It must do so in the very nature of things. The movements which set in in the stomach as soon as food is introduced for disintegrating the boluses, would have the effect, then, of milking the secretions, the object being to bring the food into rapid contact with the solvents. But this, in turn, is supplemented by the force in the *muscalaris mucosæ* for increasing the action in the tubes. Thus numerous small fasciculi proceeding from the *muscalaris mucosæ* extend some distance up the tubes, crossing and interlacing around them, and so forming, as it were, a minute muscular envelope to this portion of the follicles for expressing the contents into the stomachal cavity. Hence, the most comprehensive arrangements obtain in the stomach for compelling the secretions into the food.

Finally, since the gland cells are contained in the thinnest of membranes (*membrana propria*) (Figs. 65, 66), it will at once be seen that mechanical force is necessary for effecting rapid expulsion of the secretions.

Concerning the Capillary Network in the Stomach.—In

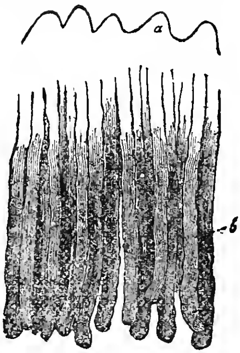

Fig. 65.—Vertical Section of the Human Gastric Mucous Membrane. *a*, ridges; *b*, peptic glands.—Frey.

Fig. 66.—Peptic Glands from the Human Stomach after Treatment with Alkalies.—Frey.

order to maintain secretion in correspondence with the amount of ingesta it calls for appropriate arrangements in the capillary network to the gastric glands, for increasing the blood supply, which ebbs and flows with digestion, and in correspondence with this being increased the moment that food is introduced, diminishing as it passes out of the cavity, and lowest during the interim.

The vascular turgescence which the stimulus of the food produces in the gastric mucous membrane (previously pale) has forcible illustration in injected preparations (Fig. 67, *A B*); but in order to fully understand the mechanics, it will be necessary to go a little deeper in the tissues passing through and through the membrane, for the purpose of getting at the network between the tubes as well, as also to obtain a view of the relations which they sustain to the arterial and venous systems, or the afferent and efferent vessels to the mucous membrane, which is given us in the following beautiful cut (Fig. 68) by that accomplished German histologist at Zürich, from whom we have borrowed so copiously. For example, it will be seen that the arterial feeder (*A*), in passing up between the tubes to reach the mucous surface, breaks up into a capillary network for feeding the gland cells in the tubes, continuing thence to the mucous surface, where each tubular orifice is surrounded by a vascular collar, while out of this telangiectatic plexus a great efferent vessel (*d*) carries the blood into the portal vein. This bird's-eye view will give some idea of the vascular arrangements over the entire surface of the gastric mucous membrane.

Now, then, we can readily understand how stimulation of the mucous surface by *springing open* the arterial feeder under the action of the special nervous ganglia should *at once* produce a rush of blood into the plexuses; the high pressure in the arterial system compelling this to be done the instant that expansion sets in, and which, of course, should increase the action in the gland cells correspondingly for maintaining this in due proportion with the quantity of ingesta. But the circumstance to which attention is directed more especially is *the great relative size* of the *efferent* vessel to the plexuses (*d*), and which is certainly needing explanation, since the amount of depletion to which the long-meshed capillaries are necessarily subject for supplying the gland cells before reaching the round-meshed network upon the surface would naturally lead one to expect the very opposite of this, or a small rather than a large efferent vessel. Nevertheless, we have this great vessel springing out of this last network; and since this can effect *no* action in the peptic glands—being at the free end of the tubes—it must have reference to *other important functions*, either absorption, or else to pour out gas in the intestine; most probably both are included. It will thus be seen from the arrangements that obtain in the parts, that rapid absorption is made inevitable from the very nature of things, dialyzable with non-dialyzable substances, otherwise inexplicable; notably, the rapid absorption of alcohol, which should *never* enter the circulation at all, nevertheless is rapidly absorbed;* since the high pressure, which

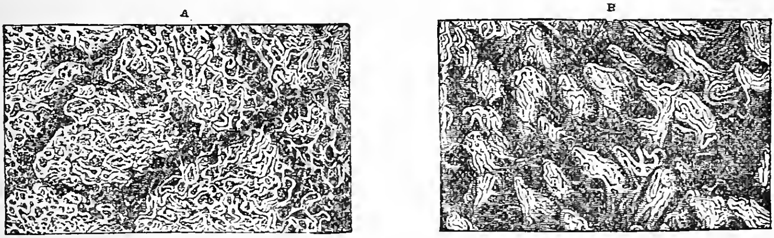

Fig. 67.—Appearance of the Lining Membrane of the *Stomach*, in an Injected Preparation. *A*, from the convex surface of the rugæ; *B*, from the neighborhood of the pylorus, where the orifices of the gastric follicles occupy the interspaces of the deepest portions of the vascular network.—Carpenter.

is produced in the stomach by means of the firm contraction in the circular muscles must inevitably have this effect upon the liquid contents, compelling them through the membranes. Furthermore, the necessity for such short and expeditious journey of the fluids to the blood, is made sufficiently obvious in the case of water, for the enormous demands in the nutritive processes and for maintaining a balance in body-temperature, which is accomplished

* "The rapidity with which alcohol is absorbed in the stomach is forcibly shown by the experiments of Dr. Percy, who found that when strong alcohol was injected into the stomach of dogs, the animals would sometimes fall insensible to the ground *immediately* upon the completion of the injection, their respiratory and cardiac movements ceasing within two minutes; and that on post-mortem examination in such cases, the stomach was nearly empty, while the blood was highly charged with alcohol." "Experimental Inquiry Concerning the Presence of Alcohol in the Ventricles of the Brain," p. 61.

by surface evaporation, would soon make it impossible to carry on circulation; hence, this open door for rapidly filling the vessels and the eagerness with which thirst is quenched. So, then, this circumstance, in the special anatomy of the organ, is strictly in accord with the physiological requirements, the results of daily experience and physiological experiment. Of course, absorption is in correspondence with the stimulus to action, and alcohol being a powerful stimulant, producing rapid expansion in the vessels, with energetic action in the

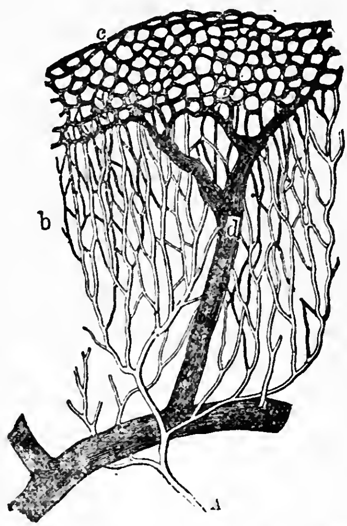

Fig. 68.—Vascular Network of the Human Gastric Mucous Membrane—half diagrammatic.—Frey. *A*, fine arterial twig, which breaks up into a long-meshed capillary network (*b*), which passes again into a round-meshed one (*c*) around the openings of the glands. From this latter the vein (the large dark vessel) takes its origin.

muscular walls, which contract firmly upon it, the most favorable conditions would obtain for compelling rapid absorption, the great tenuity of the liquid also favoring it. Indeed, every one knows the liquids are rapidly absorbed in the stomach, while the mechanics is sufficiently obvious, the force in the muscular walls being available for this purpose. Finally, another important fact remains for mention, notably the air secreted in the cavity, passing out through the surface capillaries; a quantity of air being also ingested with the food, and which assists in distending or ballooning the organ, smoothing out the folds in the mucous membrane, and making the force in the walls available in the work of digestion and absorption ; at the same time acting mechanically for effecting rapid disintegration of the boluses. The oxygen carried in with the atmosphere passes into the blood through the plexuses—a remnant of the old or primitive method of respiration ; while carbonic acid passes out of the blood into the stomach in large quantities, for *increasing pressure* in the organ, the force in the arterial system at the same time aiding it. And not carbonic acid only, but nitrogen as well. the two gases being thus poured into the stomach and the other portions of the intestinal canal from the surface capillaries during digestion, the mechanics being fundamentally the same throughout, and which is regulated by nervous force so as to maintain a given amount of pressure in the canal and the cavity of the abdomen. Moreover, it would explain the following well-known facts, otherwise inexplicable ; notably : 1st. The function possessed by the intestines of rapidly secreting air, which is proven to demonstration by drawing out a loop of intestine, isolating it by ligature, freeing it of its contents, and returning it again to the abdomen, the collapsed walls soon becoming distended, as previously.

2d. It would account for the disappearance of carbonic acid and nitrogen in respired air. For example : the carbonic acid expired does not represent the chemical equivalent of the oxygen inspired ; also, that an amount of nitrogen disappears ; while both are contained in arterial blood and are present in large quantities in the intestines, especially during digestion, which they serve to expedite by their mechanical action, and increase the absorptive processes correspondingly, as before remarked.

Finally, it would explain the rapid evolution of gas in the intestines produced by a vegetable diet, which is harder to digest than one of meats ; also, why the condition of colic can be induced by substances that resist digestion. and which stimulate an over-production of the gases, leading to distension and pain. And that this is not due to fermentative processes, is proven by the fact that the gases, when liberated—as I have done by means of a trocar and canula in the horse—are perfectly free from any odor of putrefaction or fermentation; in fact, nearly odorless.

Also, the rapid evolution of the gases in dyspepsia, hysteria, etc., in which they are poured out with extraordinary rapidity, producing enormous distensions of the abdomen in the shortest space of time.

Furthermore, the power to secrete air to subserve other uses than those immediately connected with the digestive and absorptive processes is seen in the air-bladders of fishes, by means of which they buoy themselves in the media, raising and lowering the body readily to any depth by simply expanding the air-sacs and body-walls, thereby diminishing or increasing body-density, according to whether they desire to ascend or descend, as the case may be; at the same time, they expedite it by the action in the fins and tail. Another application of the principle is seen in the eggs of birds, etc., in the formation of an air-chamber (Fig. 141), by means of which the rhythmical changes in pressure can be made within the egg, in connection with the actions in the heart, etc, otherwise impossible. Finally, we have this latest application in the intestines for expediting the digestive and absorptive processes in the mammalia, of which we have been speaking.

Concerning the Movements in the Stomach.—According to Beaumont, soon after digestion sets in the stomach becomes divided by a circular constriction into two distinct compartments, in which the action differs; the rhythmical contractions and expansions in the cardiac end being slow and gentle, while in the pyloric they are more rapid and energetic.

This division in the organ is produced by a firm contraction of transverse muscular fibres near the pyloric end, the smaller compartment occupying about one-third and the large about two-thirds of the organ; while between the two ends a constant current of the fluids is maintained, by means of which the boluses are soon disintegrated and penetrated in every portion with the gastric juices. "As the alimentary bolus enters the stomach by the cardiac opening, it turns to the left, descends into the great pouch, and follows the great curvature to the pyloric end. It then returns to the cardiac orifice by the lesser curvature, and takes again the same course as before.

While these revolutions, so to speak, of the alimentary mass are going on, the food is turned over and over, so that it becomes intimately mixed with the digestive fluids and subjected to a certain amount of trituration." "When the thermometer bulb arrived at the contracted septum, which was three or four inches from the pyloric end, it was at first stopped by the forcible contraction; but in a short time there was a gentle relaxation, which allowed it to pass, when it was drawn quite forcibly for three or four inches toward the pyloric opening When in this portion of the stomach, the bulb was firmly grasped and made to undergo a spiral motion; and if drawn forcibly out, it gave to the fingers the sensation of being held by a strong suction force. As soon as relaxation occurs, the bulb is passed back to the seat of stricture, and, when pulled through this, it moves freely in the great cavity Each of these revolutions occupied from one to three minutes. They were slower at first than after digestion had been somewhat advanced."

These graphic excerpts of practical observations made upon the stomach during digestion would leave no doubt, then, of the mechanical principle which applies for increasing digestion and absorption, namely, *rapid rhythmical changes in pressure*, the alternating contractions and expansions in the two ends serving to maintain a current of the viscid chyme through the limits in the organ, but all the while flowing from high to low pressure, in conformity with organic law. When contraction sets in, however, the sudden reversal of the current which this effects produces the spiral motion—a miniature whirlpool, as it were—while the suction-force spoken of was simply a pulling-force produced by the current setting into the compartment and the energy of the contraction twisting the current upon itself, and, of course, pulling the bulb along with it. As soon as expansion is effected, however, this restores the horizontal line again, when the current, deflected by the opposite wall, simply carries the bulb back to the seat of constriction. It is all simple enough.

When the bolus enters the stomach, it, of course, falls into the surface current which sets into the great *cul de sac*, the force in the muscular contractions in the pyloric end, by reason of greater energy, producing this surface current; while "the food is turned over and over" by reason of the deeper current setting in the opposite direction along the floor of the organ into which the boluses project, and, of course, causing them to turn over and over. Furthermore, it is also easily perceived, from the nature of the mechanical adjustments that obtain in the gastric glands and capillaries, that secretion and absorption are maintained in correspondence with the *churning-action* in the stomach. I do not see necessity for adding another word, the matter being so obvious. Something might

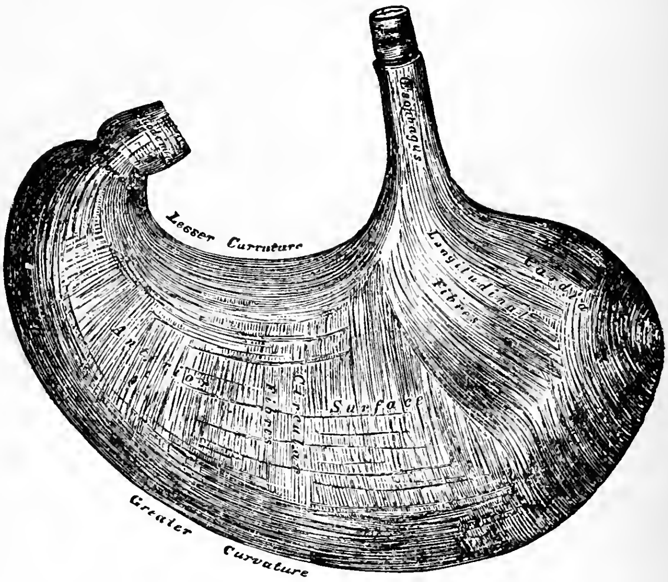

Fig. 69.—External Muscular Fibres in the Stomach.—Gray.

be said, however, in regard to the muscles in the walls of the stomach, which is the real force in digestion and absorption; as it is through them the rhythmical changes in pressure are produced. They are nearly all circular muscles (Figs. 69, 70); with these exceptions, however, that upon the external surface scattering longitudinal fibres extend along the sides, and greater and lesser curvatures (thicker in these two localities), with a thick fan-shaped layer spread out over the upper portions of the great *cul de sac* formed by the longitudinal muscles in the œsophagus (Fig. 69); while upon the internal surface we have a wide, thin layer of longitudinal muscles, embracing the great *cul de sac* and extending some distance toward the pyloric end, but fading out, however, and disappearing upon the sides of the organ (Fig. 70). The firm constriction near the pyloric end is, of course, produced by the contraction of a band of circular muscles, as are also the rhythmical contractions and expansions in the two ends, while the longitudinal fibres in the great *cul de sac* should greatly expedite the pumping action by compelling the contents toward the pyloric end during their contraction, since it must

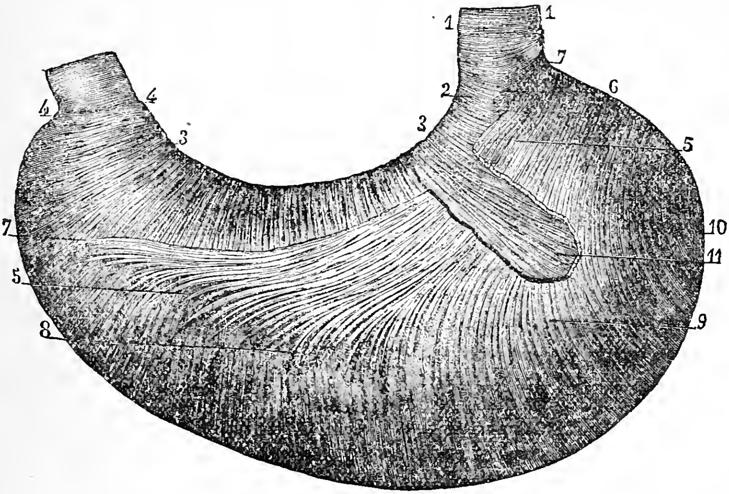

Fig. 70.—Fibres seen with the Stomach Everted.—Sappey. 1, Œsophagus; 2, circular fibres at the œsophageal opening: 3, 3, circular fibres at the lesser curvature; 4, 4, circular fibres at the pylorus; 5, 5, 6, 7, 8, oblique fibres; 9, 10, fibres of this layer covering the greater pouch; 11, portion of the stomach from which these fibres have been removed to show the subjacent circular fibres.

inevitably effect a corresponding shortening in the longitudinal axis of the organ. One result of the circular constriction would be to shorten the longitudinal fibres embracing the *cul de sac* (Fig. 70, 5, 6, 7, 8); at the same time, by giving them a firm point to contract upon, would make their action upon the *cul de sac* still more effective for compelling the contents toward the pyloric end, while the greater number of the circular muscles in this end, together with the diminished area, should increase the energy in the rhythmical expansions and contractions correspondingly, increasing the frequency and force of the pumping actions in this end for compelling movement in the contents.

In this manner, then, muscular force is so distributed as to make it effective upon every portion of the gastric contents for compelling rapid digestion and absorption, the energy of which is, of course, regulated by nervous force, while this in turn is determined by the requirements in the organism. Furthermore, we can also readily understand how the mechanical action in the *air-cushion* should increase the *churning-action* correspondingly, since the immediate result is a great gain in space in which to effect it; at the same time the air serves for disintegrating the boluses by *transmitting the force in the muscular walls upon them.* In fine, the air is a great and essential factor in the mechanics in the abdomen.

Concerning the Action in the Small Intestines.—The mucous membrane of the small intestines is more complicated than that of the stomach; but we shall pass over the more prominent features as rapidly as we can, for the purpose of showing the principle in the mechanics and the great rôle which is performed by the muscular cylinder. Beginning with the duodenum, we have the mucous membrane arranged in crescentic folds [*valvulæ conniventes*] (Fig. 86), which continue throughout the jejunum and into the ileum to about the middle portions, where they fade out and disappear. They extend about one-half to three-fourths around the cylinder, springing from every portion of the circumference, the evident object being for increasing the secretory and absorptive processes, at the same time providing for free action in the muscles or peristalsis; but in contraction they are made more prominent. Through the rest of the ileum it is smooth, and in the large intestine is evenly applied over the surface of the sacculi; while in the *rectum* it is again thrown into longitudinal folds, as in the œsophagus and stomach, as the necessary provision for effecting the wide expansions which occur in this pouch, which functions as a receptacle for the fæces before final expulsion. The three valvular folds corresponding with the upper, middle and vesicle portions tend to delay the onward movement, as in the sacculi of the colon, at the same time increasing the absorptive surface; while the arrangement that obtains at the ileocæcal valve serves for obviating reflux in the small intestines.

The following diagram will give some idea of the arrangement of the glandular structures in the duodenum (Fig. 71). In the so-called *Brunner's* glands (*c*) found in the duodenum only—in the upper portions especially—we have a group of *open gland vesicles* of microscopic dimensions, flask-shaped, with short necks, that discharge their contents through an axial canal; and are simply transitional forms of the simple gland tubes that have coalesced near the blind ends, forming a new anatomical unit, or a so-called *racemose* gland (Frey). In the compound peptic glands the same circumstance is seen, only that coalescence occurs higher up the tubes and nearer

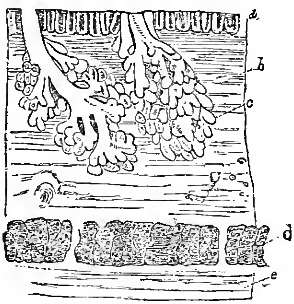

Fig. 71.—Vertical Section of Mucous Membrane of Duodenum, showing Brunner's glands. *a*, Follicles of Lieberkühn ; *b*, cellular coat of intestine ; *c*, Brunner's glands ; *d*, annular fibres of muscular coat ; *e*, longitudinal fibres of muscular coat.—Wilson.

the mucous surface, is also limited to several tubes only ; here a whole group coalesce.

They secrete a clear alkaline mucus, free of form elements. Arranged around the central canal as foot-stalk, they bear striking resemblance to a bunch of grapes (Fig. 72). The relations they sustain to the bases of the villi is shown in the following cut (Fig. 73). The simpler forms, however, are seen in the crypts or follicles of *Lieberkühn* (Fig. 71, *a*), arranged perpendicularly to the surface, upon which they open by circular apertures, and occupy the whole free surface of the small and large intestines, opening around the bases of the villi and the solitary glands. Their walls, however, are exceedingly thin, at times nearly indistinguishable from the surrounding tissues

(Fig. 74). The contents of these crypts, unlike those of *Brunner's* glands, consist of delicate, columnar, nucleated cells (a), with the bases resting against the membrana propria,

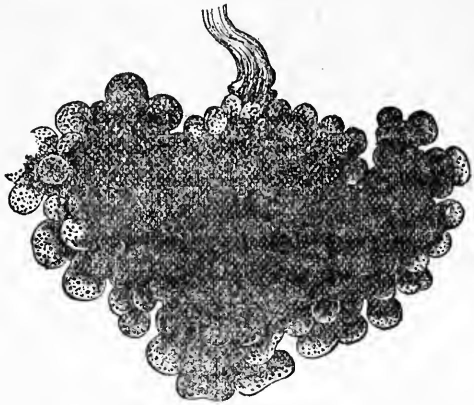

Fig 72.—One of *Brunner's* Racemose Glands, from the Human Being.—Frey.

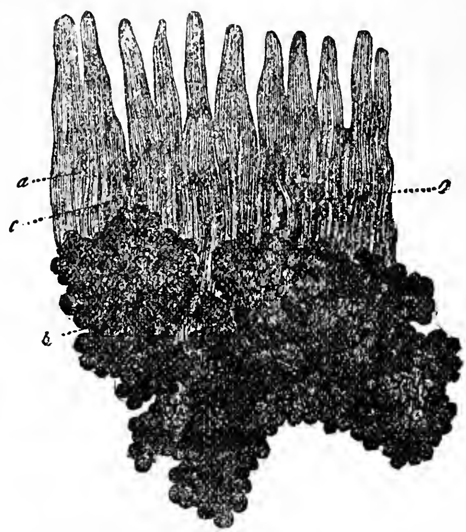

Fig. 73.—*Brunner's* Glands, from the Duodenum.—Frey. *a*, Villi ; *b*, bodies of glands ; *c*, excretory canal opening between the villi.

the apices presenting in the crypt (Fig. 74, *K*; Fig. 75, *d*). These, together with the axial canal, may be seen in every transverse section (Fig. 75, *d*). According to *Schulze*, between these cells other goblet cells may present themselves (Fig. 76, *a*). They were thought to be confined to the surface of the villi. While the orifices of the Lieberkühnian follicles are neces-

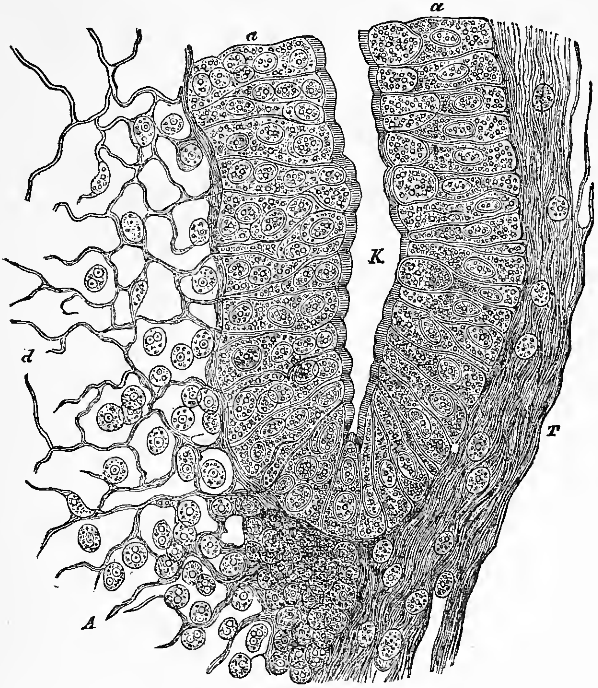

Fig. 74.—Follicle of *Lieberkühn*, greatly magnified.—Verson. *K*, follicle ; *a*, *a*, epithelium ; *d*, adenoid tissue, from which the cells have been removed by penciling ; *T*, fibrous tissue on the opposite side.

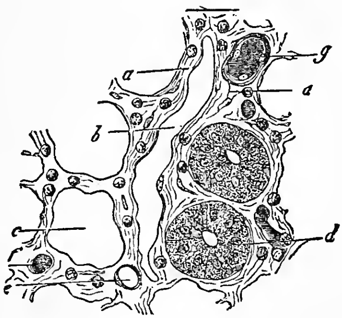

Fig. 75.—From the Small Intestine of the Rabbit; *a*, Tissue of the mucous membrane ; *b*, lymphatic canal ; *c*, an empty transverse section of a gland of *Lieberkühn ; d*, another of the same occupied by cells.—Frey.

sarily separated by the villi, the tubes dilate beneath them in such manner as almost to bring them in contact, leaving only small interspaces for the passage of vessels and muscular fasciculi. Finally, we have to mention the *lymphoid follicles* or *glandulæ solitariæ*, that are scattered over the mucous membrane of the small intestine, and when agminated forming *Peyer's patches*, and which are analogous to lymphatic glands. They are situated either in the tissue of the mucous membrane, or, when of considerable length, project down into the submucosa, as occurs in Peyer's patches, in which the bases of the follicles are approximated to the circular muscles, while the apices project upon the mucous surface surrounded by villi, the fibres of the *muscalaris mucosæ* being separated and pushed aside by the enlarged follicles (Fig. 77, *m*, *S*, *K*). They are ductless glands, and the means for

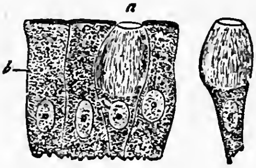

Fig. 76.—Epithelial Cells from a Human Intestinal Villus (after *Schulze*). *a*, Goblet cells ; *b*, ordinary elements.

increasing circulation in them and for compelling out the secretions possesses special interest.

They occur *opposite* to the attachment of the mesentery, consequently their caps are kept constantly submerged in the intestinal fluids, gravitation compelling this circumstance; are from one to three inches in length and about an inch in breadth, are covered with villi, and the Lieberkühnian follicles form a circle around them ; are more numerous in the lower portions of the ileum, while they vary from twenty to thirty, and even more, in number, becoming less and less, however, as age advances. The usual number of follicles in a patch is from twenty to thirty, but they vary from as low as three to seven, while the large patches may contain from fifty to sixty (Frey). The following illustration will show the character of the mucous membrane in the large intestine, and the relations it sustains to the circular muscles (Fig. 7~).

The crypts of Lieberkühn continue, but the villi extend no further than the free border of the ileo-cæcal valve. It presents the same structure and arrangement of its constituent parts as the small intestine, of which it is a direct continuation. Now, then, the point to which attention is specially directed concerns the action in the muscular cylinder in which the mucous membrane is placed. From the nature of these

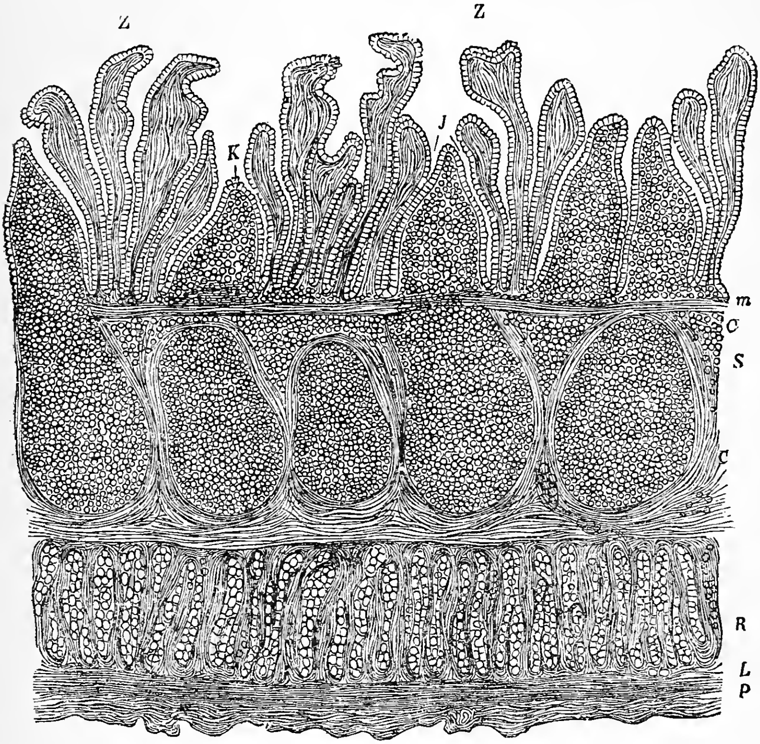

Fig. 77.—A Longitudinal Section of the Small Intestine of a Rabbit, through a Peyer's Patch (*S*).—Verson. *Z*, *Z*, villi ; *J*, follicles of Lieberkühn ; *K*, cap of a gland ; *m*, muscalaris mucosæ ; *C*, *C*, submucosa ; *S*, glands of Peyer ; *R*, circular muscles ; *L*, longitudinal muscles ; *P*, peritoneum.

anatomical dispositions in the mucous membrane, and the mechanical adjustments that obtain in the intestine, it follows that contraction in the muscles must have the effect of forcibly compressing the gland follicles and lymphoid follicles (Figs. 71–78), and compelling the secretions out of them, gently but effectually constringing them, and milking them, so to speak, of their contents by means of the uniform compression exerted through the elastic air-cushion under the energy in the muscles.

Sandwiched as they are between these forces, with the muscles as the firm floor of support, the cushion pressing against them, it could not otherwise than have this effect upon the glands. It at once settles the matter. The air is *in* there and it *cannot get away*, and the muscles certainly *contract;* the rest follows as an inevitable sequence. Now, then, to this must be added the fine adjustments in the muscularis mucosæ,

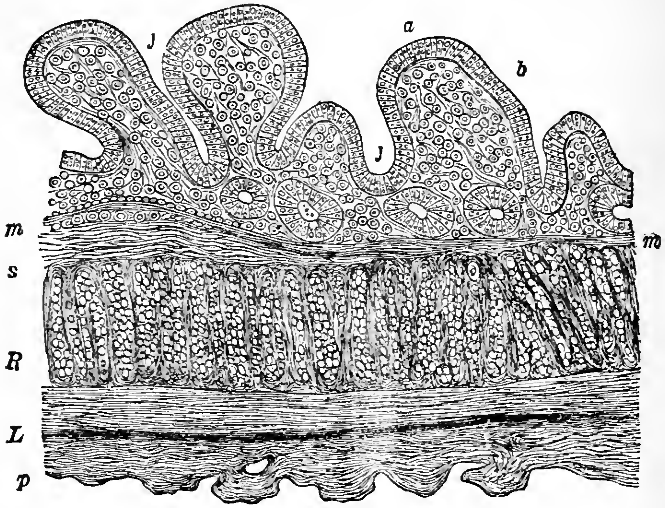

Fig. 78.—Section of the Large Intestine of a Rabbit. *J*, crypts of Lieberkühn; *a*, epithelium; *b*, mucosa; *m*, muscularis mucosæ; *s*, submucosa; *R*, circular muscular layer; *L*, longitudinal muscular layer; *p*, peritoneum.—Verson.

and the thing will be complete. It must be borne in mind that the viscid secretions are difficult to move; hence, force must be applied *directly* to the follicles, which is done by means of small muscular fasciculi extending from the muscularis mucosæ between the acini of Brunner's glands and between the follicles of Lieberkühn; but are much more numerous in the villi, running upward into the parenchyma, so as to form the wall of the central lacteal (Fig. 98, *m*, *l*).

This, together with the force in the circular muscles, exerted in the manner as stated, compel the secretions out of the follicles. It now remains to take up the work of absorption, for which these adjustments are equally effective, bringing out, however, some fresh features in the mechanics which are extremely beautiful and charming to look upon. There is nothing more wonderful than animal mechanics.

The following illustration will give some idea of the general appearance of the mucous membrane of the small intestines (Fig. 79). By means of the villosities, together with the crescentic folds in the membrane, the mucous surface is enormously increased; but the former have more to do with the absorptive processes simply, though, by reason of the special

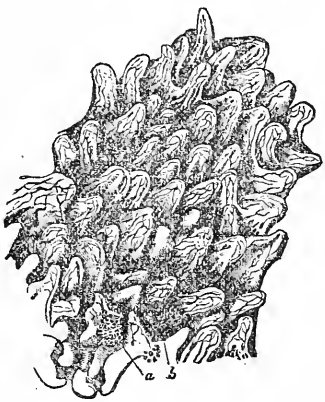

Fig. 79.—Portion of the Mucous Membrane of Small Intestines, showing the villi and the apertures of the simple follicles, magnified 19 times.—Wilson. In the hollows between the villi are seen the apertures of simple follicles (*b*); and near the bottom of the figure is a zone of follicles (*a*) surrounding a solitary gland.

capillary arrangements which obtain around the outlets to the follicles of Lieberkühn (Fig. 80, *d*), or the same as obtains in the stomach (Fig. 68, *c*), absorption goes on quite actively, independently of the villi; only that it is not so rapid as in the stomach, for the vascular network is not so extensive, the greater portion of the capillaries going into the villi And it will be seen that here also there is a great contrast in the *size* of the arterial feeders and the discharging vessels or veins (*a*, *c*), the veins being out of proportion to the arterial feeders, the import of which has already been stated. Now, then, between these vascular loops and the liquids to be absorbed is the layer of columnar epithelium; and the question before us concerns the manner this barrier is passed, or how fat, albumen and other non-dialyzable substances effect a rapid passage into the interior of the cells, the membrane (*membrana propria*) beyond, and so get into the interior of the villi to the capillaries and central lacteal. Furthermore, keep the fact in mind that the fat is simply emulsified, *not* saponified, while albumen passes in freely *unchanged*, especially when given in large quantities, thereby showing conclusively the existence of a mechanical force for compelling them through the membranes; otherwise is inexplicable. This mechanics is

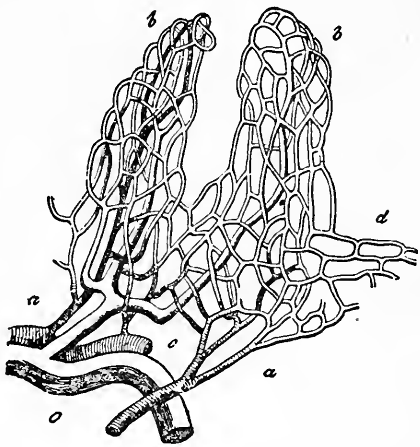

Fig. 80.—Vascular System of an Intestinal Villus in the Rabbit. *a*, The arteries (shaded), breaking up first into a capillary network around the glands of *Lieberkühn* (*d*) ; *b*, network of capillaries in the villus ; *c*, venous vessels (unshaded).—Frey.

also easily understood. Thus, the columnar epithelia are covered by a perforated lid of thickened epithelium (Fig. 81, *a*, *b*), which acts as a sieve or colander for straining the chyle, while the muscular cylinder contracts for forcing it into the epithelia, whence it is passed in due time into the parenchyma of the villi, and compelled thence into the capillaries and the central lacteal, the coarser particles passing by the vessels into the latter, which functions as a drainage system to the villi. The lids fit neatly over the surface of the cells, and being in close apposition and firmly consolidated by animal cement, which fills up the interstices

(Fig 82, *b*), present an appearance not unlike a mosaic pavement (81, *b*). But when macerated in water, they are easily loosened by pressure (Fig. 82, *a*) ; the splitting up of the lids through the perforations giving them the appearance of cilia, is a result of post-mortem changes in the cells. Thus constituted, then, the force in the muscular cylinder is readily brought to bear for compelling the liquid aliment into those myriads of little organs (each one of which may be regarded as a distinct gland in itself) that are spread out like a sheet over the external surface of the villi for effecting further metamorphosis upon the aliment, thence into the parenchyma of the villi, thence into the vessels, as before stated ; the structures in the villus—epithelium, blood-capillaries, and central lacteal embraced by its special muscles (Fig. 98, *l*, *m*), all acting together and in harmonious concert with the force in the muscu-

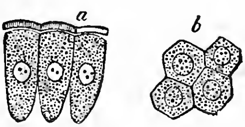

Fig. 81.—Columnar Cells from the Small Intestine of the Rabbit. *a*, Side view of cells with thickened raised lids traversed by pores ; *b*, view from above, in which the orifices of the pores appear like dots.—Frey.

lar cylinder for compelling rapid absorption. This additional force in the fine adjustment spoken of in the muscularis mucosæ must necessarily increase the action, since the rhythmical contractions and expansions in the muscular fasciculi that penetrate the parenchyma and form the wall of the central lacteal, could not otherwise than have that effect, must do so, in the very nature of things, acting as a little suction-pump and increasing circulation in the vessels correspondingly. And with high intra-intestinal pressure produced by the muscular cylinder and the gases in the intestines, together with this pumping action in the villi, absorption should go on very rapidly, as a matter of course ; while the rhythmical expansions and contractions taking place in the gut itself, diffusing the aliment over the mucous surface, at the same time increasing pressure should increase the action correspondingly. And through these combined actions in the organ effected by means of nervous force, we can very readily understand the rapid absorption of non-dialyzable substances, otherwise inexplicable. Nay, how even particles of finely-divided charcoal may present in the mesenteric veins (Oesterlen); and why similar results have been obtained by Eberhard, Mensonides, and by Donders, not only with charcoal, but also with sulphur, and even with starch, the latter substance being at once detectable in the blood by the iodine test. Furthermore, there can be no doubt but that they enter the circulation through the epithelial cells of the villi, as the presence of psorosperms in the interior of these has been distinctly seen (Klebs); while they are nearly double their size soon after digestion sets in, and of a milky appear-

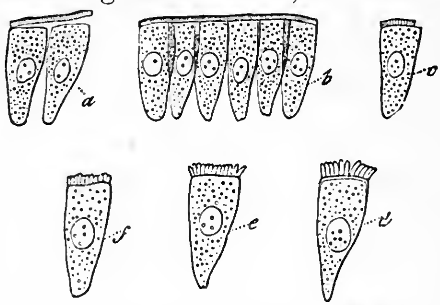

Fig. 82.—The same cells. At *a*, the border is loosened by water and slight pressure ; *b*, natural condition ; *c*, a portion of the lid destroyed ; *d*, *e*, *f*, the latter is resolved into a number of rod-like or prismatic pieces, by maceration in water.—Frey.

ance from the quantity of fat they contain ; and that fat enters the blood-vessels also, as well as the central lacteals, is proven by the opalescent whiteness of the superficial capillary network, and the quantity of fat contained in the portal veins, fully one-half the fat being taken up by the veins.*

And with all these muscles in the gut, the fine with the coarse adjustments that obtain, the nerves for operating them, together with the air-cushion as the lever for effecting the changes in pressure upon the contents, no reason on earth presents why absorption should not be very rapid. And the miserable device which comes to us as a suggestion by a prominent English microscopist, that the fat finds its way to the central lacteal by passing *between* these cells, cannot be entertained for a single moment even ; since this would pass it

* Zawilski, Ludwig's *Arbeiten*, 1876, p. 147.

through the long line of cement binding these minute organs together, and should undermine the very foundations of this beautiful structure; while it would leave unexplained the rapid absorption of fat by the blood vessels, together with the entire anatomy in the gut as means to ends. What! The chief force-producer burrowing under the foundations in order to get into the building? *Nein! Nicht zu glauben!* Never under the canopy of heaven but by the public way through the open front-door—*i. e.*, the sieve-like openings in the epithelium—with the force in the muscles, the fine and coarse adjustments for assisting the passage. The one explains everything; the other explains nothing, which at once exposes it. Besides, we positively know the fat enters the cells very rapidly, so that they soon become twice the size in the empty condition, and the fat is easily detectable in the milky appearance it imparts to the cells. For increasing the action we have only to increase pressure in the cavity by contracting the muscular walls of the gut, at the same time increasing the action in the villi, the whole performing as a single organ only for pumping the fluids into the vessels. Hence the *slow* and *sustained contraction* which follows peristalsis. And with the anatomical dispositions which obtain in the organs and the mechanical principle which applies for increasing circulation, no reason presents why digestion and absorption should not be made commensurate with the physiological requirements. This explains everything; whereas the old method explains little or nothing—nay, is pitiful in its utter helplessness and power to help itself; vainly groping in the tissues with the microscope in search of the key to the vexed problem, *not* to be found with the microscope, but in the organic law itself underlying animal structure. And from this stand-point the whole mechanics in the animal circulation is at once made intelligible, from the cell itself to the cell-empire, the multitudinous arrangements in the structures falling readily into line in regular order and succession. But in the absence of this law of pressure and fluid equilibrium, which is being thus incessantly invoked in the measure of the physiological requirements, all are inexplicable, all is chaos.

CHAPTER X.

RESPIRATION AND THE PORTAL CIRCULATION

Circulation in the Liver Dependent upon Respiration—Mechanics in the Diaphragm and Walls of the Abdomen Respecting it—The Mesentery a Soft, Elastic Cushion for Effecting Gentle Compression of the Liver-Substance, under the Action in the Diaphragm and Walls of the Abdomen during Inspiration for Increasing its Circulation—Mode of Demonstrating this Circumstance—Effect upon the Portal Vessels and Lower Cava-System—Absence of Valves in the Veins within the Abdomen, save in the Pelvic Viscera Only—Explanation for the Latter Circumstance—Physiological Anatomy of the Liver, with Reference to Circulation—Why the Hepatic Veins are *Incorporated* with the Liver-Substance—Relations of the Portal System to the Hepatic Viens—Why Rhythmical Compression of the Liver-Substance during Respiration should Increase Circulation in the Inter- and Intra-Lobular Vessels Correspondingly—Automatic Action in the Portal Vessels Synchronous with Respiration for further Increasing it—Mechanics for Circulating Bile—The Action in the Gall-Bladder and Bile-Ducts—The Action in the Duodenum, in Connection with the Biliary and Pancreatic Secretions—Adjustments in the Viscera Necessitated by the Action in the Diaphragm—Mechanics Connected with the *Openings* in the Diaphragm—Œsophagus Constricted during Inspiration, while the Vena-Cava Lumen is thrown *Widely Open;* as also the Aortic—Elongation and Contraction of Œsophagus with Inspiration and Expiration—Ditto Venæ Cavæ—Ditto Portal Vessels and Renal Veins—Similarity in the Anatomical Dispositions of the Muscles in these Organs.

Before taking up the nervous apparatus to the intestines, it will be necessary to make a rapid survey of the glandular appendages and the incidental adjustments rendered necessary by the action in the diaphragm; since the nervous apparatus effects coördination, to the end that the whole should work together harmoniously, without let or hinderance, within certain prescribed limits, that automatism may be maintained in the organs and structures, which is necessary to the existence of the organism. It is very comprehensive. But it is equally manifest that all of it is based upon pressure, and the power of producing rapid rhythmical changes in pressure for increasing circulation and compelling this to be in correspondence with the physiological requirements, which, of course, would include the secretions in the glands, with the arrangements for compelling them into the cavity of the intestine. For example, we can readily understand why the liver-substance is spread out, so to speak, upon the incurvated surface of the diaphragm, to which it is fastened by the overlying peritoneum (Fig. 25, *L*), and why it is itself excavated for receiving the abdominal viscera which rest against its surface, since this would favor the rhythmical compression of the organ during respiration for increasing circulation in it; at the same time promoting the secretory functions and metabolic processes in the organ, which are very extensive. There is a reason for all the arrangements that obtain. In short, the organ is sandwiched, so to speak, between two opposing forces, notably the diaphragm and muscles in the abdomen; while the intestines serve as a soft, elastic cushion for effecting the rhythmical compression under the force in the muscles during respiration, transmitting this upon it, and which, of course, increases its circulation correspondingly. And not this only, but all the other actions as well, inclusive of the intestines and the lymphatics or lacteal system and terminal duct. It also admits of easy demonstration. For this purpose a dog was chosen, and several hours after the animal had been fed it was dispatched, and the abdomen separated from the chest by division effected above the insertions of the diaphragm in the ribs, and was completed by severing the spine between the last dorsal and first lumbar vertebra, ligating the vena cava, œsophagus and thoracic duct for preventing escape of the contents. As will be seen, the abdomen separated from the chest forms an egg-shaped organ (Fig. 83), the large end of the ovoid looking anteriorly, or toward the chest; the small ending posteriorly in the pelvic basin in which it terminates; the differentiation of this bony compartment having reference to the crural supports for sustaining the posterior end of the trunk during locomotion, and of the body itself in the erect position, as in man. The cava (*B*), œsophagus (*C*), and aorta, with the accompanying duct (*D*), occupy the mid-region upon a line extendding from the sternum to the spine, with the cava a little to the right (left in the picture). And everything being ready, the stump of the cava was then snipped with a sharp pair of scissors. The blood spurted with great force out of the vessel, leaping ten feet, and as though shot out of a syringe, under the force in the abdomen; but was not sustained, falling down immediately upon the diaphragm in a running stream. I then placed my open hand upon the convexity of the diaphragm, pushing it downward in imitation of inspiration, when the jet was renewed instantaneously, rising and falling with the increase and diminution of the pressure; hence, there could be no doubt on earth that inspiration rushes the venous blood in the abdomen toward the lungs. Of course, a great deal of the blood had come from the lower cava system, rushing out of

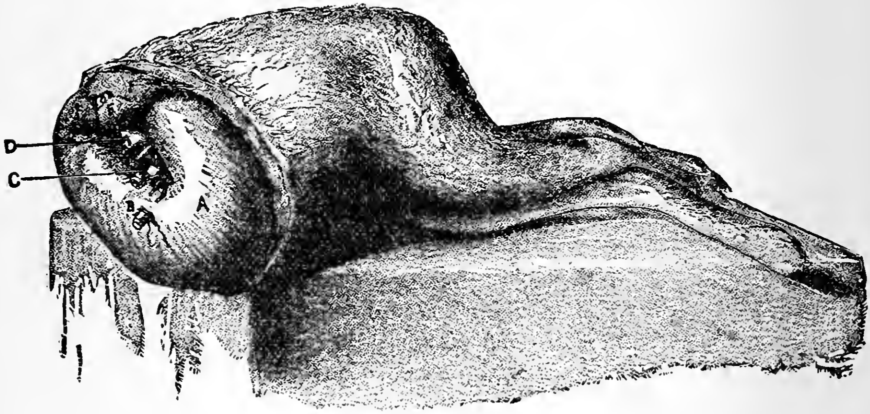

Fig. 83.—Transverse Section of the Trunk through the Inferior Margin of the Chest around the Circle of the Diaphragm, showing the form of the abdomen, which is egg-shaped, the large end of the ovoid presenting in the chest-excavation, the small in the pelvic basin, which forms the posterior end of the cavity. *A*, diaphragm; *B*, stump of lower cava, ligatured; *C*, œsophagus, ligatured; *D*, thoracic aorta and thoracic duct, ligatured; *E*, first lumbar vertebra; *F*, lumbar muscles (quadratus lumborum, etc.).

both under the action of the elastic air-cushion, while the force transmitted from the containing walls, in imitation of the action in inspiration, increases it. In the first instance, the intra-abdominal pressure of itself was sufficient for producing the jet, showing it to be considerable. It should be mentioned here that the valves in the femoral veins obviate reflux in the lower extremities, so that the systole in the abdomen produced by inspiration should act as a lifting force upon the blood in the venous system, as well as the portal blood, the two being affected simultaneously. (We may remark, *en passant*, that the presence of valves in the veins of the pelvic viscera has its explanation in connection with the special functions in these organs for obviating reflux during expulsive efforts which will come up further on.) In this manner, then, the abdomen functions as a great ventricle upon the venous blood for forcing it toward the lungs during inspiration. That there might be no mistake, however, about the portal blood and the blood in the liver, I introduced my hand through an opening in the linea alba and compressed, first one, then another portion of the liver; and every time I did this, and the moment I did it, the blood spurted out of the caval opening, showing conclusively, and beyond the shadow of a doubt, that inspiration increases circulation in the liver. Now, then, we can readily understand why the hepatic veins are fastened to the liver-substance, being incorporated with it for maintaining patency in the canals, as this would favor venous efflux during inspiration, the blood rushing out of every portion of the liver *directly* into the vena cava in place of converging in a common trunk, as in the usual way; the right, left and central portions emptying their blood *immediately* into the venous system. It is very pretty.

Concerning the Relations which the Portal Vessels Sustain to the Hepatic Veins for Producing Correspondence and an Uninterrupted Flow of Blood through the Liver.

Briefly, the portal vein is intercalated between two extensive capillary systems—one in the mucous membrane of the intestines, the other in the liver-substance; consequently, the force in the arterial system can have but little effect upon circulation in the liver, which must have other force applied to it for making it commensurate with the physiological requirements, and for maintaining correspondence with the absorptive processes in the intestines; otherwise impossible. This, as we see, is made dependent upon respiration for producing rhythmical compression of the liver, and which is supplemented by the action in the portal vein itself, which is very muscular, and connected with respiration by means of the rich, nervous plexuses embossing the vessels the same as the arteries, and, like them also, enabling an increase and decrease in the local actions by expanding and contracting the lumen, the portal vein dividing up in the liver exactly like an artery; moreover, are free to move by reason of Glisson's capsule, and not fastened to the liver-substance like the hepatic veins. In short, they possess automatism, and being intimately connected with the solar plexus and pneumogastric nerves, should greatly expedite circulation in the organ during respiration, at the same time it constitutes the fine adjustment in this mechanics in correspondence with the universal rule; otherwise, the local actions could not be carried on. In other words, the vessels have a separate sheath of their own in the liver, with the nerves extending over the vessels the same as in the cavity of the abdomen, and which certainly justifies this conclusion. Furthermore, we have seen that during inspiration a wave of contraction pervades, first the arterial, then the capillary, then the venous systems, which, of course, would include the portal vessels, no reason presenting why it should not do so, but every reason for it, bringing it in correspondence with the systemic current, which the scheme calls for. And since respiration is all-pervading, it is hardly to be doubted that such is the case. But this dependence of the portal circulation upon respiration calls for its check and balance also, in order to preserve equilibrium, which is furnished in the nervous plexuses that embrace the vessels, the strain to these, which is occasioned by over-distention, producing the reflex action for relieving it, and known as "sighing," which is simply an effort to relieve an overcharged portal system; in this manner exciting the reflex actions in the medulla oblongata, or the same as regulates the actions in the lungs and in the heart, the whole connecting through and through; otherwise, correspondence could not be produced for maintaining a balance in the circulation for conserving the functions. Its connection with mental causes is due to the fact that profound mental disturbance diverts nervous force from respiration for protracted periods, the blood in consequence accumulating in the portal vessels, till finally comes the deep and noisy inspiration for relieving it, which would also include the venous stasis in the systemic capillaries, as this, too, is dependent upon respiration. But any circumstance that should embarrass respiration, mental or mechanical, would soon produce over-distension of the portal vessels, and invoke this effort for relieving it. Hence, full diet, with sedentary habits, or tight corsage, as in the case of females, who are notorious for these sounds, preventing free action in the diaphragm, consequently producing engorgement, while free exercise and loose corsage are effectual remedies. It is very disagreeable, the more so because deceptive, since it suggests pain when none exists, and if the ladies should release the abdomen and burn up the infernal bandages, or put them on occasionally when they go from home, taking more exercise, too, we would hear no more from them in this direction. The whole trouble is in the abdomen, and freer respiration is needed for relieving it. But man has no monopoly of this action, since the very fishes, after remaining stationary for long periods, are seen to make this deep inspiratory effort, which compresses the viscera and flares open the opercula and branchiæ at one and the same time, for relieving venous stasis, the principle in the mechanics being fundamentally the same as in the higher animals, due allowance being made for the stage in development. The connection of the muscles in the abdomen with the lower jaw causes it and the opercula to fly widely open at one and the same time, when the abdomen contracts for increasing pressure, thereby increasing the action in the branchiæ, all the parts being fully coördinated in the medulla oblongata. The horse and ox, standing quietly in full digestion, are seen every now and then to take one of these deep inspiratory efforts, rocking forward so suddenly upon their feet as to rouse them from the doze. Anything which should hasten respiration, therefore, such as singing, laughing, talking or bodily exercise, would greatly expedite the portal circulation. Hence the trite saying "Laugh and grow fat" is a truism in physiology, since the effect of the former is to pump the portal blood and lymph into the systemic current and produce fullness in the vessels, which favors the nutritive processes and the formation of fat. It was a sharp, true saying. The effect of the rapid pumping action in the abdomen in reducing the volume of the portal blood has forcible illustration in the vocalist, who complains of "a feeling of emptiness in the stomach," and rushes to the restaurant to fill himself full again, eating ravenously to appease the appetite. The deep and long inspiratory efforts, followed by the long forced expirations, had literally emptied the portal circulation, as it were, also the viscera of the force-producing elements. In fine, for increasing the portal circulation it calls for rhythmical compression of the liver and portal vessels synchronous with respiration.

The following beautiful cuts (Figs. 84, 85) show the mode of termination of the portal vessels in the inter-lobular veins, and

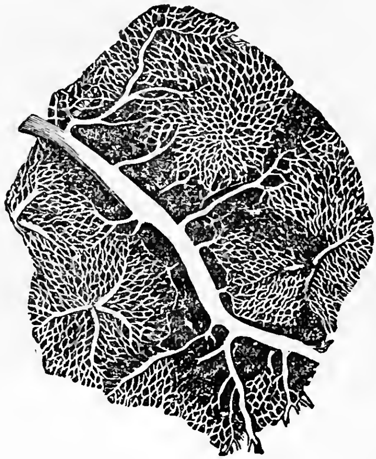

Fig. 84.—Rabbit's Liver Injected, showing a portal branch, the *venæ inter-lobulares*, the capillary network, and a *vena intra-lobularis* in the centre of a lobule.—Frey.

these again in the intra-lobular (Fig. 85, 3, 2, 1), or radicals of the open hepatic veins; so that one can readily understand why rhythmical compression of the liver should increase circulation in the venous channels, while the speed of the current thus produced would depend upon the energy in the respiratory rhythms. Of course, the action in the portal vessels should be considered as in connection with this, while the increase of pressure in the parenchymatous tissue promotes absorption, but increase in arterial pressure exerts no influence upon it (· enersich);* hence, rhythmical com-

* Ludwig's *Arbeiten*, 1871, p. 53.

pression of the liver during respiration is essential for expediting absorption in the liver for maintaining this in correspondence with the absorptive processes in the intestines; otherwise impossible. In this manner, then, the portal circulation is maintained in correspondence with the absorptive processes in the intestines and liver, the pressure produced by the gases, together with the respiratory rhythms, acting upon both alike for compelling this circumstance. In other words, the fluids in the parenchyma are pumped into their respective channels simultaneously with the fluids in the intestines.

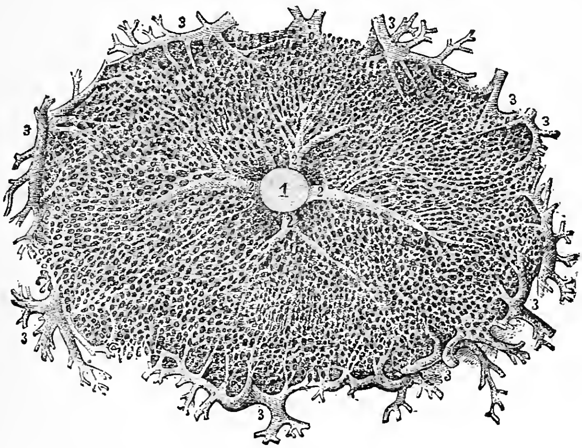

Fig. 85.—Transverse Section of a Single Hepatic Lobule.—Sappey. 1, Intra-lobular vein, cut across ; 2, 2, 2, 2, afferent branches of the intra-lobular vein ; 3, 3, 3, 3, 3, 3, 3, 3, 3, inter-lobular branches of the portal vein, with its capillary branches, forming the lobular plexus, extending to the radicles of the intra-lobular vein.

Finally, to this mechanics must be added the action in the heart, the diastoles in the right side serving to aspirate the hepatic veins, at one and the same time that they aspirate the venous system, the vessels also debouching in the cava close to the heart. whereby an uninterrupted flow is maintained in the organ, the same as in the lungs, but is not sufficient to make it uniform, the blood tending to accumulate during expiration ; and which affords opportunity for effecting metamorphosis, an amount of time being required for this purpose, which is also in correspondence with the action in the lungs—indeed, in every organ.

Concerning the Action in Bile.—Of course, the same mechanics apply for compelling the bile through the gall ducts as the blood through the hepatic veins, the force in respiration affecting both alike and simultaneously. But here also a special force applies for increasing the actions, and interesting anatomical dispositions obtain for separating the bile from the blood, which it would be as well to mention in this connection. According to Professor Hering, the gall capillaries or intralobular gall ducts do not run along the boundary walls of the liver cells, but are incorporated with them, blending with the walls in which they lose themselves, as it were; thus bringing them into intimate relations with the cell contents. Furthermore, that the blood capillaries occupy the spaces between the cells upon the *opposite* side, the cell-substance *intervening between* them, the effect of the arrangement being to isolate the gall capillaries, separating them completely from the blood capillaries; so that, when pressure is made upon the liver during inspiration, the blood passes in one direction, the bile in quite another, or opposite direction. It is very pretty.

Now, then, to this must be added the special adjustments in the ducts for compelling movement in the bile, which involves automatic action in this tubular system, the same as the portal vessels and hepatic artery, with which they are inclosed in Glisson's capsule, since they also require independent movement in connection with their special functions, or the power to expand and contract upon the contents, which, of course, is influenced by nervous force propagated from the intestinal mucous surface during digestion, for compelling the secretions into the duodenum, at once the purpose of this arrangement. But as the biliary secretion is going on all the while, we have a special arrangement in the gall-bladder for storing the bile in the interim of digestion; and this mechanics also contains several very interesting features. Thus, the gall-bladder occupies an elevated position against the liver-substance, to which it is fastened by an overlying layer of peritoneum and connective tissue fibres, while its neck is occupied by a spiral valve (Fig. 8), the whole whipped off to one side of the main hepatic duct. Hence, when the orifice of the duct closes during the interim of digestion the effect would be to cause reflux of the bile up the cystic duct, the force in the diaphragm compelling this circumstance. Muscles and nerves to the gall-bladder also. Why? As we have already said, muscles and nerves are the provision for producing force; hence, they must relate to the

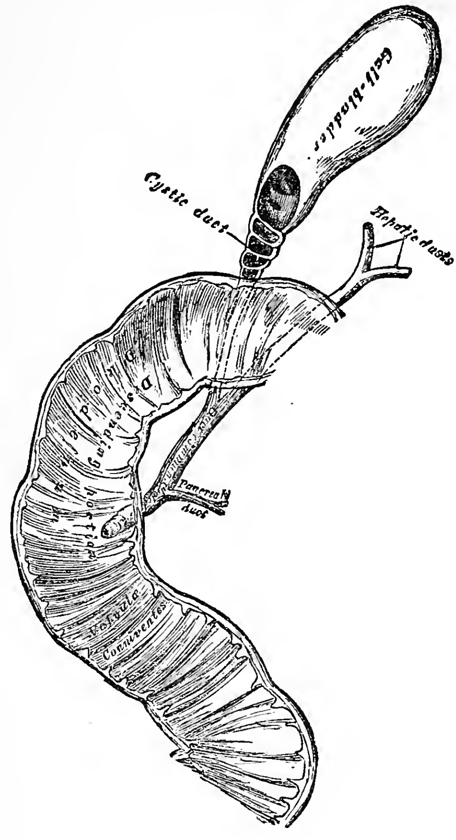

Fig. 86.—Longitudinal Section of Duodenum, showing the crescentic folds of the valvulæ conniventes, pancreatic, hepatic and cystic ducts, together with the spiral valve at the neck of the gall-bladder.—Gray.

bile, for compelling it into the cavity during the interim of digestion, and for compelling it into the intestines in correspondence with the functions in the latter, muscular and nervous force being applied all along the line for increasing the actions and producing correspondence; otherwise, this also would be meaningless. According to *Henle*, the coats of the gall-bladder are formed of layers of connected tissue, alternating with laminæ of unstriped muscles, the fibres crossing each other in all directions, the nerves for the most part springing from the solar plexus. It results from this arrangement in the parts that the gall-bladder, inclusive of the ducts, must be influenced by respiration and the local actions, being under control of the central nervous system and the local ganglia. And by looking closely into the mechanics, it is also easy to perceive how the action in the diaphragm should materially assist the ascent of the bile up the duct into the bladder. Notably, the gall-bladder is fastened to the liver while the terminal end of the common duct is inclosed in the walls of the duodenum, which is firmly secured to the spine by connective tissue, and the overlying peritoneum (for it would not do to have it sagging by the ducts); hence, the to-and-fro movements in the diaphragm with the mouth of the duct closed must produce reflux of the bile into the gall-bladder, the spiral valve serving to assist the action, at the same time that it functions as the floor of support. It follows, however, that the ducts must *contract* and *elongate* with inspiration and expiration in order to obviate strain, otherwise inevitable, since the diaphragm oscillates as much as two inches, and which could not otherwise than affect the movement of the bile. At the same time, we must remember that there is automatic action in connection with the flow, since the functions in the gut call for this, the sensory impressions produced in the mucous membrane by the food being transmitted to the special local ganglia for the purpose. It is all connected by nervous force for effecting coördination and producing correspondence in the local actions. The bile, then, flows down the ducts into the gut during digestion, responsive to the calls made upon it; while during the interim it flows up the cystic duct, while the bladder expands *pari passu* with the afflux, the same as the urinary bladder, or from sensory impressions in the mucous membrane produced by the bile. Hence, it is easy to perceive how it should become enormously distended with the bile when greatly in excess of the wants in the digestive processes; not that it is forcibly distended by the action in the diaphragm and gall-ducts, any more than the urinary bladder is distended by the action in the ureters and kidneys, which cannot be thought of; but that the organ expands till it can expand no more, and pain is produced by the traction upon the nervous filaments. We might mention here the existence of the close capillary plexuses in the mucous membrane of the gall-bladder, which would effect rapid absorption, so that the bile soon becomes thick and viscid; hence, cannot be retained long at a time without danger of becoming inspissated, producing gall-stones.

Concerning the Action in the Pancreas.—Taking up the circumstances in anatomy as we go along, the pancreas comes next in order, its duct emptying into the bile duct (sometimes opening independently in the gut), the separate secretions thus intermingling in the common duct previous to debouching in the duodenum (Fig. 86). Why the two fluids should be thus intimately admixed, bringing them together as speedily as possible before undergoing admixture with the chyme, must have reference to interchanges between them, whereby they gain in effectiveness, which would be the natural explanation; but what they are, chemical or otherwise, I am not prepared to say, only throwing out the suggestion that the circumstance gives rise to. The organ is conical in shape, the broad end or base, known as the "head," abutting against the gut, which bends around it, above and below, embracing it (Fig. 87), while the long, tapering body extends across the crura of the diaphragm behind the stomach to the spleen attached to the great end or *cul de sac* of the stomach, where it terminates in the tail. It results from this arrangement in the parts that the organ is rhythmically compressed during respiration, the same as the liver, both simultaneously, which should cause the secretions to flow out at one and the same time with the bile, and, like it, also flowing from high to low pressure, since the churning action in the duodenum connected with its functions must inevitably determine low pressure around the terminal duct with every expansion in the gut. Then, again, the churning action in the stomach itself should effect changes of pressure in the gland for promoting the discharge of the secretions.

Finally, we have to mention the automatism in the gland cells and discharging ducts, without which nothing could be accomplished in the secretory processes; while this in turn is connected with the action in the gut by means of the special nerves and ganglia for unifying and coördinating the movements, the same as the liver and bile ducts, whereby uniformity is produced throughout, otherwise impossible; the pancreatic secretions being controlled by sensory impressions in the mucous membrane, produced by the food, the same as

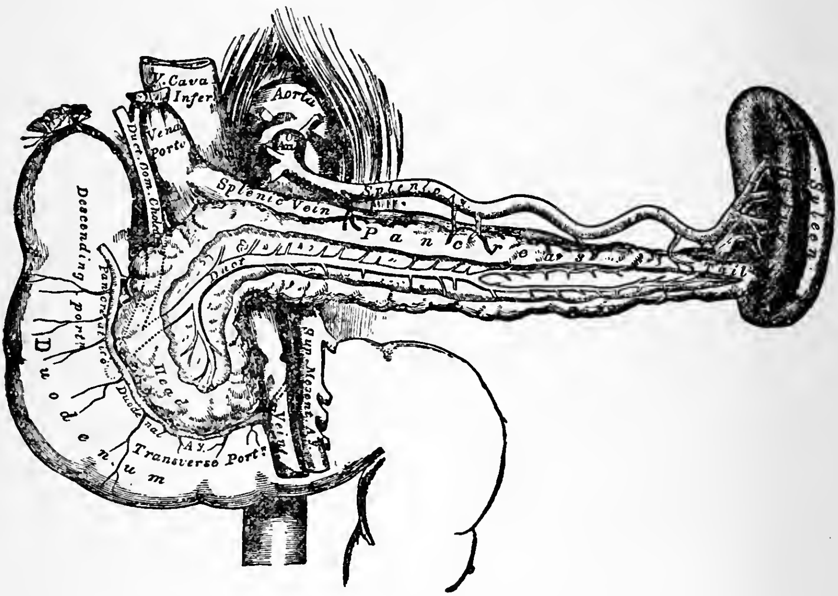

Fig. 87.—Pancreas and its Relations.—Gray.

the hepatic, and salivary glands with which it is homologous, the structure being the same or racemose. All of which is plain enough.

Concerning the Action in the Spleen.—That the spleen possesses certain powers of expanding and contracting in connection with the functions in the organ, there is small room for doubt, for the following reasons—namely: 1. The investing capsule forming the framework of the organ (giving off the cords or trabeculæ, in which the parenchyma or splenic pulp is situated—being traversed and inclosed by the trabeculæ—and passing in at the hilus with the vein and artery, incloses them also) is homologous with arterial structure, being composed of fibro-elastic tissue and muscles. Elastic tissue fibres are abundantly intermixed with connective tissue fibres in the outer or external portions of the capsule, while the deeper or internal portions are rich in unstriped muscle fibres, which are interspersed with the cords or trabeculæ through the parenchyma, and being inserted into the walls of the veins with which the trabeculæ are incorporated, it is manifest that contraction of those fibres would have the effect of flaring open the veins, and expansion the oppposite effect; while contraction of the envelope itself should condense the spleen and drive out the blood in the veins, expansion would have the opposite effect. But with the actions coördinated would make it still more effective for compelling the venous blood in and out of the organ; and the terminal ends of the veins being open, the whole cell-structure, the lymphoid follicles, and Malpighian corpuscles are thus bathed in the portal blood brought into them by this action in the gland. In short, there must be some reason for the presence of elastic-tissue fibres and muscles in the gland, and the special relations they sustain to the veins.

2. The walls of the veins, where they enter the hilus, and for some distance in, are very thick and dense, by reason of being incorporated with the trabeculæ, blending together; while in the case of the artery and its branches, the walls are *not* joined to the trabeculæ, but the vessels are contained in a loose sheath of areolar tissue, thus allowing free action in them, which is essential to the life in the cell-broods of the lymphoid follicles and Malpighian corpuscles, enabling them to increase or diminish the supply of arterial blood for maintaining the life that is in them, and fulfilling their proper functions; increasing or diminishing the actions upon occasion in response to nervous stimulus, in correspondence with the universal method. In short, there must be some special reason for the anatomical dispositions that obtain in the arteries as well as in the veins, for they cannot be purposeless.

3. The great relative *size* of the veins, which is greatly in excess of the arteries, the same applying for the trunks of the

vessels, the splenic vein being a number of times larger than the artery; there must be some reason for this also, for it neither can be purposeless. And there can be but little doubt that the organ functions as a reservoir for relieving an over-distended portal system, expanding during this time under special stimulus, and thus diverting the blood from the liver, and so relieving it. It would account for the elastic tissue fibres and the muscles in the spleen, together with the special arrangements in the walls of the veins in the spleen Furthermore, we know the organ does rapidly increase in size in acute febrile disorders, from the congestions they produce in the

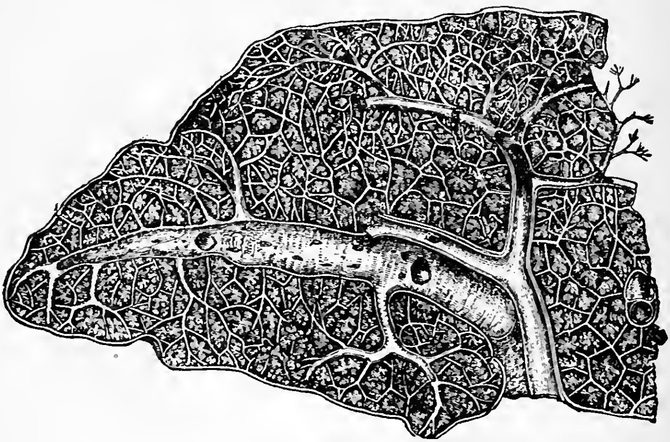

Fig. 88.—Transverse Section of the Human Spleen, showing the distribution of the splenic artery and its branches.—Gray.

liver and portal system; nor is it possible for this condition to be produced by the action in the vein simply, the organ absolutely inhibiting it; the walls of the vein yielding long before the dense structures in the spleen. Besides, it would involve the whole portal system. It cannot be thought of. The sharp pain in the left side, induced by running, has its explanation in an over-distended spleen, the organ rapidly expanding for relieving a surcharged liver and portal system, thereby pulling upon the nervous filaments and producing pain, just as an over-distended bladder produces pain, only the one is more rapidly produced than the other, and the pain sharper. Finally, the simple experiment of dipping the spleen into warm water condenses the organ; the galvanic current also; though by reason of the density of the structure the action is necessarily slight; hence, there can be no doubt that it also expands. Moreover, the vessels are embossed by a dense plexus of nerves connecting with the solar plexus, which at once shows that there must be great activity in the organ; otherwise, it were all meaningless. The special anatomy is deeply interesting, but it is difficult to produce

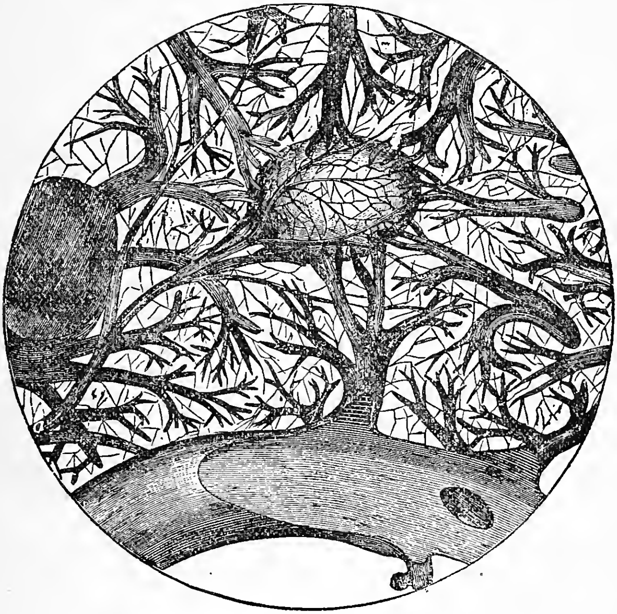

Fig. 89.—One of the Splenic Corpuscles, showing its relations with the blood vessels.—Gray. *a*, Arterial twig, embracing a Malpighian corpuscle. The terminal branches of the splenic vein are seen losing themselves in the corpuscle, in which they open

a mental picture of it; indeed, altogether impossible, though some general idea may be formed. The lymph follicles, cells and Malpighian corpuscles are in close and intimate relations with the arterial vessels, as a matter of course, the arterial capillaries surrounding them (Fig. 88). The manner in which the veins lose themselves in the Malpighian corpuscles, and the intimate relations they sustain to the arterial feeder, are very forcibly shown in the following beautiful cut (Fig. 89, *a*).

For the rest, the reader is referred to the literature of the subject and works on histology.

The portal system is brought into prominence in the following beautiful cut (Fig. 90) for impressing the special anatomy upon the mind. It would seem a bold thing to disconnect the viscera from the containing walls in order to increase the action in them, and to send the vessels and nerves to the organs over floating ligaments; but a bolder one to break up the portal veins into a second capillary system in the liver, threading it in every direction and supplying every cell with the fluid, and as though the vein were itself an artery with the force of the heart at its root, as in the aorta, whereas the heart is far removed, the vessels floating in a ligament and a capillary barrier between, to be re-collected through the radicals of the hepatic veins that debouch in the lower cava, and to send the vast bulk of the alimental fluids over such a route, the organism itself depending upon it: there is a problem for you, but all worked out and open for inspection. But the solution is only possible upon the basis of the fundamental law underlying the organism and autonomy in the structures, the local actions intimately blending with the systemic mechanics, by means of the nerves leading out of the solar plexus, in which the visceral nerves converge (Fig. 108, 5, 2, 1), this connecting with the respiratory and vaso-motor centres through the pneumogastric (Fig. 109, 2) and great splanchnic nerves (3, 3), together with the pumping actions in the lungs, heart, arteries and capillaries, inclusive of the force in the venous system; the whole coördinated through the medulla oblongata, whirls it over the road-bed in the vascular lines with such expedition as to make the journey within a minute from the cavity of the stomach. But all plain enough in the light of the law that applies and automatism in the tissues, the muscular and nervous forces swelling at the difficult points for compelling the passage and completing the circuit; otherwise is utterly inexplicable.

There is more! In all the expanse of venous territory in the portal system, not a valve presents. Why? The answer is not far to seek. The presence of a valve in the portal vein would prevent reflux, so that congestion of the liver could not find relief in copious transudations in the intestinal canal, producing diarrhœa, thereby conserving liver-structure, which is the object of this arrangement, and would inevitably end in disaster. Indeed, we have example of this in the partial constrictions which occur in the liver from hyper-

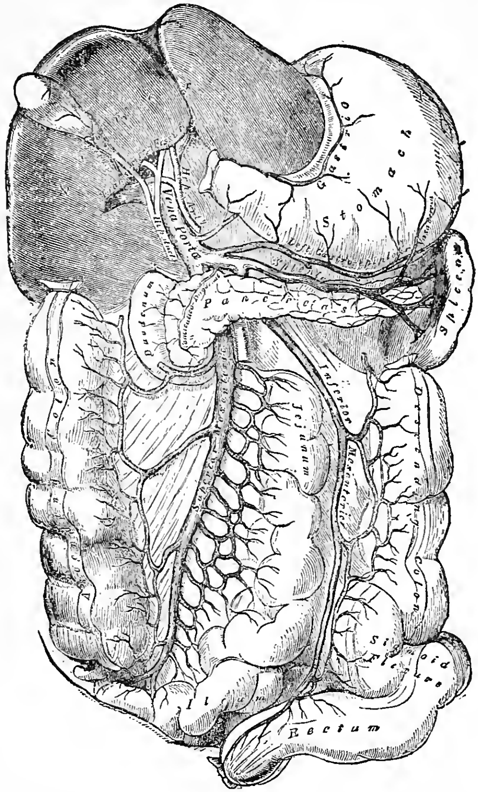

Fig. 90.—Portal System in Diagram.—Gray. The transverse colon is removed, the duodenum divided near the pyloric orifice and the stomach pulled aside, in order to expose the vena portæ, with the mesenteric arteries omitted, for better definition of the mesenteric veins.

plasia of connective tissue produced by alcohol, interfering with the course of the blood through the liver, tending to dam it back in the portal system, leading to diarrhœa and effusions in the cavity of the abdomen, producing the drunkard's dropsy. But with valves in the veins, this reflux could not occur, and life would have a speedy termination, closing upon it, sharp and terrible as the jaws of a mastodon. It is well, then, for the drunkard that there are not valves in the portal vein; while temporary congestions of the liver are passed over and never known, finding prompt relief in copious evacuations through the bowels. And it is no wonder that purgatives are so much lauded, since overfeeding is extremely liable to overload the portal system, while purgatives effect rapid depletion, thereby restoring the balance, and everything runs on as before. Not at all strange. But it would be far better to stop short of gluttony, and not overrun the capacity in the mechanics. Abernethy was very close to the mark: "Half of the diseases come from fretting, the other half from stuffing." The first we can readily understand, from the effects it must inevitably exert upon the local and systemic actions, from the diversion of nervous force it must inevitably produce, tending to engorgements and disaster; the second has already been considered.

In conclusion: The soft, compressible portal veins spread out in the viscera could not otherwise than undergo rhythmical compression during respiration, which should tend to force the blood along the channels in the liver with corresponding energy; this, together with the actions in the vessels in connection with respiration and the functions in the liver, constitutes a dual force for speeding the blood through the liver, comprising the coarse and fine adjustments in this mechanics in correspondence with the universal rule, muscular and nervous force applying everywhere for speeding it through the channels. And with this arrangement in the parts, we can readily understand the rapidity in the absorptive processes in the stomach;* otherwise is utterly inexplicable. The force in the stomach for compelling it in the vessels, the force in the walls of the abdomen and portal vein for compelling it through the liver, and, finally, the force in the pump-

* Thus, in a case of extraversion of the bladder observed by Professor Erichsen (Medical Gazette, Vol. XXVI., p. 363), in which the urine could be collected immediately, it was found that when a solution of ferrocyanide of potassium was taken into the stomach, the salt was detected in the urine in one instance within one minute, and in three other instances within two and a half minutes.

ing actions in the lungs, heart and arteries, inclusive of the venous system for completing the circuit—it is all plain enough and easily understood. But in the absence of this law, night comes again, and utter darkness pervades it all.

Adjustments Necessitated by the Action in the Diaphragm. —We have now to mention a number of adjustments in the organs necessitated by the action in the diaphragm, notably the portal vein lower cava, diaphragm, and œsophagus. Begin-

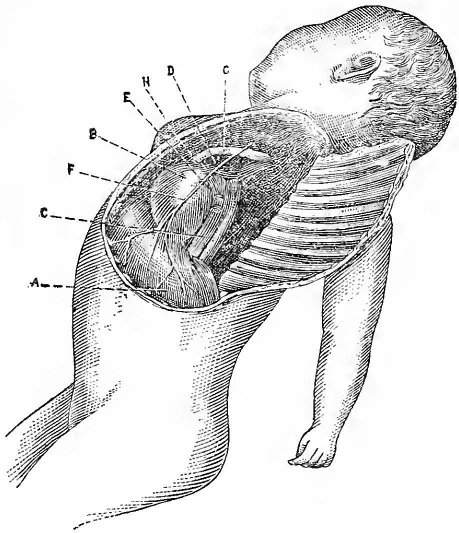

Fig. 91.—Lateral Section of the Chest and Removal of Left Lung, showing the point at which the gullet pierces the diaphragm: *A*, diaphragm ; *C*, œsophagus ; *B*, heart, showing through the pericardium, with the phrenic nerve (left) running over it to reach the diaphragm ; *D*, arch of aorta ; *E*, left bronchus ; *F*, left phrenic nerve ; *G*, superior vena cava ; *H*, left pulmonary artery.

ning with the last, attention is directed to the manner in which the œsophagus penetrates the diaphragm, which is through the most active portions, entering it at its greatest convexity (Fig. 91, *A*, *C*), and expanding at once to form the stomach ; the cardiac orifice fitting close up against the diaphragmatic opening, while the portion included in the diaphragm is the *narrowest* portion of the gullet ; furthermore, is secured to the diaphragm by means of connective tissue fibres and the close-fitting muscular collar in the diaphragm (Fig. 92, *N*), so that there can be no slipping up and down of the collar upon the gullet during respiration. It results, therefore, that the œsophagus elongates during inspiration and contracts during expiration, while coördination is effected by means of the pneumogastric nerves, as may be readily inferred, being the nerves of motion to the organ. The great number of the longitudinal fibres has its explanation in this circumstance; at the same time are of service in passing the bolus, the expansions and contractions in deglutition involving elongation and contraction of the tubing. Magendie had noticed that the lower third of the œsophagus remained firmly contracted for about thirty seconds after the bolus had passed into the stomach, feeling like a cord firmly stretched; the object of this, of course, being to afford the requisite time for equalizing pressure in the stomach by means of the reflex actions propagated through the medulla oblongata to the muscles in the abdomen, as before remarked; and the action continues during digestion for the reason that the churning action in the stomach tends to regurgitation. This is proven by the fact that the contraction is always increased by pressing the stomach with the object of forcing some of the contents through the cardiac orifice. Now, then, since inspiration increases pressure in the stomach and abdomen, we can readily understand the significance of the muscular collar in the diaphragm, and why constriction of the œsophagus should correspond with the depth of inspiration, the one calling for the other to obviate regurgitation. Furthermore, why there should be suspension of respiration during deglutition, in order to effect relaxation or expansion in the muscles of the diaphragm, which not only effects reduction of pressure upon the gullet, but in the stomach and abdomen as well. Thus, all this mechanics is easily understood. The several openings in the diaphragm involve a number of very pretty adjustments, well worthy of undivided attention—are simply wonderful. Thus, taking the powerful muscular bundles that embrace the œsophagus, and looking from their points of origin in the tendinous centre of the diaphragm to their points of insertion in the lumbar vertebræ, it will be seen that they form two arcs around the œsophagus and aorta (Fig. 92), much in the form of the figure 8, so as to form the elliptical openings, or the œsophageal and aortal respectively. Now, then, since the muscles contract upon a line between their origin and insertion, both openings would be occluded during inspiration but for the following disposition of the fibres; notably: 1st. The arc upon the left side of the aorta is bounded by a tendon, which is the point of insertion for the

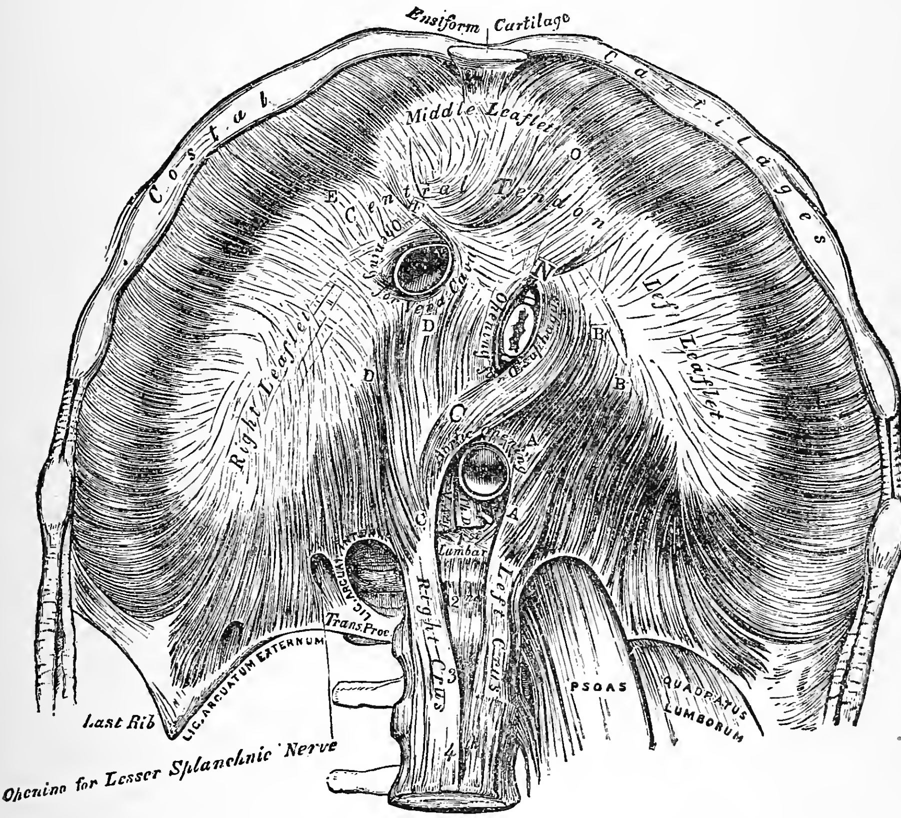

Fig. 92.—The Diaphragm as Viewed from Below.—Gray. The letters *A*, *B*, *C*, *D*, *E*, *N*, *O*, are added.

thick layers of muscular fibres proceeding from the left leaflet of the central tendon of the diaphragm (*A*, *B*), so that during inspiration this is pulled away from the aorta at the same time that it compresses the œsophagus upon the right in the upper arc. 2d. The arc upon the right of the aorta is also bounded by a tendon, which is the point of insertion for the thick muscular layers proceeding from the right leaflet of the central tendon (*C*, *D*), so that during inspiration this is pulled away from the aorta at the same time that it compresses the œsophagus upon the left in the upper arc. It results from this arrangement, therefore, that the aorta is relieved from pressure during inspiration, while there is progressive increase of pressure upon the œsophagus, the necessity for which has already been given.

Finally, looking from the aortic to the vena caval opening, we find that the same principle in mechanics is maintained here also. For example, this opening occurs at the point of juncture of the middle and right leaflets in the central tendon, while the muscular layers that have insertion in the right aortic arc have their points of origin upon the left of the vena cava opening (Fig. 92) ; hence, when these muscles contract during inspiration, they must inevitably pull upon the left side of this lumen and flare it open, at the same time relieving the aorta by pulling upon the lower arc. Then, again, upon the right or external side of the vena cava opening, we have the horizontal muscular fibres connected with the inferior ribs (*E*), for pulling upon this edge of the lumen simultaneously during inspiration, and throwing the flood-gate wide open for affording ready egress to the large amount of blood flowing into the lungs during this time, the muscular layer (*o*) upon the left of the middle leaflet pulls also upon the caval opening. In the band of fibrous tissue which skirts the opening anteriorly (*F*, *N*), we have a needed brace for obviating strain from the too energetic action of the powerful muscular bundles, especially from the one to the right of the œsophagus, which would tend to pull upon this portion unduly, and twist it upon itself, and so disarrange the parts during inspiration ; hence this strong brace of fibrous tissue. Nothing could be more beautiful than these dispositions of force, with the systematic arrangements in the structures for accomplishing the important ends in view. It is comprehensive and superb mechanics. The ligamentous arcs, formed over the psoæ and quadrati lumborum muscles, are constructed upon the same principle, so as not to interfere with their functions or the splanchnic nerves. The *ligamentum arcuatum internum*, which is thrown across the upper part of the psoas magnus muscle on either side, is connected by one end to the outer side of the body of the first (occasionally of the second) lumbar vertebra, and by the other to the front of the transverse process of the second lumbar vertebra; while the *ligamentum arcuatum externum*, thrown across the quadratus lumborum, is attached by one extremity to the apex and lower margin of the last rib, and by the other to the transverse process of the second lumbar vertebra, with which the ligament for forming the opening for the splanchnic nerves also connects. It is all very prettily arranged.

Adjustments in the Lower Cava.—We now have to note the adjustments in the walls of the lower cava with the action in the diaphragm. We have seen that during deep inspiration the diaphragm descends as much as two inches; hence, did not some adjustment obtain in the walls of the cava, the canal would be bent upon itself during this time and obstruct the blood, when the purpose is to expedite the flow of venous blood to the lungs, thereby bringing all the arrangements in the diaphragm to naught. On the other hand, during forced expiration, and the elevation of the diaphragm in the chest cavity which this produces, it must inevitably subject the lower cava to a degree of traction terrible even to contemplate. Besides it should greatly reduce the lumen, thereby obstructing the flow of blood were the vessel capable of enduring such rude mechanics, which cannot be thought of for a moment even. Now, then, for obviating these circumstances, we have the great increase which occurs in the *longitudinal* muscles in the walls of the lower cava, adjacent to the diaphragm, together with the nerves for connecting it with the solar plexus, pneumogastric and phrenic nerves for coördinating it with the action in the diaphragm and respiration, so that it contracts the longitudinal axis during inspiration, at the same time the lumen is thrown more widely open, both *within* and below the diaphragm, by expansion of the transverse muscles, the muscles in the diaphragm contracting; and *vice versa* during expiration, the vessel elongating *pari passu* with expansion in the diaphragm, thereby obviating traction; hence, these muscles and nerves to the lower cava for coördinating it with respiration and the action in the diaphragm. But in the portion of the cava *above* the diaphragm, adjacent to the heart, the muscles are *absent* for two reasons: For the reason that the lungs and heart *move downward* during inspiration, and *upward* during expiration, moving together and simultaneously; which compels the upper cava and primitive branches to elongate and contract in similar manner with the œsophagus and lower cava, only the action alternates in the two localities, those above the diaphragm elongating as those below it are contracting, and *vice versa;* and the anatomical dispositions for effecting the actions are perfect, for the *upper* cava and primitive branches are similarly endowed with the œsophagus and lower cava system, possessing both longitudinal and circular muscles. 2. For the reason that strain tends to fall in this locality, produced by reflux in the right ventricle during the systole, and the weight of the fluid from above meeting the force in the diaphragm from below, making this the point of resistance, subjects the vessel to unusual pressure, especially during expiration, when the blood tends to dam at the right side of the heart; hence the dense fibrous tissue in this portion of the lower cava for resisting strain. But we may remark, *en passant*, that the absence of the muscles does not necessarily imply a totally passive condition, since the same deduction would have to be made for the entire venous and arterial systems, by reason of the *intima*, or elastic inner coat, and the fibrous and elastic ti sues in the outer coat, only that muscles are essential for *increasing* force and producing *energetic* action. Finally, this disposition of the muscles in the walls of the lower cava, as the necessary physiological adjustments with the action in the diaphragm, would account for a similar arrangement of the muscles in the renal veins, since the kidneys, by reason of their lying *against* the diaphragm, are also made to oscillate with respiration, moving to and fro upon the soft cushions of fat in the long axis of the body; and did not a similar arrangement obtain in the renal veins, these also must inevitably be seriously affected by the to-and-fro movements; hence the numbers of the longitudinal muscles and nerves in the walls of the renal veins, together with the nerves for connecting them with the solar plexus and pneumogastric nerves, for coördinating them with respiration, with which the renal functions are also necessarily connected; and looking thence to the vena porta and its tributaries (since all the viscera with which they connect oscillate in similar manner with respiration), we see that this anatomical arrangement is maintained throughout, the whole being rich in longitudinal muscles. But perhaps one of the most striking illustrations of this function in the vessels occurs in connection with the splenic vein, which has adjustment with the functions in the stomach. For example, the spleen is attached to the great *cul de sac* upon the left, with the vena portæ at the liver (Fig. 87); consequently when the stomach is distended with ingesta, the splenic vein is fully twice the length it has in the interim of digestion—is not pulled into extension by the dilating stomach, but elongates *pari passu* with it; otherwise, there would be prodigious strain, ending in inevitable disaster.

Accordingly, we find the splenic vein exceedingly rich in *longitudinal* muscles; whereas, the splenic artery adjacent is nearly destitute, the muscles being nearly all *circular*. In consequence, during the interim of digestion, when the splenic vein is little more than half its length when the stomach is full, the artery is thrown into serpentine folds, or the form it presents in the dead body; the vein measuring upon an average less than five inches, while the artery approximates nine inches. But when the stomach is full they are both of the same length; hence, there can be no doubt that the great elongation and contraction in the vein is due to the number of the longitudinal muscles, which corresponds with the action in the leech, with which it is homologous. In the case of the renal *artery*, however, the matter is again different; here we have *longitudinal* fibres in abundance, in correspondence with what occurs in the renal vein, to enable the lateral movements in respiration, while its powers of elongating and contracting are readily inferred from what occurs in the *arteria dorsalis penis* during states of erection and quiescence; since the arrangement of the muscles is fundamentally the same in both, the vessel elongating and contracting with the penis by means of the longitudinal muscles.

Thus, it is perceived that adaptation of means to ends produces *correspondence* in the structures, whether it relate to respiration or the action in the penis; but remote as these functions would appear to be from each other, they both sustain the same relation to the organic laws, compelling similar arrangements in the structures, in order to produce the actions, as must appear obvious. And it is the same in every stage in development and every organ in the body, contrasting structure with structure, and function with function; as also in widely separated organs and functions where similar actions are called for, the same laws applying universally, and adaptation of means to ends must be in correspondence, in the very nature of things.

CHAPTER XI.

AUTOMATISM IN THE LYMPHATICS AND THE MECHANICS FOR CIRCULATING LYMPH.

The Lymphatic System Intercalated between the Arterial and Venous Systems, Arising in the Tissues and Debouching in the Veins at the Root of the Neck—The Dual Functions in these Organs Concerned in Drainage and Hæmatosis—The Vessels Connecting with Respiratory Movement in the Tissues, Expanding and Contracting with the Blood-Capillaries by Means of the Nervous Connections Subsisting between Them—The Action in the Larger Vessels and Gland-Structures—Muscles and Nerves to the Organs for Producing the Actions—The Action in the Lacteal System and the Manner in which it is Affected by the Action in the Gut for Compelling Rapid Movement of the Fluids in the Vessels—The Relations which this Sustains to Inspiration and the Action in the Venous System—Physiological Experiment Proving that Inspiration Pumps the Lymph into the Venous System simultaneously with the Portal and Hepatic Blood—Proof of Automatism in the Vessels.

The lymphatic system is intercalated between the arterial and venous systems, taking its rise in the tissue spaces and interstices and emptying into the venous system at the root of the neck, at the junction of the subclavian and jugular veins (Fig. 100). The left trunk, much larger than the right, and known as "the thoracic duct," receives the chyle and the lymph from the lower portions of the trunk and inferior extremities, inclusive of the left upper half of the body; the right, known as "the right lymphatic duct," a small trunk of about an inch in length, receives the lymph from the right side of the head, right arm, right side of the body, inclusive of the convexity of the liver, right lung and right side of the heart, the orifice guarded by two semilunar valves for preventing ingress of the venous blood; the left is similarly guarded.

According to Recklinhausen, the lymphatics function as a drainage system for the tissues, the particles too large to pass the stomata in the capillaries making their way through the open ends of the lymph-channels with which the tissue-spaces communicate, the tissue-spaces being as so many lymphlacunæ. It seems reasonable only that the drainage is unduly interrupted by the numerous glands thrown across the channels in which circulation is extremely difficult, the dense structure inhibiting rapid movement. Then, too, there are the thymus and thyroid glands, supra-renal capsules, and spleen of similar nature to be accounted for, which are inexplicable by this theory. Let it be, however, for Nature is utilitarian to the last degree, and may combine *two* schemes—blood-making with tissue drainage—in this manner working the old products for a new rôle in the organism, in the genesis of white corpuscles for tissue-structure and other purposes; the matrix in the gland-structures, the slow circulation and rich materials conducing to the nutritive processes, thus serving as the womb of the tissues, so to speak, life springing out of the ashes, and ready to commence again the labor of living. *Mirabile!*

Without entering into the mooted question of the mode of origin of the lymphatics, whether by a closed network of capillaries (larger than blood-capillaries), or in the fine wall-less spaces in the tissue interstices traversed by the fluids to and from the cell-brood and blood-capillaries, matters not in the argument. What immediately concerns us is the force of this circulation for compelling the lymph through the channels in the measure of the physiological requirements in the tissues and lymphatic glands, which it has to traverse on its way to the venous system, together with the manner of coördinating the vessels with the blood-vascular system, for producing continuity in force and a continuous current with the blood-stream, which the scheme calls for; at the same time, maintaining automatism in the vessels and glands, which must not be lost sight of for a single moment, all the others depending upon it. The mechanics is easily understood. Thus, when the blood-capillaries expand for reducing pressure within themselves and increasing it in the tissue interstices (pp. 175–178), in order to compel the fluids into themselves, the lymph-vessels also expand simultaneously, the same nerves and nerve-ganglia acting upon all alike, so that they get their share of the tissue fluids. But, being larger than blood-capillaries, the action is necessarily slower and more difficult, but is sufficient to determine the coarser particles, which were too large to pass the stomata in the more energetic blood-capillaries, into themselves, floated into them upon waters, the medium of transportation; passing in through the open lumen in the tissue-spaces or the larger stomata in the capillary walls, in the absence of these open ends to the lymph-vessels; while during the subsequent contraction the valves obviate reflux, so that suction-force is made effective upon the fluids in the tissue interstices, and no reason presents why it should not.

And the vessels being composed of the same material as the blood-capillaries, namely, protoplasmic substance, and connected with them by nerves, the respiratory movement in the tissues should affect both alike; hence, it should have the effect of pumping the lymph into the lymph-channels simultaneously with the fluids in the blood-capillaries, the same law applying to both. In this manner, then, the lymph passes into the lymph-channels during expansion in the vessels, and the high pressure this produces in the tissue interstices, inclusive, of course, of the action in the blood-capillaries, the fluids flowing from high to low pressure; while during the subsequent contraction the valves would obviate reflux, at the same time pushing the fluid up the channel toward the glands intercalated in the vessels by a series of rhythmical expansions and contractions similar to what occurs in the gullet, with which the vessels are homologous, due allowance being made for the special adaptations with the functions in the organs. Moreover, Heller * has seen the lymph-vessels in the mesentery of the guinea-pig expand and contract regularly and rhythmically. Then, again, the veins contract for pushing the blood toward the heart and lungs, and no reason presents why the lymphatics may not do likewise; seeing, also, that they connect with the vaso-motor and respiratory centres, the same as the blood vascular system. Finally, the great difficulty in circulating lymph, by reason of the glands intercepting the stream, would account for the strength of the vessels, or the number of muscles, elastic and fibrous tissue in the walls of the vessels. Just here it were well to give some idea of the anatomy in the

* *Cbt. Med. Wiss.*, 1869. p. 545.

glands to show the difficulties which beset the way, and the necessity for this increase of force for compelling circulation in the measure of the requirements. In the first place, the glands are composed of a congeries of lymph-nodes communicating with afferent and efferent vessels (Fig. 93, *f*, *f*, *h*). The

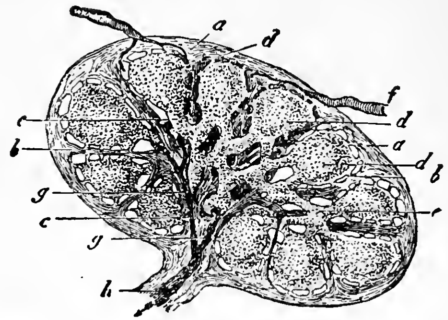

Fig. 93.—Section of a Small Lymphatic Gland, half diagrammatically given, with the course of the lymph. *a*, The envelope; *b*, septa between the follicles or alveoli of the cortical portion; *c*, system of septa of the medullary portion, down to the hilus of the organ; *e*, lymph-tubes of the medullary mass; *f*, different lymphatic streams which surround the follicles, and flow through the interstices of the medullary portion; *g*, confluence of these passing through the efferent vessel; *h*, at the hilus of the organ—Frey.

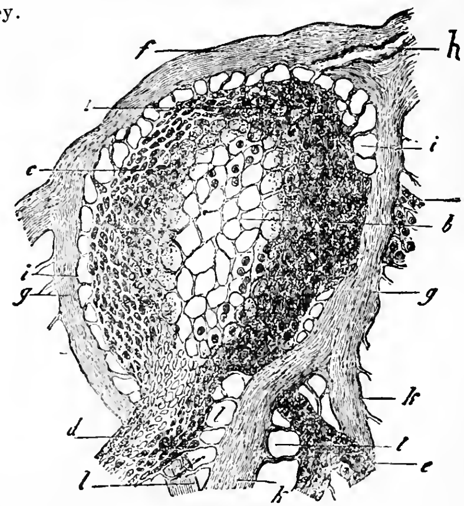

Fig. 94.—Follicle from the Lymphatic Gland of a Dog in Vertical Section. *a*, Reticular sustentacular substance of the more external portion; *b*, of the more internal, and *c*, of the most external and finely webbed part on the surface of the follicle; *d*, origin of a thick lymph-tube; *e*, the same of a thinner one; *f*, capsule; *g*, septa; *k*, division of one of the latter; *i*, investing space of the follicle with its retinacula; *h*, vas afferens; *l*, *l*, attachment of the lymph-tubes to the septa—Frey.

internal arrangements, as far as made out, are substantially as follows: From the investing capsule, composed of fibrous connective-tissue intermixed with numerous smooth muscular fibres, septa (*b*, *c*) corresponding with the number of the lymph-nodes are given off, composed of the same materials as the capsule, and pass through the gland (*c*) to the hilus, investing each of the nodes and forming a similar capsule around them also (Fig. 94, *f*, *g*), while in the nodes themselves the numerous minute individual follicles of which they are composed are surrounded by reticular tissue (Fig. 94, *a*, *b*, *c*), which serves the purpose of a capsule to them also (*f*), the whole thus connecting through and through, since the reticular tissue of the follicles connects with the septa (*i*, *i*) forming the sustentacular tissue, the lymph-tubes also connecting with the septa (*l*, *l*).

"But no follicle is completely ensheathed at its under surface in this system of septa. On the contrary, either one or several gaps, or even wide deficiencies, are left, through which the follicular tissue comes into immediate contact with the medullary substance. In the same way, the partitions passing inward between adjacent follicles may be interrupted by massive bridges, as it were, of lymphoid tissue, by which these are connected one with another, the muscular fibres being present in large numbers" (Frey).* Then we have the lymph-tube, with its complicated system of vessels (Fig. 95, *a*),† traversing the reticular spaces *between* the follicles and the investing reticular septa (*d*, *d*), so that a continuous passage is effected by the lymph at the same time that it is brought into intimate relations with the follicles, for effecting interchanges between them. Finally, we have a system of arterial and venous capillaries setting in and out of the gland in such manner as to bring the blood into intimate relation with the follicles and gland-tubes (Figs. 96, 95), the gland-tube itself possessing its own system of blood-capillaries, so that blood circulates freely through the gland, and in the measure of the physiological requirements, so that every cell can get its due supply of arterial blood, as in every other organ. Now, then, what can be the purpose of all this capsular investment, with the muscular fibres richly interspersed, other than to effect rhythmical

* Histology and Histochemistry of Man, p. 408. † Ibid., Fig. 404.

changes of pressure in the follicles and lymph-channels for expediting circulation in connection with the special functions in the gland, seeing that muscular structure is for producing force, here as elsewhere ?

According to *Schwartz*, the muscles of the capsule at the

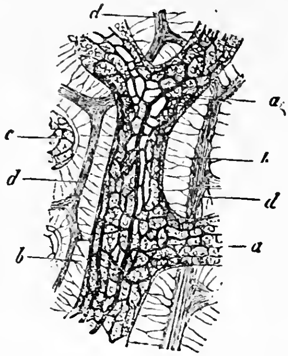

Fig. 95.—From the Medullary Substance of the Inguinal Gland of the Ox (after *His*). *a*, Lymph-tube with its complicated system of vessels ; *c*, portion of another ; *d*, septa ; *b*, retinacula stretched between the tube and the septa.

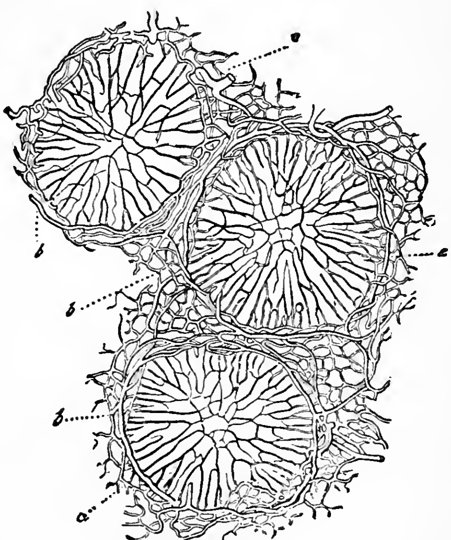

Fig. 96.—Transverse Section through the Equator of three *Peyer's* Patches of the same Animal. *a*, The capillary network ; *b*, of the larger circular vessels.—Frey.

line of junction of the medullary and cortical portions have a principally radiating arrangement, which is precisely what is needed for constringing the gland by producing contraction in the muscles, and *vice versa*, during expansion ; while the septa, passing inward between the nodes with the broad bases at the capsule (Fig. 83, *b*), and splitting up into numerous septa and coming together again for embracing the follicles for applying a special force to them, which the functions call for, constitutes the *fine* adjustment in this mechanics, in correspondence with the universal rule, the difference being only in adaptive changes with the functions in the gland, which follows as a matter of course. This, together with the force in the afferent and efferent vessels, is sufficient to produce circulation through the glands, the force in the chest and arterial system also applying ; but is not the force in this circulation, being too far removed for overcoming the difficulties in the glandular circulation, the force being *upon the ground* where the work is done in the gland-structures and intercommunicating vessels. Moreover, the vessels themselves bear testimony to this circumstance in the number of the valves they contain, which are strung like beads (Fig. 97) along the vessels, and the number of muscles and nerves to them for producing action upon the lymph by means of the rhythmical expansions and contractions taking place in them, and acting in this respect as so many hearts upon the stream, each one representing a little ventricle or cardiac chamber for the purpose ; else this also would be meaningless. Moreover, Heller has observed such movements in the lymphatics of the mesentery, as has already been observed.

Turn we now to the lacteal system and the lymph-channels of the mesentery for further corroborative evidence of the principle which applies, here as elsewhere in the organism, individualism pervading the whole of it, and must do so in the very nature of things, in order that the vessels and glands may perform *their* functions and maintain existence, while force is added in the measure of the physiological requirements. For example, contrast the action in the villus with the special anatomy in the lymph-channels in order to see adaptations of means to ends beautiful to look upon. In the first place, we have the central lymph-channel (Fig. 9·, *l*) inclosed in muscular walls (*m*), running the entire length of the channel, forming the sides over which the pavement epithelium is spread, the muscles extending from the *muscularis mucosæ* at the base of the villus. Now, then, when the muscles contract, the effect is to drive the lymph into the lymph-channels under the *muscularis mucosæ* (*rete amplum*) (Fig. 99, *b*), the force in the muscles compelling it. On the

Fig. 97.—Showing the Number of the Lymph-Valves, with the Local Dilatations in the Vessels in the Warm-Blooded Animals.—Sappey.

other hand, when the muscles expand, the low pressure this produces in the channel aspirates the lymph; then another contraction followed by another expansion, and so the little mechanism runs like a heart for pumping the lymph into the lymph-channels below. But to this we must add the force in the muscular walls of the gut for compelling the fluids into the columnar epithelial cells through the sieve-like openings upon the free surface; thence through the *membrana propria* (*e*, *e*, *e′*) into the interior of the villus, the high pressure it produces in the intestine, together with the actions in the villus and the epithelia (for they are all connected by nervous force) compelling this circumstance. No wonder, then, that fat or anything else absorbable should be rapidly absorbed. And there is no necessity for endowing any portion of the mechanism with extraordinary powers in order to account for the circumstance, such as that the epithelial cells act like

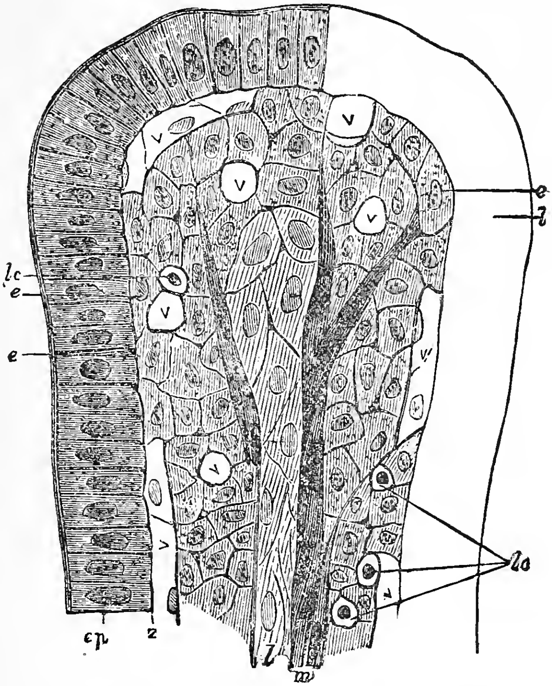

Fig. 98.—Diagrammatic Section of a Villus.—Watney. *ep*, Epithelium only partially shaded in ; *l*, central chyle-vessel—the cells forming the vessel have been less shaded to distinguish them from the cells of the parenchyma of the villus ; *m*, muscle fibres running up by the side of the chyle-vessel. It will be noticed that each muscle fibre is surrounded by the reticulum, and by this reticulum the muscles are attached to the cells forming the membrana propria, as at *e'*, or to the reticulum of the villus. *lc*, Lymph corpuscles, marked by a spherical nucleus and a clear zone of protoplasm ; *l'*, upper limit of the chyle-vessel ; *e*, *e*, *e'*, cells forming the membrana propria. It will be seen that there is hardly any difference between the cells of the parenchyma, the endothelium of the *upper* part of the chyle-vessel, and the cells of the membrana propria. *v*, Blood-vessels ; *z*, dark line at the base of the epithelium formed by the reticulum. It will be seen that the reticulum penetrates between all the other elements of the villus. The reticulum contains thickenings or "nodal points." The diagram shows that the cells of the upper part of the villus are larger and contain a larger zone of protoplasm than those of the lower part. The cells of the upper part of the chyle-vessel differ somewhat from those of the lower part, in that they more nearly resemble the cells of the parenchyma.

amœbæ and eat the fat.* But in my heart of hearts I thank the distinguished author for the large individualism in the cells and tissues it shadows forth, and he, of all men, is closest to the mechanics in the animal organism. But the amœba must yield up some of its license in the compound organism for the common weal, and must take a subordinate position in blending with the common functions with which their actions are coördinated. And in the case before us, it is not compelled to extend branched processes into the canal for embracing the food, but only to expand the oral orifices or sieve-like openings, while the food is pushed into them under the force in the gut, the body of the cell expanding in order to receive it; in consequence, the epithelia rapidly become double their size, and of a milky appearance from the amount of fat and other aliment they contain. And if Professor Foster meant this, we are in full accord; but I do not think he included the pressure in the gut for assisting the action.

We have but to follow the lymph to the channels beneath the *muscularis mucosæ* to see how the force in the gut applies to this also, together with the force in the numerous muscles forming the walls of the lymph-vessels, by means of which the local action is increased and the stream regulated with the capacity in the mesenteric glands, with which, of course, it must have adjustment; otherwise, choking and engorgement would follow as an inevitable sequence of excessive action in the lymph-vessels. The following beautiful illustration,† from Teichmann, on the lymphatic system, will serve for impressing the matter. For example, the lymph-channel (there are several given here) in the villus debouch into the close-meshed lymph-vessels (*rete angustum*) beneath the *muscularis mucosæ* (not given in the picture) at the base of the villi (*a*, *b*), which rapidly expand into great lymph-chambers (*c*), in contact with the muscular cylinder (*g*, *h*), through which the efferent vessels (*d*, *d*) pass to get beneath the peritoneal layer of the gut in order to reach the mesenteric glands, situated in the folds of the mesenteric ligament.

* A Text-Book of Physiology, p. 319. M. Foster, M. A., M. D., F. R. S., Prælector in Physiology and Fellow of Trinity College, Cambridge.

† Ludwig Teichmann, "Das Saugader System." Leipzig. 1861.

Finally, that the lymph-vessels and chambers are muscular organs provided with valves for obviating reflux, and furnished with nerves from the adjacent ganglionic layers (Meissner's and Auerbach's, which we will come to presently) for producing the rhythmical expansions and contractions which occur in them, and which also connect with the great pumping movement in the muscular cylinder itself, the nerves

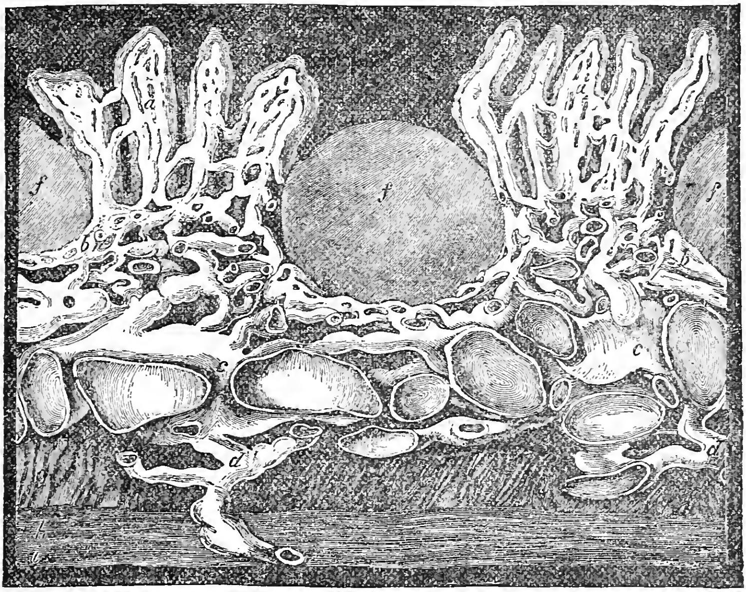

Fig. 99.—Perpendicular Section through one of Peyer's Patches in the lower part of the Ileum of the Sheep.—Teichmann. *a*, *a*, Lacteal vessels in the villi; *b*, *b*, superficial layer of the lacteal vessels (*rete angustum*); *c*, *c*, deep layer of the lacteals (*rete amplum*); *d*, *d*, efferent vessels provided with valves; *e*, Lieberkühn's glands; *f*, Peyer's glands; *g*, circular muscular layer of the wall of intestine; *h*, longitudinal layer; *i*, peritoneal layer.

connecting through and through, the same as in the case of the villus, gland-structures and blood-vessels for producing simultaneous action throughout, the principle being the same. But once within this system of reservoirs, it is easy to perceive that the force in the gut is available for compelling the lymph through the channels, and no power can prevent it but paralysis in the gut itself, as must appear obvious. In other words, every contraction of the muscular cylinder by compressing the air and aliment firmly against the mucous membrane and submucosa, in which the lymph-vessels and reservoirs are situated, thence against the resistent muscular cylinder, whence there is no escape, should have the effect of constringing the organs, closing upon them like the hand for the purpose. Please look at the anatomy well. No mechanics in the body exceeds it for simplicity and effectiveness. It is a work of the gods. By the action in the gut, then, and the action in the lymph-vessels and reservoirs, which are coördinated with the muscular cylinder, it is passed by the efferent vessels (*d*, *d*) through the gut, thence through the vessels to the glands in the mesentery, by means of rhythmical expansions and contractions in the vessels, the same as in the systemic lymph-vessels, and which would include the action in the glands, and therefore need not detain us. Finally, to this we must add the force in the walls of the abdomen and the pumping action in respiration, the same as in the venous system, into which it empties, for producing simultaneous action and correspondence in the currents, which the scheme calls for, the same mechanics applying to both alike. In order to definitely ascertain this circumstance, also, I performed the same experiment as in the case of the portal blood and liver circulation, taking the body apart in the same way, carefully ligating the vessels before dividing them; also the vena cava and œsophagus. And everything being ready, the thoracic duct was snipped, when the lymph spurted out with force to some feet distant; and not waiting for the vessels to empty themselves; I bore down upon the diaphragm with my open hand in imitation of inspiration, and every time I did this, the stream rose instantaneously into a jet the same as the venous blood had done. So, then, there can be no earthly doubt that inspiration pumps the lymph and venous blood simultaneously into the chest-cavity and lungs, the amount being determined by the energy and depth of inspiration and the fullness of the vessels. The following beautiful diagram of the lymphatic system (Fig. 100), by Professor Dalton, will serve for impressing the matter. The lacteal system, spread out in the vast mucous surface, acted upon by the muscular cylinder and the muscles in the lymph-channels, this supplemented by the force in the walls of the abdomen for compressing the gut, mesenteric vessels, and glands during inspiration, lifts the lymph to the lungs the same as the portal and hepatic blood and the blood in the lower cava system, and simultaneous with them. Please look at it. I do

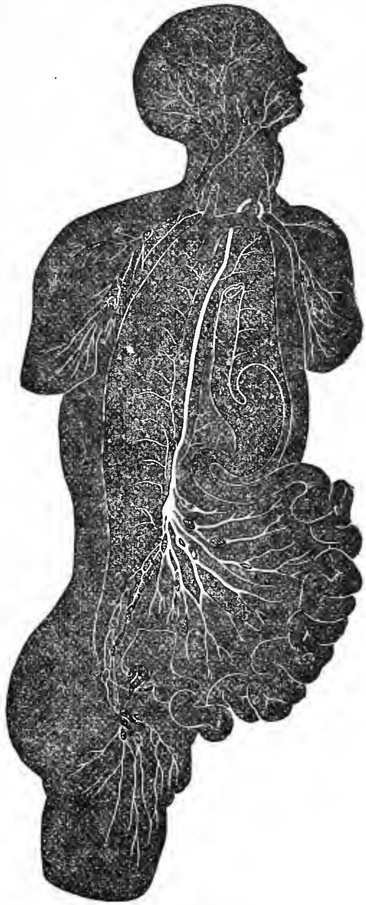

Fig. 100.—Diagrammatic Representation of the Lymphatic System.—Dalton.

not see necessity for adding another word, the matter being so very obvious.

In conclusion: That there is automatism in the lymph vessels is not only logically true, but the fact is scientifically ascertained. Notably, in batrachia four lymph-hearts present, one behind each femoral joint, for pumping the lymph coming from the hinder portions of the body into the ischiadic veins, and one in front of each scapula for pumping the lymph from the anterior portions into the jugular veins, the organs expanding and contracting regularly and rhythmically from fifty to sixty times per minute. Moreover, they are not synchronous with the action in the heart or with respiration, or even with one another, possessing independent action.

"In the large *ceratophrys cornuta* two pairs of ischiadic lymph-hearts have been found. In the tortoise the pelvic lymph-hearts are two, of a more circumscribed, rounded form, situated on each side of the bodies of the vertebræ, between the femoral joints and the hind-border of the carapace; the valves at the inlets and outlets of the lymph-conduits, impressing the course of motion of the fluid, are here readily seen."

"In Lizards and Crocodiles the pelvic lymph-hearts are situated near or upon the diapophyses of the first caudal vertebra. In *Pseudopus Pallasii* they lie between the muscles upon the sacral diapophyses, receiving the lymph each by a single conduit from the great abdominal sinus, and transmitting it to the umbilical veins; *they pulsate about fifty times in the minute.* In true serpents (Python, *e. g.*) the lymph-hearts are elongate, and situated behind the last pair of ribs and upon the rib-like diapophyses of the anterior caudal vertebræ; they receive the lymph by three orifices at one end, and transmit it by two opposite orifices to conduits communicating with the caudal vein. The three tunics of these hearts. of which the middle one is *muscular*, with the inferent and afferent *valvular structures*, are well displayed in python" (Owen).* Italics are added.

The following from Hermann possesses renewed interest:

"In amphibia and certain birds (ratitæ), the movement of the lymph is assisted by the rhythmical pulsation of lymph-hearts, of which four exist in the frog, two in other amphibia, and one in the ostrich. The central nervous organ connected with this rhythmical motion is said by some to be in the spinal cord, and by others in the hearts themselves. In guinea-pigs a rhythmical contraction has recently been observed (A. Hel-

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* Comparative Anatomy and Physiology of Vertebrates, vol. I., pp. 459–460.

ler) in the lymphatics of the mesentery. As this proceeds along those portions of the vessel between the valves with a regular progression toward the larger trunks, it must be regarded as a species of cardiac mechanism.

"In the frog, the rhythmical movement of the lymph-heart seems to be dependent upon the integrity of spinal centres (Volkmann), one situated opposite the third vertebra for the anterior pair, and one opposite the sixth vertebra for the posterior pair. It is, however, affirmed (Eckhard, Schiff, Goltz, Waldeyer) that the power of regular movement may sometimes be recovered after it has been abolished by dividing the spinal nerves, supplying the hearts, or by destroying the spinal cord.

"The lymph-hearts are, further, constantly inhibited from the optic lobes (Suslowa), this inhibition being controlled by centripetal stimuli, proceeding from skin or intestines (Goltz)"

The following is from Gegenbaur :*

"The lymphatic trunks of birds have the same characters, but in them both the large trunk in front of the aorta (thoracic duct) and the small vessels are more independent. As in the reptilia, the thoracic duct opens into the superior venæ cavæ (venæ brachiocephalicæ). At the commencement of the tail the lymphatic system is also connected with the ischiadic veins, or with the afferent renals, in which point they resemble the amphibia and reptilia. In the mammalia, the *walls of the lymphatic system are still more differentiated*, although it often happens that in them also the sheath of the arteries bounds the course of part of the lymphatic current. Where they do not accompany the blood-vessels, they form frequent anastamoses, or wide-meshed plexuses, and *are distinguished by valves, as are the same parts in birds*. The lymphatic vessels of the hinder extremities, as well as the chyle-ducts, unite into a chief trunk in the abdomen, which is rarely paired, and the origin of which is frequently distinguished by a considerable enlargement (cisterna chyli). Thence they are continued into a thoracic duct, which opens into the commencement of the left brachio-cephalic vein; the trunks

* Elements of Comparative Anatomy, p. 595.

of the lymphatics of the anterior parts of the body (of the head and anterior extremities), and of the wall of the thorax, open into and on either side of the same vein." Italics are added. Thus, with progress in development the lymph-hearts disappear. but in lieu of them we have increasing differentiation in this system of vessels, which become more and more muscular; and in place of the local dilatations forming the so-called lymph-hearts, which contain three coats, the middle one muscular, in the warm-blooded animals the muscular coat extends over the *entire* walls of the vessels, the same as in the veins with which they are homologous, only that the valves are greatly increased in number and the external fibrous tunic is thicker and firmer, which more than compensates for the "hearts" by greatly increasing the force in the vessels which it effects. At the same time, it is seen that automatism is maintained, and must be so in the very nature of things.

CHAPTER XII.

NERVES TO THE VISCERA IN THE ABDOMEN, AND MODE OF CONNECTING THEM WITH THE CEREBRO-SPINAL AXIS.

The Double Ganglionic Dorsal Chain in Vertebrates the Analogue of the Double Ganglionic Chain in the Worms—Nerves of Meissner—Nerves of Auerbach—Mode of Connecting them with the Solar Plexus and Central Nervous System—Relations of the Nerves of Meissner and Auerbach with the Intestinal Mucous Membrane and Epithelium—Mode of Controlling the Blood-Supply from the Aorta-Trunk by Means of the Cœliac Axis, Superior and Inferior Mesenteric Arteries and their Branches, so that Every Organ and Fractional Portion of the same can Regulate their own Supplies in the Measure of the Functional Activities—Connection of the Pneumogastric Nerves with the Solar Plexus—Mode of Connecting the Solar Plexus and Spinal Ganglia with the Dorsal Nerves and Spinal Medulla, the Nerves of the Ganglionic Chain running up *Both* Roots of the Spinal Nerves to reach the Spinal Medulla—Every Nervous Ganglion a Centre of Nervous Force, Possessing both Sets of Fibres, or Dilator and Contractor Nerves—The Manner Reflex Action is Produced in the Spinal Cord and Medulla Oblongata through Sensory Impressions in the Mucous Membrane and Cutaneous Surface, for Expanding and Contracting the Vessels and Maintaining a Balance in the Circulation—Relative Amount of Nervous Force sent to the Viscera through the Pneumogastric and Splanchnic Nerves, Illustrated by a Case of Fracture of the Fourth and Fifth Cervical Vertebræ, Producing Displacement, with Laceration and Compression of the Spinal Cord—Effects from Division of the Pneumogastric Nerves in the Neck, upon the Lungs, Stomach and Intestines—Death by Thirst and Starvation, Precipitated by Pulmonary Congestion from Paresis in the Capillary Network—The Action in the Kidneys, and the Relations they Sustain to the Solar Plexus and Spinal Axis through Intercommunicating Nerves—Ditto Ureters and Urinary Bladder.

It will now be necessary to briefly refer to the nervous apparatus for producing the movements in the intestines, and for coördinating them with respiration, which, of course, would include the glandular appendages with the portal and lacteal systems for producing correspondence throughout, which the scheme calls for. Separate action in the alimentary canal is well enough for maintaining automatism in connection with the special functions in the organs; but since the whole relates to the cell-brood in the tissues, it is manifest that this involves correlation of the nervous forces with the federal centre for the organism for compelling response to the wants in the cell-brood, which is effected by means of the double rows of spinal ganglia and pneumogastric nerves which converge in the solar plexus, the common nervous centre for the viscera, so that the whole performs as but a single organ, only, under the action of the nervous forces radiating from the medulla oblongata and respiratory centre, in harmonious concert with the action in the lungs, with which everything is coördinated, to the end that a balance may be maintained in the organism; otherwise impossible. Now, then, with reference to this double ganglionic chain extending the length of the spinal column, the analogue of the double ganglionic chain in the worms, as it were, a remnant of this, which the principle in the mechanics compels to be retained, the structures in the gut being fundamentally the same as in the worms, as before remarked. And the gut being folded upon itself in the central portions, in form of the mesentery, which the shortness of the animal compels, the ganglionic chain necessarily undergoes a similar folding, whereby the solar plexus is formed; while continuity with the basal cerebral ganglia is maintained in the manner as stated, or by means of the trisplanchnic and pneumogastric nerves; the former being thickened and elongated links, resulting from the folding up of the chain, the latter an adaptation to the changes in the intestines which are now detached from the muscular envelope, compelling this mode of nerve-distribution for effecting coördination with the containing walls, as has already been fully set forth. In this manner, then, we have the massing of the ganglia in the solar plexus readily accounted for, and which would include all the other arrangements that obtain respecting it, as we shall see further on. The spinal axis is an outgrowth of the basal cerebral ganglia, and possessing separate reflex nervous centres connecting with the viscera, vascular system, and the voluntary motor apparatus, represented by the gray central portions, subserves important functions in the mechanics for maintaining the local actions and enabling ready coördination with the federal centre in the medulla oblongata.

Commencing with the mucous surface, we have, then, the following separate lines of nervous ganglia, with the intervening nerves, for producing the local actions in the intestines and for connecting them with the central nervous system, namely: 1. The thick ganglionic layer of nervous ganglia in the submucosa, or nerves of Meissner (Fig. 107, 1), with the nerves running thence into the villi to connect with the epithelium (2), which includes the whole mucous surface, at the same time supplying the capillaries and muscularis mucosæ.

2. Next to this ganglionic layer, or between the circular and longitudinal muscles, is the thick ganglionic layer of Auerbach (Fig. 107, 4), for supplying the muscular cylinder, at the same time giving off inter-communicating nerves (3) to the ganglionic layer of Meissner, which also gives off inter-communicating nerves, whereby the muscular cylinder and the mucous membrane are fully coördinated, so that it all works together harmoniously—vascular apparatus, glandular apparatus and muscular cylinder, inclusive of the muscularis mucosæ, and which includes the stomach as well, since the nervous arrangements are fundamentally the same in it.

3. Next to this ganglionic layer, but outside the gut and removed to a distance from it, we have the federal centre for the intestines in the great solar plexus (Fig. 109), with the nerves extending thence over the superior mesenteric artery (Fig. 108, 1, 2) to the intestines to connect with the other two layers (Fig. 107, 5, 5), whereby the whole intestinal apparatus, inclusive of the glandular appendages, is coördinated and force is increased in the gut; the same remark applying to the stomach, the nerves extending to it and the glandular appendages over the branches of the cœliac axis (Fig. 109, 4).

4. Finally, we have the solar plexus connected with the central nervous system by means of the splanchnic and pneumogastric nerves (Fig. 109, 2, 3), as before remarked. In this manner, then, the whole is connected through and through with the cerebro-spinal axis for coördinating the viscera with respiration, and for increasing nervous force as occasion may require. It is comprehensive, but the continuity of relation effected by means of the nerves for producing the actions with respiration is easily seen and readily understood.

In order to perfect the mental picture of the nervous apparatus, however, it will be necessary to enter a little more into the minutiæ. While the two ganglionic layers in the walls of the intestines are plain enough, and minutely described, unfortunately this cannot be said of the nerves to the villi and columnar epithelium, which are not yet definitely ascertained; and we are compelled to have recourse to analogous structures; notably, the columnar cells of the salivary glands, in order to fully complete the nervous connections that obtain in the intestines. According to the exhaustive researches of Pflüger, the columnar cells sustain the most intimate relations to the nerves, which blend with them and form, so to speak, the footstalk of the cells (Figs. 101, 102), the nuclei of the columnar cells being evolved, as it were, in the terminal extremity of the nerves (Fig. 103). The following extensive excerpt* will place the matter fully before the reader:

"When we see the axis cylinder and its fibrils to be directly continuous with the fibrils of the columnar cells, without any difference being perceptible between the axis cylinder and the fibrils of these cells, we may legitimately describe the nerve as extending to the point where it joins the substance of the body of the cell. That is the most natural explanation that can be given. This explanation, however, possesses the greatest significance in regard to the mode of development of the glandular epithelium, because it directly follows that the young nuclei originate in the axis cylinders, and that the gland cells, which at a later period seem to constitute a thickening of the axis cylinder, bud forth, as it were, from the nerves. This explanation renders it intelligible why the nuclei of the columnar cells are so indifferent during the multiplication of the epithelium. In opposition to this view, which I regard as the most probable, it may be urged that, in consequence of the intimate fusion of nerve substance and epithelium at the periphery, no sharp limit can be drawn, showing where the one ceases and the other begins; and that, moreover, it is probable that imperceptibly fine processes are given off by the nucleus of the columnar epithelial cells, which become detached at an early period by fission. That the nuclei of the salivary cells have processes cannot, however, be regarded as forming a valid objection to my view, since the young nuclei may really be thickenings of the axis cylinder fibrils.

The Salivary Glands. Stricker's Manual of Histology, p. 314.

"I may further adduce, as a weighty argument in favor of my view, that the fibrils of the axis cylinder do not terminate at the surface of the fully developed salivary cells, but, as in the case of the ganglion cells, may be traced into their very substance.

"Now, since the finest axis cylinders and fibrils extend to the columnar epithelial cells, and are connected with the processes

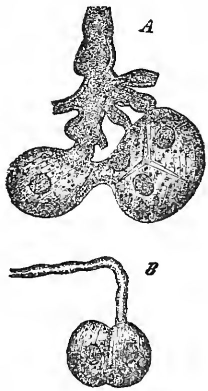

Fig. 101.—Termination of Medullated Fibres Treated with Perosmic Acid in Isolated Salivary Cells. *A*, thick branched fibres distributed to large salivary cells ; *B*, fine nerves distributed to smaller salivary cells. From the submaxillary gland of the Rabbit. Magnified 590 diameters.—Pflüger.

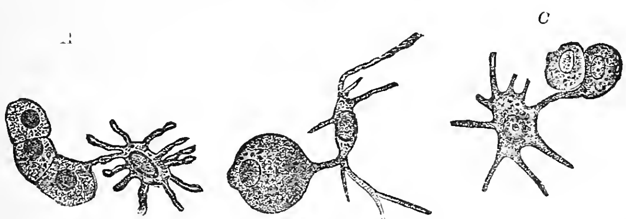

Fig. 102.—*A*, *B*, multipolar cells in connection with salivary cells. Magnified, *A* 480, *B* 500 diameters. *C*, peculiar cells with round thick processes, and containing refractile fat particles. Magnified 590 diameters.—Pflüger.

that are in course of development, and since portions of these processes subsequently become large salivary cells, connected with thick medullated nerve fibres, it follows that the nerves must increase coincidently with the young epithelium to which they belong. Among these metamorphoses there also occurs a mode of termination of the medullated nerves, to which I some time ago called attention, and which consists in the nerve suddenly undergoing frequent division, then enlarging, and containing finely granular protoplasm, with many nuclei of various sizes. I have named this mode of nerve termination, that by a 'protoplasmic foot.' If, as I have sometimes observed, many of the nuclei appear to be provided with fibres, which can be followed into the interior of the nerve fibres, it is highly suggestive of the development of the gland cells from the nerves.

"In regard to every explanation, it must be observed that transitional forms may occur, respecting which it is impossible to say whether they are epithelial or nervous. The continuous and luxuriant neoplastic formation taking place in the substance of the salivary ducts presupposes their regeneration, respecting which I have formed my own opinion, but have arrived at no definite conclusion. In like manner the persistent neoplastic formation of the alveoli in adult animals determines an atrophic detachment of those already present In moles I have sometimes found the alveoli with pale offshoots of various forms, and pale finely granular contents, which may be such atrophied and separated alveolar segments.

"I first comprehended the complexity of all forms of salivary glands when I recognized the constant production and disintegration taking place in them, which is referable to the nerve substance."

This genesis of the columnar cells in nerve-extremities may be seen in the different stages of cell growth in the following cut (Fig. 103, *a*, *b*, *c*, *d*, *e*), beginning with the nuclei and progressing till the cell is perfected (*E*) Accordingly, I have ventured to connect the columnar cells of the villi with the nerves proceeding from the ganglionic layer of Meissner (Fig. 107, 1) to the villi (2) This portion of the picture, therefore, is ideal. But considering the energy in the absorptive processes and the rapidity with which the cells expand, and especially the quick response to stimulus I deemed myself justified in doing so. Not that a nerve fibre proceeds to each individual cell in the manner as given, for several may connect with a nerve (Fig. 103, *E*), but that they promptly propagate sensory impressions produced by the food, for setting up the reflex actions in the ganglia for producing the movements in the muscular cylinder, inclusive, of course, of the blood-capillaries. For example, as soon as food is introduced into the stomach

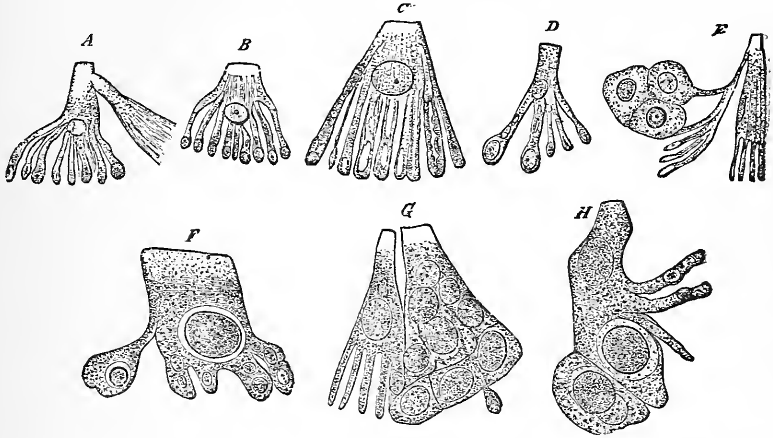

Fig. 103.—*A*, *B*, *C*, *D*, *E*, isolated cylindrical cells with processes containing nuclei; *A*, *B*, *D*, *E*, magnified 590 diameters; *C*, magnified 1,200 diameters; *F*, *G*, *H*, cylindrical cells with processes, which are evidently young cells, and form at *G* a beautiful mosaic. Magnified 1,100 diameters.—Pflüger.

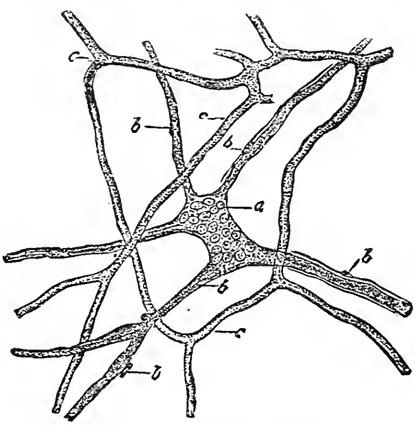

Fig. 104.—A Gland from the Submucosa of the Small Intestine of a Suckling, ten days old. *a*, Ganglion; *b*, nervous twigs given off by the latter; *c*, injected capillary network. This preparation had been macerated for a very long period in pyroligneous acid.—Frey.

or mechanical irritation applied to the mucous membrane—*e. g.*, touching with a glass rod—the capillaries expand and the movements in the walls begin, which would seem to show intimate nervous connections subsisting between the epithelium and the ganglionic layers, the same applying, of course, for the whole of the alimentary canal, while the investigations of Pflüger would show a reason for it. The following illustration (Fig. 104) exhibits the appearance of a ganglion (*a*) from the submucosa or Meissner's layer, with the nerves radiating from it (*b*). The following illustration (Fig. 105) is a section of the ganglionic layer between the circular and longitudinal muscles, by Auerbach, and named after him. Fig. 106 is a similar section by Klein,* in which the nerves are differently treated and more highly magnified.

Then, again, looking to the blood vessels and nerves, with reference to the local actions, we can readily understand how the vascular supply may be increased or diminished in a given viscus, or in a portion of the same, without interfering with neighboring organs or adjacent parts, and so as to limit the action to the special work in hand, in the measure of the requirements, which division in labor necessarily involves, as the whole is founded in individualism or automatism in the organs, as before remarked.

Thus, in the case of the stomach (Fig. 110), the blood is supplied from the cœliac axis, which is embraced by the solar plexus (Fig. 109); hence the sensory impressions in the gastric mucous membrane produced by the food are reflected to the appellate ganglionic centres over the vessels when these are expanded correspondingly, the pressure in the arterial system causing them to be filled instantaneously. And any portion of the stomachal mucous surface may be flushed in order to increase the action in the part, whether in the cardiac or pyloric end of the organ, by expanding the local feeder, which is readily done. It is very pretty. The vessel to the great *cul de sac*, which gives off the feeder to the spleen, the separate ones to the mid-regions or central portions and pyloric end of the organ (Fig. 110) and the hepatic, all springing out of the cœliac axis with the great semilunar ganglia of the solar plexus at its root for compelling response to local demands, with the separate ganglia along the individual vessels for reporting the demands and enlarging the lumen of the vessel. The great anastomosis of the vessels

* Hand-Book for the Physiological Laboratory.—Burdon-Sanderson.

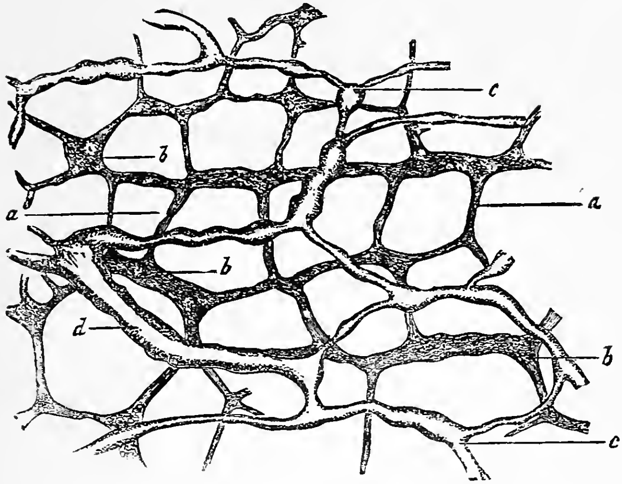

Fig. 105.—From the Small Intestine of a Guinea-Pig.—Auerbach. *a*, Nervous interlacement; *b*, ganglia; *c*, lymphatic vessels; *d*, lymphatics.

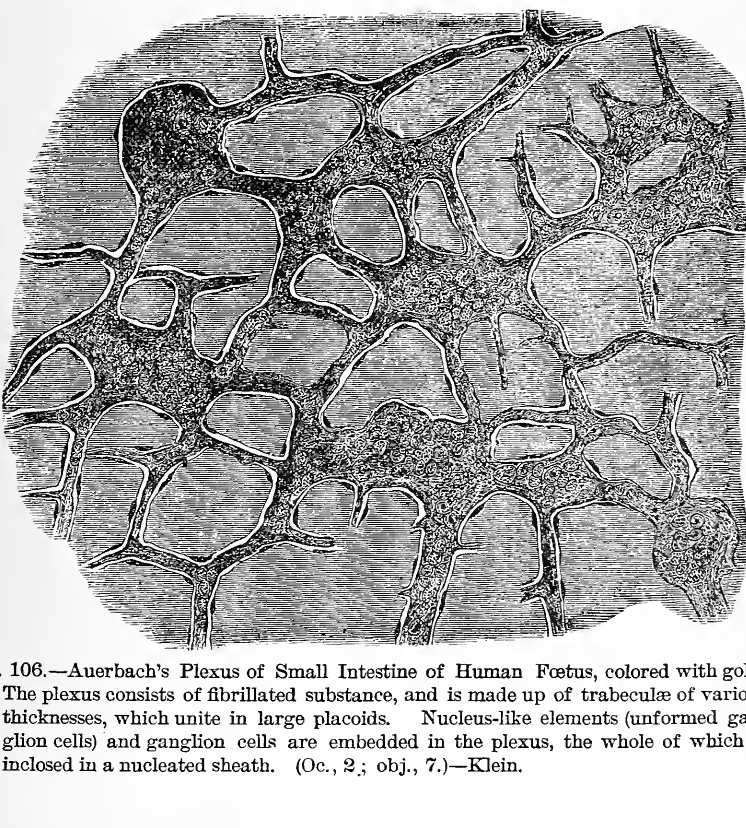

Fig. 106.—Auerbach's Plexus of Small Intestine of Human Fœtus, colored with gold. The plexus consists of fibrillated substance, and is made up of trabeculæ of various thicknesses, which unite in large placoids. Nucleus-like elements (unformed ganglion cells) and ganglion cells are embedded in the plexus, the whole of which is inclosed in a nucleated sheath. (Oc., 2.; obj., 7.)—Klein.

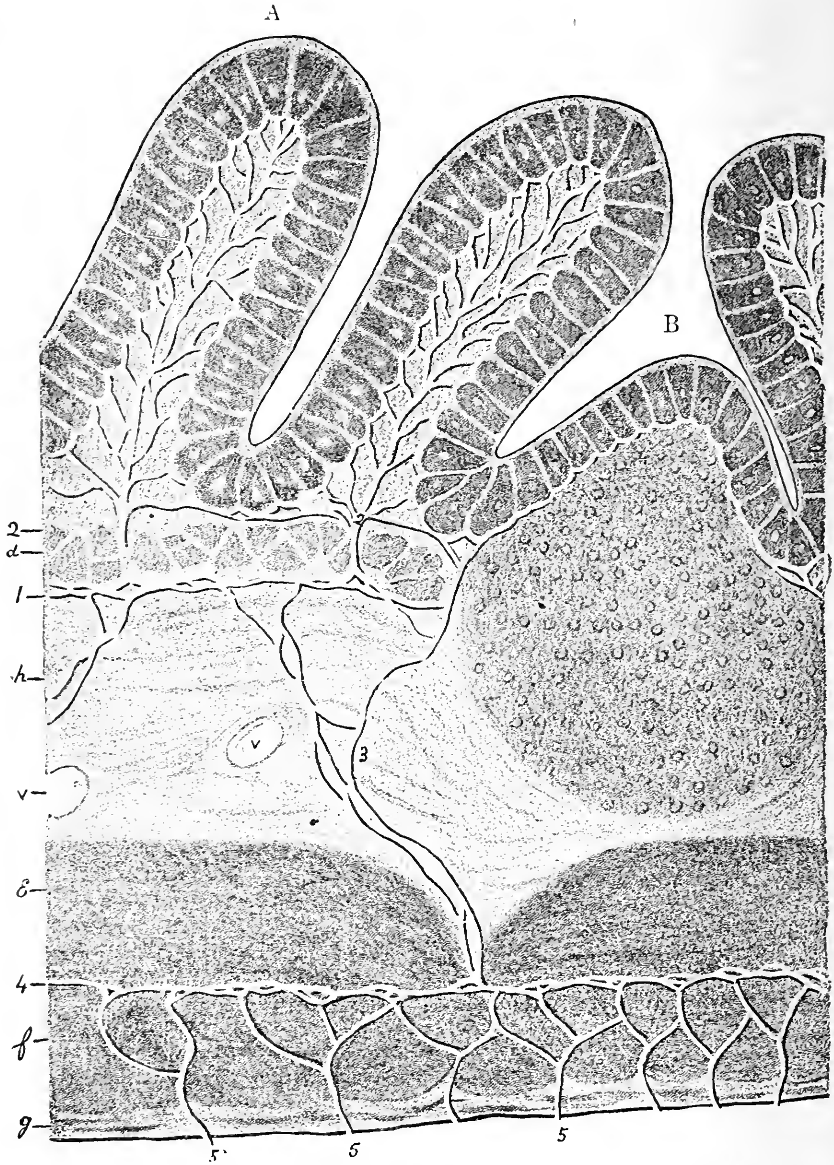

Fig. 107.—Nerves to the Intestines—partly ideal. 1, Ganglionic layer of Meissner; 2, nerves from the same to the villi and columnar epithelium; 3, nerves connecting same with the ganglionic layer of Auerbach; 4, ganglionic layer of Auerbach; 5, 5, 5, nerves connecting the intestinal apparatus with the solar plexus. *A*, *A*, villi; *B*, summit of a lymphoid follicle; *d*, muscularis mucosæ; *E*, circular muscles; *f*, longitudinal muscles; *g*, peritoneum; *v*, *v*, arterial capillaries; *h*, submucosa.

along the greater curvature provides against obstruction, should this occur in either the hepatic or splenic branches, so that compensation is readily effected by commensurate expansion in the other. In this manner, then, afflux of arte-

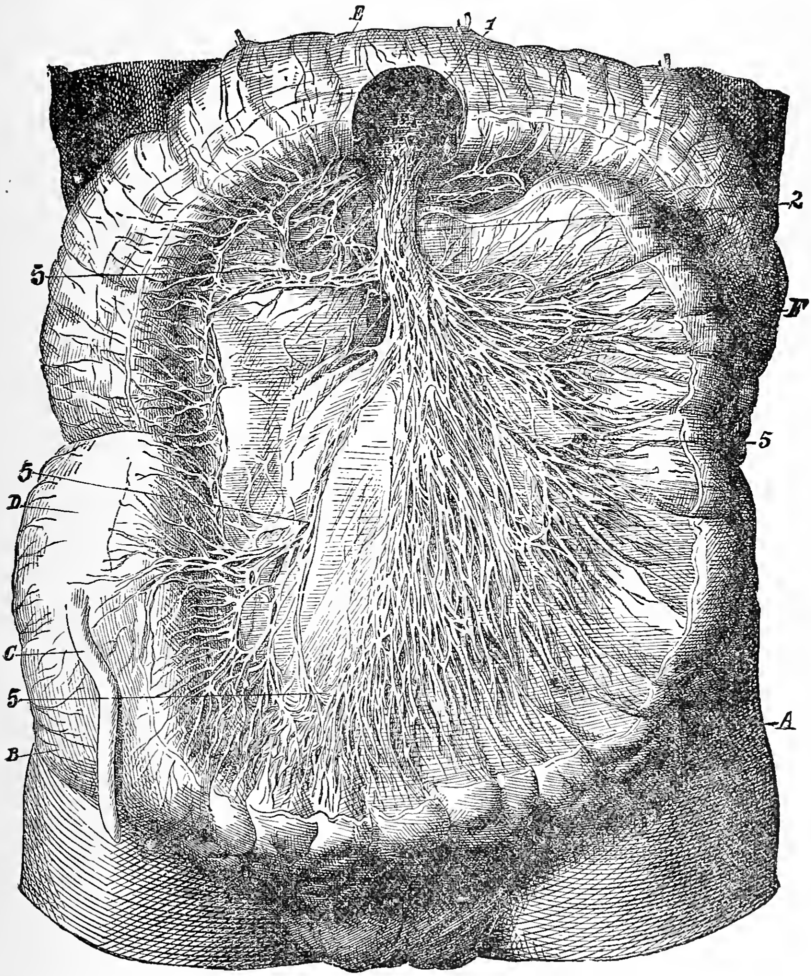

Fig. 108.—Nerves of the Mesentery (reduced).—Bougery, etc. 1, Root of superior mesenteric artery and nervous plexus (a portion of the transverse colon is excised, in order to show this circumstance); 2, superior mesenteric plexus; 5, 5, continuation of same over the walls of the vessels to the intestines; *A*, intestines; *B*, cæcum; *C*, appendix vermiformis; *D*, ascending colon; *E*, transverse colon; *F*, descending colon.

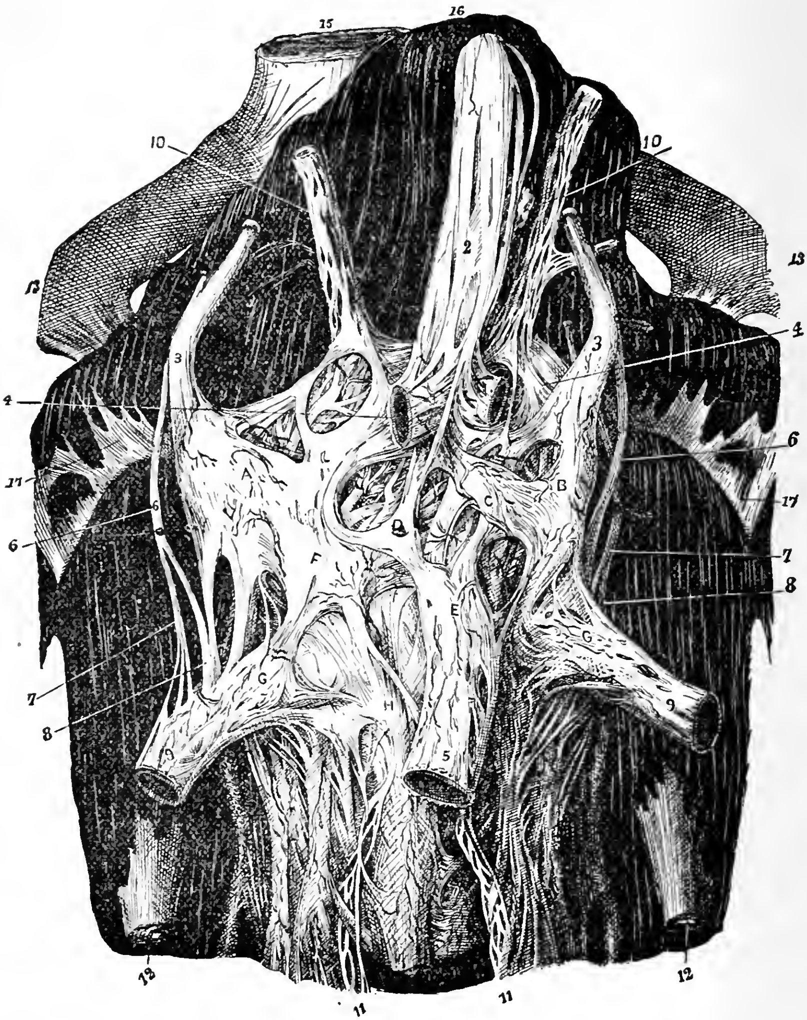

Fig. 109.—Solar Plexus (reduced).—Bougery, etc. The letters of reference added. *A*, great right semilunar ganglion; *B*, left ditto; *C*, *D*, ganglia connecting right pneumogastric nerve (2) and great splanchnic (3) nerve with the ganglion of the superior mesenteric plexus (*E*. 5); *F*, ganglion connecting right pneumogastric and great splanchnic nerves (2, 3) with the renal (*G*) and aortic ganglia (*H*); 4, cœliac axis, showing intimate blending of the right pneumogastric nerve; 5, superior mesenteric artery and plexus; 6, 7, 8, lesser splanchnic nerve, terminating in renal plexus: 9, renal artery and plexus; 10, diaphragmatic plexus and artery; 11, spermatic artery and plexus; 12, tendon of small psoas muscle; 13, eleventh rib; 15, eleventh dorsal vertebra; 16, crura of diaphragm; 17, ligamentum arcuatum internum, the fibres irregularly divided.

rial blood is compelled to be in correspondence with the local actions in digestion. And looking from this to the small and large intestines, in which the action begins later on, it is readily perceived that there is extension of the

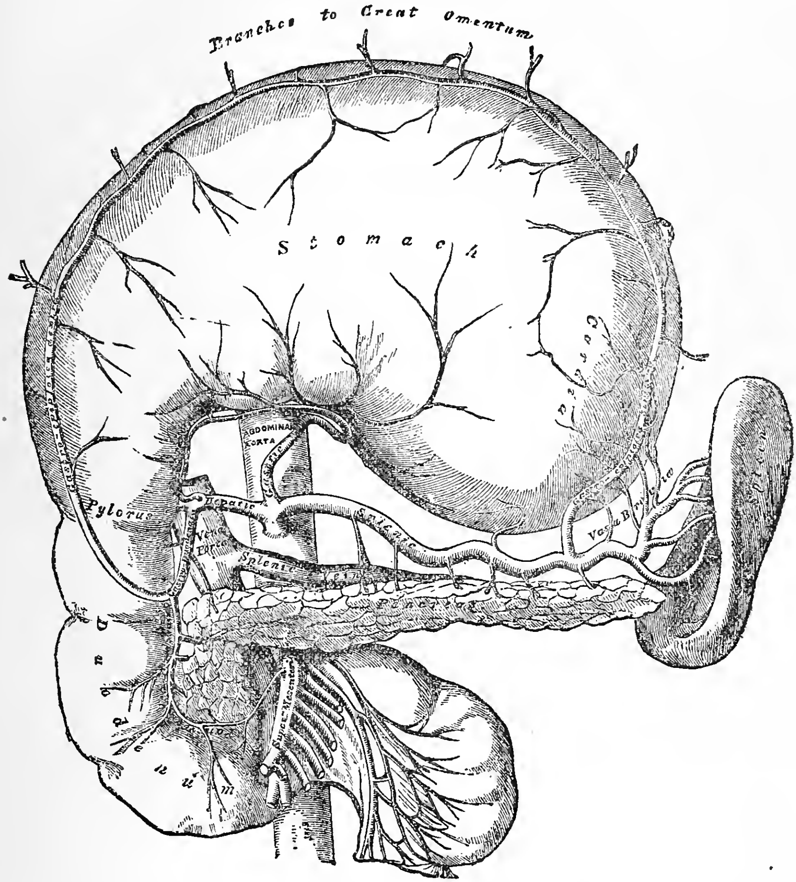

Fig. 110.—The Cœliac Axis and its Branches, the Stomach having been raised, and the Transverse Mesocolon Removed.—Gray.

same principle in mechanics to them also. For example, the small intestines are supplied by the superior mesenteric artery (Fig. 111), which functions as the feeder to these portions, the vessel giving off lateral branches to feed the various portions, the vessels being given off at regular intervals, commencing with the duodenum. The transverse and ascending portions of the colon and cœcum are supplied by the colica media (11), colica dextra (14), and ilio-colica (15), given off from the opposite side of the vessel; while the descending colon and rectum are supplied by the inferior mesenteric artery (Fig. 112, 9), the superior hæmorrhoidal (13) descending as low as the middle of the sacrum, where it divides into two

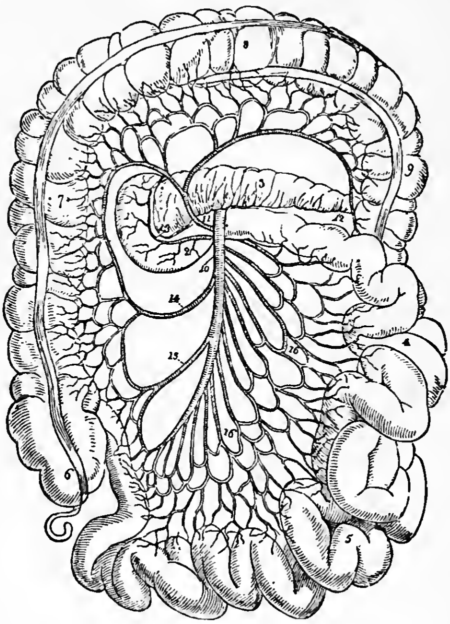

Fig. 111.—Course and Distribution of the Superior Mesenteric Artery.—Wilson and Buchanan. 1, Descending portion of the duodenum; 2, transverse portion; 3, pancreas; 4, jejunum; 5, ileum; 6, cæcum and appendix vermiformis; 7, ascending colon; 8, transverse colon; 9, descending colon; 10, superior mesenteric artery; 11, colica media; 12, the branch which inosculates with the colica sinistra; 13, pancreatico-duodenalis inferior; 14, colica dextra; 15, ileo-colica; 16, 16, vasa intestini tenuis.

branches, which continue along the sides of the rectum, dividing up into still smaller branches, to be distributed between the mucous membrane and the muscles, nearly to the anus, anastomosing with the middle and inferior hæmorrhoidal branches of the internal iliac and internal pudic arteries. By means of this arrangement, then, together with the local ganglia and nerves for operating them, the vessels are readily expanded and contracted for regulating the blood-supply. One other thing! Bear in mind that *every* nervous ganglion is a *dilator* and *contractor* centre for the vessels; hence, it is readily perceived that the actions can be carried on in the several portions *independently*, and without involving other portions. For example, expansion in the lateral branches to the ascending and

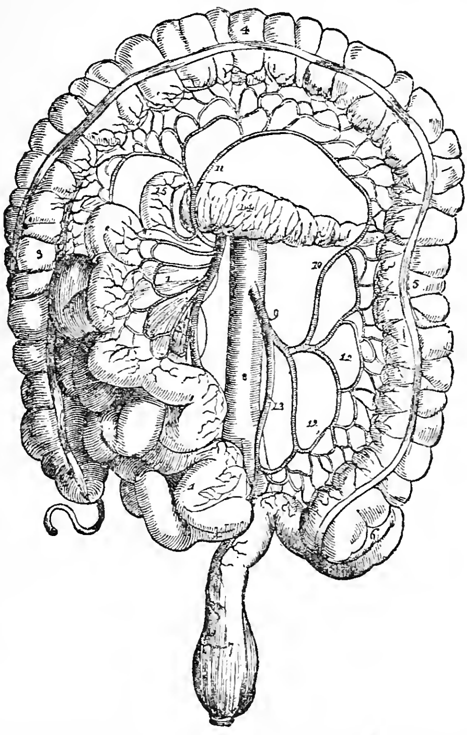

Fig. 112.—Branches of the Inferior Mesenteric Artery.—Wilson and Buchanan. 1, 1, The superior mesenteric, and small intestines turned over to the right side; 2, cæcum and appendix cæci; 3, ascending colon; 4, transverse colon raised upwards; 5, descending colon, 6, sigmoid flexure; 7, rectum; 8, aorta; 9, inferior mesenteric artery; 10, colica sinistra, inosculating with, 11, colica media; 12, 12, sigmoid branches; 13, superior hæmorrhoidal artery; 14, pancreas; 15, descending portion of the duodenum.

transverse colon (Fig. 111, 12, 14, 15) should not affect the vascular supply to the small intestines, the vessels remaining at a given calibre, since pressure in the arterial system would compel them all to be filled *simultaneously* But, since the actions alternate, it is easy to perceive how one set of vessels may contract their calibre as others expand; which must be done in order to obviate too great depletion of the arterial system; otherwise inevitable. So that this also has its metes and bounds for maintaining a balance in the organism. During full digestion a vast amount of arterial blood is thus poured into the organs; so that the arterial system is compelled to condense itself in order to maintain pressure, tending to produce brain-anæmia; hence the heavy sleep of the glutton, which is especially well marked in cases in which a degree of anæmia exists—*e. g.*, convalescence from essential fevers and wasting diseases. For this reason, also, it acts beneficially in cases of cerebral irritation by calling off the blood, thereby inducing sleep. In the lower animals, in which arterial pressure is low, it induces a semi-comatose condition for many days together, since digestion is slow in them. But in the warm-blooded animals provision is made for digestion during the maintenance of the activities, but which requires that arterial pressure should be maintained, since it is by means of this that the local actions are increased, while the necessity for connecting the vessels in the intestines with the spinal medulla and rhythmic centre is to set a limit to the local actions and maintain a balance in arterial pressure; otherwise the arterial system itself might be emptied into the viscera, as is seen in "congestive chill" and acute peritonitis, in which the action is more slowly accomplished, every inch of ground contested, the nervous centres not being suddenly overwhelmed as in congestive chill. The blending of vaso-dilator and constrictor nerves in the solar plexus, and the intimate relations it sustains to the cerebro-spinal axis, has its explanation, then, in this circumstance; or, in other words, for maintaining a balance in circulation during respiration, digestion and the various bodily functions, the voluntary movements especially; while the whole relates to evolution of force expended in the organism.

Mode of Connecting the Double Ganglionic Chain and Solar Plexus with the Central Nervous System or Cerebro-Spinal Axis.

The following beautiful illustration (Fig. 113) of the *fine* anatomy in the roots of the spinal nerves furnishes a ready explanation for the mode of effecting continuity in force between the viscera and central nervous system. The section includes the roots (A, B) of the spinal nerves with the ganglion on the posterior root, carried beyond the point of junction (C) of the connecting links of the dorsal ganglionic chain,

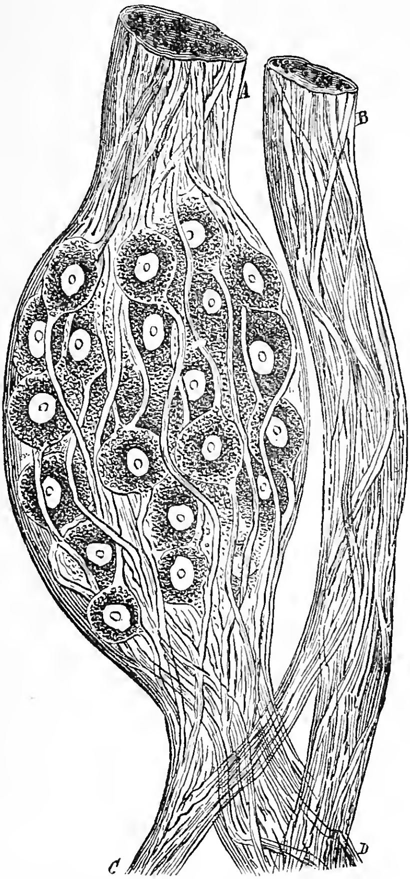

Fig. 113.—The two Roots of the Spinal Nerves, showing relation of the fibres of the sympathetic (C) to them.—Leydig. A, posterior root; B, anterior root; C, nerve from the sympathetic spinal chain at the point of division into the roots of the spinal nerves; trunk of a spinal nerve at the point of union of the two roots.

while the two roots (D) of the spinal nerves come together to form the single nerves of which the so-called intercostals form the major portion.

As will be seen, some of the fibres of intercommunication (c) between the dorsal ganglia and the spinal medulla pass up (or pass down, as the case may be) the anterior or motor root of the spinal nerves (*c*, *B*), while others pass up the posterior or sensory root (*c*, *A*), connecting with the nerve cells of its ganglion, and through these connecting with the spinal medulla. Thus, we have the roots to the ganglionic chain splitting their fibrous bundles and dividing up into anterior and posterior roots, in correspondence with the spinal nerves with which they are blended. Now, then, we may readily understand how nervous force may travel up and down the ganglionic chain to and from the central nervous system readily enough, and why sensory impressions in the mucous surface should be promptly reflected thence to the cerebro-spinal axis; also, why sensory impressions in the skin should be similarly reflected, and why stimulation of the cutaneous surface—*e. g.*, cold and hot applications, cups, blisters, etc.—should be beneficial in internal inflammations—pneumonia, for example—the impressions being reflected by the special spinal nerves (Fig. 114, *A*, *A*) to the spinal medulla, thence through the intercommunicating nerves (*S*, *S*) to the posterior pulmonic plexus (*P*, *P*) to the lungs, producing contraction in the dilated and engorged vessels; the same remark applying for the cutaneous surface and viscera in the abdomen as well.

The rapid condensation of the relaxed and bleeding womb from cold applications made to the hypogaster has undoubtedly its explanation in this circumstance, all of which is plain enough. But the principle involved in this intimate nervous connection between the internal and external parts is the maintenance of a balance in circulation during the multiplied and diversified experiences, the cardinal circumstance being to bring it in correspondence with the functions in the lungs and digestive processes, for producing force in the organism and maintaining a balance. The expeditious manner in which the blood is shifted from part to part commensurate with the physiological requirements in the organs and organism, has its explanation in the high pressure in the arterial system and the power of expanding the local vessels, the blood in consequence rushing into them instantaneously to equalize pressure. The necessity for a vaso-motor centre to effect expansion and contraction in the vascular system for coördinating it with the functions in the lungs, and for maintaining a balance in circulation, is, therefore, sufficiently obvious; while to expand and contract the lumen inheres in the vessels themselves, the nervous apparatus serving to energize the actions and coördinate them in the functions; otherwise, it were utterly impossible to carry on the functions in the organs.

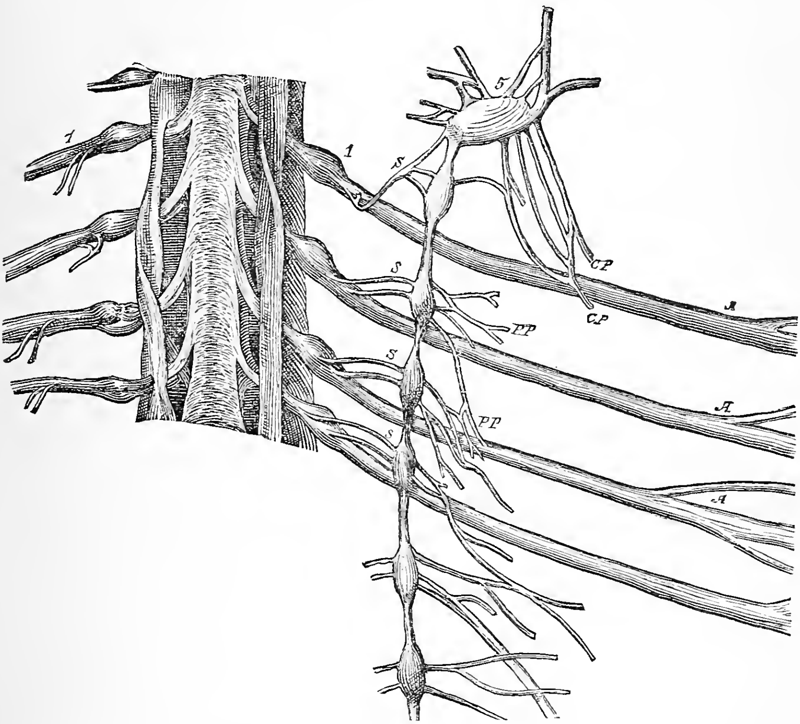

Fig. 114.—Transverse Section of Spinal Cord and the Ganglionic Chain of Sympathetic Nerves, showing mode of connection between them. *A*, four upper intercostal nerves; 1, ganglion on posterior root; *S*, nerves connecting the ganglia of the sympathetic with the two roots of the spinal nerves; *P P*, posterior pulmonic plexus; 5, inferior cervical ganglion; *C P*, branches to the cardiac plexus.

In fine, this law of pressure and the power of producing rapid rhythmical expansions and contractions in the vessels for changing pressure inheres in the vessels themselves to the minutest capillaries, and by means of which circulation is made to respond to the physiological requirements in the organs and organism, otherwise impossible; while for producing equilibrium it requires the correlation of the two nervous forces which these opposite actions represent in the medulla oblongata—indeed, in every nervous ganglia or centre of the local actions.

The point we wish to make is, that while opposite nervous forces are thus indicated in the two roots, the ganglion *itself* possesses independent action for producing the opposite movements in the muscles, otherwise inexplicable; proving conclusively a correlation of the forces in the ganglion and the power of coördinating the local actions, while this again is augmented by the force through the roots for energizing the movements. And it is a notable circumstance that the spinal ganglia possess *two* roots connecting them with the spinal nerves (Fig. 116). Not that they necessarily are opposing lines of force, for each root may contain both sets of fibres; but the fact, nevertheless, is deeply suggestive.

Accordingly, I have ventured to connect the columnar epithelium in the intestines with the nerves proceeding from the ganglionic layer of Meissner (Fig. 107, 1, 2). This portion of the picture is, therefore, ideal. But, considering the rapidity of secretory and absorptive functions in the intestines, the quick response to stimuli, I have felt justified in extending the nerves to the muscles and capillaries (of which there can be no question) to the adjacent epithelium. Not that it occurs in the exact manner here depicted, but that something similar to this does actually exist, I hold to be a reasonable deduction from the evidence in the salivary glands. Still, it is not essential to the argument, for we know the cells have power to expand and contract in the entire absence of muscles and nerves for effecting it; only it would seem to be necessary for bringing them into correspondence and for increasing their functions. And to bring the muscular walls and the blood vessels into correspondence with the actions in the mucous membrane, is the explanation for the intercommunicating nerves between the ganglionic layers of Meissner and Auerbach (3), and between the latter and the solar plexus (Figs. 108, 5, 5, 5; 109, 5, 5, 2, 1). The lines of nervous force to and from the solar plexus are upon the blood-vessels; hence, it it is easy to perceive how these are brought into correspondence with the physiological requirements in the organs, or with the digestive and absorptive processes. Hence, as soon as food is introduced in the stomach, or mechanical irritation is applied to the mucous surface—*e. g*, touching it with a glass rod—the capillaries expand and the movements in the muscular walls begin.

The intimate relations which the intestines sustain to the cerebro-spinal axis and respiration may be seen in the blending of the pneumogastric and splanchnic nerves in the solar plexus (Fig. 109, 2, 3, 5).

Finally, it is well known that stimulation of the pneumogastric nerves produces peristalsis, the same remark applying to the ganglia in the solar plexus, and that stimulation of the pneumogastric nerves produces expansion, while stimulation of the splanchnic nerves produces contraction in the vascular network in the mucous membrane of the stomach and intestines, showing conclusively the power in the medulla oblongata to produce the movements in the intestines, and to expand and contract the vessels in the mucous membrane, the same as in the cutaneous surface and systemic vessels; otherwise, it were utterly impossible to maintain a balance in the circulation, or carry on the functions in the organs, the one involving the other.

"Inhibitor centre!" "Inhibitor nerves!" Inhibit what? The heart expands and contracts in conformity with the law for changing pressure. In which direction, then, does your "inhibitor" act? You irritate the pneumogastric branch, and because diastole is made excessive thereby, producing an intermittent pulse, you term it an inhibitor nerve, whereas the heart is expanded to its utmost limit, when the "cardiac inhibitor" is stimulated, and when excessive producing death, the heart in extreme diastole, while the response is prompt and energetic; moreover it performs work, reducing pressure in the organ, the blood in consequence rushing into it and filling it instantaneously. And yet it is to count for nothing. Nature *withdraw force* from the heart and blood-vessels, *let go*, as it were, yet controlling the blood and compelling circulation in the measure of the physiological requirements in the lungs, in the heart, in the blood-vessels, in the cell-brood, and in the very blood itself, as has been fully set forth! A pretty let go that is. Fie on it! Nature works by law; your theory does not, and you must bring it into correspondence, else stay in outer darkness. You offer no reason for it, whereas there is a reason for everything that Nature does. It is a true saying: "One lie is the father of many." But Truth is a sleuth-hound —terrible, and the progeny is doomed.

This action of the nerves upon the vessels has forcible illustration in the case of the vessels and nerves to the salivary glands, notably the submaxillary and sublingual glands (Fig. 115). Thus, when the chorda tympani (*c*) is irritated, the

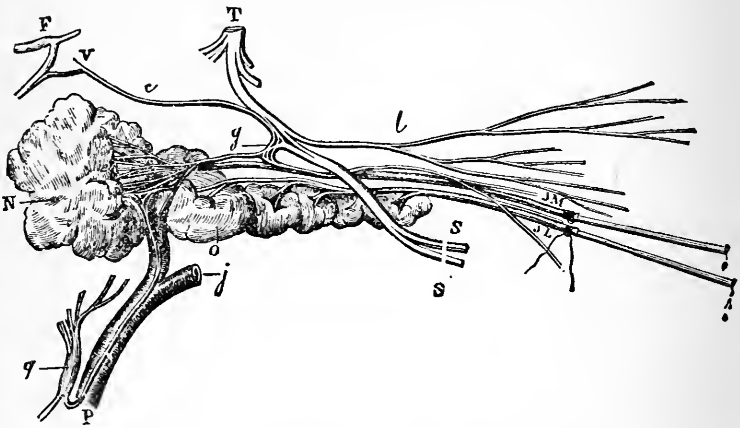

Fig. 115.—Nerves of the Submaxillary and Sublingual Glands of the Dog.—Bernard. *N*, submaxillary gland; *O*, sublingual gland; *JM*, Wharton's duct, in which a canula has been placed; *JL*, duct of the sublingual gland, also furnished with a canula; *T*, *S*, *S'*, the lingual branch of the fifth nerve; *F*, the facial nerve; *c*, chorda tympani; *g*, the submaxillary ganglion; *q*, the superior cervical ganglion; *P*, sympathetic twig passing from the ganglion to the submaxillary gland; *j*, internal maxillary artery; *V*, vidian nerve; *l*, branch of the lingual nerve ramifying in the buccal mucous membrane.

arteries of the gland dilate, the blood surging into them under the pressure in the arterial system, while the veins leading from the organ are made to pulsate under the force, and when they are divided the blood spurts like in an artery. But when the sympathetic fibres from the cervical ganglion (*q*, *P*) are excited, the arteries contract and circulation in the gland is retarded correspondingly; and if the veins are now cut they discharge "black" blood in a slow stream.

Now, then, when the chorda is irritated force is not *withdrawn* from the blood-vessels any more than in the cervical fibres when they are irritated, only that *different kinds* of electrical force pass along the nerves, positive or negative, as the case may be, but opposite kinds of force evidently for producing the opposite movements in the vessels, according to whether it is desirable to increase or to diminish the circulation in the parts, and which, of course, is determined by the sensory impressions propagated from the mucous membrane of the mouth by the food for increasing the saliva during mastication, the flow diminishing with this, and ceasing nearly altogether when there is no stimulus in the mouth for producing sensory impressions. Furthermore, there must be *prompt* response, for food cannot be kept forever in the mouth, and the saliva is needed for preparing the bolus and making dry substances moist so they can be swallowed.

Finally the ganglia or mind-centres have both sets of fibres —vaso-dilator as well as vaso-constrictor nerves—running into them, which is essential for effecting coördination and maintaining a balance in the local circulation; otherwise impossible. For example, the submaxillary ganglion (Fig. 115, *g*) connects with the chorda tympani, *c'* (a branch of the facial), and lingual, *T*, *S*, *S'* (a branch of the fifth pr.), upon the one hand and with the superior cervical ganglion (*q*, *P*, *g*) upon the other. All which is plain enough.

You are over anxious about contraction, but seemingly indifferent about expansion; and yet the fact is undeniable that without the latter you could not have the former—nay, more than this, that it must have *precedence* or *first* place, whether it relate to fluids or solids, living or non-living matter. Who denies *that* his opinion is not entitled to respect, for he talks without authority and without knowledge. Being correlated forces in Nature, they are, therefore, inseparable; while in the animal organism the tissues are kept in constant motion by their alternating actions, whether it relate to circulation or the voluntary movements, while coördination is effected by means of the appellate ganglionic nervous centres for the organs and organism.

So, then, the power for coördinating the viscera, inclusive of the blood-vessels, inheres in the medulla oblongata, the rhythmic centre for the organism.

The following instructive diagram (Fig. 116) will give some idea of the vast number of the sympathetic nerves and ganglia to the vessels and viscera in the abdomen. The spinal ganglionic chains (one side (left) only represented in the figure) connect with the solar plexus by means of the splanchnic nerves (extended links indicating where the ganglia belong in the chain in the respective sides); below, they connect with the aorta and lower cava, following the branches into the viscera, increasing in numbers as we approach the pelvic viscera, the occasion for which will appear later on; above, with the viscera and vessels in the chest, and blending with the pneumogastric and phrenic nerves in the solar plexus. In this manner, then, the whole is consolidated, and the action in the viscera is unified with the central nervous system, so that a balance is readily maintained in the circulation during respiration and the voluntary movements, etc.

In other words, the parts are unified through the nervous apparatus. The question as to which of the two lines of nervous force from the central nervous system to the stomach and intestines—this by way of the pneumogastric nerves or that of the splanchnics—is the more important, would seem to be in favor of the former, judging from the evidence before us and our own observations; though, perhaps, a true comparison cannot be made for the reason that the two sets of fibres, or dilators and contractors, are not equally distributed between them, the pneumogastrics containing more of the former, the splanchnics more of the latter fibres; while the one relates more particularly to the action in the muscular cylinder, the other the vascular apparatus; while neither are exclusive in their functions. But strong currents of nervous force set in and out of the viscera to and from the central nervous system through the pneumogastric nerves, for producing correspondence between them and the containing walls, at the same time increasing the actions in the muscular cylinder and vascular apparatus, expanding the network of capillaries and producing peristalsis; since stimulation of the pneumogastric nerves produces these effects, while stimulation of the splanchnic nerves produces contraction of the capillary network, though it also produces peristalsis; but they cannot effect the actions in the stomach nor set up the movements in the medulla oblongata during ingestion for bringing the containing walls into correspondence with the expansile action in the stomach for producing the requisite room for the food and maintaining a balance in pressure, otherwise impossible; *at the same time expanding the capillary network in the gastric mucous membrane* for increasing the digestive and absorptive processes in the organ. It comes to this in the main: that the pneumogastric nerves produce expansile action in the viscera, while the splanchnics have the opposite effect—producing contraction, especially in the vessels. And when the pneumogastrics are divided in the neck, the stomach and abdomen can no longer be expanded nor any food be taken, the animals dying from thirst and starvation, precipitated by pulmonary congestions from two to five days, the nerves not uniting, which has occasionally happened; while the respiratory rhythms fall from twenty-five to thirty per minute in the dog to seven and eight, sometimes as low as two per minute. But important corroborative evidence is obtained also at the bedside in cases of spinal injury, in which the nervous currents through the spinal cord are cut off, thus throwing the burden of effecting coördination in the stomach upon the pneumogastrics, and showing the great rôle they perform in the mechanics in the abdomen, as well as in the chest, in connection with respiration and circulation, which has already been fully considered. Thus, in a case of spinal injury which came within my own knowledge, in which the fourth and fifth cervical vertebræ were fractured and displaced so as to crush the cord, producing complete paralysis, with anæsthesia from the clavicles down, a little sensation only being perceptible about the clavicles, not knowing, indeed, "which portion of the body was in contact with the bed but by actual sight," as he said, commenting upon it, and deeming it very curious, the patient living, however, over twenty days, the following facts were ascertained; notably: 1. Respiration was diaphragmatic and labored, shallow, and from 25 to 30 per minute; pulse, 120 to 130 per minute; *polyuria*, with complete paralysis of the bladder, the urine having to be drawn every

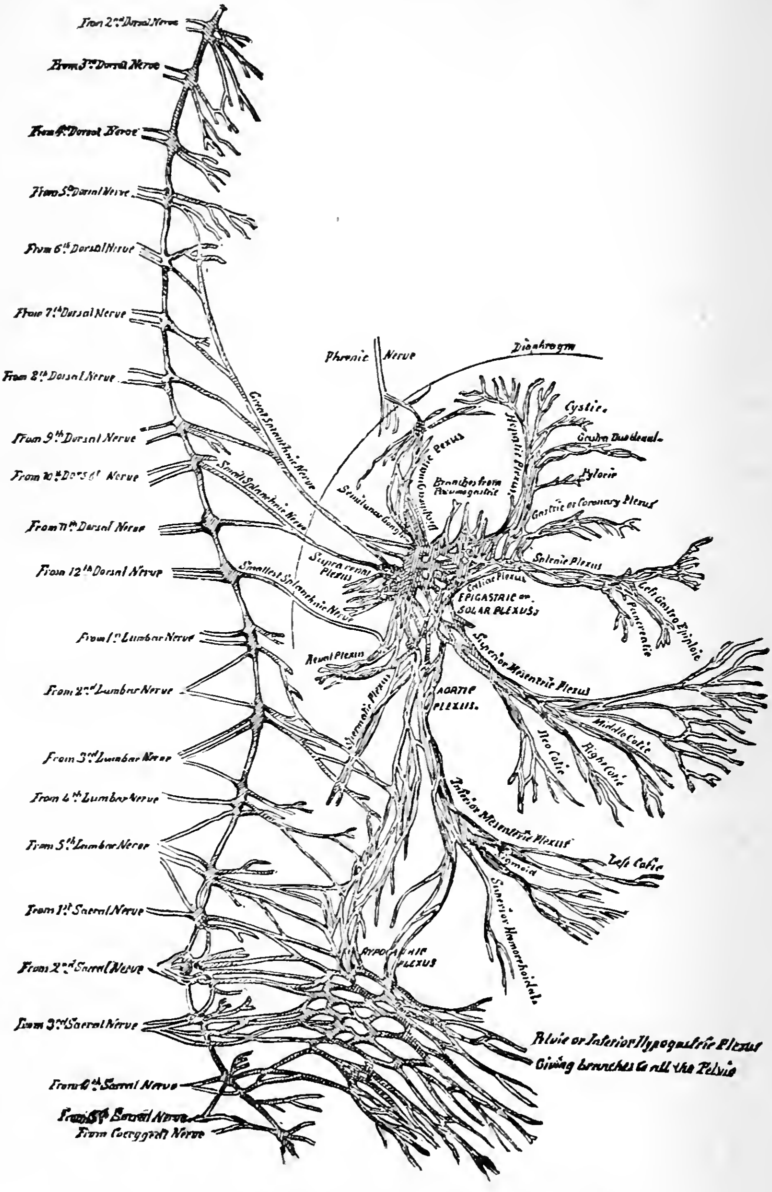

Fig. 116.—The Abdominal Sympathetic Nerves in Diagram.—Flower.

three or four hours, the patient being made aware of the passing of the instrument by *sight only;* tendency to diarrhœa, but no sensation about the anus, the patient cognizant, however, *when an action of the bowels was expected, directing the attendant to the circumstance;* and when the bed-pan was placed under him, presently there would be an action. Occasionally he relished food; there was considerable venous stasis in the systemic capillaries, with tendency to serous effusions in the connective tissue, the result rather of defective absorption. He lingered twenty-one days, and the post-mortem examination showed the nature of the injury to the spinal cord, which was crushed and completely disorganized at the seat of injury. Now, then, attention is specially directed to the interesting circumstances italicized in the notes—namely, the polyuria and the sensory impressions transmitted from the colon during a fæcal action.

Of course, the polyuria, with the tendency to diarrhœa, should be explicable, since they flow out of the mechanics as a result of the lesion in the spinal cord, and are easily explained. The spinal cord being crushed, this cuts off the nervous force from above through the splanchnic nerves, so that the cervical chain and cardiac plexus must be the route of the nervous supply; this, together with the contractor fibres in the pneumogastric nerves, which is not sufficient for maintaining the lumen and tonus in the vessels; in consequence, an amount of dilatation results, producing unusual fullness in the vessels and hyperæmia in the organs; hence, the polyuria and the tendency to diarrhœa. Then, again, the embarrassed respiration also tends to produce fullness in the portal vessels and lower cava system, which should increase the secretory actions, so that it is not at all difficult to account for the polyuria and tendency to diarrhœa, under the circumstances. The consciousness of the fæcal action is undoubtedly produced through the pneumogastric nerves. The contiguity of the transverse colon to the stomach suggests direct extension of the nerves to the colon, the left pneumogastric nerve especially, which is distributed principally over the anterior portions of the stomach; but in order to do this, the nerves would have to penetrate both layers of peritoneum, gastric and colonic; besides, it would interfere with the free action of the organs. The nervous force, then, passes through the solar plexus, thence up the colonic ligament, colica-media, colica-dextra, colica-sini tra, and inferior mesenteric arteries to the colon; showing, also, that the current is not broken at the ganglia, but passes to and fro between the viscera and central nervous system without let or hindrance. The pain in colic from over-distension of the colon by the gases, and the traction upon the nervous filaments which this produces, has similar explanation; the sensory impressions being propagated over the pneumogastric nerves, and so promptly reaching the brain And the lungs become filled up and carnified after division of the pneumogastric nerves, for the reason that the fibres from the posterior pulmonic and cardiac plexuses are not sufficient for maintaining the normal lumen in the capillary network in the alveoli with the pneumogastric fibres divided, the vessels consequently become engorged, leading to effusions and hæmorrhage; hence this circumstance. According to Latschenberger and Deahna,* the vagus (pneumogastric) contains both pressor and depressor (vaso-contractor and vaso-dilator) fibres; consequently, we should have congestions in the vessels of the chest and abdomen after division in the neck; and the pulmonic congestions should therefore have this explanation: the flood-gates thrown open, we must have inundations in the lungs as well as in the abdomen flowing out of this circumstance, to the contrary, notwithstanding. At any rate, it would explain the pulmonic congestions and the other would not, which places it under a cloud. The thick bundles of nerve fibres, continued from the pneumogastric nerves to the central ganglia of the solar plexus (Fig. 109, 2, *C*, *D*, *E*), are reflected thence over the cœliac axis (4, 4) to the stomach, liver, spleen and pancreas; and over the mesenteric artery (5) to the small and large intestines, the cæcal and sigmoid portions, by way of the inferior mesenteric artery; while that by the splanchnic nerves (3, 3) passes by way of the semilunar (*A*, *B*) and central ganglia (*F*, *E*, *C*).

Concerning the Action in the Kidneys.—Now, then, let us

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* Latschenberger u. Deahna, *Pflüger's Archiv*, vol. xiii., p. 22.

look from the mechanics in the intestines to the action in the kidneys for interpreting the special phenomena, anatomical and physiological, appertaining to them also. Briefly, the renal artery (which is a very large vessel), previous to entering the kidney, divides up into four or five branches that pass into the organ at the hilus—the vein in front, the ureter behind; and after dividing and subdividing to form the *arteriolæ rectæ* between the *tubili recti*, send off lateral branches (Fig. 117, *ai*, *va*), which terminate in the capillary tufts inclosed in the expanded ends of the convoluted tubes known as corpora Malpighiana (*gl*); and from which proceeds an efferent vessel (*vc*), which also breaks up into a capillary network around the convoluted tube (*c*), and medullary substance, or very much as the portal vein in the liver, and which again converge in a common vein (*v*, *z*) that discharges into the interlobular vein, or vena recta, side by side with the arteriola recta (*vi*).

The convoluted tubes are composed of two layers, the *membrana propria* and an *epithelium*, consisting of a single layer of polygonal nucleated cells, in which metamorphosis is effected. The epithelium occupies about two-thirds the diameter of the tube, the remainder representing the lumen; but that within the glomerulus itself is thinner. Finally, these convoluted tubes lying in the cortical portion are gathered up into the straight bundles that form the conical masses known as the pyramids of Malpighi (Fig. 118, 3), coalescing and joining at acute angles at the bases and within the pyramids to bring about this result, each one containing from two to five hundred tubes, which open upon the apices (4) of the pyramids (from eight to fifteen in number), that project into the calices and pelvis of the kidney.

Now, then, the effect of this arrangement is, when the lumen of the renal artery is enlarged for increasing the action in the organ, it first flushes the capillary tufts in the glomeruli (Fig. 117, *va*, *gl*), extending thence to the vascular plexuses of the convoluted tubes (*ve*, *c*); but as the tufts are the proximal portions, of course arterial pressure should be more effective here, tending to strain out the substances that pass easily through the animal membranes, passing out with the stream of water in which they are suspended, or down the tubes, washing out the secretions as it goes along; while the remainder, which is under reduced pressure by reason of this depletion, passes out through the efferent vessel to the capillary network of

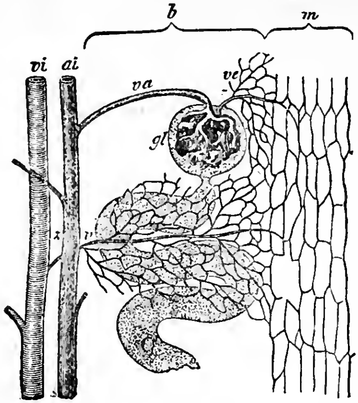

Fig. 117.—Course of the Blood-Vessels within the Cortex Proper (diagrammatic). *m*, The space occupied by the medullary radius; *b*, that occupied by the convoluted canals; *ai*, arteria inter-lobularis; *vi*, vena inter-lobularis; *va*, vas afferens glomeruli; *ve*, vas efferens glomeruli; *gl*, glomerulus; *vz*, venous twig of the inter-lobular vein.—Ludwig.

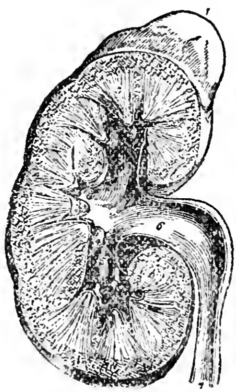

Fig. 118.—Section of the Kidney, surmounted by the Supra-Renal Capsule.—Wilson. 1, Supra-renal capsule; 2, vascular portion of the kidney; 3, 3, tubular portion, consisting of cones; 4, 4, papilla projecting in the calices; 5, 5, 5, infundibula; 6, pelvis; 7, ureter.

the tubes, the slower circulation in them affording opportunity for effecting metamorphosis in the epithelium, as in the case of the portal circulation, to which it sustains close resemblance in more respects than one, since the rhythmical compression of the liver-substance during respiration for increasing the venous circulation in the liver, should have the same effect upon the venous circulation in the kidneys, for the principle is precisely the same The gentle and uniform compression of the kidneys during inspiration must certainly compel the blood into the renal veins, while the suction force in the chest should pull it toward the lungs—the same as the portal blood, and the blood in the hepatic veins. Of course, the same mechanics also applies for the secretions, tending to force them out into the pelvis of the kidney (Fig. 118, 6). But here we have to note a special arrangement that obtains for increasing the action, constituting the fine adjustment in this mechanics; notably, the action in the pelvis and ureter. The ureter, which is expanded at the kidney to form the pelvis and infundibula (6, 5), is a *muscular* organ richly supplied with nerves from the renal plexus (Fig. 109, 9), while the special ganglion or mind-centre (*G*) directs the reflex actions; and there is but little reason to doubt that by means of this systematic arrangement there is a pumping action going on in the pelvis of the kidney, much in the same manner as takes place in the expanded buccal cavity of the leech during imbibition for aspirating the blood in the capillaries, or the still more striking example furnished in the nursing infant aspirating the milk through the lacteal tubes, the papilla of the mammary gland bearing close resemblance to the renal papillæ which project into the cavity of the pelvis for the purpose. So that, while the infant is aspirating the mammary gland, the ureters at the same time are aspirating the kidneys. Is it fanciful? Answer this question, then: What is this mind-centre doing here, and what are muscles and nerves doing in the ureter, since they cannot be purposeless? Can it be doubted for a single moment, even, that they relate to the functions in the kidneys, designed to expedite them? I think not. And wherever found, muscles and nerves perform *work* in correspondence with the special physiological requirements for which they are the relative adjustments, here as elsewhere. What matters it where they are located? Work is their office, and work they do. Then, too, look at the *shape* of the expanded portion of the ureter (Fig. 118, 6), and compare the muscles with the muscles in the leech and œsophagus; notably, the internal layer of *circular* and the external layer of *longitudinal* muscles, layer for layer, in them all, while each is operated by nerves from a special ganglionic nervous centre, for producing and coördinating the actions, or the same as the pneumogastric nerves and ganglia in the case of the œsophagus, the special arrangements which obtain in them being adaptive changes to meet the requirements in the case. Keeping in mind, also, that the kidney, with the afferent and efferent vessels and discharging duct is an entity, or independent organ, therefore endowed with automatic action, which is essential for maintaining the life that is in it and carrying on its functions, otherwise impossible. And it is well to look over the organs in this way, for pressure is the basis of all of them, and must be so, in the very nature of things. Well, what does it all mean, if not to act alike in pumping the fluids into themselves in connection with the special functions, pressure applying to all alike? Nay, there is other evidence proving they *must* act alike; otherwise, it would be utterly impossible to carry on the functions in the kidneys, since the uriniferous tubes would be choked from the accumulations in the pelvis from inability to effect expansion in the urinary bladder at the distal end of the ureters, which must expand in similar manner under the stimulus of the urine for receiving it. Thus the waves of expansion and contraction, passing along the ureters to the bladder, causes the bladder to expand, the waves losing themselves in the general expansion which results in the bladder, or the same as in the stomach, when ingesta passes into it from the œsophagus, finally the same as in the worms, notably the leech (Fig. 16, 1, 2, 3), the structures being also homologous, the principle the same; otherwise, it would be utterly impossible to introduce the urine into the bladder. Besides, the urinary bladder is rich in all the elements in arterial tissue; namely, unstriped muscles, elastic and connective tissue fibres, the bundles running in every direction, and when contracted, as in the empty condition, the structure is very dense. And to think of straining it open, as when fully distended with urine, by the action in the ureters and kidneys, thereby producing strain to the delicate tubuli recti and convoluted tubes extending back to the glomeruli, or through and through the organ from hilus to cortex, is nothing short of madness. The force is not *there* for expanding the bladder, but *upon* the *ground,* where the work is done in the walls of the viscus itself, otherwise it were utterly impossible to introduce the urine into the bladder, or operate the kidneys.

The strong muscular walls of the viscus are *not* forced into extension by the ureters and kidneys. *Ach Gott!* Never in *that* way, under the canopy of heaven! Impossible! Then, if you would not have the urine damming back upon the delicate renal structures, thereby arresting the functions in these organs, the ureters in common with the bladder must respond to the stimulus of the urine; the same as the œsophagus and stomach, the cystic ducts and gall-bladder, under the action of the special stimulus in the organs, the structures being fundamentally the same, and pressure applying alike to all of them.

Then, again, as the bladder fills and expands with the urine, it *rises* into the cavity of the abdomen; and when the contents are being discharged, it *sinks* again to the bottom of the pelvic basin. Accordingly, we have the *longitudinal* muscles *increased* in the ureters *as the bladder is approached,* and the addition of an *internal* layer, so that the tubes may readily elongate and contract under the action of the special nerves in the parts, which extend over and coördinate them so that correspondence is readily effected with the changing volume of the viscus; otherwise, the ureters should be bent upon themselves during the filling, thereby interrupting the flow, while during expulsion they would be subject to terrific strain, painful even to contemplation. Finally, the to-and-fro movements in the kidneys themselves during respiration, from the action in the diaphragm, would also call for the longitudinal muscles in the ureters, the same as in the œsophagus, vena cava, etc. Hence these muscles.

Displacement of the kidneys is obviated by the layer of peritoneum that covers and holds them against the posterior wall of the abdomen; though occasionally we have "a floating kidney," the organ seeming to slip about too freely in the general cavity, not being securely held by the overlying peritoneum and connective tissue, forming a kind of mesenteric ligament to the organ, which also shows the necessity for the special anatomical dispositions in the artery, vein and ureter for effecting elongation and contraction during respiration, so as not to interrupt the functions in the organ. And looking at all these beautiful adjustments for special work, can it be doubted for a single moment that the arrangements which obtain in the pelvis of the kidney should not expedite the functions in these organs, whereby the whole is brought in correspondence? Thus, in the expanded portion forming the buccal projection of the pelvis (Fig. 118, 6), the muscles are thick, but thin in the calices, and cease altogether at the papillæ; it follows that expansion in the muscles must inevitably exert a suction force upon the contents in the papillæ and uriniferous tubes. It is all very wonderful; but what more wonderful than Life itself? And when undifferentiated protoplasm locomotes from place to place—moreover, is highly sensitive—it looks still more wonderful.

And if the ureters should do nothing more than elongate and shorten with respiration, and with the filling and the emptying of the bladder, this of itself would exert a suction force upon the renal secretions; but there is every reason for believing in a special action in the pelvis of the kidney.

In order to account for the rapid appearance of substances in the urine, the old authors conceived that a short route existed from the stomach to the kidneys. Well, there is a short and direct route—as direct as it can be made—but it is through the nervous channels that the thing is effected—namely, by the renal ganglion (Fig 109, *G*), and the nerves and ganglia of the solar plexus, reflected thence over the cœliac axis (*G*. *F*, 4; *G*, *C*, 4); and since sensory impressions made upon the gastric mucous membrane would tend to enlarge the lumen of the renal arteries by reflex action, and thereby flush the glomeruli and increase the secretions in the organs correspondingly, we can readily understand the rapid reappearance of the substances in the urine, especially when we remember the mechanics in the stomach for compelling absorption, and that the entire circuit of the blood is made within a minute. In this manner, then, we can readily understand the specific action of diuretics, which, by acting upon the nerves and ganglion of the renal plexus, expands the lumen of the arteries and increase the blood supply to the organs correspondingly.

The rich nervous connections subsisting between the renal plexus and the splanchnic nerves (Fig. 109, 9 ; *G*, *A*, 3), *the third splanchnic terminating in the plexus* (7, 8), will give some idea of the importance of the renal functions for maintaining a balance in the organism, since it is through these nerves that the lumen of the artery is regulated ; also, why applications made to the skin surface in the lower dorsal and upper lumbar regions should be reflected thence upon the renal arteries for contracting the lumen in cases of engorgement or inflammatory processes in the organs. Look at it, please ; it is of great importance. The sensory impressions in the skin, where the applications are made, are transmitted over the relative intercostals to the appellate reflex centre in the spinal cord, thence through the third splanchnic nerve (7, 8) to the renal plexus. Of course, force is also transmitted through the other splanchnic nerves, but the relations of the third splanchnic would indicate it to be the main channel. It is needless to extend the matter.

CHAPTER XIII.

ADJUSTMENTS IN THE WALLS OF THE ABDOMEN WITH RESPIRATION AND THE FUNCTIONS IN THE PELVIC VISCERA.

Action in the Mesentery—Adjustments with Respiration and the Functions in the Pelvic Viscera—Adjustments with Gravitation and the Erect Position—Formation of the Sacral Promontory in Man—Adjustments in the External Oblique Muscles—External Oblique Muscles and Diaphragm Antagonizing each other in Respiration—The Respiratory *Plane* upon which the Viscera Move in Respiration—Action in the Transversalis—Action in the Internal Oblique; the Relations it Sustains to the Pelvic Viscera—Mode of Coördinating the Muscles in the Abdomen with the Pelvic Viscera—How the Diaphragm Assists the Action—Os Sacrum and Sacro-Ischiadic Ligaments, the Floor of Support to the Pelvic Viscera, as also the Point of Resistance to the Detrusor Force in the Abdomen—Functions of the Levator Ani—Mechanics in Emesis—The Stomach Energetically Compressed by the Simultaneous Contraction of the Diaphragm and Muscles in the Abdomen, Compelling Rapid Regurgitation.

Frequent reference has been made to the action of the mass of intestines known as "the mesentery" (Fig. 119), in connection with respiration and circulation; transmitting the force in the walls of the abdomen upon the stomach, liver, portal and lower cava systems, spleen, pancreas, thoracic duct, and the glands of the mesentery for increasing the action in them all, and compelling the venous blood and lymph within the abdomen to flow into the chest-cavity simultaneously during inspiration, as has already been fully set forth; and it remains to show the relations it also sustains to the viscera in the pelvis for increasing the action in them, in the bladder during urination, and in the colon and rectum during defecation, since the action in the walls of the abdomen is in concert with the action in the pelvic viscera; for the parts are fully coördinated by means of the nerves extending into them from the cerebro-spinal axis, and it all performs as but a single organ only for expelling the waste products, while the reflex actions for producing it are propagated from sensory impressions in the mucous surface of the special viscus; the same mechanics also applying for the contents in the womb. This mass of intestines, occupying the mid-abdominal regions, is in a manner isolated by the ligament (Fig. 119, 3), the only points of connection being the duodenum above, where the jejunum (1) terminates, and the cæcal pouch below, where the ileum (.) ends; and by simply dividing the intestines at these two points, and the ligament (3) connecting it with the lumbar vertebræ, the mass is readily removed from the abdomen;

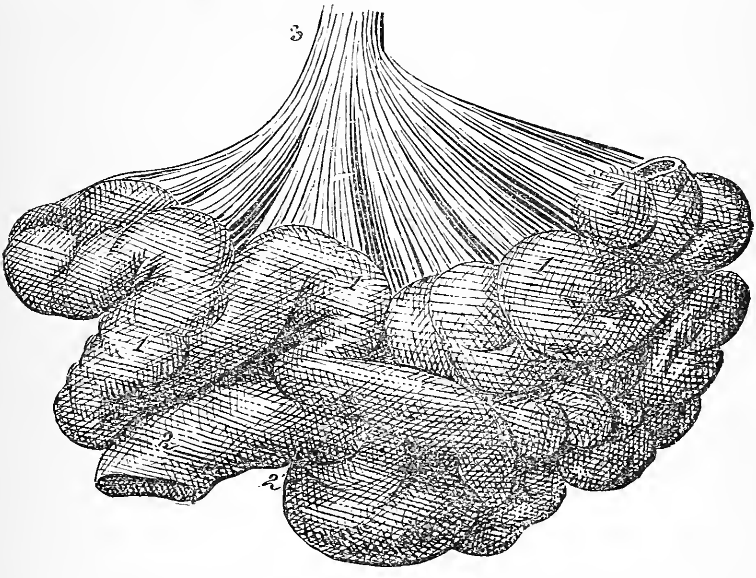

Fig 119.—The Mesentery. 1, 1, 1, Coils of jejunum; 2, 2, coils of ileum; 3, ligament of mesentery.

while the ligament itself may be spanned by the hand; this, notwithstanding 15 to 20 feet of intestines in the man, 40 to 50 in the horse, and 50 to 60 in the ox, are thus embraced by the ligament. *Mirabile!* Well, by reason of gravitation, the ligament in the quadruped (Fig. 25, *M*) is perpendicular, while in the erect position of the trunk, as in man (Fig. 120), the viscera gravitate against the lower abdominal walls (*I*, *E*) and the widely-expanded ilia, carrying the ligament with them, so that it now occupies an oblique position in the abdomen (*M*, *E*), gravitation compelling this circumstance. Of course, the weight in the colon (*c*), stomach (*s*), spleen, and liver (*L*) is also sustained by the mesentery, but transmitted of necessity to the walls of the abdomen and pelvis as the common floor of support, since it would not do to have them sagging to the diaphragm or any strain to the ligaments; otherwise inevitable. But one thing calls for another. Thus, for obviating the pressure in the pelvic

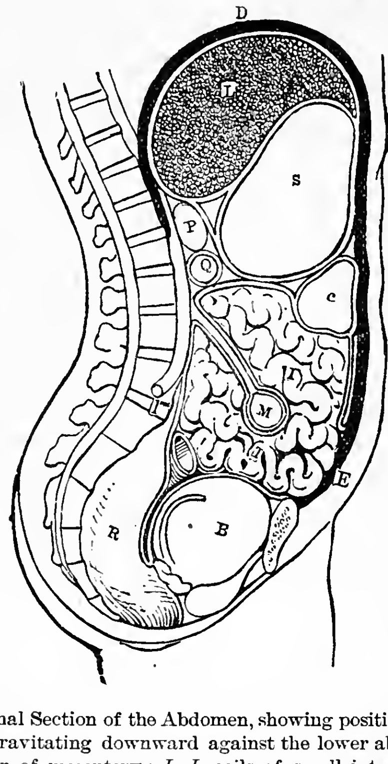

Fig. 120.—Longitudinal Section of the Abdomen, showing position of the mesentery with the body erect, gravitating downward against the lower abdominal walls and false pelvis. *M*, center of mesentery; *I*, *I*, coils of small intestine; *E*, anterior wall of the abdomen; *B*, bladder; *R*, rectum; *C*, colon; *S*, stomach; *L*, liver; *D*, diaphragm; *P*, pancreas; *Q*, duodenum.

viscera produced by the weight of the viscera, the pelvis is *tilted backward* in man, so as to throw the mesentery against the lower abdominal walls (*M*, *E*) and the expanded ilia, a few loose coils only lightly resting against the pelvic viscera (*R*, *B*), whereby impact from the diaphragm during inspiration and from locomotion, otherwise inevitable, which would tend to force out the contents in the organs, subjecting them to strain as well, is avoided. It is simply wonderful. But there is an obvious reason for every one of the adjustments that obtain in man. Please think over it carefully. I can do no more to make it plainer. But to me, however, it seems sufficiently obvious. This backward tilting of the pelvis, producing the sacral promontory in man, is the result of the *erect* position of the trunk and the reactionary forces *in locomotion*—gravitation, the propelling force for driving the body forward, together with *impact in the acetabula* transmitted through the crural bones, making them the points of resistance, tending to carry the pelvis backward; hence, the sacral promontory in man. It is deeply interesting, containing a number of features connected with the bones. It is needless to add that the great development of the pelvic bones in man has similar explanation, strain tending to fall here during locomotion from the weight in the body and viscera.* Before proceeding to the adjustments with the pelvic viscera, however, it will be necessary to first consider the adjustments with respiration, since this is fundamental in the organism; when it will be in order to regard the pelvic arrangements, making it logical and scientific, at the same time omitting nothing which a physiological treatise should do, taking in all the relative anatomy by showing the adaptations of means to ends, since the whole relates to special work for which they are the relative adjustments.

Action in the External Obliqui.—The external oblique muscles (one for either side), *obliquus externus abdominis*, is so called from the obliquity of the fibres which bisect the longitudinal axis in the body at an acute angle (Fig 121). It springs by eight fleshy digitations from the external surface of the eight inferior ribs, and sweeping boldly downward and inward embraces the entire abdomen in front and upon the sides, the dense fibrous leaflet, in which the muscular bundles terminate, sweeping over the powerful rectus abdominis (Fig. 121), indicated by the band of dark fibres (lineæ transversæ) to inosculate with the fibres from the opposite side in the *linea alba*, whereby the anterior portions of the abdomen, where

* For full particulars, see work on "Gravitation and Development."

strain tends to fall from the weight in the viscera, is greatly strengthened; at the same time, this aponeurosis subserves important purposes in conjunction with the aponeuroses from the other muscles, in maintaining the rectus abdominis in position, forming a strong sheath for the powerful cable-like mus-

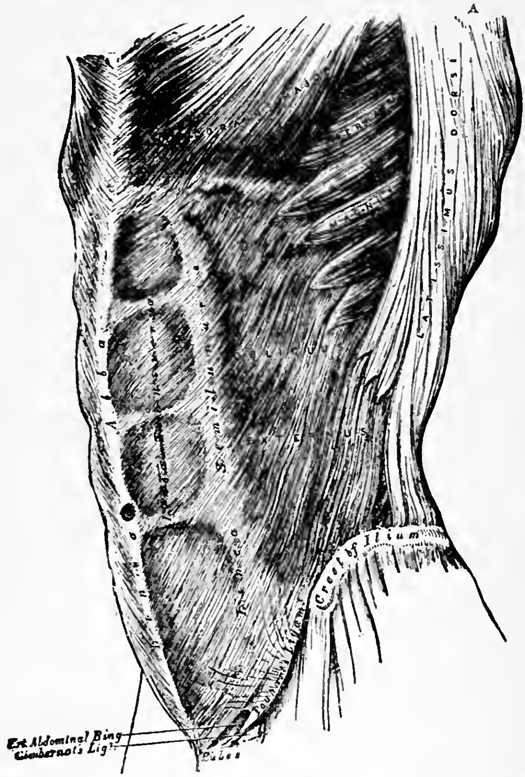

Fig. 121.—Showing direction of the fibres of the external oblique muscle.—Gray. The letter *A* is added.

cle extending from sternum to pubes, that it may not slip out of position in the rude experiences to which the animal is subject; also, tending to fly up from its bed with every contraction in the muscle, especially when energetic, as when the body is being flexed. Below, the fibres are inserted into the anterior portion of the crest of the ilium and pubes, which assist the recti abdominis and internal obliqui in flexing the trunk at the lumbar vertebræ in bending over or stooping. Now, then, why should the fibres in the external muscular layer of the abdomen have this oblique direction, downward and inward, embracing the abdomen, since the matter has relation to special work which these muscles perform and are the relative adaptations? It is readily answered. When they contract, *they pull the viscera upward and backward*, the direction of the force being upon a *plane* extending *from the umbilicus* (*a*)* *to the upper dorsal curvature* (*A*), which is the respiratory *plane*, all the fibres running in this direction. Look at it well, please; it will pay you, for the gods have left their mark. Well, when these muscles pull the mesentery with the adjacent viscera toward the deeper portions of the chest during expiration, the diaphragm expands, in order to admit of the movement, which produces high pressure in the lungs, while the insertions into the lower ribs have the effect of pulling *them* downward, whereby the action in the lungs is greatly increased, causing the air and blood to rush out of the alveoli with corresponding energy But when the action is reversed. this lets down the viscera again, since they must follow the floor of support, while the action in the diaphragm, by reason of the insertions into the *ends* of the seven lower ribs (Fig. 26) and lumbar vertebræ, and the manner it is ballooned in the chest-excavation, throws the viscera forward and downward (downward and backward in the horizontal position), pressing them against the anterior abdominal walls, while the ribs are thrown upward, flaring them open upon the sides, caused by the muscular fibres in the diaphragm (Fig. 27, *F*, *F*) pulling upon the cartilaginous ends of the ribs in the long axis (pp. 89–91); hence this circumstance. This action produces low pressure in the chest, the lungs at the same time expanding for confining it to the alveoli; whereby the air and blood are compelled into the chambers simultaneously. And by this alternating action in the diaphragm and muscles in the abdomen we have the pumping movements produced in respiration, the lungs, of course, acting in concert. In this manner, then, the respiratory *plane obviates impact in the pelvic viscera* during inspiration; otherwise inevitable, as must appear obvious.

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* The terminal letter of "linea."

The wide fibrous aponeurosis, spreading out like a sheet over the anterior portions of the abdomen, distributes force evenly over the viscera, so that undue pressure cannot fall upon any one of the organs, each one sustaining its relative amount of pressure according to extent of surface. And the great rôle the muscles perform in respiration has forcible illustration by simply placing the open hand upon the sides of the abdomen when talking, whistling or singing, the faintest vocal resonance being promptly reported by the movements in these muscles, while the action swells with the volume of the sound. There is no mistaking it. And there is nothing more perfect than the arrangements that obtain in this respect. The rounded lower border of the aponeurosis, known as Poupart's ligament, inserted into the spinous processes of the ilium and pubis, spans the femoral artery, vein, crural nerve, flexor muscles of the thigh (psoas and iliacus internus), like a ligamentum arcuatum in the diaphragm, while the powerful deep fascia of the thigh (*fascia lata*) inserted into it hold it firmly, so that during contraction of the muscle strain cannot fall here. At the same time it gives protection to the vessels. Very pretty—all of it. We now pass to the *transversalis*, the auxiliary muscles for increasing the action in the obliqui, which includes the internal as well as the external obliqui, the action in both sets of muscles receiving important aid from the pair of muscles we shall now bring before you.

The Action in the Transversalis (*lumbo-abdominalis*).—The transversalis (Fig. 122) is the innermost of the three muscular layers to the abdomen, the peritoneum covering it, and the viscera lying against it. As the name indicates, the fibres run transversely; the muscular fibres spring from the internal surface of the cartilages of the six inferior ribs, lumbar fascia, crest of ilium, and Poupart's ligament; while the fibrous aponuerosis in which the muscle-fibres terminate inosculates with that from the opposite muscle in the linea alba, passing *under* the rectus abdominis, forming the inner layer of its sheath, save at the lower portion, where the fibres pass in front of it, blending with the fibrous layer from the internal oblique muscle (Fig. 122), the rectus muscle having three layers of fibrous aponeurosis at this point for supporting the muscle, strain tending to fall in this locality (Fig. 120, *E*), from the weight in the viscera; hence this circumstance. And for giving the transverse muscles a firm point from which to contract upon the abdominal viscera, the posterior aponeurosis forming the lumber fascia (Fig. 122) is divided up into three broad leaflets, the anterior

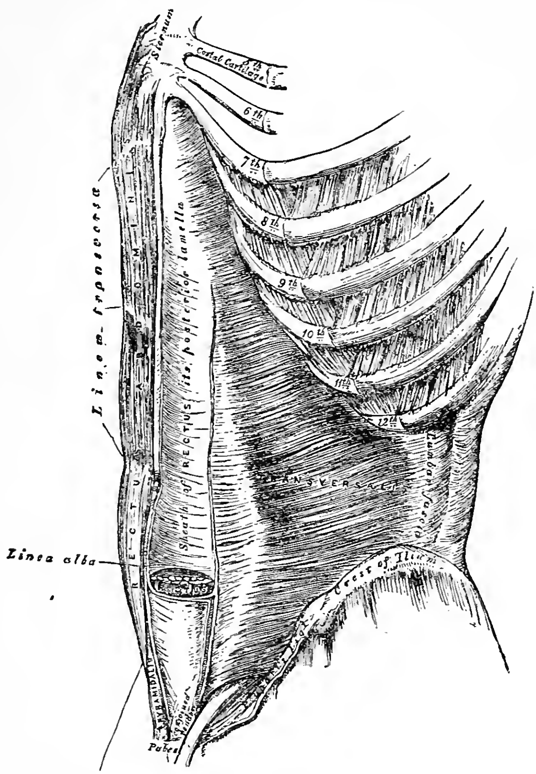

Fig. 122.—Showing direction of the fibres of the transversalis muscle.—Gray.

and middle being inserted into the base and apex of the transverse processes of the lumbar vertebræ, and the posterior into the powerful aponeurosis of the latissimus dorsi, so that force with security are insured. Now, then, contraction in the transversales must inevitably *diminish* the *transverse axis* in the abdomen; and should this occur simultaneously with contraction in the external obliqui (which is the case), it is easily perceived that it would assist the action in these muscles correspondingly. It could not do otherwise, in the very nature of things. In short, the whole anterior walls of the abdomen from sternum to pubes are pulled backward by contraction in these muscles, thereby increasing pressure in the abdomen correspondingly for compelling the viscera toward the chest during expiration, while the extensive insertions into the ribs should keep them down for increasing pressure in the lungs; in this way also aiding the external obliqui. Finally, the two pairs of muscles act together and simultaneously, the action alternating with the action in the diaphragm; and by aid of these muscles the mesentery is moved to and fro in a muscular casket, as it were, the great pendulum in the clock-work, by the force in the medulla oblongata. That will answer for respiration. Now, then, in regard to the action in the pelvic viscera and the mode of concentrating force in the pelvis in connection with the special functions in the viscera. Here comes in the great rôle in the internal oblique muscles, to which the other two pairs, the transversales especially, are auxiliary; as also the diaphragm, the whole being available for concentrating force in the pelvis.

Concerning the Mechanics for Expelling Waste Products in the Pelvic Viscera and the Contents in the Womb.

The disposition of force in the walls of the abdomen for compelling out the contents in the pelvic viscera, which function as receptacles for waste products, notably the bladder and rectum, inclusive of the contents in the womb, is also very perfect. By reason of density in the fæcal matter from absorption of the aqueous portions in the colon, much force is needed for effecting expulsion, which is also available for increasing the action in the bladder and womb during urination and parturition, the parts being fully coördinated with the viscus, by means of the nerves running into them from the spinal axis, as before remarked Now, then, for producing this force we have the following arrangement in the muscles, notably: 1. The powerful internal oblique muscles, or *obliqui internus abdominis ascendens* (Fig. 123), springing from the middle of the crest of the ilium for two-thirds its length, outer half of Poupart's ligament and lumbar fascia, whence the fibres proceed upward and inward, to be inserted into the lower border of the four inferior ribs, and the whole of the linea alba from the ensiform cartilage to the pubes by means of the broad aponeurosis, where the fibres inosculate with those from the opposite side Along the border of the upper three-

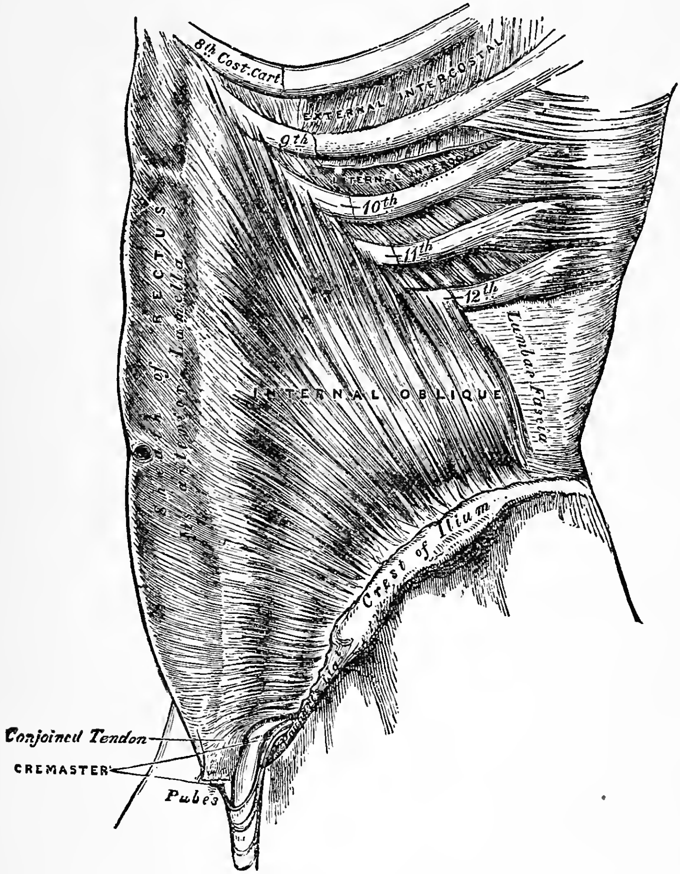

Fig. 123.—Showing direction of the fibres of the internal oblique muscle.—Gray.

fourths of the rectus abdominis the aponeurosis splits into two layers for embracing the muscle, forming the middle layer of its sheath, but at the lower portion it again comes in front of the muscle, following the course of the transversalis (Fig. 122), and for the same reason; near Poupart's ligament the fibres come downward over the spermatic cord to be inserted into the pubes. That will serve the purpose of description. Now, then, what can be the purpose of this arrangement in the fibres of the internal oblique muscle, if it be not for increasing pressure in the pelvis in connection with the special functions in these organs? At the same time, they also assist in flexing the trunk at the lumbar vertebræ, as well as the expiratory effort by pulling the ribs downward during this time, and when the action is energetic they pull vigorously upon them. But the major number of the fibres extend out over the walls of the abdomen, and by means of the dense aponeuroses the whole mesentery is embraced, and when contracting vigorously, as in passing the fæcal contents, this is pulled into the excavation, pressed, piston-like, down upon the pelvic viscera for compelling out the contents in the rectum or bladder, as the case may be. First, the body is flexed or bent upon itself (Fig. 124), for shortening the longitudinal axis in the abdomen, which is accomplished by the action of these muscles and the recti abdominis, at the same time the thighs are flexed by the action of the psoæ and iliaci interni, which brings the long axis in the pelvis in correspondence with the long axis in the abdomen, whereby the force in the diaphragm is brought to bear upon the pelvic viscera. Everything being ready, the diaphragm contracts by inspiratory effort for increasing pressure in the abdomen; finally, *the internal obliqui are put into action*, which *force the mesentery downward into the excavation* (Fig. 124, *M*), the loose coils of intestine gliding readily over one another under the force in the abdomen, *downward* and *backward against the rectum* (*R*), which cannot escape and must endure the pressure, at the same time contracting energetically for assisting the action, while the sphincters expand simultaneously for reducing resistance, as also for obviating strain and rude friction in the parts, otherwise inevitable. It is simply perfect. As will be seen, the ligament is carried downward, and is no longer upon the *plane* it occupies in the erect position or toward the anterior abdominal walls (Fig. 120, *M*, *E*). And by thus pulling the mesenteric piston with great force down upon the bladder and rectum, together with the action in the viscus, the contents are expelled. In short, nothing could be more admirable than the arrangements which obtain for increasing pressure in the pelvic excavation commensurate with the functions in these organs, the same remark applying for every stage in development. Thus in the quadruped the lumbar vertebræ are flexed

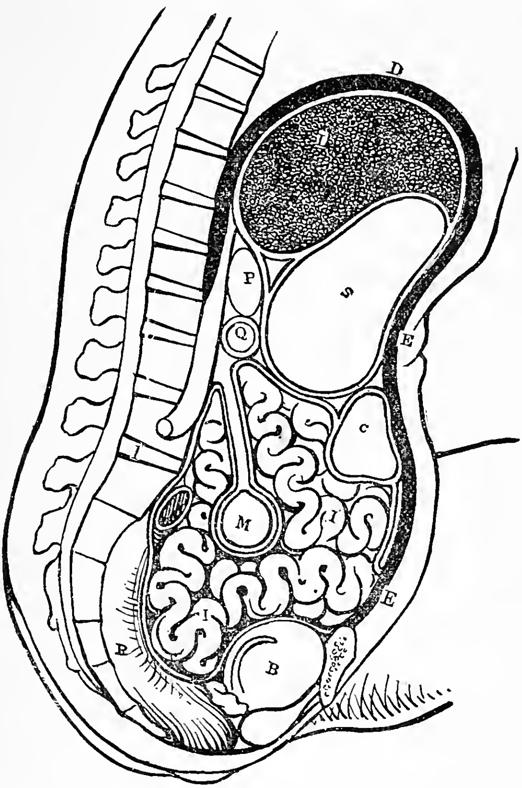

Fig. 124.—Longitudinal Section of the Abdomen, showing position of the mesentery during expulsion of waste products. *M*, middle of mesentery ; *I*, *I*, coils of small intestine ; *E*, anterior abdominal wall ; *B*, bladder ; *R*, rectum ; *C*, colon ; *S*, stomach ; *L*, liver ; *D*, diaphragm ; *Q*, duodenum ; *P*, pancreas.

by incurvating them upward, which is done by contracting the recti and obliqui, as in man, the muscles upon the dorsal surface at the same time expanding or elongating *pari passu* with this movement. Then the diaphragm is contracted for shortening the longitudinal axis; finally, the transversales and internal oblique muscles are energetically contracted for shortening the transverse axis *and compelling the mesenteric piston into the pelvic excavation.*

The action is studied to great advantage in the dog and cat, in which the excrement is hard, and unusual force is needed for expelling it. It goes hard with them, and they work away vigorously in performing it, concentrating their force in the pelvic viscera, the rectum especially, greatly arching the spine upward and bringing the force in the diaphragm and abdominal muscles to bear upon the rectum transmitted through the mesenteric piston. This condition of the rectal contents would explain the great development of the muscles in this locality, which are much more numerous than in any other portion of the canal.

In the bladder, on the contrary, the contents are liquid; hence, not so much force is needed for expelling them, unless, forsooth, there is obstruction to the natural flow—*e. g.*, stricture—when the walls are hypertrophied, becoming extremely thick in course of time. When the animal desires to pass urine, he puts himself into a proper position, when the mechanics is set in motion for effecting expulsion, all the parts being coördinated by the central nervous system, so that the whole performs as but a single organ only, as in the case of the rectum.

In the parturient woman, this reflex action, which is propagated from the viscus through the spinal cord, is forcibly illustrated by simply *drawing upon the perineum* by means of the index and middle fingers inserted between the labia, when a tremendous expulsive effort at once sets in, the patient contracting the diaphragm and holding her breath, then powerfully contracting the internal oblique and transversales, the womb at the same time contracting, all the parts acting in concert, as in the other cases, the cervix at the same time expanding.

In the case of birds the legs are brought further under the body, which is tilted a little up anteriorly and lowered posteriorly (which favors gravitation); at the same time, the abdomen and cloaca are contracted for expelling the contents, fæcal matter or ovum, as the case may be. the principle being the same. For expelling the ovum great force is needed, while time is required for effecting the requisite expansion in the sphincters. The event is announced with great joy. In all the mechanics it is fundamentally the same, requiring the action in the mesentery and the muscles in the abdomen, in connection with the action in the special viscus for effecting expulsion of the contents.

Finally, we have to note several adjustments for conserving structure and increasing function, charming to look upon; notably: *a.* The incurvation of the sacrum, which is bent in both the longitudinal and transverse axes, or *dished*, so to speak, in two directions, the rectum occupying the long diameter, and by means of the articulations with the ilia is inclined at an oblique angle with the spine; in other words, tilted backward in the upper portions; but being bent upon itself, the lower portion is again brought forward, across the longitudinal axis in the pelvis, and forming with the sacro-ischiadic ligaments (Fig. 125, 10, 9) the true floor of the pelvis for sustaining the weight in the viscera and the force in expulsion, the mesenteric piston being driven plump up against it with the rectum sandwiched between them (Fig. 124, *M*, *i*, *R*), thereby saving the perineum The rectum, thus lying in the hollow of the sacrum through its whole length, sweeps out over the end of the coccyx to reach the external surface to form the anal opening. It is easily retained in position by means of the overlying peritoneum and connective-tissue fibres, while the terminal end is supported by the broad muscular leaflets of the levator ani (Fig. 125, 7), proceeding from the sides of the rectum, to be extensively inserted into the adjacent sides of the pelvis, forming the portion of the floor corresponding with the perineum; and supporting the bladder and vagina as well. It results, from this arrangement in the parts, that but little of the detrusor force in the abdomen falls *directly* upon the perineum, the sacrum sustaining it; at the same time, it is made more effective upon the fæcal matter, the rectum, of course, contracting simultaneously for increasing the action, while the levator ani are in concert so as to obviate strain to the perineum, the parts being fully coördinated.

The manner Nature has solved this difficult problem in mechanics, which is truly wonderful, must be set down to necessity, and as a prerequisite to the *erect* position, gradually brought about in connection with the other changes in the pelvic framework.

The following illustration (Fig. 126) will show the arrangement and distribution of the spinal nerves to the chest and walls of the abdomen. As will be seen, the nerves to the abdominal walls are nearly all intercostals, so called, save the ilio-hypogaster (16) or first lumbar nerve, to the inguinal regions, but in the abdomen the intercostals are greatly enlarged in correspondence with the amount of muscles for evolving the force in the walls in connection with respira-

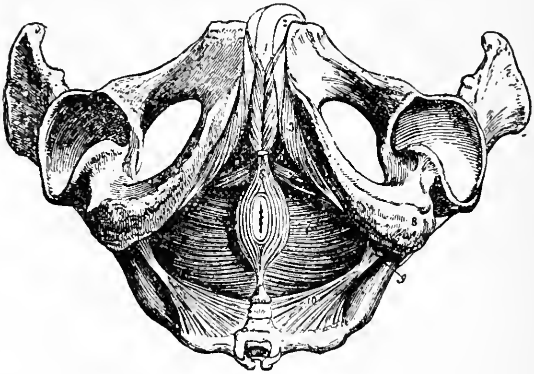

Fig. 125.—Muscles of the Perineum.—Wilson and Buchanan.

tion and the functions in the viscera. And one may readily perceive how the action in the abdomen may be made to alternate with the action in the diaphragm in respiration, since the phrenic nerves are correlated with them in the respiratory centre; as also how the viscera are brought into correspondence with the walls through the reflex actions set up by means of the pneumogastric and splanchnic nerves, correlated with the intercostal and phrenic nerves. Finally, how sensory impressions in the pelvic viscera should concentrate the force in the pelvic excavation, in connection with the special functions in these organs, while the enormous web of nerves and nervous ganglia in the hypogastric plexus (Fig. 116), together with the nerves running into it and the special viscera from the spinal axis, notably from the fifth lumbar and sacral nerves (*Ibid*), would make us readily understand how the viscus itself should be influenced by the force from the central nervous system, at the same time it effects the actions in the abdominal walls, all the parts acting in concert to this end. It is complex, but readily understood.

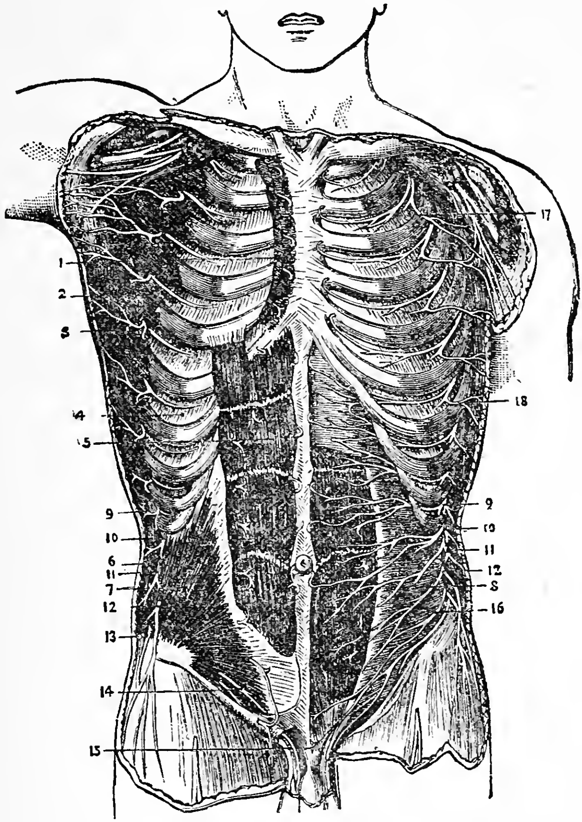

Fig. 126.—The Nerves of the Abdominal Wall (from Hirschfeld and Leveillé). 1, Pectoralis major (cut) ; 2, serratus magnus ; 3, latissimus dorsi ; 4, intercostal muscles ; 5, rectus abdominis ; 6, section of obliquus externus ; 7, obliquus internus ; 8, transversalis abdominis ; 9, 9, ninth dorsal nerve ; 10, 10, tenth dorsal nerve ; 11, 11, eleventh dorsal nerve ; 12, 12, twelfth dorsal nerve ; 13, lateral cutaneous branch of first lumbar (ilio-hypogastric) ; 14, anterior cutaneous branch of ilio-hypogastric ; 15, anterior cutaneous branch of ilio-inguinal ; 16, ilio-hypogastric and ilio-inguinal nerves ; 17, lateral cutaneous branch of second intercostal nerve ; 18, lateral cutaneous branch of intercostal nerve.

Concerning the Action in Emesis —The action in emesis is also easily understood. Thus, in place of alternating in their action, as in the usual way in respiration, the muscles in the abdomen and diaphragm *contract simultaneously* and the stomach, caught between these two forces, as in the grip of a vise, is compelled to yield up its contents, which is by regurgitation; for the enormous pressure within the abdomen precludes it in the other direction, flowing from high to low pressure, in conformity with organic law. This would ex-

Fig. 127. Fig 128.

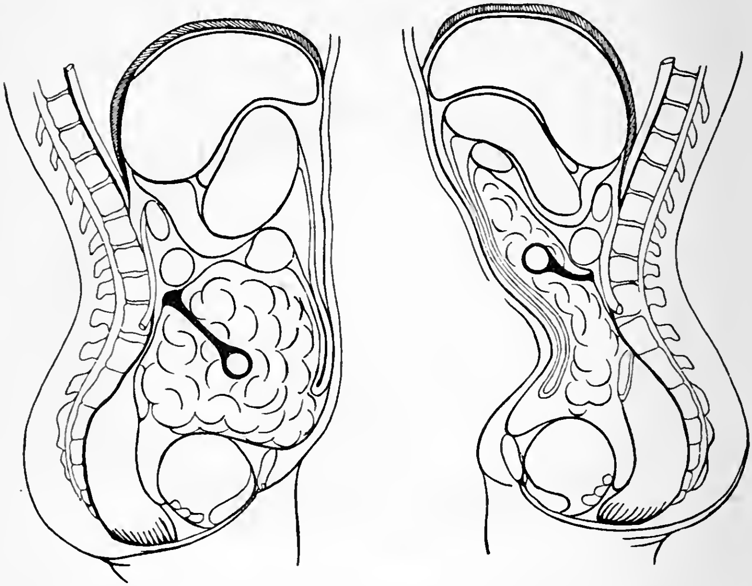

Fig. 127.—Longitudinal Section of the Abdomen, showing position of the mesentery.
Fig. 128.—Longitudinal Section of the Abdomen, showing position of the mesentery during vomiting.

plain why emesis may be produced when a bladder containing water is substituted for the stomach by irritation propagated from the pharynx, which is obvious enough. But here, as elsewhere, the viscus acts in concert with the muscles in the abdomen, contracting vigorously upon the contents, as in the case of the rectum, bladder and womb, producing a reverse peristalsis, since this would assist the action; for Nature concentrates all her available force in expulsive efforts. The short, loud inspiratory sound characteristic of vomiting is produced by energetic inspiration *suddenly arrested* by *the stronger action in the abdominal muscles.* The above illustrations will serve for impressing the matter (Figs. 127, 128).

Thus the mesentery is forcibly compressed against the stomach under the energetic action of the muscles in the abdomen, the contracted diaphragm being the point of resistance, since both act in concert; while the correlation of the pneumogastric, phrenic, and intercostal nerves in the medulla oblongata enables this concert of action in the stomach, diaphragm, and the muscles in the abdomen to be produced. The irritation is propagated from sensory impressions in the gastric mucous membrane, which sets up the action in the me-

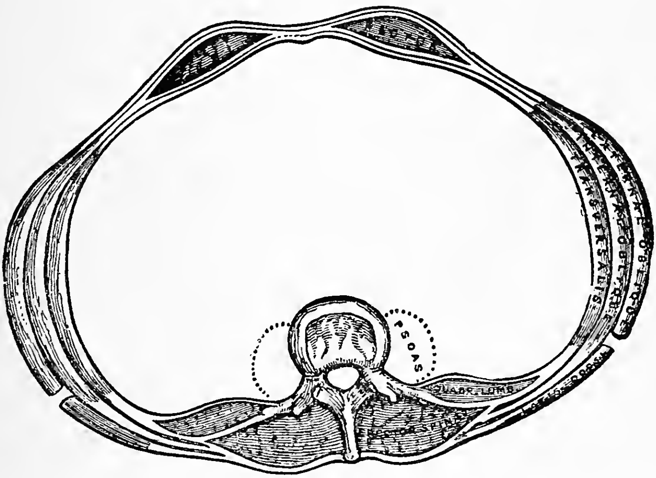

Fig. 129.—Transverse Section of the Muscles in the Abdominal Walls.—Gray.

dulla whence it is reflected over the structures. It is all very simple and easily understood. The extreme pressure upon the liver and gall-bladder would also account for the escape of the bile.

The above instructive diagram (Fig. 129) will show the relative position of the muscles in the abdominal walls and the manner the recti abdominis are kept in position by the strong fibrous aponeuroses. In the quadruped the weight of the viscera is largely sustained by these powerful muscular beams; at the same time, their aid is readily invoked for assisting in flexing the spine at the lumbar vertebræ, for which there is frequent occasion in connection with the functions in the pelvic viscera, as before remarked. In man, still more frequently for effecting the bending and stooping posture.

CHAPTER XIV.

CIRCULATION IN THE EMBRYO, MECHANICAL PRINCIPLE IN.

The Embryo, an Aquatic Animal, being Submerged in the Liquor Amnii, Deeply Buried in the Maternal Tissues, and Sustaining Itself the same as the Fishes, only that a Special Arrangement Obtains Respecting it, by Means of which it both Respires and Feeds at One and the Same Time in the Maternal Blood—Placental Souffle the Analogue of Respiration, the Rhythms being as One to Four of the Fœtal Heart, or the Same as Obtains in the Lungs and Heart in the Air-Breather—Mode of Connecting the Maternal and Fœtal Circulations—The Pumping Action in the Placenta Aspirating the Nutritive and Force-Producing Elements in the Blood in the Sinuses and Expelling Waste Products—Rhythmical Expansions and Contractions Taking Place in the Womb and Placenta, but which Alternate with Each Other, so that when the Placenta is Expanding, the Womb is Contracting, and *vice versa;* whereby the Blood in the Sinuses is Rapidly Renewed, and Absorption Increased Correspondingly—Nerves for Controlling the Arterial Feeders to the Womb for Making Circulation in the Sinuses Commensurate with the Physiological Requirements in the Embryo, and for Producing Correspondence throughout, so that the Pumping Action in the Uterus and its Contents is Made Universal, as in the Air-Breather—Rhythmic Centre for the Pumping Actions Located in the Lumbar Enlargement of the Spinal Medulla—The Rhythmic Expansions and Contractions in the Womb Contrasted with the Action in the Amnion of the "Chick," which is Rocked to and fro in the Egg-Shell by the Rhythmical Expansions and Contractions in the Amnion for Effecting the Requisite Changes of Pressure in the Embryo and Allantois for Increasing Circulation, Making it Commensurate with the Physiological Requirements.

This brings us to circulation in the embryo. We have seen that the animal organism is based upon pressure and the power of producing rapid rhythmical changes in pressure for increasing circulation commensurate with the physiological requirements, otherwise impossible; that respiration and circulation necessarily form a connected movement for producing an uninterrupted and continuous current of the fluids between the cell-brood and environment from which the supplies are obtained, and into which the waste products are returned for *re*distribution. We now follow this matter and take up circulation in the embryo, in order to give the true interpretation of the phenomena, anatomical and physiological, appertaining to it also. There is increasing complexity, but from the standpoint afforded by this law for the circulation it is readily explained, so that a mental picture may be formed by aid of illustrative diagrams and the special anatomy. But we must begin with the special environment and the mode of maintaining existence. After all, the mammilian is amphibious, the earlier portions of its life being passed under water, since the embryo (Fig. 130) is submerged in the liquor amnii and deeply buried in the maternal tissues, while the arrangements that

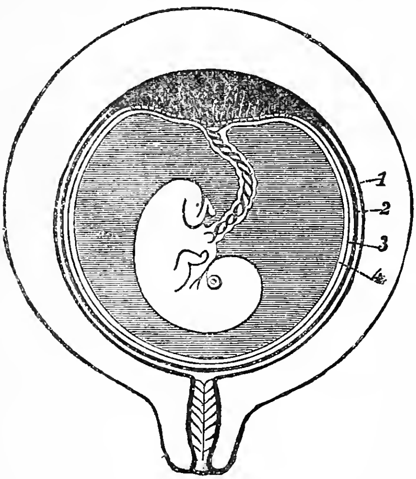

Fig. 130.—Gravid Human Uterus and Contents, showing the relations of the cord, placenta, membranes, etc., about the end of the seventh month.—Dalton. 1, Decidua vera ; 2, decidua reflexa ; 3, chorion ; 4, amnion.

obtain for producing growth and evolving force are fundamentally the same as in the fishes, due allowance being made for the special environment ; the one feeding and respiring in the sea, the other in the maternal blood by means of a composite organ known as the placenta, feeding and respiring at the same time through the placental organ, which thus subserves a double function, like the intestine in the early stages in development, the animals feeding and respiring through it. And, indeed, a remnant of it is still seen in mammalia in the consumption of air and absorption of oxygen in the stomach when feeding.

The physical conditions under which the embryo is evolved determine the special vascular arrangements for effecting circulation, while the transformations which accompany this provide for the radical physical changes which are ushered in at the end of the term, when it becomes an *air-breather*, the fundamental circumstance underlying it all being *an adjustment with pressure, and the power of effecting rapid rhythmical changes in pressure*, for compelling circulation in the measure of the physiological requirements. For example, we have seen that the rhythmical expansions and contractions pervading the body in the air-breather, and known as *respiration*, compel oxygen and aliment into the circulatory apparatus for evolving force and producing growth; so, in like manner, a similar necessity exists in the embryo for compelling the nutritive and force-producing elements into *its* circulation for producing growth and evolving force, which is principally expended in elaborating its structures. But since the embryo feeds in the uterine sinuses from which the commerce is obtained, and into which the waste products are returned, this calls for the differentiation of the placenta organ, which answers to the more highly differentiated lungs and intestinal canal which are to substitute it at the end of the intra-uterine term as the relative adjustments with the larger environment, lower pressure, and higher order and amount of work which this involves. The placental souffle, then, which is distinctly heard through the maternal structures, is the analogue of respiration in the air-breather, the relative ratio of the movements to the pulsations in the fœtal heart being also the same, or as 1 to 4 of the latter, while the villi are the analogues of the villi in the intestinal canal, the one submerged in the sinuses, the other in the juices in the intestines. Since the pumping action in respiration is absolutely essential for compelling the commerce into the vessels, it follows that this circumstance should be represented in the embryo, as the maternal blood does not enter the embryo, the latter feeding out of the sinuses simply by means of the villi in the placenta and this pumping action spoken of; for here, as elsewhere in the body, there are no means for increasing circulation *but* by *rhythmical changes in pressure.* The result must, then, be the action in the placenta simulating respiration. The relative frequency of this movement to the action taking place in the fœtal heart is as 1 to 4, or the same as in respiration, as before remarked.

Thus, in the case of the placental souffle it is 30 to 35, and in the fœtal heart the pulsations are from 120 to 140 per minute; while, in the case of the air-breather, the pumping action in the trunk or respiration is from 16 to 20, and in the heart from 60 to 80 per minute. Again, this action in the placenta serves not only to pump the fluids into and out of the sinuses, but at the same time it also aspirates the venous blood in the embryo for effecting oxygenation in it the same as obtains in the lungs; the heart and vessels assisting in the one as well as in the other, since it all forms a connected movement. We now see that by reason of the great increase in pressure that obtains in the embryo, the action in the organs for changing pressure is materially assisted, since the fluids flow more readily in consequence. And here comes in the benefit of the amniotic fluid, which not only increases pressure in proportion, but at the same time it serves to transmit the force in the placenta and uterine walls upon the embryo for compelling the blood to and from the sinuses for respiratory purposes, by first *increasing*, then *diminishing* pressure in the embryo, which the actions in the womb and placenta must inevitably effect.

Thus, when the placenta expands for aspirating the fluids in the uterine sinuses, the organ *advances into the uterine cavity*, it *swells out* and occupies *more room*, in consequence; and, by thus encroaching upon the embryonic area, it produces corresponding increase in pressure upon the liquor amnii and embryo, with low pressure in itself, which fulfills the conditions for increasing circulation from the embryo to the placenta, at the same time that it should aspirate the fluids in the uterine sinuses. It could not do otherwise, in the very nature of things. But during contraction in the placenta, the opposite conditions should obtain, since this would determine high pressure in the latter with low pressure in the embryo, the blood in consequence flowing through the umbilical vein with augmented speed, for the reason that contraction should *reduce* the *volume* of the placenta, which would inevitably reduce pressure in the embryo in proportion, the blood flowing from one into the other in conformity with organic law. To this, again, must be added the action in the fœtal heart for aspirating the blood in the placenta. The amniotic media in which the animal lives obviates the necessity for the extensive arrangements for reducing pressure in the chest, which obtain in the lighter media of the atmosphere, the heart, together with the force in the placenta and umbilical vein, being sufficient for the purpose.

A subaquatic existence calls for but slight reduction in pressure in order to compel circulation ; accordingly, we have the blood rushing into and out of the fœtal heart as a result of the rhythmical expansions and contractions taking place in this organ, the same as in the fishes, the principle being the same in this organ ; but for increasing the action, the heart and vessels are more muscular. The right ventricle is *thicker* and *stronger than the left*, as the relative physiological adjustment with this mechanics, since the force in the diastole is increased correspondingly for aspirating the blood in the umbilical vein and venous system, while the force in the systoles should have similar increase for compelling the blood through the umbilical arteries to the placental tufts and sinuses, the womb and placenta at the same time assisting these actions in the manner as stated, the whole forming a connected movement the same as in respiration, since there can be no doubt that the principle is the same in both, the vascular apparatus and the heart being coördinated with the placenta and womb, the same as in the lungs and muscular envelope in the air-breather, else *the relative ratio of the movements* would be meaningless.

By means of this combined action in the womb and placenta, heart and vessels, together with the high pressure that obtains in the womb, a rapid circulation is readily effected in the embryo and sinuses ; but anything which should reduce pressure—*e. g*, escape of the amniotic fluid—would promptly destroy life. The lividity of the skin, which occurs in these cases, proves conclusively the existence of venous stasis in the systemic capillaries, and insufficiency of the heart's action to carry on circulation in the absence of the normal pressure upon the embryo. How otherwise account for this circumstance, since the vascular connections are *uninjured?* Moreover, the same circumstance occurs to the air-breather when pressure is too greatly reduced, as when suddenly carried to too great an altitude in the balloon, the skin becoming livid from venous stasis in the systemic capillaries, producing insensibility and death, as occurred in the celebrated case at Paris, in which the voyage was made by two persons, the one losing his life, the other unconscious when the balloon descended; this notwithstanding the extensive arrangements for changing pressure in the chest, which exist in the latter; and in persons ascending mountain ranges, respiration and circulation become more and more embarrassed as the journey is proceeded with, and venous stasis more and more conspicuous, till the limit of endurance is reached or life itself is terminated. In short, animal life has adjustment with pressure, and whether in the air-breather or in the embryo, itself, the balance must not be too greatly disturbed, else life would have a speedy termination.

Such, in brief, is the principle in the embryonic circulation; but in order to make the matter fully intelligible and easily understood, it will now be necessary to go briefly over the formative changes till the animal is compelled into the great environment and becomes an air-breather, the same as the parent. Commencing with the matrix or mucous membrane of the womb, we have, then, a dense mass of uterine follicles or tubular glands (Fig. 131), packed closely together, the orifices opening upon the mucous surface (*a*), the blind, convoluted ends against the muscular walls of the womb, and composed of columnar epithelium (Fig. 132). When the impregnated ovum enters the uterine cavity from the Fallopian tube, it pushes the deciduous membrane before it, and comes into immediate contact with the congested and swollen mucous membrane produced by the physiological changes brought about by impregnation, all the parts being in correspondence from the action of the special nervous forces in the organs, the decidual membrane forming, as a result of the nutritive changes set up in the mucous membrane for feeding the ovum during the early period before intimate attachment is formed with the womb, and enabling it to develop the tufts in the chorion for that purpose. Now, then, when the ovum (Fig. 133) comes into the uterine cavity, incased in an albuminous fluid and an outside fibrous membrane or chorion answering to the egg-shell in the birds (which is simply calcified chorion, the lime-salts being deposited through the structure, while the vitelline membrane (*b*), *zona pellucida*, inclosing the vitellus (*e*) or yolk, is the same in both), the epithelium of the chorion begins to prolifi-

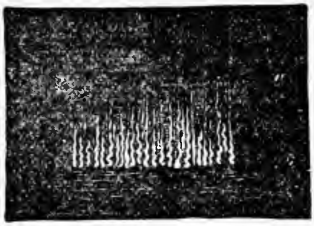

Fig. 131.—A Vertical Section from the Uterine Mucous Membrane, showing the numbers and position of the tubules.—Dalton. *a*, Free surface ; *b*, attached surface.

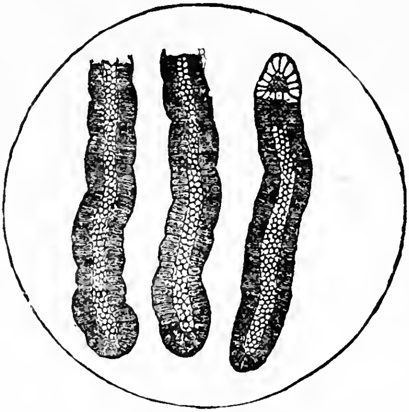

Fig. 132.—Same tubules, greatly magnified.—Dalton.

cate, multiply and send out processes similar to what occurs in the *zona pellucida* (*a*) in the unimpregnated ovum, which rapidly increase in size in the rich albuminous fluid poured out by the uterine follicles, completely surrounding it, pushing the decidual membrane before it and filling the uterine cavity, so that the ovum is completely submerged. In this thick albuminous substance, containing a large number of nucleated cells, the growing tufts of the chorion are embedded, at the same time the *decidua reflexa*, formed by the contiguous mucous membrane, grows up around the ovum, bringing the orifices of the expanded tubules into contact with the project-

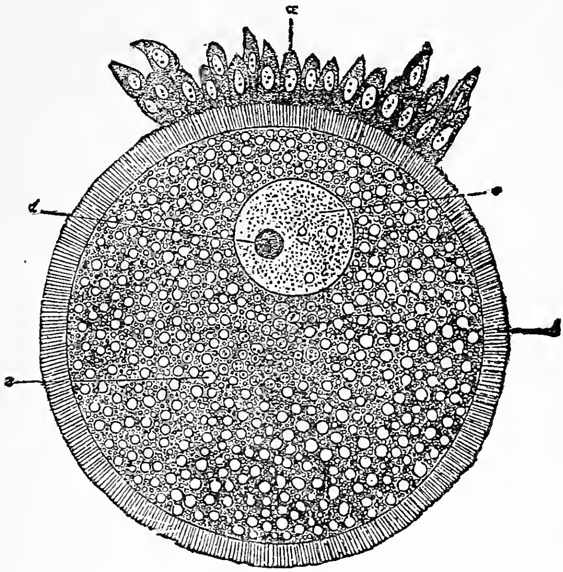

Fig. 133.—Ovum of the Rabbit, from a Graafian follicle one-fiftieth of an inch in diameter.—Waldeyer. *a*, Epithelium of the ovum; *b*, vitelline membrane, showing the radiating striæ forming the pore canals through which the spermatizoon makes its way to the germinal spot; *c*, germinal vesicle; *d*, germinal spot; *e*, vitellus.

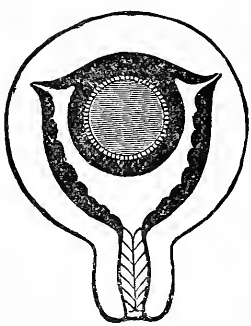

Fig. 134.—Impregnated Uterus, showing connection between villosities of chorion and decidual membranes.—Dalton.

ing ends of the growing tufts, which readily find their way into the lumen of the expanded uterine tubules (Fig. 134), rapidly growing and branching in the follicular cavities, which increase correspondingly, the two growing *pari passu* with each other, the branched processes constituting the villi of the chorion (Fig. 135); but which are only provisional, the greater number soon fading out, so as to make the chorion "bald" save in the locality elected for the placenta, the portion in immediate contact with the walls of the womb, where they rapidly increase in size, as also the uterine follicles, so as to form the placental sinuses; the matter being one of continuous growth and amplification on the part of both. At this point the capillary loops sent into the villi (they had previously been

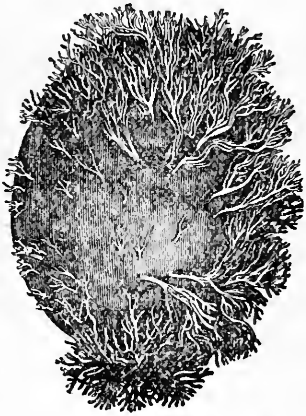

Fig. 135.—Entire Human Ovum of Eighth Week, sixteen lines in length (not reckoning the tufts); the surface of the Chorion partly smooth, and partly rendered shaggy by the growth of tufts—Carpenter.

only amplified epithelium, inclosed in a layer of basement membrane) from the fœtal vessels, undergo enlargement, growing rapidly, while the uterine sinuses project their thin endothelial lining membrane (extremely thin) into the placental sinuses, forming the lining membrane to them, also, whereby the maternal blood is brought *into immediate contact with the placental villi*, for producing rapid interchanges between them, while special arrangements obtain in the womb itself (to be mentioned presently) for rapidly renewing the blood in the sinuses, producing a continuous stream in and out of the sinuses, which the scheme calls for.

The placenta, then, is composed of both fœtal and maternal structures (Fig. 136). The structure is very dense; more so after detachment than before, from the emptying of the sinuses and the consequent condensation which this produces. But the placental tufts, with the intervening boundary wall, composed of follicular membrane, and the endothelial layer from the uterine sinuses comes out sufficiently clear in the picture. The extension of the endothelial lining of the uterine sinuses into them, so as to bring the maternal blood into immediate contact, as stated by Prof. Dalton, and forcibly illustrated by

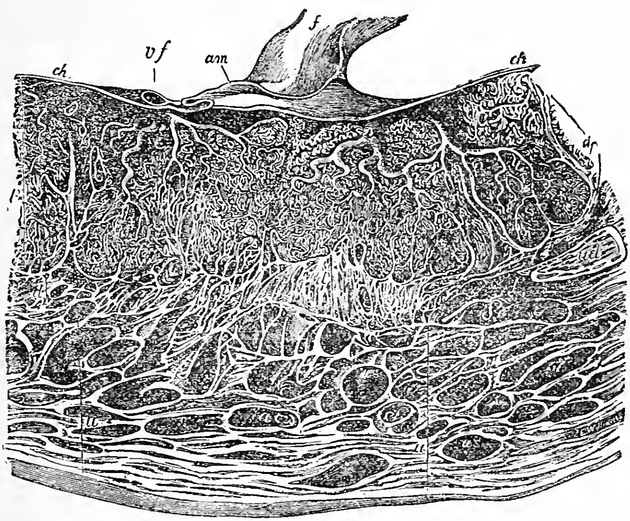

Fig. 136.—Section of a Fully Formed Placenta, with the part of the Uterus to which it is attached.—Cycl. of Anatomy, Supplement, 1859 ; Article, "Uterus and its Appendages," by A. Farre, F. R. S. *f*, Umbilical cord ; *am*, amniotic layer ; *ch*, chorion ; *us*, uterine sinuses ; *a*, *a*, lines indicating the point where the placental and uterine structures are blended ; *ud*, where the structure is unusually dense and the uterine sinuses are small ; *dp*, showing where a division-wall between the placental tufts is divided in the section ; *S*, curling arteries of uterus : *v*, umbilical vessels ; *vf*, branch from umbilical vessels to the membranes.

the following diagram (Fig. 137) is extremely probable, since it is precisely what is needed for producing *free action in the villi for pumping the fluids into the fœtal circulation* and *expelling* waste products. Then, again, the easy manner with which the placenta is peeled off and detached from the womb is precisely what we might expect from this mode of attachment, the endothelial lining of the vessels being very brittle ; so, then, everything is in correspondence. But were the uterine arteries and veins extended into the placenta, this could not be done, since the fibrous and muscular structures would inhibit it, and parturition would have a Pandora's box in the womb, leading to untold evils, and in all probability terminating fatally. But the uterine arteries and veins terminate by capillaries in the uterine sinuses, which are interspaces or canals formed by the longitudinal and transverse muscles of the womb, and lined by endothelium extended from the arterial and venous capillaries so as to form a common reservoir for the vessels, the whole bearing close resemblance to the vascular spaces, muscular trabeculæ and terminal vessels in the corpora cavernosa penis (Fig. 204), which enables the rapid filling and emptying of the hæmal chambers by expanding and contracting the muscles and the vessels by the action of the special nervous forces which apply in the organs for that purpose, pressure applying alike to both organs, and under the pressure in the arterial system, the reservoirs are rapidly filled in either case, and as readily emptied during contraction. It comes to this: that the endothelial lining of the uterine sinuses (Fig. 137, *c*) is projected into the vascular interspaces in the placenta forming the placental sinuses, and being reflected over the tufts, these are inclosed by it as the fingers by a glove, every one receiving an investment of uterine endothelium, so that the maternal blood is *necessarily in immediate contact* with them; that the blood is readily renewed in the sinuses commensurate with the physiological requirements in the embryo; that at the end of the intrauterine term the placenta is readily detached from the womb and expelled out of the body along with the embryo, the liquor amnii and containing membranes under the action of the force in the womb and walls of the abdomen, inclusive of the diaphragm, all the parts acting in concert by means of the correlation of the nerves in the medulla oblongata, or the same as for expelling waste products in the rectum and bladder, the principle being the same.

And by looking from the placental sinuses to the special anatomy in the placental tufts or villi (Fig. 138), it is readily perceived how the pumping actions may be set up in them for pumping the fluids into and out of themselves, the same as in the lungs when the animal becomes an air-breather at the end of the intra-uterine term, *perfect freedom of action* being alike secured in *both*, and the same law applying for producing afflux and efflux of the fluids ; but a still more close resemblance is furnished in the villi of the intestinal canal; only that muscles are added in the latter for producing more energetic action and a larger amount of work to make it commensurate with the force expended in the organism. Still, it is manifest from the special anatomy in these

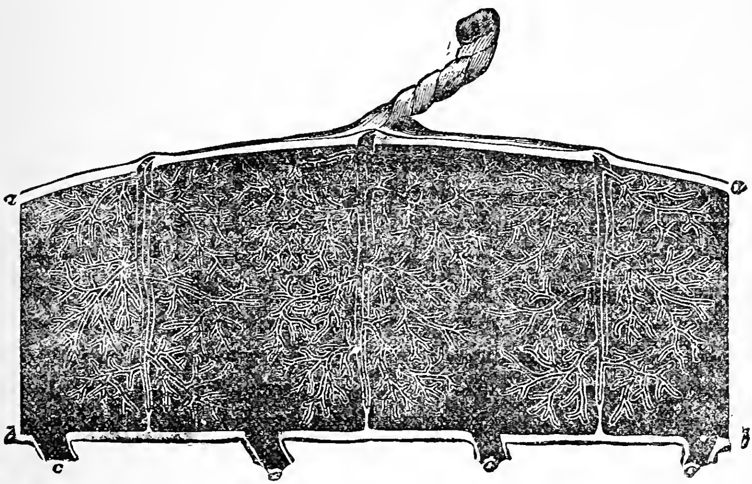

Fig. 137.—Vertical Section of Placenta, showing arrangement of maternal and fœtal vessels.—Dalton. *a*, *a*, Chorion; *b*, *b*, decidua ; *c*, *c*, *c*, *c*, orifices of uterine sinuses

organs, that absorption must go on energetically. Thus, under the epithelium (*a*, *a*) we have a basis of connective tissue fibres (*c*, *c*) running *longitudinally* from end to end of the organ, and by expanding and contracting a pumping action must inevitably be produced in the organ for aspirating and propelling the fluids to and from the fœtus and the sinuses, all the villi acting in concert. The vascular loops being placed *within* the band of connective-tissue fibres (*b*, *c*, *c*), must necessarily undergo rhythmical compression during contraction, thereby increasing pressure in them, causing the blood to flow into the umbilical vein ; while during expansion the opposite obtains, causing the fluids to flow into the vessels from the sinuses and umbilical arteries from a reduction in pressure which this effects, while the vessels, by acting in concert, expanding and contracting simultaneously, should increase the action correspondingly. Furthermore, it is easily perceived that considerable force is necessary for compelling the fluids through the animal membranes, since this outside wall of the placental villus (Fig. 138) is composed of two layers, the inner one of epithelial cells (*a*), the outer, connective-tissue fibres (*b*); finally, the capillary wall itself, *intervene* between the maternal and fœtal blood, and that interchange would have to be effected through these membranes. Now, then, for compelling this circumstance, we have the force in the placental tufts and the *force* in the *walls* of the *womb itself*, which expands and contracts regularly and rhythmically for *diminishing* and *increasing pressure* in *the sinuses*, which are simultaneous with the movements in the placenta, only that the actions alternate, the womb contracting as the placenta is expanding, and *vice versa*, whereby circulation in the uterine and placental sinuses is readily produced. In other words, the circulation of maternal blood in the uterine and placental sinuses is the same in principle as that for circulating air in the lungs—namely, by rhythmical changes in pressure in the sinuses, which is produced by the actions taking place in the womb and placenta; taking the placental sinuses to represent the alveoli, and the uterine the tracheal system, the blood flowing into and out of this system of canals by reflux action for renewal, just as the pulmonic air flows into and out of the tracheal system for renewal, only that in the former the fluid passes into the venous system of the mother and is returned by the arterial, both terminating by capillary openings in the canals, while the placental souffle answers to the respiratory murmur. And when the womb contracts for increasing pressure in the sinuses, the action is not unlike that which occurs in the walls of the intestines for increasing pressure in the gut, whereby the fluids are compelled more rapidly into the respective villi, flowing from high to low pressure. *Mirabile!*

The following facts may be given in support of this opinion:

1. The womb must expand and contract regularly and rhyth-

mically in order to increase circulation in the sinuses, since this is essential for changing pressure upon the blood, while the vast number of muscles and nerves in the walls of the womb are the provision for more energetic action than is possible to the placenta, which is composed almost entirely of vascular loops.

2. The womb *surrounds* the embryo, and its action would therefore be more effective for producing the changes in pres-

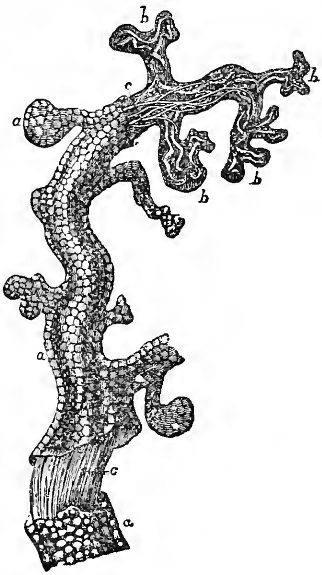

Fig. 138.—Portion of one of the Fœtal Villi, about to form part of the Placenta, highly magnified.—Farre. *a*, *a*, Its cellular covering; *b*, *b*, *b*, its looped vessels; *c*, *c*, its basis of connective tissue.

sure upon it, which is also *in imitation of what takes place in the amnion* of the growing chick, it being rocked to and fro in the egg by the slow, rhythmical expansions and contractions taking place in the amnion, and by alternating this action with the one taking place in the placenta, it is readily perceived how a rapid circulation could be maintained in the maternal and placental sinuses for compelling correspondence between this and the energetic circulation in the embryo, since it all forms a connected whole. This would also be in conformity with the principle in the circulation, the blood flowing from high to low pressure. As the placenta *expands* for reducing pressure within itself, and for increasing pressure in the embryo, *simultaneously* and *pari passu* with this action, the entire muscular walls of the womb *contract* for increasing pressure in the maternal sinuses for compelling this blood in the placenta, at the same time by increasing pressure upon the embryo it should determine a more rapid movement from the latter to the placenta; the one involving the other. But when the placenta contracts for increasing pressure (thereby compelling the blood out of itself in two directions, or toward the embryo and the maternal sinuses), the uterine walls *expand* for reducing pressure in the embryo and the uterine sinuses, thus greatly expediting the placental efflux; and, taking it all in all, there can be very little doubt but that the force which is represented in the muffled murmur of the placental souffle is mainly the product of the muscular uterine walls, though both undoubtedly contribute to it.

3. This action in the uterus and placenta would account for the very curious and suggestive *obliquity* in that portion of the canals connecting the uterine with the placental sinuses, being upon a line *almost parallel* with the transverse axis of the uterus and placenta, which is precisely what is called for by the special mechanics, in order to effect the lateral or to-and-fro movements which the separate action in the womb and placenta necessarily involves, the vessels simply elongating and contracting with these, as the case may be, without interfering with the calibre of the tubes. Were the vessels straight, however, it would be utterly impossible to operate this mechanics, since the lateral movements should obliterate the vessels by closing the calibre. It could not be otherwise, in the very nature of things. In the diagram (Fig. 137, *c*), the vessels are represented as nearly perpendicular, but this is done simply for better definition.

4. But the strongest proof of this higher function of the womb is furnished in the vascular and nervous connections subsisting between it and the maternal organism and the law underlying the mechanics. And as all this relates to circulation for building up and elaborating

the embryo, obviously the mechanics for increasing circulation in the womb commensurate with that in the embryo should extend to the vessels of supply or the feeders, as also the discharging vessels, or the arteries and veins. It must be shown how this new movement, this new life set going within the other, twines its arms around the maternal vessels and feeds itself in the measure of its necessities, by means of this pumping action in the womb and placenta which represents respiration. The spermatic and uterine arteries are the feeders (Fig. 139, *s*, *u*), while the accompanying veins are the discharging vessels. To this must be added the uterine lymphatics, which are very large in the impregnated womb. They terminate in the pelvic and lumbar glands. The spermatic arteries and veins have similar origin and termination, as in the male, while the uterine artery is a branch of the internal iliac, with the venous return through a vein of the same name. The deeply suggestive fact to note in this connection is that the dense plexuses of nerves to the fundus and sides of the womb *converge in the nervous ganglia* about these vascular trunks, or the spermatic and hypogastric ganglia (Fig. 140, *e*, *w*, *r*). It will be seen that the nerves to the fundus (*v*, *x*) converge in, or radiate from, the spermatic ganglion (*w*) which *surrounds* the spermatic artery and vein (*e*) (which corresponds with the attachment of the placenta), while those in the neck and sides from the hypogastric ganglion (*r*) are brought in direct relation with this ganglion by means of intercommunicating nerves (*t*) for unifying the action throughout.

Thus, nervous force to the womb is literally *banked upon the blood-vessels* ; and if this means anything, it means that circulation *shall* be in correspondence with the physiological requirements, or supply equal to demand, the cardinal circumstance being the *growth* and *elaboration of the embryo*, which is the object and purpose of the organ, the others being simply incidental.

It comes to this, namely, that the nervous force for expanding and contracting the uterine sinuses should expand and contract the uterine blood-vessels at *one and the same time*, thereby causing afflux and efflux of blood through them for compelling correspondence throughout, which the scheme calls for. Furthermore, this would accord with the action in the vessels in respiration, as indicated by the *undulations* in arterial tension. But would not this mechanics interfere with the due circulation of blood in the *placental* sinuses? Certainly not, and for the following reasons:

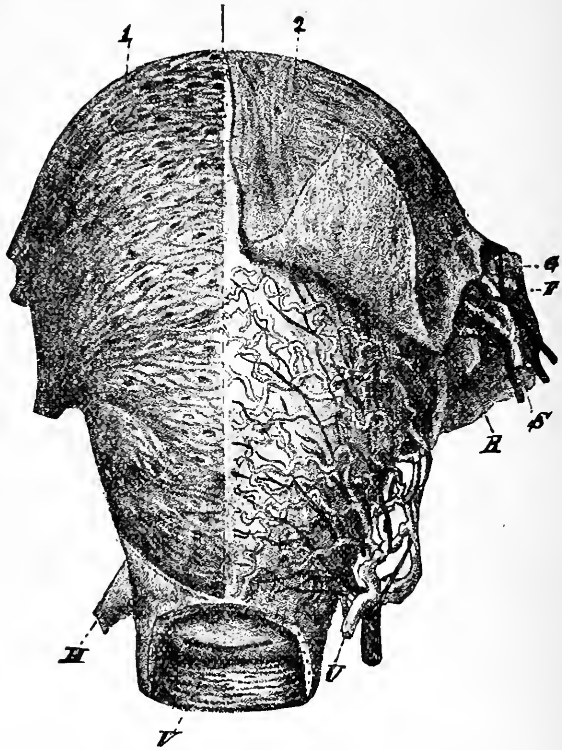

Fig. 139.—Showing the Arteries and Veins to the Womb (left side). *S*, spermatic artery and veins (ovarian); *U*, uterine artery and vein; 1, vessels passing between the muscular fibres; 2, peritonæum; *G*, Fallopian tube; *F*, ligament of ovary; *R*, round ligament; *H*, inferior ligament or duplicature of peritonæum corresponding with Douglas' cul de sac; *V*, vagina.

1. Efflux of blood in the *uterine* sinuses through the veins is by means of *capillary* vessels, which tend to retard escape, while the flow of blood into and out of the *placental* sinuses takes place through large canals (Fig. 137, *c*, *c*), whereby afflux and efflux has corresponding increase. But in addition to this, the *expansion* in the placenta, which occurs during systole of

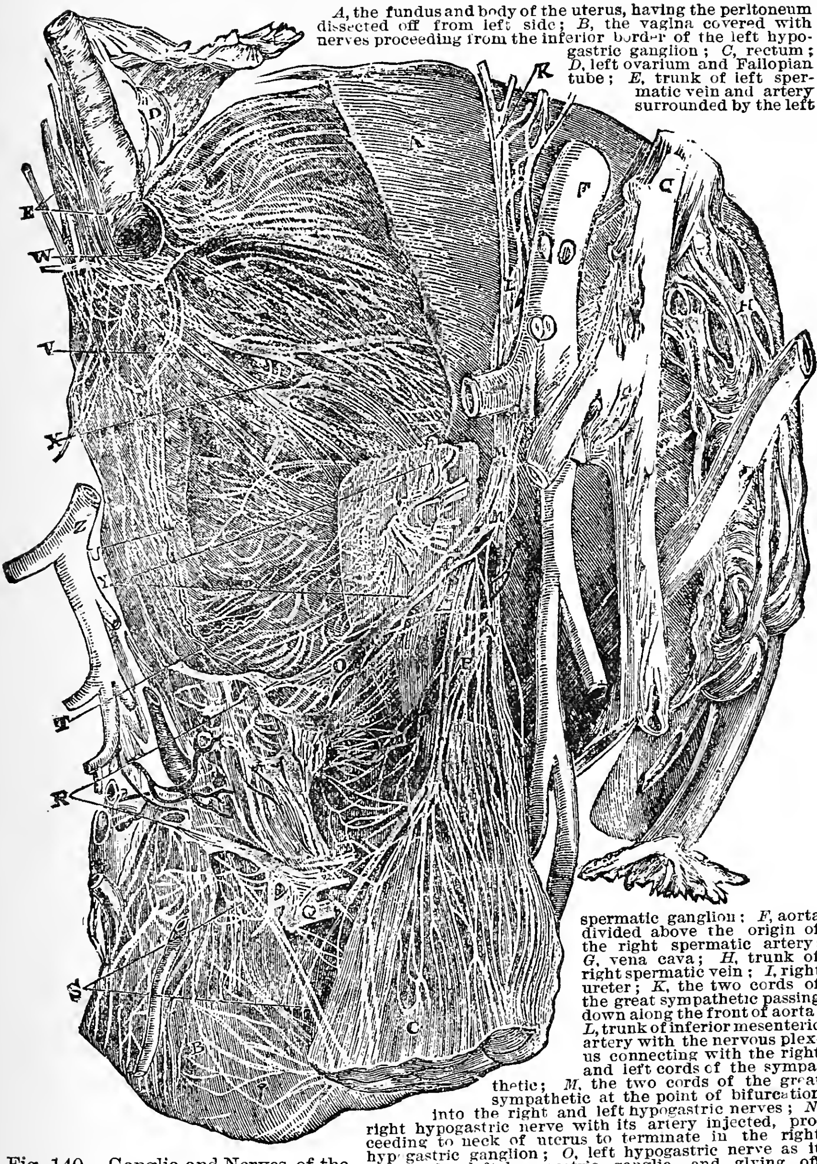

Fig. 140.—Ganglia and Nerves of the Gravid Uterus at the End of the Ninth Month.—R. Lee.

A, the fundus and body of the uterus, having the peritoneum dissected off from left side; *B*, the vagina covered with nerves proceeding from the inferior border of the left hypogastric ganglion; *C*, rectum; *D*, left ovarium and Fallopian tube; *E*, trunk of left spermatic vein and artery surrounded by the left spermatic ganglion; *F*, aorta divided above the origin of the right spermatic artery; *G*, vena cava; *H*, trunk of right spermatic vein; *I*, right ureter; *K*, the two cords of the great sympathetic passing down along the front of aorta; *L*, trunk of inferior mesenteric artery with the nervous plexus connecting with the right and left cords of the sympathetic; *M*, the two cords of the great sympathetic at the point of bifurcation into the right and left hypogastric nerves; *N*, right hypogastric nerve with its artery injected, proceeding to neck of uterus to terminate in the right hypogastric ganglion; *O*, left hypogastric nerve as it enters the left hypogastric ganglia, and giving off branches to the left sub-peritoneal ganglia; *P*, hæmorrhoidal nerves and artery; *Q*, sacral nerves entering the whole outer surface of the hypogastric ganglion; *R*, left hypogastric ganglion with the arteries injected; *S*, nerves of the vagina; *T*, nerves with an injected artery proceeding from the upper part of left hypogastric ganglion along the body of the uterus, and terminating in the left spermatic ganglion; *U*, continuation of these nerves and the branches which they give off to the sub-peritoneal plexuses; *V*, some nerves passing upward beneath the sub-peritoneal plexuses, and anastomosing freely with them; *W*, left spermatic ganglion, in which the nerves and artery from the hypogastric ganglion, and the branches of the left sub-peritoneal plexuses terminate, and from which the nerves of the fundus uteri are supplied; *X*, left sub-peritoneal plexuses covering the body of the uterus; *Y*, left sub peritoneal ganglion, with numerous branches of nerves extending between it and left hypogastric nerve and ganglia; *Z*, left common iliac artery cut across and turned aside to expose left hypogastric nerve and ganglion.

the womb, should also determine the blood in this direction, so that most ample arrangements exist for producing the freest circulation in the placental sinuses.

2. During diastole in the womb and its sinuses, for aspirating the venous blood in the placental sinuses, the *high pressure* in the arterial system causes the arterial blood to flow into the uterine sinuses as rapidly as the blood coming from the placenta; at the same time, the valves in the veins of the uterus obviate reflux in *the venous system.* And when the womb contracts for compelling the blood in the uterine sinuses into the placental sinuses and venous system, the *pressure* in the *arterial system inhibits* reflux in *this* direction. Thus the mechanics for increasing circulation in the uterine and placental sinuses is complete in every respect; nor does it require extensive expansion and contraction in the womb in order to effect increased circulation through the sinuses, but a moderate and limited amount, sufficient only for producing *rhythmical changes in pressure upon the blood*, as must appear obvious; something similar to what takes place in the spongiæ, which have muscles (Norway) for producing a more rapid circulation in and out of this canal system; while in reference to the action in the vessels, their rhythmical expansions and contractions with the movements in the womb and placenta, this has its analogue in the mammalia, the maternal arterial system, which maintains a similar action synchronous with respiration, as has been fully shown; and is it unreasonable to make similar deduction for the womb and embryo for increasing circulation in them as well, more especially when no other means exist for increasing circulation and for making it commensurate with the physiological requirements in the growing embryo? I think not.

This expansion of the womb and arterial feeders would explain the sudden and enormous escape of arterial blood in postpartem hæmorrhage, for the placenta being no longer attached, the flow of blood through the uterine sinuses must necessarily be purely arterial. In other words, when contraction ceases and the movement of expansion sets in, the flood-gates are thrown open to the arterial system, hence the rush of blood from it.

In reference to the nervous centre for this pumping action in the womb, which answers to respiration in the fœtus. There can be very little doubt but that the spinal cord functions as the common reflex centre of nervous force for producing the rhythmical expansions and contractions in the gravid womb simulating respiration. In short, that the lumbar enlargement of the spinal medulla is in point of fact the respiratory centre for the fœtus, regarding the pumping action in the womb and placenta as the respiratory movement, of which there can be but little doubt. And since the local nervous ganglia control the local actions, maintaining them also in action as in the case of the locomotor apparatus, is it illogical to make the same deduction for the womb and the reflux centre in the spinal cord? I think not. In short, there *must* be a nervous centre for coördinating and unifying the movements in *every* organ, in the uterus as well as elsewhere, as must appear obvious. The following are the reasons for this allegation:

1. The very intimate connection subsisting between the womb and spinal cord by means of the hypogastric ganglia and sacral plexus with the intercommunicating nerves extending from the spinal medulla (Fig. 116).

2. The fact that *the lumbar portion of the spinal cord undergoes enlargement during gestation.*

3. The fact that reflex action in the womb is *readily* produced *by applications to the skin surface*, a circumstance well known and practiced by the profession. All these facts, then, fall readily into line when viewed from *this* stand-point; and, no scientific reason existing to the contrary, we may conclude the fact as logically proven, while the vast number of the muscles and nerves in the womb make it absolutely certain there is such rhythmic movement going on. Indeed, the gist of the question is not whether there is a reflex centre in the spinal cord for the womb, but whether this centre produces the rhythmical expansions and contractions in that organ, as alleged. A full and sufficient answer to which is furnished in the fact of the total absorption of the relative phenomena, anatomical and physiological, otherwise utterly inexplicable; while underneath all which is the organic

law on which animal life itself is constructed, calling for rhythmical changes in pressure in the contents of the gravid womb and in the uterine sinuses for increasing circulation, and for making it commensurate with the physiological requirements in the embryo; otherwise impossible. Nor is it reasonable that the enormous number of muscles and nerves in the womb are for compelling out the contents at the end of the term simply; but, on the contrary, that they perform an active and essential part *in the work of construction* which *precedes* expulsion. Beyond a shadow of a doubt, they are not idle in all this while, especially when supreme necessity would have it otherwise; on the contrary, they are *evolved as force is needed* for carrying on circulation, while at the end of the term they are available for assisting in expelling the embryo; hence, perform an active rôle from the beginning to the end of their existence, as is ever the case with the muscles and nerves.

One other circumstance in this connection, namely: the very *tortuous* course of the arteries in the womb (Fig. 139, *u*), which undoubtedly has reference to this action in the womb, permitting the rhythmical expansions and contractions to take place without involving strain to the vessels, otherwise inevitable. The veins, it will be perceived, take a straight course, while the arteries are serpentine or bent upon themselves. This is due to the fact that the veins are more extensile, and possess greater powers of elongating and shortening than the arteries, the yellow elastic coat of the latter tending to limit their actions. It will be remembered that this circumstance has forcible illustration in the splenic artery and vein, the former being almost twice the length of the latter, to allow for expansion in the stomach when food is taken; otherwise, this would involve prodigious strain to the vessels, with great reduction of the calibre. But the same remark will apply to the vessels of all the hollow viscera. Thus, everything is in correspondence. Of course, the movement in the womb and placenta is necessarily more limited than in the lungs, in which considerable space is required for sucking in the air simultaneously with the venous blood, but which would not apply for the fœtal circulation, as the oxygen is furnished by arterial blood at *one and the same* *time* with the nutritive and force-producing elements, which the scheme calls for in order to generate force, since it is by a combination of the two that force is evolved, as before remarked. In fine, differentiation in the organs cannot, for obvious reasons, work any change in the fundamental principle underlying the mechanics for increasing circulation, which is by rhythmical changes in pressure involving a pumping action for compelling the commerce in the blood-vessels and expelling waste products, while the *speed* of the currents thus produced is determined by the rapidity and energy of the rhythmical expansions and contractions pervading the organs, inclusive of the heart and vessels, since it all forms a connected movement for increasing circulation between the cell-brood and environment, from which everything is obtained and into which, in due time, everything is returned for redistribution, in the embryo the same as in the maternal tissues, only the journey to and from the environment is by way of the maternal blood-vessels, inclusive of the uterine sinuses, the common ground where interchange is effected betwen the maternal and fœtal blood.

With the expiration of the intra-uterine term, expansion of the maternal passages sets in for reducing resistance to the egress of the embryo, and the womb and abdomen contracting simultaneously for increasing pressure in the womb, the contents are compelled into the environment. Here, as elsewhere, *the law of pressure applies for compelling movement in the contents of the hollow viscera, for which special adjustments obtain in the organs and organism*, the underlying principle being *ryhthmical changes in pressure.*

Pressure being invisible, it is difficult to realize the important relations it sustains to the mechanics and the enormous rôle it performs in the organism; nevertheless, the fact is incontrovertible that from centre to circumference, and from surface to surface of the body, it is the fundamental and controlling circumstance, the foundation, so to speak, of the temple, pervading the superstructure, and interwoven with all the phenomena, which spring out of it as waters from a fountain.

It is passing strange the matter should have escaped attention so long, especially in this age, when *thought* is reaching down into the organic basis of life. Indeed, one needs to go there if he would unravel the tangled skein in animal structure and function, since the definite arrangements that obtain in the organs with every stage in development show unmistakably a common relation to fundamental forces in Nature underlying it all, notably *pressure and gravitation*, while the arrangements which obtain in the structures represent the relative adjustments for special work, and in the mea ure of it.

Respiration in the New-born: The Change in Mechanics which this Involves.—The first thing in the new-born is to start respiration for compelling in the commerce in the environment in place of the uterine sinuses, and the action in the placenta for which this is the substitute, the oxygen passing in by way of the lungs and the aliment through the intestinal canal. But it requires fresh adjustments in the mechanics of circulation to bring it in correspondence with this circumstance; notably, circulation of the blood in the lungs, and the attaching of the intestinal apparatus to this movement by means of the nerves connecting in the medulla oblongata, a matter which has already been fully considered in the preceding pages. The first thing, therefore, is to start respiration, when it will be in order to consider how the mechanics in circulation swings into this pendulum movement for compelling correspondence throughout, with the blood ever flowing from high to low pressure, in conformity with the organic law underlying the organism itself. One end of the nervous system, so to speak, is *spread out* in the skin surface, the other through the organism, while the medulla oblongata functions as the common centre to it all; any impression, therefore, made upon the skin surface is promptly reflected to the medulla oblongata, thence over all the structures for producing the reflex actions connected with respiration and circulation. The irritations attendant upon parturition from friction against the maternal structures are calculated to produce these reflex actions; but the contact of the sentient surface with the stimulus in the atmosphere itself would also excite it. And if the child should be injured by the rude experiences incidental to parturition, a yet more powerful means for exciting the reflex actions connected with respiration is furnished by the sudden application of cold to the surface, as in sprinkling cold water upon it,* or a sudden, sharp slap with the open hand may be substituted instead, as is commonly practiced. Last, but not least, carbonic acid, as it accumulates in the blood, acts as a special stimulus to respiration. It cries out in pain, and, presto! the hæmal mechanics is changed. The low pressure which is produced in the alveoli by expansion of the lungs during inspiration compels *simultaneous* afflux of air and blood in the alveoli; while the high pressure which is produced by the subsequent contraction during expiration causes *simultaneous* efflux in these fluids, which flow from high to low pressure in conformity with organic law—the one flowing out by reflux action through the route of ingress, the other passing into the left chambers of the heart and arterial system on its way to the cell-brood, as has already been described in the air-breather. This abandonment of the old route for the new is readily explained, since it is in strict accordance with physical law, being in the direction of least resistance.

For example, we *begin* the mechanics with high pressure in the arterial system, since this extends through the ductus arteriosus to the semilunar valves of the pulmonary artery, the floor of support to the arterial column. Hence, when the alveoli expand during inspiration for sucking in air through the trachea, the high pressure in the pulmonary artery and ductus arteriosus compels this blood to flow straight on to the low-pressure areas in the alveoli *simultaneously* with the afflux of air, or in the direction of least resistance, in place of forcing its way into the arterial system against high pressure, which would be contrary to law. And the ductus arteriosus, though still filled with blood, as in the case of an artery, beyond the ligature to where a collateral branch is given off, shrinks and contracts till it becomes a solid, impervious cord.

For closing the foramen ovale, the following mechanics

* The intimate connection subsisting between the respiratory centre and the skin surface is of easy demonstration in the adult by the same means. For example, every impact of cold water against the skin produces spasmodic inspiration or expansion in the lungs; not deep, however, but very energetic.

apply: After birth, the inpour of blood in the left auricle by way of the pulmonary veins is as rapid as it is in the right auricle through the venæ cavæ, and with pressure at equilibrium in the two auricles, this at once suspends all tendency in the blood to pass from one side into the other during auricular diastole; while during the auricular systole and the high pressure this produces in the auricles, causes the blood to flow into the expanding ventricles, where low pressure invites it, at the same time gravitation also should compel it in this direction, since the ventricles are *under* the auricles, the same applying for either auricle. Thus, a dual force applies (suction and gravitation) for compelling this blood into the ventricles during the auricular systole, and the foramen ovale, being thus abandoned, is closed and obliterated by membranous formation.

But in intra-uterine life the matter is different; here the whole blood is poured into the right auricle, that from the upper cava passing at once into the right ventricle, while that in the lower cava (which includes the blood from the umbilical vein) passes through the right into the left auricle, with which it directly communicates, guided by the Eustachian valve, but also pushed over and deflected in this direction by the weight of the descending current from the upper cava; but if the head be downward (which is geuerally the case), then by its own weight the blood would gravitate in this direction, the influx of blood from the upper cava also compelling it. And with the absence of blood as a *counter-force* in the left auricle, this blood is necessarily compelled into the latter, thence into the left ventricle and aorta, while that in the right ventricle passes into the arterial system at the aortic arch by way of the pulmonary artery and ductus arteriosus. After birth, however, the pumping action in the lungs reverses all this, in manner as above described. The pulmonary artery in the embryo, in place of discharging through the lungs, left auricle and ventricle, empties its blood at once into the aorta as it passes under the arch, and which is also in the direction of least resistance, since it is impossible for this blood to thread its way through the capillary meshes of the *unexpanded* alveoli; a circumstance which has forcible illustration in the air-breather, and when the alveoli are filled with residual air, by simply inhibiting inspiration by closing the mouth and nose so as to prevent expansion in the lungs, the blood, in consequence, rapidly accumulating in the right side of the heart and venous system. In the space of a minute there is lividity of the lips and whole cutaneous surface from venous stasis in the systemic capillaries. If longer than this, an appalling venous suffusion pervades the surface; in the face most, for this is the most vascular portion, with the large venous trunks in close proximity to the heart. Even the eyes are forced outward, becoming prominent from distension of the intra-orbital veins caused by obstruction in the cavernous and lateral sinuses But the instant the obstruction is removed and the lungs are permitted to expand, so as to reduce the intrapulmonic pressure, the dammed-up blood surges into the alveoli, and all runs on as before. In other words, the heart and vessels are unable to carry on circulation in the absence of the pumping action in the lungs, for which afflux and efflux of air is essential; all of which has been sufficiently explained in the preceding pages.

Concerning Incubation and Circulation in the Egg.—Why should there be an air-chamber to the egg (Figs. 141 and 142)? We are now prepared to furnish a scientific explanation to this physiological problem, otherwise inexplicable, viz.: the contents of the egg for developing the chick are inclosed by a firm, unyielding wall of living marble, and since the animal circulation is dependent upon rapid rhythmical changes in pressure, it follows that provision should be made *within* the shell for effecting this; otherwise the actions in the heart and vessels could not take place. This air-chamber (*a*), together with the important relations it sustains to circulation and elaboration in the growing chick, organilogically, therefore, must be regarded as one of the most essential and important elements in egg-structure, the underlying principle to all the nutritive changes which are ushered in under the action of external temperature. The accompanying illustration (Fig. 142) will serve for impressing the matter.

The discipline in the nutritive processes requires the blood to be brought from the vitellus and aërated in the allantois, thence to be dispatched through the body territories. Accordingly, two great venous trunks (omphalo-meseraic veins), one in each fold of the splanchnopleure, embracing the vitellus, are the first evolved, while at the terminal ends or confluence the heart is formed by the blending of the walls of these venous trunks.

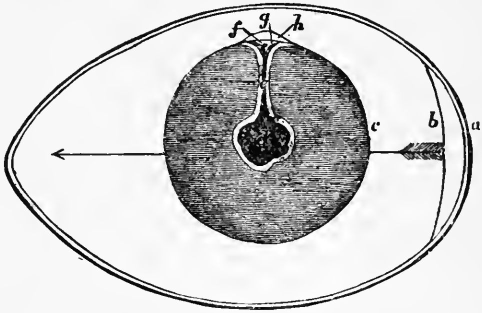

Fig. 141.—Anatomy of the Egg.—Jones. *a*, *b*, Air-vesicle ; *b*, arrow indicating the position of the central axis of the egg ; *c*, the yolk ; *f*, Purkinjean vesicle ; *g*, cicatricula ; *h*, thickening of the vitelline membrane ; *e*, canal leading to *d*, the central chamber of the yolk.

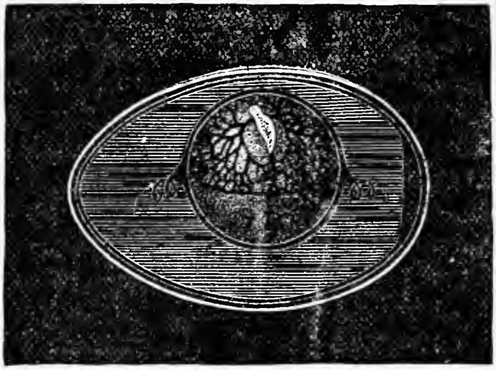

Fig. 142.—Egg of Fowl in Process of Development, showing area vasculosa, with vitelline circulation, terminal sinus, etc.—Dalton.

According to His, the heart is developed by the coalescence of a layer of the splanchnopleure with a similar layer from the somatopleure, the hollow cavity formed by the union being in free communication with the adjacent omphalo-meseraic veins. According to Foster and Balfour, "the upper end of the heart is developed out of the mesoblast of the splanchnopleure," but "increases in length step by step at the expense of the continually coalescing omphalo-meseraic veins." Thus the fact is undeniable, that the heart is developed in the *venous system in connection with the vitellus.* The rhythmical expansions and contractions in this organ (the *punctum saliens* of early authors) serve to pump the vitelline fluids in the bulbus arteriosus and the two aortæ which are developing at the other end of the heart. But for this air-cushion within the egg (Fig. 141, *a*, *b*), neither these rhythmical expansions in the heart nor the changes in pressure for compelling circulation in the vitelline fluids could take place, since the unyielding shell would inhibit these actions, as must appear obvious.

Respiration is provided for in the following manner: The allantois (a diverticulum of the intestinal canal) is pushed out around the amnion which contains the embryo, and expanding its vast capillary network of vessels (whose footstalks spring from the two iliac arteries, as do the umbilical arteries in the mammalian embryo) against the shell-membrane or chorion, becomes the respiratory organ of the chick, by means of which the venous blood is constantly arterialized, the oxygen passing in and the carbonic acid passing out through the pores in the shell by the action of the polar forces. But "at the time the heart first begins to beat, the capillary system of the vascular and pellucid areas is not yet completed, and the fluid which is at first driven by the heart contains, according to most observers, very few corpuscles. . . . . The course of the blood then, during the latter half of the second day, may be described as follows: The blood brought by the omphalo-meseraic veins falls into the twisted cavity of the heart, and is driven thence through the bulbus arteriosus and aortic arches into the aortic trunk. From the aorta by far the greater part of the blood flows into the omphalo-meseraic arteries, only a small amount passing on into the caudal terminations. From the capillary network of the vascular and pellucid area into which the omphalo-meseraic arteries discharge their contents, part of the blood is gathered up at once into the lateral or direct trunks of the omphalo-meseraic veins. Part, however, goes into the middle region of each lateral half of the sinus terminalis, and there divides on each side into two streams. One stream and that the larger one, flows in a forward direction until it reaches the point opposite the head, thence it returns by the veins spoken of above, straight to the omphalo-meseraic trunks. The other stream flows backward, and becomes lost at the point opposite the tail."*

The following from the same authors is deeply suggestive: "Soon after its formation the heart begins to beat, at first slow and rare pulsations, *beginning* at the *venous* and passing on to the arterial end. It is of some interest to note that its functional activity commences long *before* the cells of which it is composed *show* any *distinct differentiation* into *muscular or nervous elements*." It would be difficult to overestimate this circumstance, since it establishes beyond peradventure the power in the higher as in lower animals to effect rhythmical expansions and contractions in the soft tissues in the absence of any muscle or nerve for producing them. But at present the significance of these rhythmical expansions and contractions taking place in the heart concerns us most, since the manifest purpose is to increase circulation; and as this can only be done by pumping the blood of the omphalo-meseraic veins, it follows that both expansion and contraction is necessary for accomplishing this—the one for aspirating, the other for propelling it. This would explain why the action should *begin at this end of the heart.* Of course, as the area of circulation increases this would call for corresponding increase of force for effecting it. Accordingly, *pressure is increased* at the same time that additional force is placed upon it; notably, by the amniotic fluid and by the action in the amnion, the muscles and nerves in the heart and vessels being in correspondence.

The amnion closes around the embryo of the chick on the fourth day, and on the fifth fluid begins to collect in the sac, and by the seventh the embryo is submerged in a considerable quantity of water. "By the seventh day very obvious movements begin to appear in the amnion itself; slow vermicular contractions creep rhythmically over it. The amnion, in fact, begins to pulsate slowly and rhythmically, and by its pulsations the embryo is rocked to and fro in the egg. This pulsation

* Foster and Balfour's "Embryology."

is due, probably, to the contraction of involuntary muscular fibres, which seem to be present in the attenuated portion of the mesoblast, forming part of the amniotic fold" (Foster and Balfour).

The physiological significance of this accumulation of amniotic fluid, and the rhythmical contractions and expansions in the amnion, may not be doubted for a single moment, since the former would increase pressure, while the latter should produce the necessary changes in pressure in the embryo for compelling respiration and circulation to be in correspondence with the nutritive and functional processes in the growing chick, both of which are constantly extending their limits and requiring more and more force for effecting them. These slow pulsations in the amnion of the chick answer to the placental and uterine souffle in gestation, the principle being precisely the same. How otherwise explain this circumstance? But, as has already been remarked, *all pulsations relate to changes in pressure*, and these pulsations in the amnion, together with the amniotic fluid, relate to changes in pressure in the embryo for increasing circulation of the juices.

The explanation of the mechanics is sufficiently easy; notably, there are two cardinal points from which to regard it—one in the allantois, the other in the embryo. They may be regarded as the poles to this circulation, in which the action alternates for assisting the circulation by rhythmical changes in pressure, and following each other in regular order and succession readily produce afflux and efflux of the fluids commensurate with the physiological requirements. First, commencing with the movement of expansion in the allantois. The increase in pressure which this produces in the embryo through the amniotic fluid occupying more room, consequently encroaching upon the amniotic area, should cause a corresponding amount of the venous blood to flow with increased energy toward the allantois, the point of low pressure within the egg (the heart and vascular system, of course, assisting in this); and *vice versa* during contraction. The rhythmical contractions and expansions in the amnion have the effect of increasing and diminishing pressure in the embryo itself, and by relieving pressure in the allantois, enables this to expand *pari passu* with contraction in the amnion for aspirating the venous blood, at the same time that it aspirates the air through the outer membrane and pores of the shell. But when the movement is reversed by expansion of the amnion, the reduction in pressure which this effects in the embryo, together with the simultaneous increase of pressure it produces in the allantois by forcibly compressing this against the shell wall, causes the aërated blood in the latter to flow with augmented speed into the heart of the embryo, the allantois, itself, also participating in this action, the fluid it contains enabling it to effect such rhythmical compression of the capillary plexuses (Fig. 143). The following forcible illustration (Fig. 144) by the distinguished biologist at Jena will serve to impress the matter It represents early stage in development (third week in gestation) in the human embryo. It will be seen that pressure is increased at the cardinal points, namely, vitellus (*a*), the body of the embryo (*c*), and placenta (*b*), which is fundamentally the same as the allantois, though the office of the latter is mainly respiratory. As the embryo and allantois are elaborated out of the material in the vitellus, this would explain the greater accumulation of fluid in this locality for compelling circulation toward those two points, while the rhythmical contractions of the yolk sac should greatly expedite it. For increasing circulation between the embryo and placenta (*c*, *b*), commensurate pressure is produced by accumulation of fluid in these two points or poles of this circulation. This, together with the action in the membranes themselves, and the heart and vessels, is sufficient for carrying on circulation in the initial stages of embryonic evolution; but with the increase of growth comes increasing difficulty for effecting it; hence the pumping action which is set up in the placenta and womb, together with the accumulation of amniotic fluid for transmitting these actions upon the embryo, as described above. Thus, everything is in correspondence—the liquor amnii, the increasing growth of the placenta and the number of muscles and nerves in the walls of the womb—and so continues till the close of pregnancy. In other words, it all forms a connected whole in the mechanics of the embryonic circulation. The absence of a shell wall permits expansion in the chorion *pari passu* with the growth of the embryo, while the womb expands in concert with this action in the chorion and embryo.

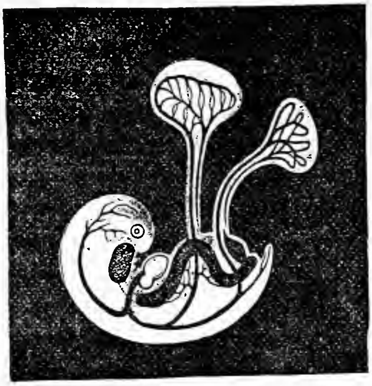

Fig. 143.—Diagram of Young Embryo (Chick) and its Vessels, showing circulation of umbilical vesicles, and also that of allantois, beginning to be formed.—Dalton.

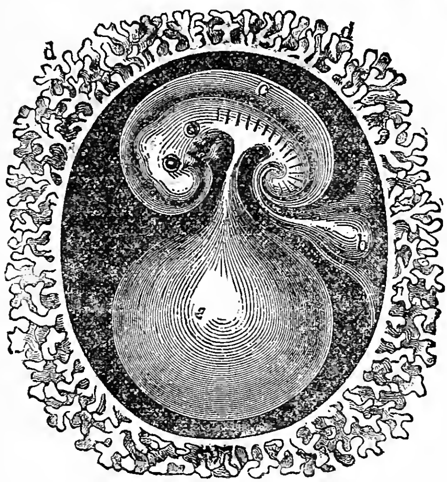

Fig. 144.—Human Embryo in the Third Week.—Haeckel. *a*, Large globular yolk sac; *b*, allantois; *c*, amnion; *d*, tufted chorion. There are yet no limbs.

In the case of the bird, the pumping action in the abdomen (the soft hinder parts of the bird) for pumping air and blood through the alveoli, is set up in the latter days of incubation, when rapid atrophic changes soon separate the umbilical vessels, and, breaking the now attenuated and fragile shell wall with its beak, it finally makes its escape, leaving the allantois and atrophied membranes behind.

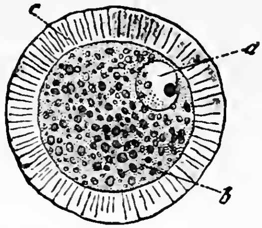

Fig. 145.—Ovum from the Mole.—Leydig. *a*, Nucleus ; *b*, cell body ; *c*, thickened corpuscle traversed by pores.

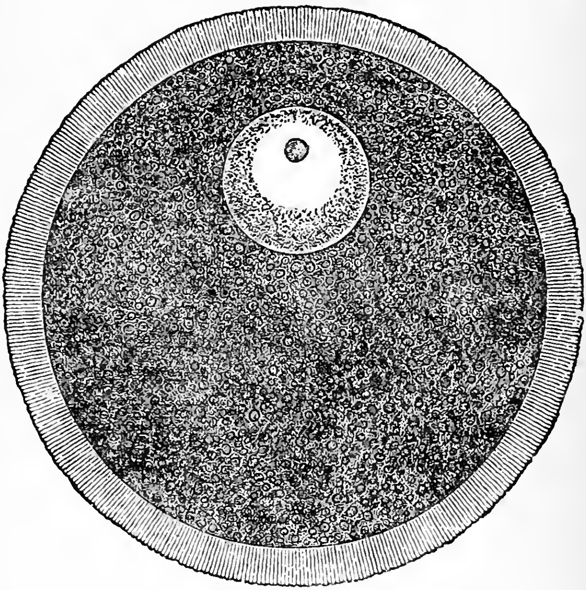

Fig. 146.—The Human Egg from the Ovary of the Female ; much enlarged.—Haeckel. The entire egg is a simple, globular cell. The greater part of the spherical egg-cell is formed by the egg-yolk, or the granular cell-substance (protoplasm), which is composed of innumerable delicate yolk granules, with a little intervening substance. The germ-vesicle, answering to the cell-kernel (nucleus) lies in the upper part of the yolk. It contains a dark nucleolus or germ spot. The globular mass of yolk is surrounded by a thick transparent egg membrane (*zona pellucida*). This is penetrated by the pore-canals, in the form of very numerous hair-like lines, which run rapidly toward the centre of the globe ; through these the thread-shaped, moving sperm-cells pass, in the process of impregnation, into the egg-yolk.

The common relation which animal life sustains to the organic laws has forcible illustration in the very ova, the structure being fundamentally the same (Figs 145, 146).

CHAPTER XV.

ANIMAL TEMPERATURE AND THE NECESSITY FOR A THERMIC CENTRE IN THE MEDULLA OBLONGATA.

Body-Temperature—Why the Thermic Centre Should be Correlated with the Respiratory, Vaso-Motor and Voluntary-Motor Centres in the Medulla Oblongata—Relations which Respiration Sustains to Metabolism—Ditto, Metabolism to Body-Temperature—The Vaso-Motor Centre and the Vascular Arrangements in the Skin for Reducing Excessive Body-Temperature so as to Maintain a Balance in Temperature in the Organism—Mode of Imitating This in Febrile Conditions by Therapeutical Device as the Most Effective Means of Controlling Body-Temperature, Thereby Conserving Life and Expediting Recovery—Use of Respiratory Sedatives in Connection Therewith, and Rationale of—Peculiarities that Obtain in Dogs and Birds for Facilitating Discharge of Body-Temperature when Excessive—Seat of Oxidation.

Temperature is treated more advantageously in connection with development, maintaining mobility among the molecules, for which a special physiological adjustment obtains in the organism, but which differs in the plants, as well as in the animals, though the oscillations from the norm in any one of them is very limited, and the sliding scale in the warm-blooded may be roughly estimated at from six to ten degrees only, either a fall or rise in body-temperature of several degrees speedily bringing life to an end. It will be necessary, however, to briefly refer to it here in order to show the relations which body-temperature sustains to respiration and circulation, whereby it is regulated so as to maintain a balance in the organism; otherwise impossible. And here we have to mention that the thermic centre for the organism (which is now almost universally conceded the elaborate researches of Pflüger, making the argument unanswerable) is also correlated with the other nervous centres in the medulla oblongata, or respiratory, vaso-motor, voluntary-motor and thermic, making four in all, unless the trophic be also included, which would seem reasonable and natural, since nutrition necessarily depends upon temperature and circulation.

The reasons upon which this opinion is based would seem to be incontrovertible. Briefly summarized, they are as follows:

First and foremost, the scheme calls for this in order to produce *continuity in force*, otherwise impossible, and the medulla oblongata being the common centre of nervous force for the organism, it would naturally include the thermic centre.

2. Since heat is the product of metabolism or the nutritive and chemical changes going on in the body, but principally the latter, produced by the oxidizing processes generating carbonic acid, especially in the muscles during musculation, and the commerce is pumped through the tissues for the purpose by means of respiration and the pumping actions in the heart and vessels, as has been fully shown; it follows that the thermic centre should be correlated with the respiratory and vaso-motor centres for compelling prompt response in order to evolve heat in the measure of the physiological requirements, furnishing the requisite fuel for the purpose, otherwise impossible; hence the correlation of the thermic with these other two centres.

3. Active musculation is the principal means for rapidly generating heat in the body; but since the muscles can endure but a limited amount of heat above the norm, which is 98.5 degrees Fahr. for man, it follows that there must be some ready means for rapidly bringing the blood to the skin-surface when body-temperature is excessive, for effecting reduction in temperature by means of radiation and evaporation effected by means of sweat, which is poured out for the purpose, the vast capillary network in the skin being widely expanded for the purpose, producing the characteristic flushing of the skin during active exercise; but in order to accomplish these results, the thermic centre would have to be correlated with the vaso-motor centre for compelling prompt response in the vessels in the measure of the requirements. In fine, respiration, circulation and temperature rise and fall together, rising and falling with the activities; while the vaso-motor centre, by being connected with the thermic centre, compels the local actions in the skin for maintaining a balance in temperature; otherwise, the muscles would be destroyed in their own

heat, and the activities would be speedily fatal, as must appear obvious. Hence, the correlation of the thermic centre with the respiratory, vaso-motor and voluntary-motor centres the whole being woven in and in, and must be so, in the very nature of things. Loss in body-temperature is announced by sensory impressions in the skin; the animal shivers, the teeth chatter, and the furnace is set going again for raising temperature, the animal moving about restlessly for starting the action in the muscles, doing so unconsciously, but *forced to it* by imperative demand in the organism. This hurries respiration and circulation for supplying the fuel, which soon puts up temperature to the norm again. At the same time the appetite is increased, while the digestive and assimilative processes are more active, and from these combined sources temperature soon rises with the swell in the activities, which puts up respiration and circulation correspondingly; so that prompt help comes with the supply of food, while force and fuel are economized, if the animal be housed so as to diminish external cold, and especially if protected by suitable clothing for diminishing radiation and conduction, the heavy coat of hair which is developed with the accession of cold weather subserving this function in the animals, while man long since has learned the art to perfection by raiding them for their shaggy coats, at the same time aiding himself with fire or artificial heat. But the physiological fact to be kept uppermost in the mind is the correlation of the great nervous centres in the medulla oblongata, making respiration the basis of all the movements, while the exhalation of carbonic acid from the lungs is, so to speak, the smoke of the automatic furnace, the principle being the same precisely as obtains in a grate and the burning of coal; only, that the tissues subserve the purpose of a grate, the fuel furnished by means of respiration and circulation, while the pumping actions invoke the law of pressure which applies for compelling supply to be equal to demand. All plain enough, and easily understood from the stand-point of the law underlying the organism and the action of the special forces which apply in the case.

The increase in temperature when the bodily activities are in abeyance, is produced by prolonged and excessive reflex irritation propagated from the mucous surface of some of the organs, or from the skin, or by blood-poison, as in traumatism and the essential fevers acting *directly* upon the nervous centres of respiration and circulation, and in the fact of retrograde metamorphosis from loss of vitality produced by the disturbed balance. the supply of oxygen brought into the tissues by the increased respiration and circulation being greatly in excess of the demands, consequently tending to excessive oxidation and retrograde metamorphosis, whereby the tissues are consumed and rapid wasting and shrinkage result as an inevitable sequence, while the matter is due entirely to excessive stimulation of the respiratory and vaso-motor centres. Take the temperature and count the respirations and the rhythms in the heart and arteries, in proof of this statement. Yes, there is correspondence. Now, then, how account for this circumstance, but in the correlation of the three nervous centres, as alleged? And if the respiratory and vaso-motor are in the medulla oblongata, it follows that the thermic centre is also there, for in no other way could continuity in force be produced for effecting this cycle of motion. Then, again, when temperature falls, as in the crisis, respiration and circulation are in correspondence, at the same time shifting the blood to the surface in order to cool it; the skin is reeking with perspiration welling out of every pore for carrying off temperature, the same as in bodily exercise—an heroic effort of life to throw off the toils in which she is caught by the very nature of her framework, and the rude experiences to which the animal is exposed. It is thought by some* that the action in the vaso-motor centre would explain the phenomena, but the respiratory should be included as well, so as to diminish the supplies, while there must be a heat-centre, *one exceedingly sensitive to heat*, for due notification of local increase with the power of promptly compelling the requisite vascular changes in the skin and internal parts for rapidly expanding the external and contracting the internal vessels, at the same time producing copious perspiration; otherwise life would suffer speedy ex-

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* Pflüger's *Archiv.*, iii. (1870, 504; *ibid.*, v. (1872). 77. Heidenhain.

tinction by the voluntary movements themselves, not to mention the reflex irritations and the action of blood-poison, as must appear obvious. It follows that the thermic centre must be correlated necessarily with the other centres in the medulla oblongata, the solar centre for the organism. Take a very simple, as also a very common case, notably, acute tonsillitis in the child. It is notorious that body-temperature rushes up with extraordinary rapidity in this condition. Why? The explanation is easy. Thus, the tonsils are in *close proximity* to the medulla oblongata, immediately adjacent —you might say right in front of it, so short the distance between them; hence, reflex irritation falls at once, and with all of its force, upon the respiratory and vaso-motor centres, and the increased rhythms which this produces by compelling excessive importations of the commerce into the organism and the tissues rush up the temperature correspondingly from the excessive oxidation it induces. Indeed, a fretful child may readily induce a febrile paroxysm at any time by a violent fit of crying, but the sleep which follows close upon exhaustion, by slowing respiration and circulation, together with the copious diaphoresis which accompanies it, soon reduces temperature to the norm again, so that everything runs on as before. The practical deduction to be drawn therefrom in the treatment of the essential fevers—to induce sleep *artificially* by means of chloral, etc., at the same time *bathing the skin*, or rather keeping the surface wet by means of cloths steeped in warm water—*e. g.*, sponging the night-clothes with this so as to *obviate shock* or arouse the patient; otherwise inevitable. More of this presently.

In cases of extensive burns and scalds, which are always followed by increased respiration and circulation, producing fever, how explain this circumstance if not by reflex irritation in the respiratory and vaso-motor centres, thereby producing increased respiration and circulation, and making oxidation excessive in the tissues? The very principle in the mechanism lays the whole thing bare. The office of therapeusis is, of course, to repress the irritation by appropriate local and constitutional remedies, or by soothing applications and excluding the air, at the same time administering the salts of morphia, etc., supporting the patient. In the case of blood-poisoning, permanent relief comes only by eliminating the materies morbi through the special emunctories; Medicine, as it were, sitting by the tiller and guiding the life-boat so as to keep it off the rocks and dangerous shoals, clear of the breakers and in the deep water, by *keeping down excessive temperature* by respiratory sedatives for reducing the rhythms in the lungs and circulatory apparatus, at the same time reducing temperature in the manner as stated, *repeatedly applying the thermometer* to learn the state of the temperature, *saving* the patient by *constant vigilance.* And Medicine is made a helpmate, not an executioner, for struggling life. The intimate relations which the skin sustains to the respiratory and vaso-motor centres, by reason of the sensory nerves, would account for fever induced by irritations of any kind, *e. g.*, the exanthemata, which independent of the special action of the materies morbi upon the nervous centres, interfere with transpiration, consequently producing an accumulation of heat, as it were, damming it in the deep vessels, thereby preventing its due escape from the skin-surface. The high temperature in this class of cases is undoubtedly due to *accelerated respiration* from excessive stimulation of the respiratory centre from reflex actions in the skin, together with the suppression of the secretory functions in the skin for carrying off excessive temperature. The rôle in therapeusis, however, is clear—namely, repress excessive temperature in the manner as stated. Small-pox, so malignant in times past, when the patients were treated in *close rooms*, but now in *open wards and tents*, where freest ingress of air is insured, reduces body-temperature by conduction, with very little mortality. In all these cases there is rapid respiration, induced by excessive irritation in the skin, combined with the direct action of the materies morbi upon the respiratory and vaso-motor centres. In addition to frequent bathing of the skin, for supplementing perspiration, some respiratory sedative, so as to induce sleep, *e. g.*, quinine, chloral, etc., should be administered in cases of alarming temperature, as where it exceeds 105° Fahr. In sleep, temperature falls *because* respiration *falls in frequency.* And convalescence in fever is *ushered in by sleep;* sleep and diaphoresis, the slowing of respiration and the escape of heat by evaporation putting an end to the fever.

The explanation of the fall in temperature produced by the slowing of the respiratory rhythms is obvious enough. Thus, taking the average in man, sixteen respiratory rhythms are sufficient for maintaining the body-temperature at 98.5 degrees Fahr., each volume of air inspired representing, of course, a given volume of oxygen, which is sufficient for maintaining the norm. In other words, sixteen pumps of the respiratory mechanism (which, of course, would include the actions in the heart and blood-vessels, since it all forms a connected movement) are sufficient for maintaining the body-temperature at 98.5 degrees Fahr. Now, then, *any* circumstance which should increase the rhythms would produce corresponding elevation of the temperature, but for the comprehensive arrangements that obtain for discharging heat from the body-surface for maintaining a balance, already referred to; but in abnormal conditions this is more or less interrupted.

And for that reason the public speaker "warms up" as he proceeds in his subject, speaking more and more rapidly, temperature rising correspondingly.

It is the same in the vocalist, as I have proven over and over again, by taking the temperature before the commencement of the exercise, during it, and afterward, and while the temperature varied somewhat, *always finding it higher than before*, from one to two degrees, according to the energy in the respiratory rhythms. When the temperature increases from one to two degrees, the balance is struck by reason of the action in the skin; else he must stop, from *exhaustion induced by the action of temperature upon the nervous apparatus*, which is Nature's method for putting an end to the exercise. But muscular exertion of any kind produces increase in temperature! Of course it does; but *is not respiration in correspondence?* So, likewise, the action induced by cold, since this rapidly withdraws heat, and *respiration must be hurried* correspondingly for maintaining a balance; otherwise impossible. And when the air is loaded with moisture which rapidly absorbs body-temperature, the individual exposed to it had better keep the muscles in action for rapidly evolving heat, and he "sits" at his peril. For dismissing heat, the vessels in the skin are *expanded*, and the deep vessels contracted; but for retaining it, the surface vessels are contracted, and those in the deep territories are *expanded* correspondingly, in order to shift the blood from one to the other part, at the same time *increasing respiration for supplying the additional* quantity of fuel and oxygen which are called for for evolving heat and maintaining a balance in the organism, otherwise impossible.

Thus, we have not only the vaso-motor, but the respiratory centre included in the thermal mechanics for increasing oxidation. When the loss in heat is rapid, as when cold is excessive, the appetite, digestive and assimilative processes are increased, as has already been remarked—the latter from the additional amount of blood which is sent to the organs from the external parts—so that the whole mechanics for producing temperature work together in perfect concord and unity. But for its accomplishment, there *must be a thermic centre* for receiving and transmitting the sensory impressions produced by heat and cold, and *for compelling the requisite vascular and respiratory movements suitable to the occasion.* In other words, *a special sense necessitates an appropriate nervous reflex centre* for duly impressing the appellate nervous centres for compelling the requisite movements in the mechanics for maintaining a balance in the organism, otherwise impossible. And when one reflects upon the preëminent importance of temperature in the animal organism, the occasion for this comprehensive arrangement for producing and regulating it will at once appear obvious.

Finally, the experiments of Naunyn and Quincke* show that whether division be made *above* or *below* the medulla oblongata, it is attended by a *rise* in temperature, proving that the thermic centre is in the medulla oblongata, while the very argument used by Schroff† to prove the circumstance was due to fever occasioned by the mere wound itself, but confirms it, since it shows the nervous centres in the medulla oblongata *can* produce fever, and since fever is the result of

* DuBois-Raymond's *Archiv.*, 1866, p. 151; 1869, pp. 174, 521.
† *Wien.* Sitzungsherichte, Lx. xiii. (1876).

excessive metabolism, it would show that by simply stimulating the respiratory would *necessarily involve* the *vaso-motor* and *thermic centres.*

So, then, we can readily understand why respiration should be in correspondence with metabolism, both in normal and abnormal conditions of the system, and why it should be more rapid in warm than in cold-blooded animals. Finally, why it should oscillate with external temperature, and with the states of activity and repose.

An Important Medical Case, Showing the most Effective and Kindly Means for Rapidly Reducing Excessive Body-Temperature.

The following deeply interesting medical case, which came within my own knowledge, may prove of great practical use to the profession, and since this is the chief object sought to be attained in physiological inquiry, it should entitle it to a place in the text. It occurred in connection with acute inflammatory rheumatism, with so-called metastasis to the brain, and known as "cerebral rheumatism"; but, in point of fact, is the result simply of excessive blood-temperature. It was produced in a lad thirteen years of age (son of a prominent jurist), from excessive bathing, followed by high fever and pain in the joints for the first several days, then the brain-symptoms spoken of set in. When called in consultation, I found the patient perfectly unconscious; comatose; the extremities cold, but the skin over trunk above the normal temperature; in the rectum, 108.2 Fahr.; pulse 168; respirations, 34 per minute. The cerebral symptoms had set in sometime during the night and early morning, ushered in by delirium. The treatment recommended above was adopted. All the covering save his night-shirt was removed, and this was now sponged with lukewarm water, while for facilitating evaporation fanning was resorted to. It is astonishing how rapidly the body-temperature is reduced in this manner. In something like two and one-half hours the temperature had fallen to 103 degrees Fahr., with marked improvement in all the symptoms; pulse 130; respirations, 28 per minute, with *partial return to consciousness,* showing the comatose condition had been superinduced by excessive blood-temperature The sponging of the skin, or rather the shirt, was now discontinued, but he took five grains of sulphate of quinine very readily, and swallowed it down with water, his hand to the glass regulating it. We then left him for several hours, but leaving strict orders to watch the temperature, else he would have a relapse, the head-symptoms would return. During our absence, however, complaining of cold, his mother wrapped him in blankets, his shirt also was changed, and when we returned, to my great consternation and alarm, he was *again* unconscious and breathing rapidly; the pulse accelerated; while the thermometer in the rectum registered 107 degrees Fahr., or nearly as high as at first. The treatment by sponging was, of course, at once resumed, and, fortunately, in the course of three hours the temperature fell to 103.1 degrees Fahr., with great improvement in the symptoms; respiration 27, pulse 138 per minute, with *return to consciousness*, and proving conclusively that the coma had been induced by the excessive blood-temperature. After this he was carefully watched, and made a good recovery in the course of four or five weeks, the articular affection, which returned almost at once, running its usual course.

By thus throwing wide open the escape-valve, so to speak, to body-temperature by the free use of water to the skin, together with the use of respiratory sedatives to inhibit excessive importations of oxygen, constitutes the most efficient means for controlling body-temperature. In respect to the free use of whisky, which is very beneficial, it acts in two directions: First, by springing open the skin capillaries it determines the blood to the surface, thereby cooling it. It also acts as a respiratory sedative and tends to stay metabolism. By producing expansion in the capillary network of the skin it tends to promote diaphoresis, which accelerates the discharge of heat. There is nothing better, therefore, than this supplemental treatment for controlling temperature in low febrile conditions. I think the benefit derived from quinine has similar explanation, expanding the surface capillaries and inducing sleep, but large doses are required to make it effective. In traumatism the preparations of opium, by reducing sensibility and thus inhibiting reflex action, come in well. It is needless to extend the matter.

One thing more, however, before we bring this matter to a close: The Germans (to whom we are indebted for the "cold-water treatment" in fever) are undoubtedly correct in principle, but the method adopted, or that by the cold douche, may be carried out successfully in hospitals, but it will not answer in private practice for the following reasons: 1. The prejudices of the patient and his friends are against it, and would have to be borne down by the strenuous efforts of the physician, and should the case issue fatally, adverse criticism would be rife; not to mention the labor it involves and the difficulty of obtaining the requisite nurses and appliances. 2. Infants and young patients are nearly thrown into spasm with terror, the shock being so violent. Whereas, by the more kindly method, prejudice will not seek to balk you, in place will eagerly assist you, while the patient is soothed and his high temperature filched, so to speak, from him without his knowledge.

n animals in which transpiration is not so abundant as in man—dogs, for example—compensation is made through evaporation from the mouth and bronchial mucous membrane, when temperature is excessive. Notably, the animal throws open and projects the tongue far out of the mouth and breathes very rapidly, but very shallow, so as to obviate penetration of the air to the alveoli as much as possible, which surges in and out of the mouth and proximal portions of the trachea and bronchi, and volume after volume of aqueous vapor is thus discharged, while the tongue fairly smokes with the fog arising from it. But he plunges into water the first opportunity that presents, for expediting the process. Birds have a similar action in the throat, which pumps as in the frog, at the same time spreading their wings, so as to facilitate conduction and radiation, seeking the cool places and burying themselves in the earth when they can, scratching holes for the purpose.

Concerning the Locality where Oxidation is Effected—It is believed in certain quarters that oxidation of the carbon compounds by means of which force is evolved and carbonic acid is formed, takes place principally within the capillaries; but this cannot be, for the reason that the cell-brood is the objective point for all the commerce, as they are the workmen in the tissues, therefore the seat of metabolism, and to stop short of its destination would defeat the scheme in the circulation, the vessels being a carrier simply, but under control of the cell-brood. In other words, they live upon the stream, and withdraw the commerce as it is needed in the functions and for repair of the tissues. Furthermore, the fluids flowing from the tissue-interstices into the capillaries (through the stomata in the latter during expansion), are *waste products* that are *pushed at once into the venous* system by the subsequent contraction in the vessels and the pressure in the arterial system, hence have no opportunity to mix with the arterial blood for effecting oxidation. Then, again, if the blood itself were a source of heat, the fact should be announced in the lungs, where oxygen mixes freely with the venous blood; nevertheless, it has been proven to demonstration that the blood in the left side of the heart has a lower temperature than the right, which is heated by the portal blood, and suffers actual loss in the alveoli, by reason of conduction and an amount of evaporation from the mucous surface. In fine, from the very nature of the mechanics, the cell-brood must be the seat of metabolism, respiring through the vessels which serve to connect them with the lungs and the environment, while respiration itself is increased or diminished in correspondence with their requirements. It is very comprehensive, but easily understood.

CHAPTER XVI.

THE GREAT RÔLE OF CARBONIC ACID IN THE ANIMAL ORGANISM—A FOOD FOR THE TISSUES AND A STIMULUS FOR THE FUNCTIONS.

Functions of Carbonic Acid and Nitrogen Gases in Arterial Blood—Explanation for the Disappearance of Carbonic Acid and Nitrogen in Respiration, the Amount of Carbonic Acid Expired not Representing the Chemical Equivalent of the Oxygen Inspired, while Nitrogen in Small Amount also Disappears—Carbonic Acid and Nitrogen Gases Normal Constituents of Arterial Blood—Connection with the Functions in the Intestines—Ditto the Nutritive Processes—Its Universal Diffusion in the Air, Water, Floral and Animal Juices and Tissues—The Universal Appetite for Carbonic Acid Drinks—A Stimulus to the Digestive, Respiratory, and Vaso-Motor Centres—Significance of Sleep—The Odor in Human Fæces—Genesis and Functions of the Gases in the Air-Bladders in the Fishes.

The fact that an amount of carbonic acid and nitrogen disappears in respiration, that the quantity of carbonic acid expired does not represent the chemical equivalent of the oxygen inspired, the same remark applying to nitrogen, is well known and commented upon, but no practical inference, or one relating to special functions subserved by them, drawn from it, but regarded as a curious circumstance only. But the very fact that they are *normal constituents* of *arterial blood*, therefore freely *distributed through* the organism, is of *itself* sufficient to prove they must subserve important uses in the functions, and are not to be regarded as interlopers, so to speak, and footpads bent on mischief and all possible harm. The only deduction made being that the *quantity* of gases in the blood and tissue-juices is regulated by what is known as "tension" in the gases; but what this tension itself refers to is not stated, and we are left as much in the dark in the one as in the other. But as everything in the body has its uses—moreover, is regulated by organic laws, which are put in force in the measure of the physiological requirements in the organs and tissues—we may rest assured that philosophic scientific reasons may be given for their presence also, with every other definite arrangement that obtains, and it cannot be doubted for a single moment even. Moreover, it is susceptible of easy explanation, as we shall now proceed to show, notably:

1. From the very nature of the mechanics in the intestinal canal, it is easy to perceive why the blood is charged with the gases, since this is necessary for *increasing pressure in the intestines in connection with the digestive* and *absorptive* functions, and for maintaining *a balance* in the *portal circulation*, otherwise impossible, the intestinal gases being increased with the difficulties in this circulation, notably in corpulency (pp. 187–100); and since pressure is constantly changing in correspondence with the exigencies in the functions, it follows that some comprehensive arrangement must obtain for secreting and absorbing the gases in the organs in the measure of the physiological requirements; hence the circumstance that carbonic acid and nitrogen gases are *normal* constituents of arterial blood, together with the special arrangements that obtain for circulating them in the blood.

During digestion, however, the amount of the gases expired is in excess of the gases inspired, which is due to the fact that supply is greater than demand, the quantity ingested with the food and others generated in the chemical reactions during digestion being more than sufficient for producing only a *given amount of pressure in the intestines*, in connection with the digestive and absorptive processes, otherwise impossible; since the gases already in the organs when food is ingested, together with that carried in with the aliment, and generated by the chemical reactions, must inevitably produce dangerous accumulations, but for this absorption by the blood-vessels and discharge through the lungs; moreover, if this were not as it is, it would defeat the purpose of the arrangement by preventing the due amount of ingesta; also producing pain and discomfort, besides inducing abnormal changes. Hence this absorption of the gases and their discharge through the lungs, the most expeditious way of getting rid of them.

In this manner, then, pressure in the intestines is easily regulated. And it must be borne in mind that there is a norm in pressure in the intestines, and that the object of peristalsis is to increase or diminish it as occasion may require in the exigencies in the functions simply, by expanding and contracting upon it in the manner as stated when treating of the functions in the intestines, and the mechanical action of the air-cushion in connection therewith (pp. 187–226). This, then, would explain that circumstance, and it can be explained in no other way.

2. In the second place, carbonic acid *functions as a stimulus to the digestive* and *nutritive* processes, promoting rapid digestion and nutrition, the importance of which it would be difficult to overestimate. They can be treated more advantageously under separate heads.

The following table by Bert will show the amount and relative proportion of the gases in arterial blood:

	Oxygen.	Carbonic acid, disengaged by a vacuum.	Carbonic acid, in combination.	Carbonic acid, total.	Nitrogen.	Total gas in volume per 100.
Arterial blood.	15·03	27·99	1·15	29·14	1·60	45·77
Venous blood..	8·17	31·27	2·38	33·65	1·37	43·19

It will be seen from the above table that the venous blood, in its passage through the lungs, yields up *less than one-fourth* of the free carbonic acid contained in it, the greater portion, or *more than three-fourths, passing on into the arterial system.* Now, then, as this is the rule, the normal condition, it follows that *carbonic acid gas is essential to the animal organism.* A bald, naked fact of enormous import stands out *there.* What will you do with it? Shall we write underneath: "Carbonic acid is a poison"? You may, but I never shall; and I enter my solemn protest against *your* doing so.

The universal appetite for carbonic acid drinks, and *why all natural waters* are *saturated* with *it*, must also be explained along with the rest, for there is interdependence and connection in the phenomena. And the only poison I see is in the philosophy, for never was great virtue so traduced and vilified, maligned and made hideous beyond all recognition as in this case. Because carbonic acid does not support combustion and animal life cannot therefore live in it, going out like a candle by reason of the absence of oxygen, then, forsooth, it is placarded "a deadly poison." A "negative poison," then? No! No poison whatever, any more than water is a poison, and for the same reason that *it does not support combustion.* "A coroner's jury" may have such opinion, but it is not admissible in science. Submerging an air-breather in carbonic acid gas speedily puts an end to life, but *not more* speedily than water, both producing death by asphyxia simply; while simply excluding the air by means of a "gag" would have the same effect—producing death by asphyxia. But would you call the "gag" a poison by reason of that fact? "A coroner's jury" might, forming judgment from surface appearances simply, as in the case of the still more widely circulated but exploded opinion that "The sun rises in the east and sets in the west." But to put such stuff in scientific works is enough to run one mad. (Ah me! Mind and heart alike are weary.) This, too, when arterial blood is *nearly one-half* carbonic acid gas in volume, or 44.14 in the 100—more in reality than in venous blood, which is 41.82 in the 100—while all the juices and tissues are literally saturated with it, and all natural waters as well; so that there is obviously a preconcerted effort on the part of Nature not only to shut off all escape, but to keep the tissues saturated with it. And man, instinctively coöperating all the while, demanding carbonic acid in unusual quantities in his beverages—notably, soda water, beer, champagne etc.—and should it prematurely escape from any one of them from untimely uncorking, making it "flat" and "unpalatable," is spewed out of the mouth as worthless; while water which has been boiled, driving the gas out of it, is a nauseous dose. And everything rushes to the fountain where the waters issue from the earth, and most highly charged with carbonic acid, giving them their sparkling appearance and making them more palatable, at the same time also serving as the most effective solvent for the alkaline earths and minerals. And if carbonic acid gas be a poison, as alleged, why all this? and if but a waste product in arterial blood, in the name of the All! why are there not more emunctories for maintaining cleanliness and purifying the blood of carbonic acid, the only exception being in this? What a mess they would make of it! Finally, the delightful sensations the gas produces in the gullet and stomach when swallowed shows it to be a kindly and effective stimulant to the digestive processes.

So, then, it will readily be perceived that to dub carbonic acid gas a poison, is illogical and unscientific.

And when men seek low places in the earth, let them see to it that carbonic acid is not in *there*, displacing the atmosphere by its greater weight and ready to destroy them by asphyxia.

From what has preceded, it will be readily inferred that the carbonic acid secreted in the stomach and intestines during the digestive processes subserves not only the mechanical uses for producing the changes of pressure in the gut, but at the same time it acts as a stimulus to the secretory and absorptive processes as well; thereby giving another manifestation of the comprehensiveness in animal mechanics, which may be seen from every aspect to the open eye and thoughtful mind.

There is nothing narrow or contracted in Nature, but broad, generous and wonderfully comprehensive, reaching out into unfathomable space and distance immeasurable, while method and order everywhere obtain; so that we need not fear to exceed her resources in following to their logical results the action of her laws in living organisms, knowing full well that everything in the visible universe is based upon law.

Concerning the Relations Which Carbonic Acid Sustains to the Nutritive Processes in Animal Organisms.—It is notorious that nutrition is more active during sleep, or the period when carbonic acid tends to accumulate in the blood and tissues from diminished respiration, at the same time there is tendency to venous stasis in the systemic capillaries from venous obstruction at the right side of the heart, so that when very profound in obese individuals there is a degree of lividity in the skin, especially in the face and extremities; and when produced by soporifics, and respiration is still more slowed, the whole surface is suffused with venous discolorations. Nevertheless, during this condition of venosity, nutrition is very active. Why? Undoubtedly a principle is involved, for there is method in it. Now, then, the question: What is this principle which applies to the nutritive processes? We know the one which applies for evolving force in the organism, and it remains to discover the one which applies to nutrition; the one tending to dispersion, the other to accretion, or growth; therefore representing opposite conditions. The circumstance which gives the clue here is the fact that the tissues are composed of compounds of carbon, floral as well as the animal tissues. Now, then, put these two facts together, placing them side by side, for they are complementary and belong together, animal resting upon floral life, morever, is composite, floral structure and the principle in floral life pervading it, namely: 1. Carbonic acid is the principal source of floral structure. 2. The most active nutrition in animal life is *coincident with the greatest accumulation of carbonic acid in the blood-juices and tissues.* It follows that the nutritive processes are *similar* in both, and that *carbonic acid* is the *principal agent* for *producing nutrition* in animals. Furthermore, it is the most soluble of all the organic compounds of carbon. therefore more readily diffused through the tissues, while little force is needed for decomposing it in the metabolic processes concerned in nutrition, so that no reason presents why this so-called waste product should not perform an enormous rôle in the nutritive processes, or the same as in the plant, the excess passing out through the lungs and secretory functions for maintaining a balance simply; since the evolution of force in the organism by producing carbonic acid would naturally create an excess which must be disposed of. In this manner nature works up old, effete structures in elaborating new tissues, as we have seen her do in the case of the lymph in the lymph-glands. Why not? No reason on earth, that I am aware of. And, being utilitarian to the last degree, we must conclude she works it in this manner with carbonic acid. Last, but not least, the deeply suggestive fact that all plant and animal tissues are compounds of carbon, and that the only soluble condition of carbon fit for assimilation and in universal distribution over the earth and in living organisms is carbonic acid gas. And why interdict in the formative processes in animals? Do not seek to rob nature of her most available means, nor place too wide an interval between kindred processes in plants and animals, seeing that they are only grades in development and forms of the same thing.

And bear in mind, also, the fact, which is undeniable, that *increase* in nutrition *corresponds* with *a slow circulation* and *increase of carbonic acid in the blood and tissues.* This circumstance has forcible illustration in *mania a potu*, in which sleep has at last been induced by full doses of morphia or hydrate of chloral, and though the sleepless and terrified patient is thus crushed, so to speak, into sleep at the peril of his life, with respiration as low as seven and eight per minute, breathing stertorous, the skin livid from venous stasis in the systemic capillaries (as I have seen in a number of cases), death seeming to be impending; yet he comes out of this condition, after from twelve to eighteen hours' sleep, *actually convalescent*, the mind clear and appetite voracious. And I cannot but think that the *slow* respiration and circulation, together with the *great accumulation of carbonic acid in the system* which must inevitably result, are the chief elements in the rapid reparative processes in these cases. The slowing of the circulation favoring the crystallizations in the nutritive processes, which the carbonic acid tends to increase; at the same time, force is economized, since carbonic acid is necessarily formed in maintaining temperature and producing the various movements, requiring only that special additions should be made to it—nitrogen, hydrogen, etc. To me it seems most reasonable. "Eat and sleep" is the advice in the nursery, and the child most gifted in this respect is decidedly the finest. Stock fatteners limit exercise as much as possible, restricting the animals to the smallest space, with the object of making them eat and sleep. The one reduces respiration and circulation; the other increases the nutritive processes.

And as age creeps on, and the habits become more and more sedentary, diminishing respiration and circulation in proportion, for the same reason it tends to the accumulation of fat.

Concerning Carbonic Acid as a Stimulus.—The burning sensation in the throat and the feeling of warmth it produces in the stomach is a proof that carbonic acid acts as a stimulus to the digestive functions, and being exceedingly palatable, is much sought after. And since there would seem to be enough and to spare generated in the system, the appetite for it is very probably due to its action in this way. In impaired digestion it is highly beneficial; and irritable stomachs respond more quickly to its action than to any other remedy, especially when given in the form of "mineral water" and champagne.

But perhaps the strongest evidence of its stimulating properties is furnished by its action upon respiration, being the opposite of that produced by oxygen, which acts as a sedative to the respiratory centre. For example, if pure oxygen be respired, it gradually slows respiration, till finally apnœa is induced. But when the oxygen is discontinued and carbonic acid substituted, respiration sets in again at once, growing more and more frequent; respiration jumps up in leaps, becoming very rapid until the very body palpitates, so there can be no doubt that it is a respiratory stimulant, subserving useful purpose in this respect for maintaing a balance in respiration. And oxygen being A RESPIRATORY SEDATIVE, the necessity for a special stimulus to action would at once appear obvious, while this increase of the respiratory rhythms, which it produces when in excess, soon restores the disturbed equilibrium, and all runs on as before.

In similar manner it also affects the heart, which beats tumultuously in impending asphyxia, expanding to its utmost limits before the fatal issue, from the action of this stimulus upon the nervous centres of the heart intrinsic, as well as extrinsic, affecting all of them, and the dilator equally with the contractor nerves. Indeed, the vaso-motor centre itself is included, as is fully evidenced in the wide arc of movement described by the so-called Traube's Curves (Fig. 41), which is undoubtedly produced by the increasing venosus of the blood. There can be no doubt, then, that carbonic acid is a stimulus to the *respiratory*, *circulatory* and *digestive* functions, inclusive of all the secretory processes.

One of the most difficult circumstances, however, to account for occurs in connection with sleep, when respiration and circulation are slower than at any other time—this notwithstanding the fact of an increase of carbonic acid in the blood. This, however, could be accounted for by the fact that there is *similar* obtundity in *all* of the nervous centres; *sight*, *hearing*, *smelling*, *tasting*, *feeling—all are obtunded;* so that unusual force must be applied to either one of them in order to increase the action: not produced by brain anæmia, either, only, in one sense, that there is diminished flow of arterial blood in the brain, since the veins and capillaries are *literally distended* with venous blood, and the brain larger in consequence, occupying more room than in the waking condition; which undoubtedly favors the nutritive processes, having this as the end. But, then, what induces it? The necessity for repair! The arteries contract and diminish the lumen in the vessels, while the slowing of respiration causes the venous blood to dam back in the sinuses and cerebral veins, and so producing it, that the nutritive processes may restore what is lost by attrition in evolving force or for producing the movements in animal life. Very well; we must accept *that!* Cause of causes!—show us the rest of it! Falling back upon the inevitable metamorphosis of force, we find that the arterial blood ebbs and flows in the brain according to whether sleep or animation is desirable, nutrition or force most needed in the organ and organism; but *there* we stop at the brink of the abyss in Force itself, involving the universe of matter, for matter and force are *forms of the same thing*, undoubtedly.

Concerning the Functions of Nitrogen Gas in the Animal Organism.—Briefly, an amount of nitrogen disappears in respiration to *re*appear in arterial blood, but again to disappear in the tissues, since the venous contains less than arterial blood, the relative proportion being 1.30 to 1.60 in the 100. But when we come to the gases contained in its several portions of the intestinal canal, this phenomenon has ready explanation, constituting a necessary part of the mechanics in the digestive and absorptive processes in the organs, or means to ends, the secretion of the gas being essential to the maintenance of a balance in pressure within the canal, which, of course, must have adjustment with the exigencies in the functions, and as a consequence must vary in the several portions. Thus, in a series of experiments instituted upon executed criminals, by Majendie and Chevreul, the following gases were found to be present in the stomach and intestines:

Gases contained in the Stomach.

Oxygen	11.00
Carbonic acid	14.00
Pure hydrogen	3.55
Nitrogen	71.45
	100.00

Thus, casting our eye over the chemical analyses, we find that oxygen in the proportion of 11 parts in the 100 presents for the first and last time in the stomach; hence, is very probably carried in with the boluses and liquids, whence it is absorbed and carried to the liver, to be consumed in the metabolic processes; a remnant, as it were, of the primitive mode of respiration. It would also account for a portion of the nitrogen and carbonic acid, but not all of them, leaving a large residuum still unaccounted for, save by the secretory function in the gastric capillaries. This circumstance is fully proven in the cases of the small and large intestines, notably:

Gases contained in the Small Intestine.

	First criminal.	Second criminal.	Third criminal.
Carbonic acid	24.39	40.00	25.00
Pure hydrogen	55.53	51.15	8.40
Nitrogen	20.08	8.85	66.60
	100.00	100.00	100.00

Gases contained in the Large Intestine.

	First criminal.	Second criminal.	Third criminal. Cæcum.	Third criminal. Rectum.
Carbonic acid	43.50	70.00	12.50	42.86
Carbureted hydrogen and traces of sulphureted hydrogen	5.47	.....	.....	.....
Pure hydrogen and carbureted hydrogen	.....	11.60	.....	11.18
Pure hydrogen	.....	.....	7.50	.....
Carbureted hydrogen	.....	....	12.50	.....
Nitrogen	51.03	18.40	67.50	45.96
	100.00	100.00	100.00	100.00

It will be seen from the above exhibit that carbonic acid and nitrogen are the principal gases in the small and large intestines, as well as in the stomach; in the third criminal the total amount aggregating as much as 91 and 88.82 respectively for the small and large intestines, the remainder being made up of the hydrogen gases, principally pure hydrogen.

The large amount of this gas in the small intestines of the first and second criminals is difficult of explanation; but as hydrogen is evolved in the nutritive processes in the plant, we may infer that the epithelial cells are the principal source. But there can be no doubt respecting the source of the remarkable quantity of carbonic acid and nitrogen in the *large* intestine of *all* the criminals, being respectively 94.53. 88.40, 80 and 88.82 in the *rectum* of the third criminal; the quantities of the two gases varying.

All we seek to show by this circumstance is the power on the part of the blood-capillaries to secrete these gases out of the blood in the measure of the physiological requirements in the organs in the exigencies in the functions; and since the whole matter relates to pressure, the relative amount, of course, would have to be determined by the quantities of the other gases already in the intestines or evolved by the chemical and secretory processes in the organs; and as this must necessarily vary from time to time, it would imply a corresponding power of absorbing them when in excess of the demand; hence the circumstance of the excess in expiration during digestion, as has already been mentioned.

Finally, the power on the part of the intestines to secrete the gases is proven to demonstration by physiological experiment upon the gut (p. 203), while respiration itself is *based* upon *this power* in the blood-vessels to *secrete* and *absorb* the *gases*; otherwise carbonic acid could not be excreted nor oxygen and nitrogen be absorbed.

In Reference to the Odor of Fæcal Matter.—In respect to the peculiar odor of fæcal matter, the chemical experiments of Professor Liebig afford the clue. For example, he ascertained that if albuminous compounds are subjected to heat with solid hydrate of potash, and the heat be continued until the greater portion or the whole of the nitrogen is dissipated as ammonia, and free hydrogen begins to escape, the residue, when supersaturated with dilute sulphuric acid, and distilled, yields a liquid containing acetic and butyric acid, and *possessing* in a *very intense degree* the *peculiar* and *characteristic odor* of *human fæces;* the odor varying according to the substance used, in this way accounting for all varieties of fæcal smell. Now, then, in view of the fact that the chemical reactions in living organisms without the agency of heat *per se*, but by the action of electrical force, aided by the mutual affinities in the molecules, and that oxygen and hydrogen in the form of water have their bond of union broken in this manner, notwithstanding the prodigious force it involves, the explanation of the chemical reactions detailed by Professor Liebig for evolving fæcal odor without involving any harm to the tissues, would appear natural enough, and not at all extraordinary.

Concerning the Genesis and Functions of the Gases in the Air-Bladders of the Fishes.—This function in the blood-vessels for carrying the gases to and from the internal parts for subserving important mechanical uses in connection with the special functions in the organs has forcible illustration in the air-bladders of the fishes, in which it subserves a dual function, notably:

1. For buoying them in the media, thereby powerfully assisting the action of the fins, enabling the animal to ascend or descend with the utmost ease and celerity by simply expanding and contracting the air-bladders and body-walls, using the fins and tail, of course, for assisting the action

2. For transmitting sonorous vibrations through the body-walls upon the ossicles and otolites of the auditory apparatus (Fig. 147, *o*, *m*, *l*, *d*). As will be seen, the anterior portions of the bladder (*p*) fit accurately against the expanded base of the large ossicle (*o*), this against the ossicles *m* and *l*, whence the force is transmitted upon the delicate extremities of the acoustic nerve, which are expanded upon the chamber of the vestibule by means of the two subspherical "atria" on the body of the atlas, close to the foramen magnum, and the endolymph which fills both atria and the common sinus. The sonorous vibrations thus communicated to the suspended otolites (*d*) are made to beat upon the nervous filaments of the auditory nerve in the chamber of the vestibule containing the otolites upon the lining membrane of which the nerves are expanded.

In the herring, the tubular prolongation of the fore part of the bladder (Fig. 148, *k*) advances to the basi-occipital and bifurcates; each branch penetrates the side of the base of the skull, again bifurcates, and terminates in two blind sacs, which

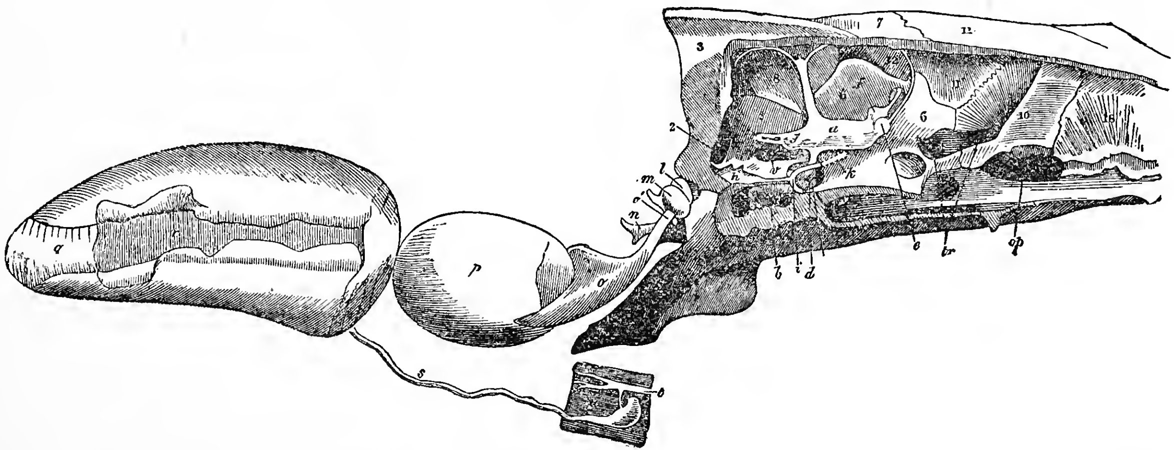

Fig. 147.—Organs of Hearing in situ, with Air-Bladder and Ossicles, Carp.—De Aure et Auditu Hominis et Animalum, 4to, 1820, by E. H. Weber. *p*, Forepart of air-bladder (*a*); *o*, *m*, *l*, three ossicles connecting air-bladder with two "atria," communicating with the sac of each vestibule (*b*), through a common "sinus impar" (*h*) in the basi-occipital bone; *s*, pneumatic duct communicating with posterior portion of the pharynx (*u*).

are in contact with similar cæcal processes of the labyrinth (Owen).

In this manner, then, the gases contained in the air-bladders of the fishes subserve two important functions: one for overcoming body-inertia, the other for transmitting sonorous undulations upon the auditory nerves; while in the mammalia, we have seen that air is utilized in the intestines for increasing the digestive and absorptive processes by means of the force transmitted from the walls of the gut and the muscular envelope of the body upon the aliment; or, in other words, for overcoming inertia in the nutritive and force-producing elements and speeding them into the vascular channels, and, in very truth, is the stepping-stone in higher development or mammalian evolution. And that the blood is the source of the gases in the air-bladders of the fishes is manifest, from the following facts, notably: 1. The air-bladder is the nascent condition of the lungs, into which it is subsequently developed; hence the power to excrete and absorb the gases inheres in the organ.

2. It would account for the *absence* of the air-duct in vast numbers of fishes, notably, Acanthopteri, *e. g.*, perch, mullet, mackerel, angler, etc.; Anacanthini, *e. g.*, cod, plaice, etc.; Plectognathi, Lophobranchi. And there being no air-duct in these fishes, it follows that the blood must be the source of the gases contained in the air-bladder, and not the intestinal canal, which serves as an outlet in the other fishes for rapid discharge of the gases, in order to obviate strain when moving from the deep to the surface waters, where sudden expansion is inevitable.

3. It would account for the *special* gases in the air-bladders of the fishes, which consist, in most fresh-water fishes, of nitrogen and a very small quantity of oxygen, with a trace of carbonic acid gas; while in the air-bladder of sea-fishes, especially those which frequent great depths, oxygen predominates, as much as 87 in the 100 in volume being reported by Biot in some of the deep-sea Mediterranean fishes; the rest nitrogen, with a trace of carbonic acid. In these cases, the air-bladders function as special reservoirs for oxygen to subserve respiratory purposes in the depths where the gas does not circulate so freely; finally, no hydrogen has ever been detected in the

air-bladders of fishes, which also shows the gases are not derived from the intestinal canal.

4 Lastly, we have to mention the peculiarities that obtain in the capillary network of the air-bladders as the special provision for excreting and absorbing the gases, while the branchiæ form an open portal for their ingress and egress to the blood vessels. The principal seat of the vascular ramifications in the air-bladder, like that in a true lung, is the mucous lining membrane, but there is variety in the terminal divisions of the arteries. In the carp, for example, they terminate in fan-like tufts over almost every part of the inner surface. In the pike they are larger and more localized, but without any special aggregation of the capillaries to form a "vaso-ganglion"; but in the perch and cod the capillaries are aggregated so as to form red, gland-like bodies (Fig. 149); the capillaries reuniting into larger vessels, which again ramify around the gland-like body; the rest of the inner surface of the air-bladder retains the ordinary simple capillary system.

It will be seen that the afferent and efferent vessels to these bodies form vascular loops, which are covered by a layer of vessels and epithelium (*a*, *a*). In addition to this, however, are a number of peculiarly arranged, elongated corpuscles, which depend in two rows from each vascular branch, and are bound together by a loose cellular tissue; the corpuscles are beset with fine villiform processes. The blood returns from the vaso-ganglions by small veins, which rarely accompany—more commonly cross—the arteries (Owen), and is certainly strong corroborative proof of this function in the arterial capillaries for excreting the gases. In the eel and conger, the two chief ganglions, which are situated at the sides of the opening of the air-duct, consist of both arterioles and venules; they consist of straight parallel capillaries (Fig. 150); their efferent trunks do not ramify in the immediate margin of the vaso-ganglion from which they issue, as in the vaso-ganglions of the cod, burbot, acerine and perch, but run for some distance before they again branch to form the common capillary system of the lining membrane of the air-bladder (Owen).

This aggregation of capillaries in arterial and venous retia is undoubtedly favorable for rapid secretion and absorption of the gases; indeed, not gases only, but liquids as well, since the Malpighian glomeruli are homologous, formed by the terminal branches of the renal artery, and from which an afferent vessel is given off to be distributed to the urinary tubules (Fig. 117, *va*, *gl*, *ve*). And they also occur in other

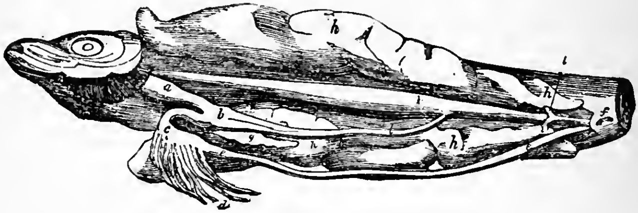

Fig. 148.—Abdominal Viscera, with Air-Bladder (*k*) in situ, Herring (reduced).—Brandt and Ratzeburg. . Medizinische Zoölogie. 4to. 1833. *a*, Œsophagus; *b*, stomach; *c*, pylorus; *d*, appendices pyloricæ; *e*, *e*, intestine; *f*, anus; *h*, *h*, testes; *i*, genital ducts; *k*, air-bladder; *l*, pneumatic duct.

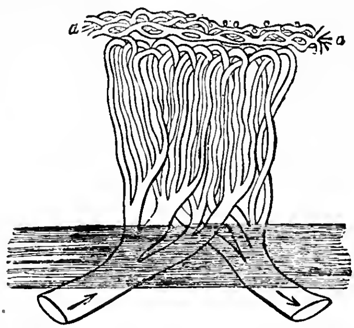

Fig. 149.—Superficial and Looped Vessels of the Vaso-Ganglion of the Air-Bladder, Cod.—Dr. Williams.

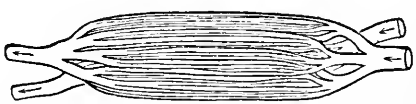

Fig. 150.—Parallel Vessels of the Vaso-Ganglion of the Air-Bladder, Eel.—Dr. Williams.

localities—notably, in the arteries of the mesentery *contiguous to the intestines*—and are common in the limbs of the sloth, the axillary and iliac arteries in these slow-moving animals, just before entering the limbs, suddenly dividing into numerous small channels, which again unite into one trunk before the members are given off; in these cases serving as reservoirs for storing arterial blood for evolving the local actions concerned in digestion, and for producing the muscular force for sustaining the weight of the animal suspended by its limbs. But this is seen upon a prodigious scale in the enormous arterial plexuses in Cetacea, wherein a vast quantity of arterial blood may be accumulated for supplying the wants of the animal during prolonged periods of submersion. For example, the intercostal arteries divide into a vast number of branches, which run in a serpentine course between the pleura and the ribs, and penetrate the intercostal muscles, everywhere lining the walls of the thorax; moreover, they pass in between the ribs near their articulation, and anastomose extensively with each other. And in like manner the central nervous system is embossed by dense arterial plexuses; more especially the medulla oblongata, where a thick substance is formed by their ramifications and convolutions—a *rete mirabile* on a prodigious scale for sustaining the functions in the great nervous centre for the organism during prolonged periods of submergence, Nature in this manner storing oxygen for the purpose. Mirabile!

CHAPTER XVII.

FACTS IN DEVELOPMENT, SHOWING THE RELATIONS WHICH THE HEART SUSTAINS TO THE MECHANICS OF CIRCULATION.

Principle in Cardiac Evolution—Respiration and Circulation in Worms—The *First* Indications of a Heart Found in Connection with the *Localization* of the Respiratory Apparatus, notably *Terebella*—Facts Revealed in Decapods—Ditto Fishes—Ditto Reptiles—Differentiation of the Left Cardiac Chambers with Air-Breathers, First the Auricle, then Ventricle—Enormous Development of the Muscles in the Heart in Tortoise—Reasons Therefor—Perfection of the Interventricular Septum in Crocodilia, but Leaving a Passage between the Left and Right Sides of the Heart, so as to Allow Reflux during Submergence—Reasons Therefor—The Changes with Progress in Development till the Birds are Reached, in which Cardiac Development is Complete—The Heart always in Intimate Connection with the Oxygenating Apparatus, since it Relates to the Evolution of Force in the Organism.

In tracing cardiac development, we must *begin*, of course, with the principle upon which development, itself, is based, when all the phenomena appertaining to it have ready explanation; otherwise are inexplicable. Since all the activities, inclusive of the movements in the viscera, blood-vessels, and heart—indeed, every variety of motion in the organism—is evolved from force which is generated by the combinations effected with oxygen, it follows that the importation and circulation of oxygen is fundamental in the organism; and the blood being the medium for receiving and transmitting it to the tissues, the comprehensive arrangements that obtain for pumping it through the lungs and tissues in the measure of the physiological requirements will be readily apprehended; also, why the respiratory and circulatory apparatus should be a connected movement, otherwise the scheme would fail The intimate relations which the heart sustains to the respiratory apparatus, then, are to be explained by this principle in the mechanics; while the changes of form which it undergoes with progress in development, are due to the peculiarities which obtain in the respiratory apparatus, which impress themselves upon the heart as the local reservoir and force-pump, for receiving and transmitting the blood to and from these organs, together with the necessity for a gradual and more and more complete separation of the arterialized blood, upon which progress in development depends, since this is essential for the production of the relative phenomena.

In fine, the vascular system is molded, so to speak, to the respiratory apparatus, undergoing special modifications in correspondence with the changes which have taken place in the stage in development, while the differentiation of a heart or central force-pump in connection with the oxygenating apparatus is for the purpose of increasing circulation in it in correspondence with the amount of force which is expended in the organism, the one involving the other. And viewed from this stand-point and the law for increasing circulation—namely, by rhythmical changes in pressure—the special rôle in the heart and the mechanical principle it involves, inclusive of the nerves for coördinating it with respiration, is at once made intelligible, together with all the relative phenomena appertaining to it; otherwise inexplicable. Thanks to numerous workers in the field and the opulence of material, the labor involved in this inquiry is enormously diminished, requiring only to be carefully collated and systematically arranged. For this purpose, we begin with the earliest stages in cardiac development; notably, worms, in which a highly complex circulation is carried on in the absence of a heart for producing it, following thence through the successive stages in cardiac evolution to the warm-blooded animals, in which cardiac development is complete. And we begin with the worms, for the reason that pulsation is *first* visible in the vessels; hence, is not necessarily dependent upon the heart or synonymous with its action, since it exists long before a heart comes into the scheme; moreover, is not limited to the blood-vascular system, for it is met with in the veins and lymphatics of amphibia and occurs in the lacteals of warm-blooded animals. At the same time, however, in the worms *local dilatations* occur in the *vessels corresponding with* the *branchiæ* and *air-vesicles*, thus early indicating the principle in the blood-vascular system for increasing circulation in the lungs by the differentiation of a heart for assisting the action.

Briefly summarized, the ground plan of the animal circulation commences by the formation of several longitudinal vessels (three or more), extending the length of the body of the *worms*, first visible in Nemertina (Gegenbaur); a median dorsal, which lies above the enteron and is pulsatile, and two

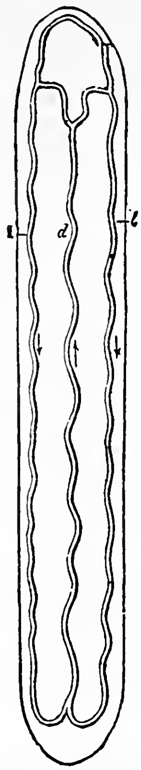

Fig. 151.—Ground Plan of the Vascular System in Nemertina.—Gegenbaur. *d*, Dorsal longitudinal trunk ; *l*, *l*, lateral longitudinal vessels. The arrows indicate the direction of the stream.

lateral vessels, one upon either side (Fig. 151, *d*, *l*, *l*), which are veins that deliver the blood into the median dorsal artery, with which they connect at the terminal ends and by transverse vessels; whence it is passed forward by successive expansions and contractions in the dorsal vessel, the lateral branches given off at regular intervals by this great trunk conveying it to the muscular parietes for generating force, and to the cutaneous capillaries for oxygenation, to be re-collected in the corresponding branches of the lateral veins, which also collect the blood in the viscera ; while a portion continues on to the cephalic end and the vascular loop or loops, as the case may be, which encompass the œsophagus. The simplest condition of the vascular system is seen in those which have no perceptible respiratory organs, oxygenation being effected through the thin integument and subjacent capillary network—*e. g.*, *nais* and *planaria*. In the transparent body of *erpobdella vulgaris*, two median vessels, a dorsal and a ventral vessel, are discernible, which, by their waves of pulsation, convey the blood into numerous lateral branches (Fig. 152, *b*), the capil-

Fig. 152.

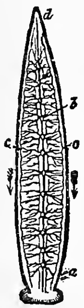

Fig. 153.

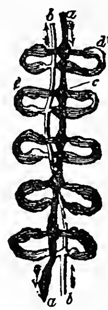

Fig. 152.—Diagrammatic Representation of the Vascular System in *Erpobdella Vulgaris*, showing the numerous lateral branches given off by the median ventral vein (*b*), and which anastomose with corresponding branches from the two lateral venous trunks (*c*, *c*), and dorsal artery (*a*).

Fig. 153.—Vascular System of *Lumbricus Terrestris* (anterior portion). *a*, *a*, Median ventral vein ; *b*, *b*, great dorsal artery ; *c*, *c*, sacculated arches. The arrows show direction of the stream.—Grant.

laries of which are continuous with those of the two great returning veins (*c*, *c*), extending backward along the sides of the body (Morren). In *annelides*, it is pretty much the same ; the venous blood of these animals is commonly returned from the system to the posterior extremity of the dorsal artery by a median ventral vein, or by two inferior lateral veins ; but considerable modifications are induced in higher genera by development of respiratory organs in the form of external cephalic or dorsal branchiæ or internal air-vesicles. In *nereis cuprea*, the long dorsal artery appears slightly dilated in each segment of the body, and receives or gives off the branchial vessels from the arterial arches which encompass the œsophagus (Grant) In other species, the branchial vessels are given off to these organs from each side of the dorsal artery in its whole course forward (Fig. 153, *d*, *b*, *b*), and the fifteen pairs of ramose branchiæ presenting in *arenicola* induce as many corresponding modifications in the vascular system of these animals ; while small pulsating vesicles are generally perceptible on the lateral systemic branches of the dorsal artery.

In the earth-worm (*lumbricus terrestris*), the direction of the internal currents, owing to the greater transparency of the body, is more perceptible than in the more opaque body of the leech, where it is necessary to examine this part in very young individuals, and where the currents have appeared often to change their direction through the vascular trunks. Successive waves of contraction are distinctly seen in the earth-worm, extending from behind forward along the wide dorsal vessel ; and by removing the integuments and pressing this artery between the forceps, it becomes empty in front and turgid behind. It appears to receive the arterialized blood from the air-vesicles, and sends off numerous lateral branches in its course, especially to the alimentary canal and the genital organs.

The venous blood is collected from the viscera chiefly by the great median subgastric or epineural vein, extending backward between the digestive canal and the nervous columns; and this vessel appears to send off branches to the numerous minute respiratory vesicles. A small inferior median vessel or hyponeural vein is also perceived, extending along the under surface of the nervous chords, and an accompanying lateral branch is seen, as usual, on both sides of the same columns.

Anterior to the commencement of the stomach, the great dorsal artery (Fig. 153, *b*, *b*) communicates with the median subgastric vein (*a*, *a*) by five or more pairs of lateral, wide, sacculated arches (*c*, *d*), which embrace the œsophagus, as the corresponding vascular arches which connect these two vessels in other annelides and in the entomoid classes. According to Dr. Williams, the following is the plan of circulation in earth-worms (Fig. 154): The circulation is very complicate.

They respire through the cutaneous surface, which is occupied by a dense capillary plexus ; also through the alimentary canal, which is similarly supplied, and which undoubtedly functions as a respiratory as well as digestive organ. It is also claimed that the stratum of viscid matter in which they are always enveloped is remarkably endowed with the property of absorbing and dissolving atmospheric air (Jones).

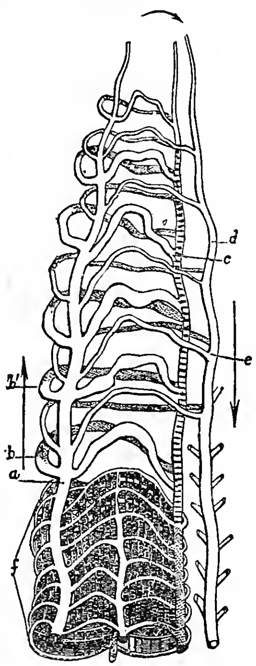

Fig. 154.—Diagram Illustrative of the Circulatory Apparatus in the Leech (*Hirudo Medicinalis*).—After Dr. Williams. *a*, Great dorsal vessel ; *c*, ventral vessel ; *d*, *d*, intercommunicating vessels between dorsal and ventral trunks ; *e*, *e*, lateral abdominal trunks ; *g*, vessels distributed over the cæcal appendages to the stomach.

From the equal development of the great vascular trunks and the numerous transverse anastomoses, it is easy to perceive how the circulation in these animals can, by the closing of the divided ends of the vessels, become accommodated to extensive mutilations, and proceed without interruption in a few segments detached from the trunk. Some of the simpler forms of annelides, *e. g.*, *styluria*, are thus enabled to extend their means of propagation by the spontaneous transverse fission of the body.

But the leech, perhaps, presents the most complicate vascular arrangements of any of the annelides, though the ground plan of the circulation is fundamentally the same as in all the other worms and entomoid classes, consisting of a number of longitudinal trunks with the median dorsal and ventral occupying the old positions, the blood passing to the caudal end through the one and the cephalic in the other, while the lateral branches pass into the segments and effect circulation transversely. The dorsal is recipient of arterialized blood, which it distributes to the organs (but venous blood also flowing into it by the anastomosing branches, especially with the median ventral), while the ventral functions as the systemic venous trunk, from which the blood is sent to the respiratory vesicles. In addition to the dorsal and ventral trunks, however, are two large lateral trunks, one on each side (Fig. 155, *e*, *e*), which, according to M. Dugès,* are appropriated to the respiratory system of lateral sacculi, of which there are seventeen pairs symmetrically disposed along the sides of the body, with thin spiracles opening along the ventral surface.

That the movement of the blood in the lateral or respiratory system of vessels is quite distinct from that which is accomplished in the dorsal and ventral or systemic trunks; sometimes it passes down one of these vessels from the head toward the tail, and in an opposite direction on the other side of the body; but in a short time the movement of the currents will be seen to become completely reversed, so that an undulatory motion, rather than a complete circulation, is kept up. By this action of the lateral canals the blood is made perpetually to pass and repass the respiratory sacculi; and, opposite to each of these, branches are given off which form so many independent vascular circles, representing very closely the minor or pulmonary circulation of higher animals.

Finally, the rich supply of arterialized blood sent to the lateral cæca of the stomachal cavity for promoting the secretory processes in these organs in connection with digestion, has

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forcible illustration in the beautiful arborescent arrangement of the vessels in the walls, with their footstalks connecting immediately with the dorsal artery (Fig. 155, *g*, *a*). The following illustration (Fig. 156) will give some idea of the relations the cæcal pouches (*k*) sustain to the stomachal cavity and respiratory vesicles; the stomach itself occupying about two-thirds of the visceral cavity, is divided by septa or diaphragms into nine or ten compartments, but communicating

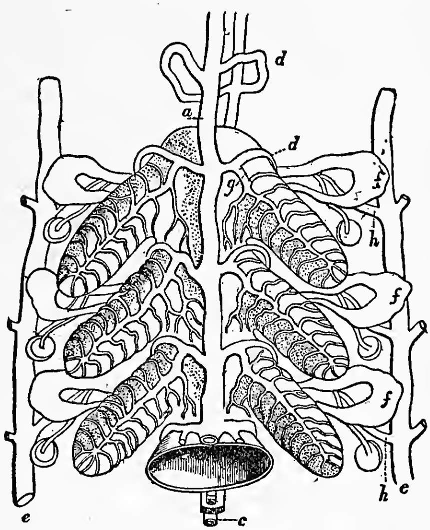


Fig. 155.—Diagram Illustrative of the Circulation in the Leech.—Dr. Williams. *a*, Great dorsal vessel; *c*, ventral vessel; *d*, *d*, intercommunicating vessels between dorsal and ventral trunks; *e*, *e*, lateral abdominal trunks; *g*, vessels distributed over the cæcal appendages to the stomach; *f*, *f*, *f*, loop-shaped organs to the respiratory vesicles; *h*, *h*, lateral branches to respiratory vesicles.

freely with each other, and in each of which are two openings communicating with the lateral cæca.

Up to this stage in development, then, in which a very complex circulation is seen to exist, no heart presents, but the vessels themselves producing it, inclusive, of course, of the action of the polar forces. Unless, forsooth, the whole dorsal vessel, running the length of the body, inclusive of the lateral branches, be considered as such, which is perfectly absurd—the outcome, in fact, of the misleading and erroneous conception that the animal circulation is *based* upon the heart, which is a means for increasing it simply, and "putting the cart before the horse," by reversing the order in nature. Furthermore, it would leave unexplained the action in the other vessels; consequently, the principle is wrong. And as the organ relates to the production of force by increasing circulation in the

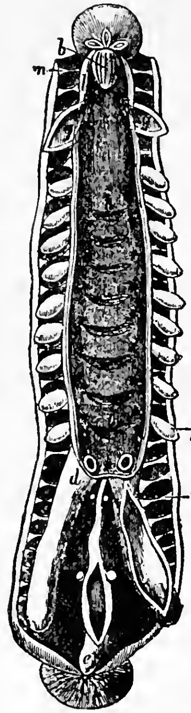


Fig. 156.—Digestive Organs of the Leech (*Hirudo Medicinalis*).—Jones. *b*, Pharynx; *h*, *i*, interior of stomachal cavity, exhibiting the diaphragms, with the lateral openings in the cæcal appendages (*k*); *g*, first pair of stomachal cæca; *d*, last pair, extending backward on each side of the intestine (*e*), which opens on the dorsal surface close to the terminal sucker.

respiratory organs, the absence of a heart in the circulatory system of the annelides is readily accounted for by the *diffused respiration* which obtains here, for in every part of the circumference of each ring the blood is being arterialized as it is being rendered venous; hence, no heart is developed, the action in the dorsal artery with the lateral vessels extending into the capillary plexuses of the skin, respiratory-vesicles, or branchiæ, as the case may be, being sufficient for the purpose and subserving the functions of a heart. But this latter circumstance is made more conspicuous in *arenicola* (Fig. 157), in which the circulation is simplified. And this beautiful diagram, by the distinguished anatomist and naturalist at Heidelberg, will serve to give a distinct mental picture of the adaptive changes in the vascular system to the *form* of the respiratory apparatus and the principle that obtains in the mechanics for increasing circulation in it commensurate with the force which is expended in the activities. As will be seen, the branchial vessels (*b*, *b*) are connected *directly* with the great dorsal and ventral trunks (*d*, *v*) the blood from the latter passing into the

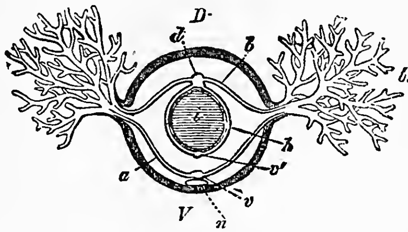


Fig. 157.—Diagrammatic Transverse Section through the Hinder Half of the Body of *Arenicola*, to show the arrangement of the vessels.—Gegenbaur. *D*, dorsal ; *V*, ventral side ; *n*, ventral medulla ; *i*, enteric cavity ; *br*, branchiæ ; *v*, ventral vascular trunk ; *ab*, branchial vessels ; *d*, dorsal vascular trunk ; *h*, branch surrounding the enteric canal ; *v′*, visceral ventral vessel.

branchia (*br*) by means of the afferent vessel (*a*), thence to the dorsal artery through the efferent vessel (*b*), one upon either side corresponding with the branchiæ ; hence, any expansile action in the branchiæ or vibratory motion tending to increase circulation in the plexuses would necessarily determine the venous blood in this direction, while the pumping action in the dorsal vessel should serve for aspirating the plexuses and propelling it through the system ; since the diastoles produce a suction-force and the systoles a driving force upon the blood. And though reflux is inevitable, by reason of the absence of valves, still this is limited, from the fact that the blood which is withdrawn from the plexuses by the diastoles is *instantaneously* supplied by the venous blood flowing into them, filling them *before* the succeeding systole sets in, or nearly so ; so that only a small amount of reflux is possible. But this mechanics would not answer when a heart comes in the scheme, for the reason that the force in the latter would tend to rupture the capillaries from the strain it should occasion; hence the differentiation of valves for obviating reflux. In addition to these vessels, however, we have now to notice another arrangement of equal importance, notably the one relating to the intestinal canal, since this is the gateway of the nutrient and force-producing elements. Here, for example, we have two lateral vessels (*h*) that embrace the intestinal canal (*i*) and connect with the visceral ventral vessel (*v'*) and the delicate plexuses in the visceral parietes on the one hand, and the dorsal vessel (*d*) upon the other; and bearing in mind the mechanics in the portal circulation, is it not apparent that striking correspondence subsists between them; nay, that here we have indeed the very thing itself in its nascent stage? Notably, the visceral blood is collected by special veins and delivered in the systemic current (*d*), passing thence into the respiratory apparatus (*br*) by the vessels (*bb*), the pumping action in the dorsal vessel being the analogue of that in the heart, while the contractions in the external muscular envelope, by increasing pressure in the viscera, should serve for expediting the action; not to mention the suction-force exerted by the branchiæ themselves, which, of course, affects the blood in these vessels in similar manner as in the corresponding vessels to the ventral venous trunk (*a*, *v*); and since the animal is in constant motion, the vermicular movements should increase the visceral circulation and respiration correspondingly. It is not fanciful, since there is definite arrangement in the parts, and there is absolute necessity for such provision, in order to maintain a balance in the organism.

Now, then, looking from this diffused respiration in *arenicola* to the localized respiration in *terebella*, where the branchiæ project from the occiput (Fig. 158, *k*, *k*), the effect upon cardiac development is at once made apparent. For example, the great dorsal vessel (*m*) is now greatly reduced in size by reason of the disappearance of the lateral branchiæ, while the vascular œsophageal collar (*n*), which receives all the blood from the intestinal system, is increased in size correspondingly and functions as an auricle to the elongated fusiform heart (*l*) lying upon the œsophagus (*e*) in immediate relation with the respiratory organs (*k*, *k*), this portion of the great dorsal artery taking on increased development in correspondence with the branchiæ, the other shrinking in size, responsive to the changes in the respiratory organs.

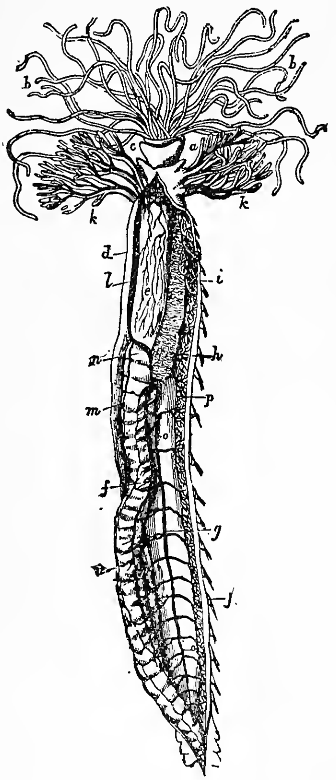


Fig. 158.—Vascular System of Terebella.—Milne-Edwards. Showing the earliest indications in cardiac development (*l*), and the relations it sustains to the respiratory organs (*k*, *k*).

Briefly, the hæmal mechanics is as follows: The fusiform heart (*d*), which is but slightly attached to the structures on which it rests, and suspended, as it were, in the fluids of the peritoneal cavity, sends off at the anterior end three lateral symmetrical branches (Fig. 159, *a*, *d*) to the branchiæ, the reduced continuation of the original trunk breaking up into minute vessels to the tentacles, in the hollow axes of which each terminates in an efferent vessel, and which are surrounded by the peritoneal fluid, which penetrates to the remotest ends of these exquisite organs. But the branchiæ are

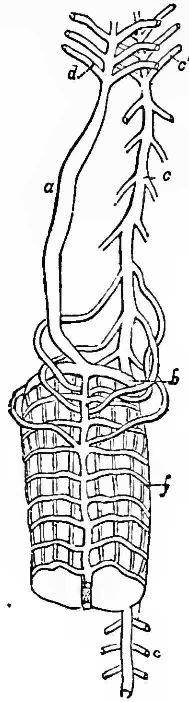


Fig. 159.—Plan of the Circulation in Terebella.—Dr. Williams. *a*, Elongated fusiform heart; *b*, vascular œsophageal collar, which receives all the blood from the intestinal system (auricular); *d*, the three pairs of branchial arteries to a corresponding number of branchiæ; *c'*, three pairs of branchial veins corresponding with the arterial conveying the aërated blood into the longitudinal systemic trunk (*c*, *c*) to be distributed to the intestines and body-territories, three pairs of lateral branches crossing the œsophageal collar (*b*) to connect with the great dorsal vessel; *f*, framework of longitudinal and transverse vessels, embracing the alimentary canal, as in all annelides.

the principal organs of respiration, the three pairs of large lateral arterial branches to which terminate in a corresponding number of efferent vessels (*c'*) that converge in the great ventral trunk (*c*, *e*), which extends to the posterior extremity of the body, beneath the intestine and immediately above the ventral chain of nervous ganglia, but is distinct from, and independent of, the intestinal system (*f*), and which gives off opposite to each ring a pair of transverse vessels, which, after having supplied branches to the integument and locomotive organs (Fig. 158, *g*, *j*),* bends upward, to be distributed over the walls of the intestine, where their ramifications contribute to form the vascular network above referred to. At the point corresponding with the circular vessel (Fig. 159, *b*), the ventral trunk, however, gives off a large branch to the intestine; and since the blood flows out of the branchiæ and tentacles through this great ventral trunk, it follows that a considerable amount of purely arterial blood must flow immediately into the vessels of the intestine for supplying its glandular parietes, and evolving the force which is expended in the digestive functions. And here, again, we have a distinct vascular system, the blood coursing, as in the external envelope, in two directions, namely, longitudinally and transversely or circularly. (In order to understand the mechanics, it must be borne in mind that the intestine is surrounded by peritoneal fluid, the organ being suspended, as it were, in the peritoneal cavity by means of limited bands proceeding from it to the external envelope, tying the two cylinders together, at the same time, however, permitting them to move freely, the one within the other.)

Finally, for re-collecting the blood in these independent tubes, we have the vessels communicating with the great circular auricle in immediate relation with the fusiform heart (Fig. 159, *b*, *a*), and by means of the diastoles and systoles occurring in these vessels, the blood is pumped into the respiratory apparatus, thus completing the circle.

But the influence exerted upon cardiac development from localizing respiration has more forcible illustration in decapods (Fig. 160). Here the venous blood is collected from body territories and locomotive organs in large venous sinuses at the bases of the branchiæ (*a*, *a*) thence by a special vessel (*e*, *e*) analagous to the pulmonary artery to the branchiæ (one for each gill), to be distributed over

* The intestine is pulled aside in order to exhibit these vessels.

the innumerable minute laminæ of the gills, whence it is re-collected by the branchial veins (*f*, *f*), and transmitted to the heart (*g*). The branchial arteries follow the outer margin, and the returning veins the inner margin of the gills, and the united trunks of the latter vessels convey the arterialized blood, by a single orifice on each side, into the large median muscular ventricle (*g*). As in other articulata, it is situate in the middle of the back, as seen in the lobster (Fig. 161, *c*), and consists of a single systemic muscular cavity, most concentrated in form in the decapods, and generally elongated on the inferior orders; its thick parietes are composed of inter-

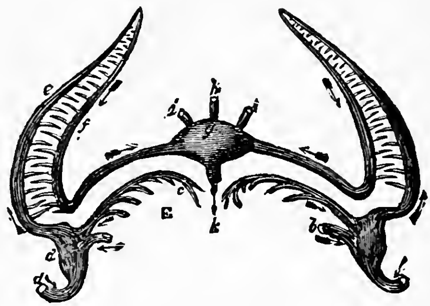


Fig. 160.—Showing Relation of the Heart to the Gills in Decapods, *Maja Squinado.*—Grant. *a*, *a*, Capacious lateral sinuses at the bases of the branchiæ; *b*, inferior abdominal veins; *c*, superior abdominal veins; *e*, *e*, branchial arteries originating from these wide sinuses: *f*, *f*, branchial veins; *g*, the large median muscular ventricle; *i*, *i*, *h*, anterior arterial branches; *k*, the great posterior median systemic artery.

laced muscular fibres, they present internal fleshy columns, there are semilunar valves at the orifices of the great vessels, and the heart is connected, as usual, with the neighboring parts by muscular bands. From the anterior and upper margin of the heart arise three arterial trunks (*i*, *i*, *h*), the two lateral of which send branches to the genital organs and the stomach, and terminate in the two antennal arteries, proceeding to the outer and inner pair of these organs, and the median vessel (*h*), advancing over the stomach to the pedunculated eyes, divides into the two ophthalmic arteries, which supply these organs. From the lower and anterior part of the heart, the hepatic arteries originate by a single or double trunk, according to the divided condition of the liver, through which they ramify ; and from the lower and posterior part of the same muscular cavity arises the great sternal artery, which, after

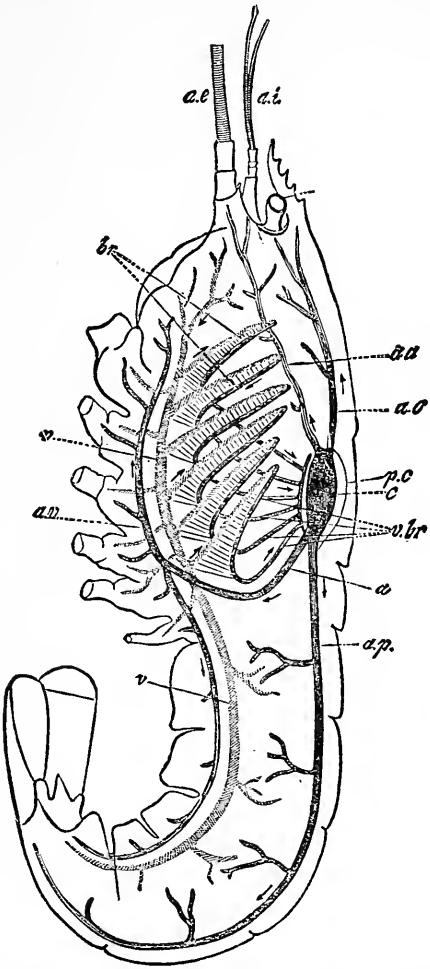


Fig. 161.—Diagram of the Circulatory System of a *Lobster*.—Gegenbaur. *O*, eye ; *ae*, lateral antennæ ; *br*, branchiæ ; *c*, heart ; *pc*, pericardium ; *ao*, median anterior aorta ; *aa*, hepatic artery ; *ap*, posterior artery of the body ; *a*, trunk of the ventral artery ; *v*, ventral venous sinus ; *v br*, branchial veins. The arrows show direction of the blood current.

descending to the sternum and dividing into an anterior and posterior trunk, supplies most of the musculo-cutaneous parts on the ventral region of the body, and gives off laterally the brachial arteries to the locomotive organs. From the middle of the posterior margin of the heart is given off the great posterior median systemic artery (*k*), which, extending backward along the median and dorsal part of the trunk, sends off numerous branches on each side to the neighboring organs, and bifurcates over the colon before distributing its terminal branches on the muscles of the tail. The venous blood of the system is returned to the great ventral and branchial sinuses and transmitted through the gills, and when arterialized is conveyed upward to the dorsal part of the trunk by the branchial veins, to be poured into the cavity of the heart by two orifices on its upper surface. The venous and arterial openings of the heart are provided with valves (Grant). Thus, we have cardiac development coming into prominence in connection with the differentiation of a *local* respiratory apparatus, and growing more and more perfect with progress in development. But the point to which attention is specially directed is the location of the heart (*g*) itself, which is between the gills and upon the *distal* side, so to speak, of this circulation, while the large venous sinuses (*a*, *a*), from which the pulmonary arteries (*e*, *e*) take their origin, are upon the opposite side; the one serving for aspirating and propelling the venous blood in the organs, the other for aspirating it thence and propelling it through the systemic vessels. Here, then, is clearly indicated the mechanical principle in the perfect heart, the right side serving for aspirating the blood in the veins, and compelling it in the alveolar capillaries, the left aspirating the capillaries and compelling the blood in the systemic vessels, only that one must not lose sight of the action in the lungs themselves, the same remark applying for every stage in development.

In the lobster (Fig. 161), the branchiæ (*br*) are increased to six or more pairs; accordingly, we have a similar increase in the number of pulmonary veins (*v br*), conveying the blood to the heart (*c*), which occupies the dorsal region, as before remarked; while the great ventral sinus (*v*) at the bases of the branchiæ sends out a corresponding number of pulmonary arteries. But we have now to notice an advance in cardiac development, notably the differentiation of a pericardial sinus (*pc*), in which the pulmonary veins terminate, and from which the blood flows into the cardiac chamber through three pairs of cleft-like openings, symmetrically arranged and guarded by valves, which project into the heart, for obviating reflux during systole ; but in the fishes (in which a true auricle is formed) is converted into the pericardium, lubricating the organ and facilitating the rhythmical expansions and contractions, in consequence making it more efficient. In other respects, the circulation is fundamentally the same as in *maja squinado* (Fig. 160). And looking from this to the corresponding stages of development in the tracheata, we find similar arrangements obtain in them also. Thus, in arachnida, for example, the respiratory apparatus is in the abdomen, the stigmata opening upon the sides and front of the abdomen, while the pulmonary sacs, which correspond with the anterior respiratory orifices, are in relation with the largest division of the heart, which is located in the dorsal region and divided into three compartments, each one of which is furnished with a pair of cleft-like openings, symmetrically arranged on the dorsal surface and guarded by a pair of valves. The arterialized blood passes into the cardiac chambers through these clefts, thence through the systemic and lateral branches ; the great anterior artery passing through the cephalothorax to supply the anterior portions, and the smaller posterior vessel to the viscera and walls of the abdomen. But the tracheæ are distributed like blood-vessels through the body, bringing every portion in immediate relation with the air, which is pumped in and out of the canals for effecting interchange of the gases, each stigma guarded by a valve, which is opened and closed for the purpose by means of special muscles ; while the blood passes to and from the respiratory organs by means of lacunar passages, reaching the heart in this manner and passing through the ostia during the diastoles, drawn by the suction-force in the heart. The pericardial sinus is also absent ; but not in scorpionea (which correspond in development with the lobster), in which the heart is much larger than in arachnida, in correlation with the form of the body and the number of the tracheæ, and surrounded by a pericardial sinus ; is divided into eight chambers, with a pair of dorsal clefts leading into each chamber, and guarded by valves which project into the cavity. "Arterial vessels are given off from the anterior as well as from the posterior end of the heart, *of which they are direct prolongations;* the anterior one, the aorta, enters the cephalothorax, while the hinder one runs to the tail. In addition to these, a number of lateral arteries are given off close to the venous ostia, and are distributed to the neighboring organs. Two of the numerous branches given off by the aorta form a vascular ring around the œsophagus, where an artery runs back (*arteria supraspinalis*) on and as far as the end of the ventral nerve-chord; this artery gives off a large number of branches. The venous blood is collected in a receptacle which lies directly on the ventral surface, just as in the higher crustacea; from this it is carried to the respiratory organs. Before the blood from them gets to the heart, it passes into the pericardial sinus" (Gegenbaur) Italics are added. It is thus made manifest that the vascular system is set to the respiratory apparatus, in which it all converges as the spokes in the "hub" of a wheel, being the basis, so to speak, of the organism; while the heart shows adaptive changes in correspondence with the local mechanics.

In conchifera are two pairs of large laminated branchiæ, while the heart, which is still more developed, is at the base of these (Fig. 162, *n*, *o*), in a cavity between the great adductor muscle (*l*, *m*) and the folds of intestine. It possesses a true pericardium, and consists, in the species under consideration, of two distinct chambers—an auricle and ventricle. The auricle (163, *b*) is large, and the walls extremely thin, the delicate muscular fasciculi and transparent membranes permitting the blood to be seen through them. It receives the blood from the branchiæ by two large venous trunks, in which the branchial veins converge (*e*, *g*, *h*), and transmits it to the ventricle (*d*) through two intermediate canals (*c*), whence it is propelled through the body by the arterial vessels (*n*, *o*, *p*), a vessel of considerable size, passing at once in the adductor muscle for producing the force which is expended in operating the valves. The veins pass directly into the branchiæ (*m*, *n*, *i*, *f*) without the intervention of a sinus, the

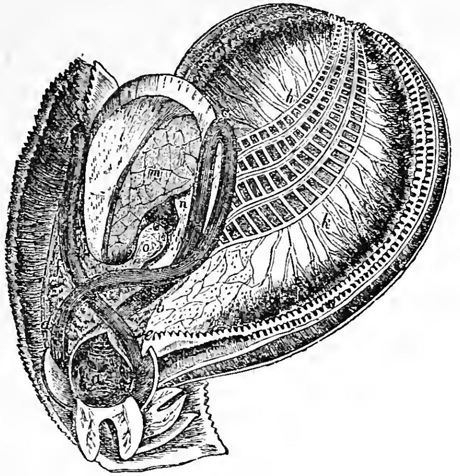


Fig. 162.—Alimentary Canal of the Oyster (*Ostrea edulis*).—Jones. *a*, The stomach laid open ; *d*, the liver ; *b*, *c*, *d*, *f*, convolutions of the intestine ; *g*, anal aperture ; *n*, *o*, auricle and ventricle of the heart ; *l*, *m*, adductor muscle ; *h*, *k*, lobes of the mantle, divided to show the large venous canals at the base of the branchiæ.

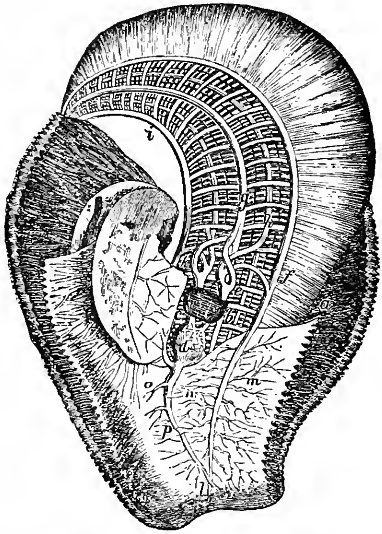


Fig. 163.—Heart and Respiratory System of the Oyster.—Jones. *a*, Portion of the mantle ; *b*, auricle, and *d*, ventricle of the heart ; *m*, *n*, *i*, *f*, veins bringing the blood from the body to the branchiæ ; *e*, *g*, *h*, principal trunks returning the blood from the branchiæ to the heart ; *o*, *p*, *l*, aorta, giving off arteries to the viscera.

action in the branchiæ appearing to be sufficient for the purpose, while the heart aspirates the oxygenated blood and pumps it in the tissues, the adductor muscle getting a large share. While the above description will hold good in all essential points for every family of conchiferous Mollusca, yet important modifications in the structure of the heart and arrangement of the blood-vessels are met with in different genera; most generally in consequence of the increase in size, since this requires more force for operating the valves, with a corresponding increase in the respiratory surface and in cardiac structure. Accordingly, we have *two* auricular cavities, one for each pair of branchial lamellæ, placed symmetrically on the two sides of an elongated fusiform ventricle, into which both auricles empty themselves, while in the forms remarkable for their breadth, *e. g.*, arca, there are not only two auricles, but *two* ventricles likewise, placed *at the base of each pair of gills*, upon opposite sides of the body, *each receiving the blood from the branchiæ to which it belongs*, and propelling it, through vessels common to both hearts, to all parts of the system; and showing conclusively the need of arterialized blood and that the *form* of the respiratory apparatus conditions cardiac development.

In the fishes the heart is carried forward to the base of the skull (Fig. 164, *a*), *for the reason that the oxygenating apparatus is also here, the branchiæ being articulated with the base of the skull.* Hence this phenomenon. And the principle in animal mechanics borne in mind, *that* fact *explains itself.*

The form of the heart varies in the fishes, but may be briefly described as consisting of an auricle and ventricle developed *in the venous system in immediate relation with the branchiæ* (Fig. 165, *a*, *v*, *br*), by means of which the venous blood is pumped in the branchiæ, whence the arterialized blood flows through the aorta (*ad*) to the body-territories; the early foreshadowing of which is seen in terebella (Fig. 158), in which the tubular auricle (*n*) and fusiform heart (*l*), with the great efferent vessel (Fig. 159, *c*, *c*), conveying the arterialized blood from the branchiæ to the body-territories, are archetypal. A momentary glance into the mechanics may not come amiss.

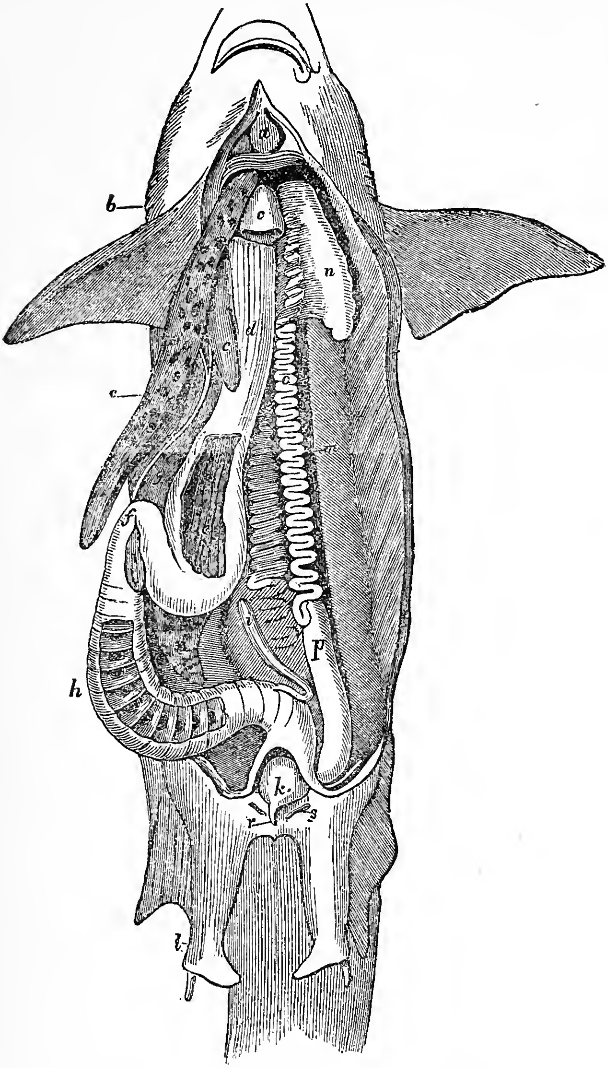


Fig. 164.—Viscera of the Shark, *in situ.* *a*, The heart ; *b*, gill-openings ; *c*, *c*, *c*, lobes of the liver ; *d*, *e*, *f*, *h*, alimentary canal ; *i*, appendage to the intestine ; *g*, biliary duct ; *n*, the testis ; *o*, *p*, vas deferens ; *k*, intromittent organ ; *s*, openings communicating with the peritoneal cavity ; *l*, claspers.—Owen.

For *force* and *speed* of locomotion (the one involving the other), the fishes eclipse all the branchiata ; but since this involves the more rapid oxygenation of the blood, the special arrangements which obtain for effecting it, are at once made intelligible. For this purpose, the respiratory surface is amplified by the formation of branchial leaflets projected from the gill arches (Fig. 166), while the branchial arteries rapidly divide and subdivide until they resolve themselves into microscopic capillaries, pervading every portion of the leaflets, and covered only by a thin tessellated epithelium, so that free interchange of the gases is readily effected between the blood and the water, which is pumped over them by the action in the mouth and opercula, and which is increased and diminished in corre-

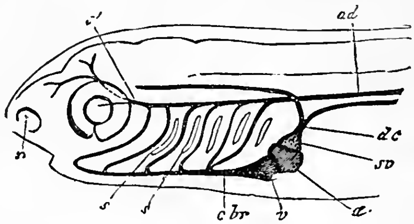


Fig. 165.—Head of an *Embryonic Teleostean*, with the rudiments of the vascular system (diagrammatic).—Gegenbaur. *a*, Auricle ; *v*, ventricle ; *abr*, branchial artery ; *c*, carotid ; *ad*, aorta ; *s*, branchial clefts ; *n*, nasal pit ; *sv*, sinus venosus ; *dc*, ductus Cuvieri.

spondence with the physiological requirements. Now, then, the point to which attention is specially directed concerns the mechanical principle which applies to this pumping action in the mouth and opercula, and the effect it has upon circulation in the fishes, the venous especially. Thus, pressure being uniform, it is obvious that with each expansion in the mouth and opercula for reducing pressure in the branchiæ, should produce afflux of the venous blood in the organs simultaneously with the afflux of fresh water, since pressure is transmitted through and through the body upon all the organs the same as in air-breathers, the fluids flowing from high to low pressure in conformity with universal law ; while during contraction for compelling the respired water out of the organs by increasing pressure, that this should also tend to drive the oxygenated blood into the aorta, since the valves in the pulmonary artery would obviate reflux, the effect being the same as in air-breathers, only there is no auricle or ventricle in the left side for assisting the action.

For evolving the force which is expended in the activities the grand object, of course, is to bring the venous blood into the branchiæ in correspondence with the afflux of fresh water, and, reasoning from analogy, can it be doubted for a single moment but that the heart is coördinated with the branchiæ the same

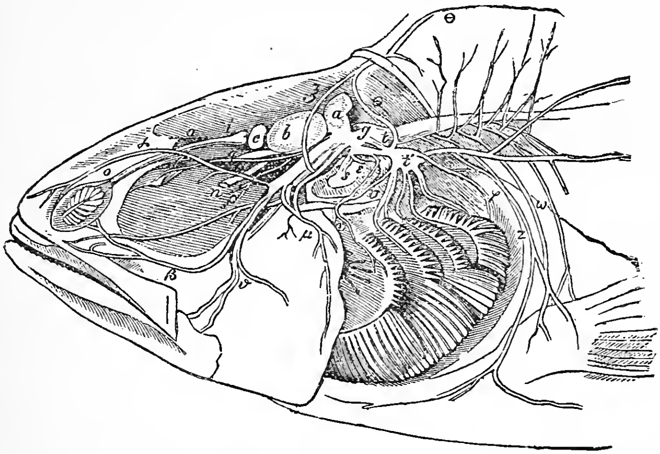


Fig. 166.—Brain and Cerebral Nerves of the Perch (after Cuvier). *a*, The cerebellum; *b*, cerebrum; *c*, olfactory ganglia; *i*, bulbous commencement of the olfactory nerve; *o*, *o*, olfactory nerve, terminating in the nasal capsule; *n*, optic nerve; *p*, *q*, third, fourth, and six pairs of nerves, appropriated, as in Man, to the muscles of the eye-ball; α, ophthalmic branch of the fifth pair; β, superior maxillary branch of ditto; θ, inferior maxillary branch of ditto; μ, opercular branch; ξ, branch of the fifth pair, mounting upwards to join Θ, a branch from the eighth pair, running to supply the dorsal region of the body; *s*, *s*, auditory nerve; *t*, *t′*, nerves belonging to the eighth pair; *w*, *z*, nerves answering to the spinal recurrent.

as in the lungs of the air-breather, the principle being the same. But for correct appreciation of the mechanics it will be necessary to bring out more clearly the action of another force which applies here, and forming, as it were, the foundation of the mechanism; namely, the *density* of the medium, which tends to equilibrate gravitation, at the same time that it increases pressure.

For example, when water is poured out of a vessel in the atmosphere, it rushes with great impetuosity to the ground from the action of gravitation, the atmosphere offering but little obstruction by reason of the rarity of the medium; but when poured in the ocean it is upheld in the surface waters, and the blood being but slightly heavier than water, it follows, that in the case of the fishes the blood needs only to be *guided* to and from the branchiæ by the vessels in order to effect oxygenation, while the pumping action in the head by reason of the high pressure in the body should compel afflux and efflux of the blood in the branchiæ. Hence. the undeveloped condition of the vessels in the fishes, together with the fact that circulation in the tissues is carried on through canalicular spaces under the play of the polar forces, *vis a tergo*, by reason of the absence of a ventricle in the arterial system, being reduced to a minimum. The grand object, as before remarked, is to arterialize the blood, which increases polar force; and for effecting this commensurate with the physiological requirements we have not only the great pumping action in the head, but a more extensive movement (reasoning from analogy) is also taking place—namely, a pumping movement in the abdomen synchronous with respiration for increasing the portal circulation, in order to maintain correspondence between the absorptive processes in the canal and respiration; the same principle applying as in land animals, otherwise a balance could not be maintained.

Then, again, judging from the celerity with which the air-bladders are expanded and contracted, which would involve corresponding movements in the walls of the abdomen for effecting these actions, we may very readily understand how this increase in the portal circulation could be produced.

Last, but not least, the correlation of the nerves in the respiratory centre (Fig. 166, *g*), extending thence over the sides of the abdomen (Fig. 167, 2, 3, 4), plainly indicate how the parts are coördinated with respiration. Nay, not the abdomen only, but the tissues of the entire body as well, since intimate nervous connections bind all the parts to respiration; the fins (*V*, *P*, *A*), tail and all the muscles in the body being intimately connected with the medulla oblongata and respiratory centre by means of the "nervus lateralis" (1, 2, 3, 4), whereby correspondence is readily produced, and respiratory movement made to pulsate through and through the body. Thus, by means of the nerves, the whole is unified with the action in the branchiæ, which should be so, for the very obvious reason that it all relates to the evolution of force, for which respiration is the relative adjustment, compelling the commerce in the organism in the measure of the physiological requirements. The very intimate connection subsisting between respiration and the voluntary movements is forcibly exemplified in the nervous apparatus in fishes. For example, the eighth pair undergoes development in proportion to *the size* and *extent* of the *branchial surface*, at the same time sending branches to the viscera; while externally it projects the great lateral branches to the dorsal and ventral regions (Fig. 167, 1, 2, 3, 4), which connect with the spinal nerves by means of the dorsal and ventral roots (Fig. 168, *a*, *v*). In other words, the dorsal root of the spinal nerves sends a filament upward (*a*), which joins a ventral filament (*b*) from the preceding nerve, forming the "ramus dorsalis," and sends two filaments downward (*c*), which unite together to form the "ramus ventralis," each of which joins the eighth pair, thus connecting and unifying the actions throughout with respiration. This, together with the fifth pair (connected with mouth and opercula), send out similar branches to the muscular envelope.

How otherwise explain these comprehensive nervous combinations and the great development of the pneumogastric nerves?

The following, from the painstaking, indefatigable and venerable Owen (now in the nineties), will serve to show how intimately every portion of the body in the fishes is connected with the respiratory centre:

"The vagus (Fig. 166, *t t'*) has a development proportional to the extent and complexity of the branchial or respiratory apparatus, and is usually larger than the trigeminal; it rises from the restiform tract forming the side of the medulla oblongata, and commonly from a specially developed lobe, and is distributed to the branchial apparatus, the pharynx and pharyngeal arches, the œsophagus and stomach; it sends filaments to the heart, and to the air-bladder when this exists, and it forms, or helps to form, the 'nervus lateralis' (Fig.

167). A branch of the vagus ascends forward to join the fifth in forming the dorsal division (2) of the 'nervus lateralis,' which escapes by a foramen in the parietal bone; the rest of the fifth emerges from the skull by a hole (carp) or a notch (cod) of the alisphenoid. The lateral nerve in the cod is formed chiefly by the fifth, and receives only a slender filament of the vagus. In the carp, the vagus chiefly forms the lateral nerve. In the cod, the lateral nerve first sends off a branch (1). which runs along the sides of the interneural spines, receiving branches from all the spinal nerves; it then curves down along the scapular arch, gives branches to the pectoral (*p*) and ventral (*v*) fins, supplies the great lateral muscular masses (2), and the mucous canal (3), and sends a nerve (4), to the interhæmal spines, which communicates with filaments from the corresponding spinal nerves; both interneural and interhæmal branches terminate in the plexus supplying the caudal fin; thus all the locomotive members are associated in action by means of the nervi laterales. . . . In the carp and herring, the vagal 'ramus lateralis' sends off a strong branch to the dorsal fin; in the garpike, it sends, as in the cod, branches to the pectoral and ventral fins; it distributes other branches to the skin and mucous ducts; and some of these, in most fishes, anastomose with branches of the spinal nerves (Fig. 167).* In the perch, there are two 'nervi laterales,' above described, and the proper lateral nerve; this is formed exclusively in the vagus, and divides into a superficial branch, supplying the lateral line, and a deep-seated branch, communicating with the spinal nerves, and supplying the myocommatal aponeuroses and the skin. . . . The vagus sends branches to the head and opercula branches to the gill-covers. The usually double roots of the nervus vagus pass out, in most fishes, by a single foramen in the occipital bone. The fore part of the root is the largest, and is ganglionic; it is the true pneumogastric nerve, supplying the gills, pharynx, heart and stomach, and sending filaments to the

* Comparative Anatomy and Physiology of Vertebrates, Vol. I., Fishes and Reptiles, pp. 303–309, by Richard Owen, F. R. S., Superintendent of the Natural History Department of the British Museum; Foreign Associate of the Institute of France, etc.

septum dividing the branchial from the abdominal cavity. . . . Each vagal nerve of the sturgeon equals the spinal cord in size, and rises by numerous roots. . . .

"The peculiar combination of the dorsal and ventral roots of the spinal nerves in osseous fishes is well seen in the cod. The dorsal root sends a filament (Fig. 168, *a*) upward, which joins a ventral filament (*b*), from the preceding nerve, and forms the ramus dorsalis (*d*); the dorsal root sends two filaments (*c*) downward, which unite together, and with a ventral filament (*e*) of the same nerve to form the 'ramus ventralis' (*v*). The filament of the ventral root sent to the ramus dorsalis of the succeeding nerve perforates the lower division of the dorsal root of its own nerve. Thus, each spinal nerve forms a 'ramus dorsalis' (Fig. 167, 10), and a 'ramus ventralis' (8); the ramus dorsalis includes a sensory filament of its own nerve, and a motor filament of the antecedent nerve; the 'ramus ventralis' is formed by a motory and a sensory filament of its own nerve; both rami 'ventrales' and 'dorsales' are associated together, and with the vagal and trigeminal nerves through the medium of the great 'nervus lateralis'" (Figs. 167, 1, 8). It will thus be seen that the entire body of the fish is intimately connected with the medulla oblongata and respiratory centre for unifying the action with respiration, the branchial apparatus, heart and viscera being alike included, to the end, that force may be evolved in the measure of the physiological requirements, for maintaining a balance in the organism; otherwise impossible.

Finally, and looking from these extensive connections subsisting between the respiratory centre and the body-tissues for compelling correspondence to the little force pump in the venous system at the base of the skull in immediate relation with the branchiæ (Fig. 164, *a*), can it be doubted for a single moment but that the entire mechanics is based upon respiration for pumping the commerce in the organism commensurate with the physiological requirements, while the heart assists in the action by increasing circulation of the blood in the branchiæ for bringing this in correspondence with the water flowing through the organs, produced by the great pumping action in the mouth and opercula but involving the

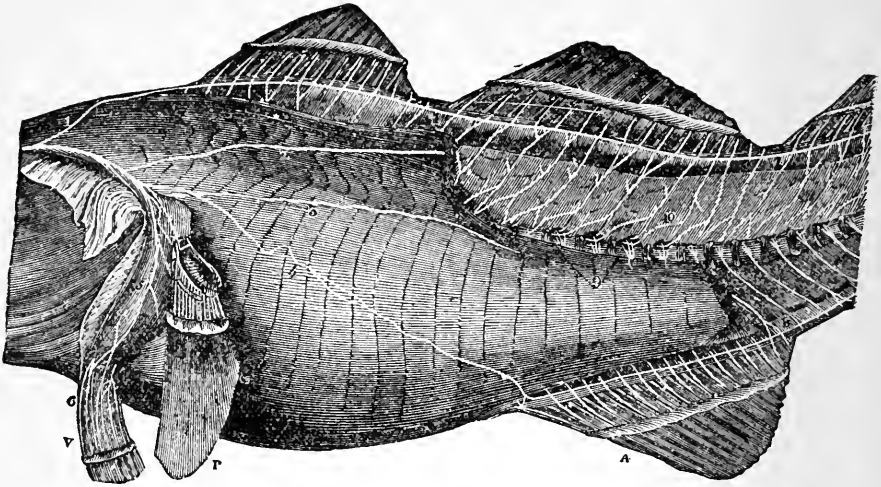


Fig. 167.—Nerves to the Cod (*Gadus Morrhua*) ; reduced.—Illustrations of the Comparative Anatomy of the Nervous System, 4to. 1835. By Joseph Swan. 1, 2, 3, 4, "Nervi laterales," formed by the union of the fifth and eighth pairs, showing how they connect with the "rami ventrales" and "rami dorsales" of the spinal nerves, so as to unify the parts with the medulla oblongata and respiratory centre ; *v*, ventral fin, showing the nerves (5, 6) running into it from the "nervus lateralis ;" *P*, pectoral fin, similarly supplied ; *A*, tail fin, showing source of nervous supply ; 10, "ramus dorsalis ;" 8, "ramus ventralis ;" 9, roots of ramus dorsalis and ramus ventralis, the whole connecting with the respiratory centre.

Fig. 168.—Connection of Spinal and Lateral Nerves, Cod.—*Ib.* *a*, *b*, Roots of ramus dorsalis ; *d*, ramus dorsalis ; *v*, "ramus ventralis ;" *c*, *c*, roots of ramus ventralis.

entire organism? Taking all this into consideration, then, together with the innumerable local actions which are increased and diminished upon occasion, the statement that "the heart is the force in the circulation is too absurd to be seriously entertained." *Nicht zu glauben.* The heart has enough to do filling the rôle in *its* functions, and there is no occasion for despoiling the vast autonomy in the tissues in order to make it appear marvelous, for it is not more so than the other organs, each doing its *own* special work in the vital drama for which *it* alone is capable, while all of life is marvelous and passing strange, a mystery of mysteries.

In the eel, the branchiæ are of loose texture and very vascular, bleeding freely when even gently rubbed between the fingers, the capillaries which cover the surface in a dense plexus breaking readily under the friction; whereas, in fishes, the organs are of dense texture and can endure an amount of rude force without bleeding; nay, have to be torn in order to make them bleed. Then, too, the organs are inclosed in a buccal pouch, which is filled through the oral orifice, and emptied through a small external opening, controlled by muscles in front of the head fin; so that when the animal respires, he can retain the fluid (air or water, as the case may be) till completely exhausted of the oxygen, then discharging it through the sinuous gill-opening. In fishes, however, the matter is different, the gills being freely exposed to the outside water by means of the wide opercula which simply cover them, and when expanded the water rushes through the organs in two directions, or through the gill-opening as well as the mouth, but more by way of the gill-opening, all the water escaping, however, in this direction when the opercula are contracted, while the action is much more rapid than in the eel. Now, then, this respiratory arrangement in the eel enables the animal to respire air as well as water, each inspiratory effort filling and distending the buccal chamber, causing it to form a large protuberance upon either side of the head, which gradually collapse again as the air is slowly discharged through the small gill-openings, when they are again inflated by inspiratory effort, doing this several times in a minute. And by thus respiring air, the animal is enabled to sustain its life from six to eight days out of water,* so that the animal can go to distant waters overland in the night-time, perhaps, for I am not aware that he has ever been caught at it. Still, there can be but little doubt of the fact, as eels make their appearance in isolated waters. At any rate, he is certainly amphibious. But this is not the route metamorphosis takes in lung development, for the lungs are not at the base of the skull, but in the common visceral cavity in amphibia and all air-breathers,† and which is necessary for affording protection to the delicate capillary network, at the same time compelling absorption and excretion of the gases, the lighter media of the atmosphere calling for this, that force may be invoked for compelling the gases through the membranes commensurate with the physiological requirements. The organ which is the seat of the changes for effecting these objects is the air-bladder in the fishes, which undergoes progressive metamorphosis, becoming more and more vascular, dividing and sub-dividing for increasing surface till all is complete in the mammalia.

In the transformations in Polypterus, as in Lepidosiren, the ductus pneumaticus, which is continued from the fore part of the posterior division of the air-bladder and opens into the ventral part of the beginning of the œsophagus, is converted into the trachea, with which it is homologous, while the bladders undergo division and sub-division by longitudinal and transverse septa into cells, the work of division for increasing the vascular surface being carried through the higher fishes to lepidosiren, thence by amphibia, reptilia and birds to the mammalia, in which lung-development is complete.

The duct presents great variety in length, diameter and place of communication with the alimentary canal. In the

* I kept a large fresh-water eel in a tub containing a thin stratum of water, or sufficient only to cover the bottom, to enable the animal to keep himself moist, but not to respire, for seven days; and while he ceased to move about, life was not extinct; but I finished it, deeming the experiment sufficient for the purpose.

† The intervention of a diaphragm for separating the viscera in the abdomen from the viscera in the chest, as occurs in mammalia, has already been explained (pp. 84–92, 185–196).

herring, for example, the posterior third of the long, fusiform air-bladder (Fig. 148, *k*, *l*) is connected with the attenuated end of the cardiac division of the stomach. The long, narrow and flexuous ductus pneumaticus is continued from the fore part of the posterior division of the air-bladder in the Cyprinoids, and opens into the dorsal part of the œsophagus (Fig. 147, *su*); the short, straight and wide ductus pneumaticus in the Lepidosteus opens also into the dorsal part of the œsophagus, the orifice being served by a sphincter; in the *Erythrinus*, the air-duct communicates with the side of the œsophagus; in *Polypterus*, as in *Lepidosiren*, with the under or ventral part of the beginning of the œsophagus.

"Under all its diversities of structure and function, the homology of the swim-bladder with the lungs is clearly traceable; and finally, in those orders of fishes which lead more directly to the reptilia, as, for example, the salamandroid *Ganoidei* and *Protopteri*, those further modifications are superinduced upon the air-bladder, by which it becomes also analogous in function to the lungs of the air-breathing Amphibia.

"The *Lepidosiren annectens* inhabits a part of the river Gambia, which in the rainy season overflows extensive tracts, that are again left dry in the dry season. Those which do not follow the retreating waters escape from the scorching rays of the African sun by burrowing in the mud, which is soon baked hard above them; but they maintain a communication with the air by a small aperture, and, coiling themselves up in their cool chamber, clothe themselves by a layer of thick mucous secretion, and await, in a torpid state, the return of the rains and the overflowing of the mud-banks. The advent of their proper element wakes them into activity: they then emerge from the softened mud, swim briskly about, feed voraciously, and propagate.

"The peculiar modifications of the gills and air-bladder of the Lepidosiren are precisely those which adapt them to the peculiar conditions of their existence. In the inactive state into which they are thrown by their false position as terrestrial animals, the circulation, which would have been liable to be stopped had all the branchial arteries developed gills, as in normal fishes, is carried on through the two persistent primitive vascular channels. Whatever amount of respiration was requisite to maintain life during the dry months is effected in the pulmonary air-bladders ; its short and wide duct or trachea, the œsophageal orifice of which is kept open by a laryngeal cartilage, introduces the air directly into the bladders ; the blood transmitted through the branchial arches to the pulmonary arteries is distributed by their ramifications over the cellular surface of the air-bladders, and is returned arterialized by the pulmonary veins. A mixed venous and arterial blood is thence distributed to the system, and again to the air-bladders. True arterial blood exists only in the pulmonary veins, and unmixed venous blood only in the system of the venæ cavæ ; whence the necessity, apparently, for that peculiar arrangement by which the arterial blood is conveyed directly to the ventricle by the pulmonary vein. When the Lepidosiren resumes its true position as a fish, the branchial circulation is vigorously resumed, a larger proportion of arterialized blood enters the aorta, and both the nervous and muscular systems receive the additional stimulus and support requisite for the maintenance of their energetic actions" (Owen).

And that this is the true genesis of the lungs is fully proven by the following incontrovertible facts, namely :

1. In Batrachia this condition of double-breathing is seen only in the immature animal, or tadpole, which in passing through the consecutive changes rids itself of the branchiæ and tail ; also involving important correlated changes in other organs, notably, heart, lungs, vascular system, etc.

2. In embryogenesis of warm-blooded animals, in which the whole thing repeats itself, the lungs is but a differentiated *diverticulum* of the intestinal canal, the same as the air-bladder, the point of in-folding of the membranous layers so as to form the trachea and lungs being at the anterior and upper end of the gullet, corresponding with the pneumatic duct and air-bladder in the higher fishes, *Lepidosiren*, *Axolotl*, Batrachia and all reptilia. Furthermore, the pulmonic, vascular and cardiac changes are easily traceable through all the subsequent changes which occur In the Axolotl (Fig. 169), in which the respiratory and circulatory organs are substantially the same as in the tadpole, we have, for example, the

fourth pair of branchial arches (*b*) continued on into the air-bladders or nascent lungs, the upper three passing, as usual, into the long fibriated branchiæ projecting from the sides of the head; the pulmonary veins, one for either side, returning the blood to the small left auricle inclosed in the walls of the large right auricle, as there is no projection externally indicating its existence (which at first led to the impression that but one auricle existed in the double-breathers or perennibranchiata amphibious); the branchiæ gradually become diminished in size, the vessels, of course, shrinking in proportion, while the lungs are progressively more and more developed, the pulmonary artery and vein expanding in proportion, till at last we have all the vascular, pulmonic and cardiac changes that obtain in the frog (Fig. 170). The branchial arches are absorbed in proportion as the circulation becomes modified, their atrophy depending upon the changes which take place in the course of the blood, owing to the dilatation of the anastomotic vessels and enlargement of the pulmonary artery. In *Lepidosiren*, which is the lowest of the perennibranchiates, the heart resembles that of a fish, consisting of a single auricle, ventricle and bulbus arteriosus. The vena cava, bringing the vitiated blood from the system, terminates at once in the auricle, while the pulmonary vein passes along as far as the auriculo-ventricular opening, where it empties its contents *into* the *ventricle* by a distinct orifice, guarded by a cartilaginous valvular tubercle (Owen).

The following brief summary by Owen* indicates the cardiac changes in the amphibia:

"The distinction of the pulmonary from the systemic auricle, first observed in Siren, has been since determined in *Menobranchus*,† *Axolotes*, ‡ *Amphiuma*, § and *Menopoma*. In *Proteus*, in which some of the blood of the puny lungs is conveyed to systemic veins, the auricular septum is not complete, according to Hurd. ‖ In *Amphiuma*, the auricle is smaller and less

* Ibid., pp. 506–507.

† Meyer. Analekten für Vergleichende Anatomie, 4to, p. 73. 1835.

‡ Calori. Sull' Anatomia dell' Axolotis Commentario, 4to, p. 45.

§ Ibid., p. 215.

‖ John Hunter. On the Blood and Inflammation. 4to, p. 258. 1794.

fimbriated than in *Siren*. The ventricle is similarly connected to the pericardium by the apex, as well as by the artery. This forms a half-spiral turn at its origin, and dilates into a broader and shorter bulb than in *siren*. In *Menopoma*, they are still more reduced in size, and lie, as in *Salamandra** (Fig. 171, *a*), when undistended, to the left of the ventricle; their outer surface,

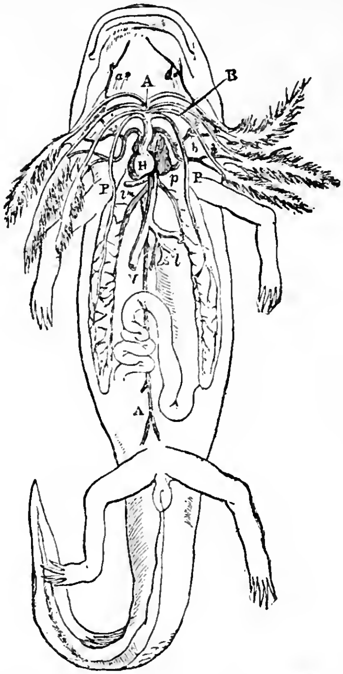


Fig. 169.—Respiratory and Circulatory Organs in Proteus Mexicanus (Axolotl).—Cyclopædia of Anatomy, Art. Respiration (Supplement). Allen Thomson. *A*, *truncus arteriosus*; *B*, the three upper pairs of branchial arteries; *P*, *P*, the lower pair proceeding to the lungs or pulmonic arteries; *b*, branchial veins; *v*, pulmonary veins; *V*, vena cava; *l*, hepatic vein; *H*, ventricle of the heart, surmounted by the large right auricle.

as in *Menobranchus*, is entire. The ventricle is of a flattened, triangular form; its cavity is occupied by the loose, fasciculate muscular structure, through which the blood filters, as through a sponge, from the small contiguous auricular apertures, each of which has a simple valve, to the 'ostium arteriosum.'

* Owen, Fig. 333.

The artery inclines, with a slight twist, to the left, and swells into a spherical bulb. The valves are confined to the narrower part, and are in two transverse rows, four in each row, each valve of a conical shape, pointing forward.* The first row is just above the ostium; the second is half-way between this and the bulb.

"The *pulmonic auricle augments in size* with the *more exclusive share taken by the lungs in respiration;* but the auricular part of the heart shows hardly any *outward sign* of its division in batrachians. It is small, smooth, and situated to the left, and in advance of the ventricle, in newts and salamanders (Fig. 171).

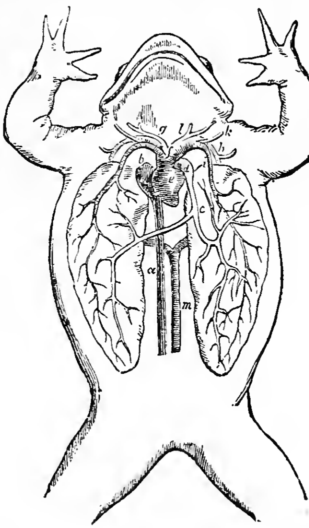


Fig. 170.—Respiratory and Circulatory Organs in the Frog, showing increase in pulmonic and cardiac development.—Williams. *a*, Vena cava; *b*, right auricle; *c*, pulmonary veins; *d*, sinus; *i*, left auricle; *e*, ventricle; *f*, *Truncus arteriosus;* *g*, right carotid artery; *k*, left carotid; *h*, vessel to anterior extremity *l*, vessels to mandibular region and face; *m*, abdominal aorta, formed by the junction of the two aortæ.

"In frogs and toads, the auricle is applied to the base of the ventricle, and to the back and side of the aorta and its bulb. The ventricle, usually of a more rounded form, is occupied by

* Catalogue of the Physiological Series in the Museum of the Royal College of Surgeons. 4to, 5 vols. 1832–1840. Second ed., Vol. I., 1852. Richard Owen.

the muscular fasciculi, except at a small part between the auriculo-ventricular and aortal orifices. The bulbus arteriosus is incompletely divided by opposite longitudinal folds, the margins of which meet, but remain free." Italics are added.

It will thus be seen that there is increasing differentiation in the cardiac chambers coincident with lung development, in the development of a left auricle especially, which comes into existence only in connection with lung elaboration, and as necessary to it for receiving and transmitting the aërated blood to the systemic vessels or aortæ for distributing it through the body; while with increasing differentiation in the lungs with progress in development a left ventricle also, by segmentation or division of the common ventricle by means of a membranous partition, which is gradually differentiated from the walls so as to form the left ventricle, into which the left auricle discharges its blood, thereby completely isolating the blood coming from the pulmonic capillaries from the venous blood coming into the right side of the heart, sending it out through the aortal system, which now communicates with the left ventricular chamber only; while the differentiation of this partition-wall is also easily traceable, being perfected in crocodilia, only that there is left a communication between the aortæ above the heart, which subserves useful purpose during periods of long submergence, allowing the venous blood to pass from the left to the right aorta. Of this more, further on.

The following from the greatest of living naturalists, perhaps, completes the description of the cardiac and vascular changes in perennibranchiates and batrachians :*

"The heart presents two auricles, a single ventricle and a *bulbus arteriosus*. A venous sinus, the walls of which are rhythmically contractile, receives the venous blood from the body, and opens into the right auricle. In *Proteus*, *Menobranchus and Siren*, the septum of the auricles is less complete than in the other *Amphibia*. The left auricle is much smaller than the right, and a single pulmonary vein opens into it. The interior of the ventricle is more like a sponge than a

* Anatomy of Vertebrate Animals. By Thomas H. Huxley, LL.D., F. R. S., author of "Lay Sermons," "Man's Place in Nature," "Origin of Species," etc., etc.

chamber with well-defined parietes. The walls of the long bulbus arteriosus contain striated muscular fibres, and are rhythmically contractile. Valves are sometimes placed at each end of it, and it may be imperfectly divided into two cavities by an incomplete longitudinal partition. It terminates, upon each side, in either three or four trunks, which ascend upon the branchial arches. The most anterior of these trunks give off the carotid arteries, the most posterior the pulmonary arteries, and arteries to the integument; the middle trunks form the principal roots of the dorsal aorta.

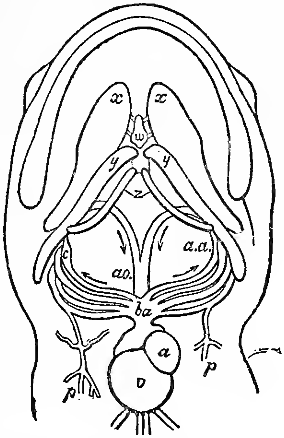


Fig. 171.—Vascular System and Hyo-Branchial Apparatus, Salamander.

"In *Proteus*, where there are three branchial arches, the bulb of the aorta splits into two trunks; each of these divides at first into two branches, and then the posterior branch, on each side, again subdivides into two others. Thus, three pairs of aortic trunks are formed, which ascend upon the branchial arches. The two anterior pairs of aortic trunks pass directly into the roots of the dorsal aorta, but each gives off a vessel which enters one of the external gills, the blood from which is brought by an efferent canal into a higher part of the same aortic arch. The third aortic trunk, on each side, is interrupted, its lower part becoming the branchial artery of a gill-tuft. The blood is carried out of this branchia by a venous trunk, which opens into the root of the dorsal aorta, and is, in reality, merely the upper part of the third aortic trunk. The facts may be expressed in another way, by saying that the bases of the branchial artery and vein anastomose in the first two gills, but not in the third.

"The adult Axolotl (*Siredon*) has four pairs of aortic trunks; the hindermost pair gives off the pulmonary arteries, the three next supply the external branchiæ, and the anterior trunk passes above into an artery which divides into hyoidean and carotid branches.

"In *Salamandra* there are four pairs of aortic trunks in the adult, but the upper moiety of the first, on each side, is obliterated, and remains as a mere *ductus Botalli.* The fourth trunk gives off the pulmonary artery; some twigs for the œsophagus and a few cardiac branches next arise from it; and it then unites with the second and third to form the root of the dorsal aorta. The basal moiety of the first trunk enlarges at its extremity, close to the angle of the mandible, into a spongy organ, the *carotid gland*, from which the carotid artery, and that for the supply of the hyoidean and oral regions, are given off.

"In the adult frog, the aortic bulb is separated by an incomplete longitudinal septum into two passages, and, at its extremity, divides into two trunks, each of which is partitioned internally into three passages. The middle, or *systemic*, passage passes directly into a trunk, which unites with its fellow beneath the spinal column into the dorsal aorta. The anterior, or *carotid*, passage ends, as in *Salamandra*, in a carotid gland and *ductus Botalli;* carotid, hyoidean and oral branches being given off from the former. The hindermost, or *pulmo-cutaneous*, passage ends in the pulmonary and the cutaneous arteries, the anastomoses of these with the roots of the dorsal aorta being obliterated. The middle pair of aortic trunks thus exclusively constitute the origins of the dorsal aorta, and are the *permanent aortic arches.* The right aortic arch is wider than the left, especially toward their junction; as the left gives off, just before this point, a large cœliaco-mesenteric artery to the abdominal viscera. Each aortic arch gives off the subclavian and vertebral arteries of its side. Only venous blood passes into the pulmonary arteries of a frog; while mixed blood enters the aortic arches, and is of a brighter arterial hue at the end than at the beginning of the systole The blood in the carotid passages is always bright. The mechanical arrangements by which this is brought about have been beautifully analyzed by Brücke, who shows, first, that the spongy interior of the ventricle contains, in its base, a transversely-elongated cavity, into which the auricles open, and which, by its right extremity, communicates with the ventricular opening of the aortic bulb; secondly, that the aortic bulb is imperfectly divided by a longitudinal septum, the upper left edge of which is attached, while its lower right edge is free; thirdly, that of the two passages into which the aortic bulb is thus divided, the one on the right side of the septum ends in a chamber, in which the carotid and systemic passages commence, while that on the left side similarly leads to the entrance to the pulmo-cutaneous passages; fourthly, that the carotid gland, in which the carotid passage ends, presents a mechanical obstacle to the flow of the blood through it; fifthly, that there is a valvular fold open toward the heart, in each systemic passage, which also offers a certain amount of mechanical resistance to the blood; and, sixthly, that after the blood has begun to flow through the bulb, it will gradually force the septum over to the left side, and so impede the flow into the pulmo-cutaneous passage.

"Thus, when the auricular systole takes place, the right auricle sends its venous blood into that division of the ventricular cavity which lies nearest the opening of the bulb; and when the ventricle contracts, the blood first driven into the bulb is wholly venous. This blood fills the passages on both sides of the septum, but finds a very much greater resistance to its exit on the right than on the left side. It therefore flows, at first, exclusively into the left division, and makes its way through the short pulmonary arteries into the lungs. But, as the pulmonary vessels fill, the pressure on the two sides of the septum becomes equalized, and the systemic passages, which offer the next least resistance, fill with blood, which is now mixed, as it comes from the middle of the ventricle Next, the septum, being driven over to the left side, prevents any more blood from going into the pulmo-cutaneous passage. At the end of the systole, the blood driven out by the ventricle is almost wholly that of the left auricle; and, by this time, the resistance in the systemic is as great as that in the carotid passages. Hence, the latter fill and send arterialized blood to the head.

"The organs of respiration of the *Amphibia*, in the adult state, are either external branchiæ, combined with lungs, as in the perennibranchiate *Urodela;* or lungs only, as in the other *Urodela*, the *Batrachia*, the *Gymnophiona*, and, probably, the majority of the *Labyrinthodonta.*

"In the perennibranchiate *Urodela*, the branchial arches (or some of them) are separated by open clefts (the number of which varies from four to two), throughout life, and three branched gills are continued by single stems into the integument, at the dorsal ends of the branchial arches. An opercular fold of the integument, in front of the gill-clefts, attains a considerable size in *Siredon*, but does not cover the gills. The branchial arches themselves bear no branchial filaments. Other *Urodela* are devoid of external gills, but (as is the case in *Menopoma* and *Amphiuma*) present one or two small gill-clefts on each side of the neck, and are thence called *Derotremata.* The rest of the *Urodela*, and all the *Batrachia* and *Gymnophiona*, are devoid of both external gills and gill-clefts, in the adult state.

"In all the *Amphibia*, a glottis, placed on the ventral wall of the œsophagus, opens into a short laryngo-tracheal chamber with which two pulmonary sacs are connected, either directly or by the intermediation of bronchi (as in the *Aglossa*), or by a trachea (as in the *Gymnophiona*). The walls of the pulmonary sacs are more or less sacculated. In most *Amphibia* the lungs are equal in size; but in the snake-like *Gymnophiona* the right is much smaller than the left. In *Proteus*, the pulmonary blood is not all returned to the heart, some of it entering the veins of the trunk. Aërial respiration is effected, in the *Amphibia*, by pumping the air from the oral cavity into the lungs. To this end the mouth is kept shut, and ingress and egress to the air is given by the nasal passages, which always open immediately behind the vomers, at the anterior part of the roof of the mouth. These passages being open; and the hyoidean apparatus depressed, the air fills the cavity of the mouth. The external nostrils are then shut, and, the hyoidean apparatus being raised, the air is forced, through the open glottis, into the lungs."

Professor Huxley, in common with all naturalists, conceives that the frog respires only by pumping the air into the lungs by means of the throat-apparatus, that action of which is very conspicuous; and while it undoubtedly is of great assistance, that it is not fundamental in respiration I have fully demonstrated by physiological experiment (pp. 61–68). In *chelonia*, however, for special reasons that obtain in them, it is substantially but not entirely correct, and since it has direct bearing upon cardiac development, we shall proceed to consider it somewhat at length, bringing out the special circumstances in the anatomy of the animal for throwing light upon its mode of respiration. We have seen that the lungs and body-envelope expand and contract together or simultaneously, regularly and rhythmically, in order to produce afflux and efflux of the fluids in the alveolar chambers for respiratory purposes, and must do so in the very nature of things, and it remains to explain the exceptional conditions which obtain in *chelonia*, and how respiration and circulation are compelled to be in correspondence with the activities, notwithstanding the seeming drawbacks and apparent obstacles. In the first place, we have to note the house-like body formed by the carapace (above) and plastron (below) (Fig. 172), containing the viscera, but with openings anteriorly and posteriorly for the head and extremities, which work out-and-in the excavation during extension and retraction, thereby producing corresponding changes of pressure in the cavity and lungs during locomotion; and the more rapid this is made, the more effective it should be. By reason of the unyielding floor of support to the viscera in the plastron, expansion is impossible in this direction, so that the animal gains nothing from the action of gravitation, as in the other animals, but ample arrangements obtain nevertheless for compelling respiration to be in correspondence with the activities; otherwise these could not for obvious reasons be produced. And by first extending, then retracting, the extremities by means of the special muscles which have their points of origin toward the central portions of the floor or plastron, scapular and pelvic bones (Figs. 172, 192), corresponding increase and diminution of the visceral area are made inevitable. But to this again must be added the action in the special muscles which apply for effecting changes of pressure in the lungs, notably: 1. The transversus abdominis (Fig. 172, 41), and obliquus abdominis (40) (one for either side), which are homologous with those in the higher animals, closing in the posterior end upon the sides, the muscles of the posterior extremities with their points of origin toward the central portions of the carapace (45, 95, 99, 103, 56, 101, 48, etc.), closing the intervening portions; while anteriorly we have the muscles of the scapulæ and anterior extremities, together with the diaphragmaticus (42), serratus magnus (57), closing in the antero-lateral regions, the head and cervical muscles the intervening portions. Now, then, in order to study the action in these muscles for determining which are the more effective in respiration, the anterior or posterior, we must place the animal in a vessel of water and note the respirations and the effect they produce. For example, when the animal is floating lazily upon the water, the limbs projecting out to the full extent, over the edge of the plastron, the head and tail also extended, it will be seen that the top of the carapace projecting partially above the water, will every now and then leap suddenly upward, then settle down again as suddenly to the former level, and if at the same time the "flanks" be observed, they will be seen to project with the former and to retract with the latter, showing conclusively respiratory movement; the former corresponding with inspiration, the latter with expiration, of which there can be no doubt, since the effect of the one is to increase the amount of air in the lungs, the other to diminish it; the one causing the upward, the other the downward movement, from the diminution and augmentation in body-density; otherwise is inexplicable.

Furthermore, these muscles in the flanks are incurvated inward, projecting into the excavation like the diaphragm in the chest-excavation, the convexity toward the lungs; hence, when they contract, tend to pull away from the lungs, thereby reducing pressure in the excavation the same as in the other case, the air rushing into the locality simultaneously to equalize pressure, the lungs, of course, acting in concert with the respiratory muscles as with the diaphragm. As will be seen, the lungs (Fig. 173, *z*, *z*) are very large, covering the entire viscera upon the dorsal surface; and while numerous longitudinal and transverse septa divide and subdivide the interior (Fig. 174), the chambers are comparatively large and freely communicate with each other and the primitive division of the trachea (*a*), the bristles indicating this circumstance; they are not bound down or fastened by the lining membrane so as to limit the action, but are free to move, gliding readily to and fro upon the viscera in respiration, expand-

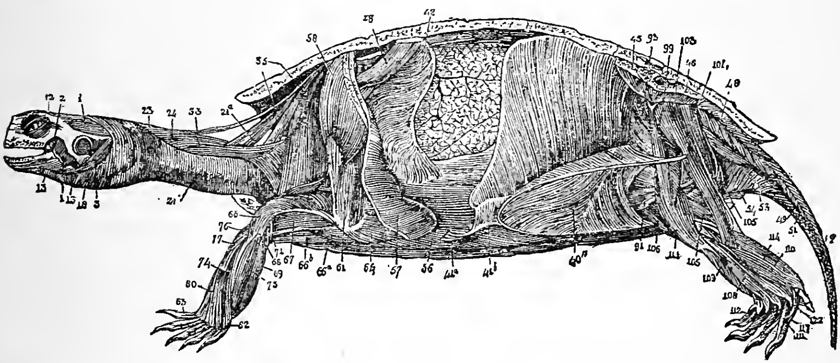


Fig. 172.—Showing the Myology of the Tortoise (*Emys Europæa*), with the special muscles relating to respiration.—Bojanus. Anatome Testudinis Europæa. Fol. 1819–1821. 41, *Transversus abdominis;* 40″, *obliquus abdominis;* 42, *diaphragmaticus;* 57, *serratus magnus.*

ing laterally as well as longitudinally, the copious secretions in the parts enabling this action, as also the actions appertaining to the viscera themselves in connection with their special functions, or the same as obtains in warm-blooded animals. Finally, for effecting coördination with respiration, we have the nerves proceeding to the several parts from the spinal medulla (Fig. 192), inclusive of the heart and vessels, all the parts being fully coördinated for producing a balance in force, the same as in all the animals, and must be so, in the nature of things; the thoracic duct (*c*) coursing upon the aortæ to reach the chyle receptacles (*b*, *b*) and veins at the root of the neck being alike included, so that when the animal locomotes, nervous force throbs over all the structures for increasing circulation correspondingly for maintaining a balance in the organism; otherwise impossible.

This gives us the respiratory action. Now, then, in regard to the throat-apparatus and the special rôle it performs in respiration, the importance of which it would be difficult to

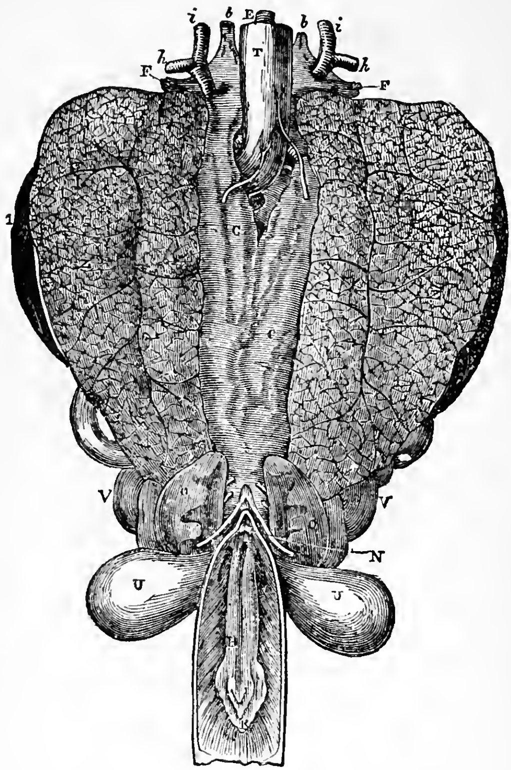


Fig. 173.—The Viscera in the Tortoise (*Emys Europœa*), as viewed from above.—Bojanus. *Z*, *Z*, lungs; *I*, liver; *7*, œsophagus; *E*, trachea; *F*, *F*, axillary arteries; *b*, chyle receptacle at the root of the neck, one for either side; *i*, jugular vein; *h*, brachial vein; *N*, urinary bladder; *o*, kidney; *H*, urethra; *V*, *V*, intestines; *U*, *U*, anal bursæ; *C*, thoracic duct.

overestimate, being essential to life. Briefly, it consists as follows: The body of the hyoid bone projects from its sides three pairs of long, curved, rib-like processes (Fig. 192, *d*), which are operated by muscles connecting with the mandible and base of the skull, similar to what obtains in the frog, but much more powerful, the whole inclosed by the muscular sheath (*latissi-*

mus colli (Fig. 172, 21, 25) expanded over it, connecting with the mandible and base of the skull, imparting the rotund appearance and fullness upon the sides and inferior aspects, the underlying hyoid-framework pushing out the soft structures. As in the frog, the pumping action is very rapid, and goes

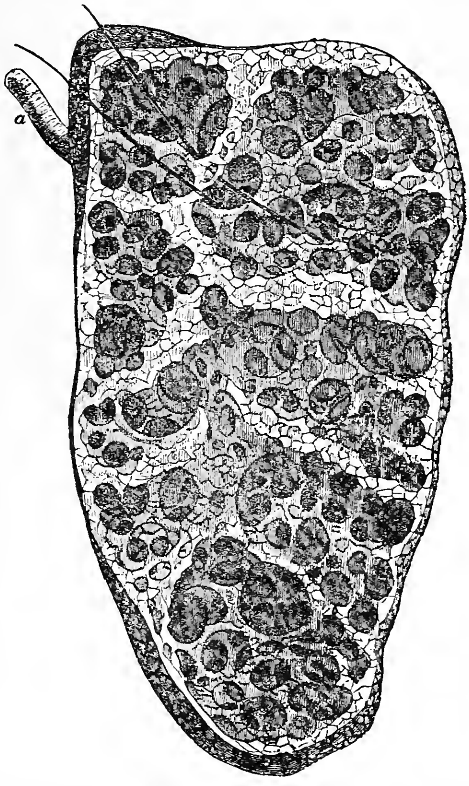


Fig. 174.—Lung of a Tortoise (*Emys Europœa*).—Bojanus. The bristles indicate the free passage of air through the lung structure, the chambers all freely communicating with each other and the trachea (*a*), or bronchus.

on all the while, in the water as well as out of it, which led John Hunter to infer that it does not relate to respiration, which, in view of the extraordinary acuteness of perception which characterized that grand pioneer in natural history, is a little remarkable, and explicable upon the ground simply that he was not guided by this fundamental law underlying animal structure and function, but seeking out the history in development itself; performing enormous labors with a singleness of purpose and devotion to make him memorable as long as reason lives and noble deeds are exemplars for men. The tortoise, as well as the frog, when it goes beneath the water, must bottle up air in the lungs and air-passages by means of the lingual valve applied to the posterior nares, pumping it backward and forward in the lungs till the oxygen is consumed (p. 66), when it must return to the surface for a fresh supply. Being an air-breather, it is necessarily compelled to this course, taking a fresh supply down with it every time it goes. All of which is easily understood.

Now, then, in order to ascertain the relative amount of work the apparatus performs in respiration, I had recourse to the same experiment performed in the case of the frog, namely, excision of a portion of the floor of the mouth. Using a tenaculum hooked under the mandible, I forcibly drew out the head and neck, and with a pair of sharp-pointed scissors, one blade of which was pushed through the structures to the interior of the mouth, I succeed in excising a portion of the floor sufficient for the purpose, cutting through two of the ribs before accomplishing it, the animal making a noise as if in pain. I was sorry it had not been chloroformed; but being deeply absorbed, it escaped me at the time The effect of the operation was very decided, the animal rapidly becoming limp and motionless, but every now and then making a peculiar, distressful noise, as if in pain—sharp, quick, vibratory sounds, very shrill, plaintive, and full of pathos to me. It touched me to the quick, but too late for repentance. At 12 P. M., ten hours after the operation, when I retired to rest, life appeared extinct; yes, to all appearance it was dead. But I was suddenly startled out of sleep at 1 A. M. by a shrill sound, which I at once recognized as the peculiar cry of distress coming from the tortoise; followed by the sound of something falling down, which I could not make out, as I had left it upon the floor in the room adjacent. Springing out of bed, for investigation, I found the animal *upon its back* in a corner of the room, where it had crawled, and, I suppose, struggling upon its hind limbs against the wall for air, fell over dead, giving vent to the expiring cry as it did so. Taking it up in my hands, the head and limbs swung loosely by their attachments: it was dead. Ah me! the sorrow. I was overworking at the time (I fear me, I have done that too long), and perhaps it had something to do with the acuteness of my senses and feelings, which was very likely; but have never felt like repeating the experiment. *Nein, das ist genug!** Upon the following day, I made a careful dissection to ascertain how the loud vocal resonance had been produced, since it involved forcible compression of the lungs for rushing the air through the vocal cords, which made it manifest that expiration is much more energetic in the tortoise than inspiration. The explanation is easy. Thus, the diaphragmatici (one upon either side) (Fig. 172, 42) closely embrace the lungs, anteriorly and laterally, and, by contracting, must inevitably compress the organs. There is no doubt, then, this was the explanation of the phenomenon. It was an error in Bojanus to have named this muscle the *diaphragmaticus*, tending to misdirection; for there is nothing in the physiology of the tortoise, nor in any of the animals antecedent to the mammalia, calling for it, the differentiation of a diaphragm being correlated with the changes in the intestines, converting them into large air-chambers for increasing the digestive and absorptive processes, etc., for restraining them so as not to interfere with respiration, but rather energizing it (pp. 186–195).

This experiment proves beyond question that the throat-apparatus in the tortoise is essential to life, while the greater development than in the frog is due to the fact of the modifications in the body-envelope inhibiting the downward movement in the floor of support to the viscera for facilitating lung-diastole, the organs being compelled to act upon a horizontal plane in a to-and-fro movement upon the viscera. At the same time, however, it involves independent automatic action in the lungs, for in no other way could the air be effectively diffused through the alveolar compartments in the measure of the phy-

* This was done in London, that would not suffer physiological investigations, its heart too tender. All the same, I made it out *there*; this and frog-respiration, with other important matters, all-pervading Intelligence blessing the time and place.

siological requirements. But the point we wish to make in this connection, is the effect produced by this embarrassed respiration upon cardiac development, since it throws more labor upon the heart. This circumstance is seen in the great increase in the muscles of the heart (Fig. 175, *A*′), the walls of the ven-

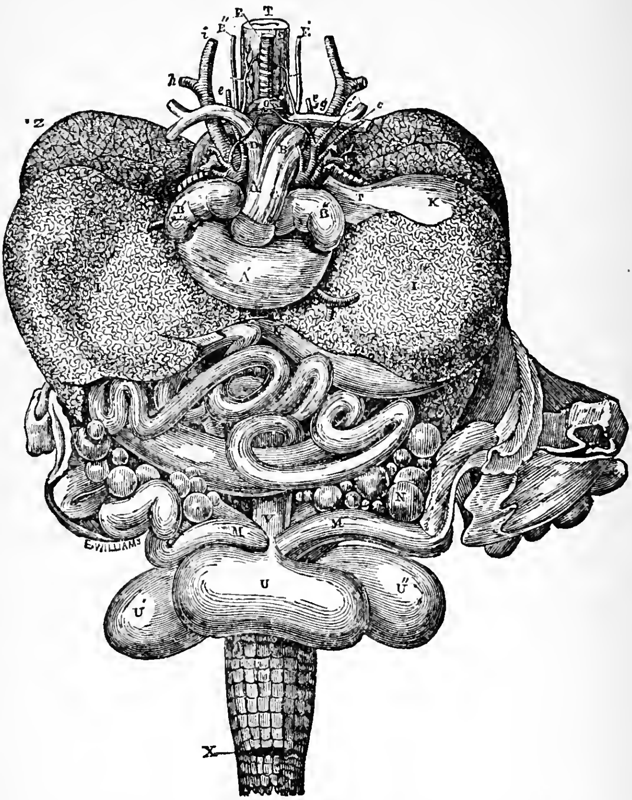


Fig. 175.—The Viscera in the Tortoise (*Emys Europæa*), as viewed from below.—Bojanus. *A*′, heart (ventricle); *A*, aorta; *B*′, right auricle; *B*″, left auricle; *B*, left aorta; *C*, common pulmonary artery; *D*, right subclavian artery; *E*, trachea; *E*′, left; *E*″, right carotid arteries; *i*, jugular; *h*, brachial veins; *e*, *g*, vertebral and subclavian veins; *T*, *T*, œsophagus; *K*, stomach, nearly covered by the liver; *K*′, pylorus; *I*, *I*, liver; *Z*, *Z*, lungs; *M*, oviducts; *N*, ovaries; *V*, intestine; *U*, urinary bladder; *U*′, *U*″, anal bursæ; *X*, cloaca opening.

tricle being much thicker comparatively than in other animals (Figs. 176, 177). That this, together with the sluggish movements of the animal, is due to defective action in the lungs, has forcible proof in the case of the flying lizard (Fig. 179), in which respiration is free, the movements energetic, the heart (*a*) comparatively small.

The reduced size and number of the muscles in the ventricle are coincident with the increased and freer respiration, while this provides for corresponding increase in the activities, which must have their equivalent in force evolved by means of respiration, the two being in correspondence, from the very nature of things. At the same time, this indicates a struggle with some force, which is gravitation; hence the extensive

Fig. 176.

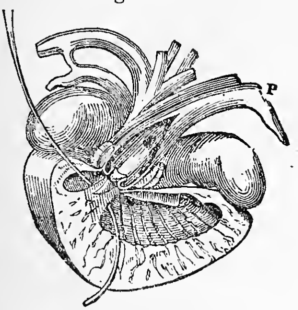
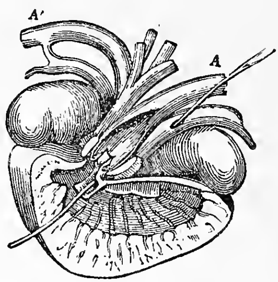


Fig. 177.



Heart of Tortoise (*Chelys fimbriata*).—Owen. Showing interior of ventricle, the incomplete interventricular septum dividing the aortic from the pulmonic cavities, through which the bristle is passed in the two sections.

Fig. 176.—*P*, pulmonary artery laid open at the root, so as to expose the bivalved orifice, the bristle passed through the incomplete septum.

Fig. 177.—*A′*, right aorta; *A*, left aorta, similarly exposed, and the incomplete septum cut through, the bristle passed through the pulmonary vein of that side; the root of right aorta (*A′*) is behind that of the left; the elongated rounded bodies are the auricles.

provisions in land animals for generating force in the organism, the increase in respiratory surface, greater development of the vascular system, and the numbers of the muscles and nerves to the heart and blood-vessels for effecting rapid importation and distribution of the force-producing elements, together with the rise and fall in frequency of the respiratory and cardo-arterial rhythms with the swell in the activities, the increased respiration necessarily involving a corresponding increase in circulation in order to make it effective, the objective point being the cell-brood in the tissues. In lizards (Fig. 179), in which the voluntary movements are rapidly performed, the lungs are more highly developed, reduced in size, and more compact from multiplication of the septa and capillary plexuses ; and by reason of the differentiation of "ribs" for assisting and facilitating expansion and contraction in the lungs and body-walls, freer respiration is provided for, whereby more energetic actions are enabled than are possible to chelonia, the effect at the same time being to relieve the heart in proportion, obviating the necessity for the number of the muscles that ob-

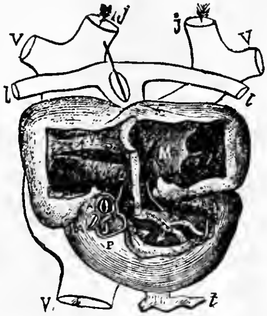


Fig. 178.—Structure of Auricles ; Heart of *Chelys fimbriata*.—Owen. The left auricle (*M*) receives the arterial blood from the lungs by a single vein, the common trunk of the pulmonary veins (*e*, *e*) ; it opens into the back part of the auricle, near the septum, and is guarded by a single oblique membranous fold (*M*). Each auricular ventricular orifice is guarded by a fold which extends across it from either side of the base of the inter-auricular septum ; to that of the left auricle a small part of the muscular structure is attached by chordæ tendinæ. Opposite to the right valve a semilunar ridge projects, in *Testudo indica*, which is the rudiment of the second auriculo-ventricular valve in the Crocodile, and of the fleshy valve of that orifice in the right ventricle of Birds. The apex of the ventricle is attached by a short fold of the serous membrane to the pericardium (*t*). The bivalved orifice between the sinus and the auricle (*v*, *o*) is a transverse slit. The white arrow (*o*) shows the course of the blood from the right auricle, past the valve supported by the base of the auricular septum, into the aortic cavity of the ventricle. In Fig. 176, a bristle passes through the orifice left by the incomplete septum between the aortic and pulmonary cavities into the latter, which is largest in *Emys*, as in *Ophidia* and *Lacertilia ;* the bivalved orifice of the pulmonary artery (*P*) is shown. In Fig. 177, that of the left aorta (*A*) is similarly exposed, and the incomplete septum is cut through ; the root of the right aorta (*A'*) is behind that of the left. The relative position of the origins of the three arteries from the chelonian ventricle is shown in Fig. 177, where (*P*) is the pulmonary, (*A*) the left aorta, (*A'*) the right aorta—the most posterior, or dorsal, of the three arteries.

tain in the heart of chelonia. Then, again, in birds, in which the voluntary actions are enormously increased in force, we find here also that respiration and circulation are in correspondence ; otherwise, they could not be produced. It follows, with progress in development in which more and more force is called for, that commensurate arrangements *must* obtain for *arterializing* and *circulating* the blood ; hence the differentiation of the *left* cardiac chambers for separating the pulmonic or aërated blood from the systemic venous current, the limitation of the arterial or aortal trunk to the left side of the heart, the *increase* in *respiratory surface*, together with

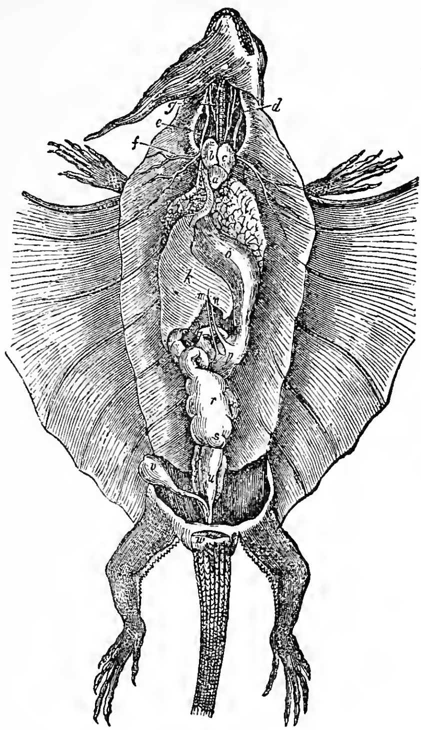


Fig. 179.—Abdominal Cavity and Viscera, *Draco Volans.*—Cyclopediæ of Anatomy ; Art. Reptilia. By T. Rymer Jones. *a*, Ventricle of heart ; *b*, right auricle ; *c*, left auricle ; *d*, carotid artery ; *e*, jugular vein ; *f*, subclavian artery ; *g*, trachea ; *k*, liver ; *l*, lower venous sinus, commencing from liver and extending to right venous sinus ; *m*, biliary duct ; *o*, stomach ; *p*, beginning of small intestine ; *q*, small intestine ; *r*, beginning of large intestine ; *s*, its attenuated region ; *t*, *t*, kidneys ; *u*, cloaca ; *v*, bladder ; *w*, anus.

the *high pressure* which obtains *in the arterial system* for increasing circulation in the capillaries and cell-brood, which is gradually brought about in the reptilia and perfected with the birds. And the crocodile is the connecting link between the birds and reptiles, the interventricular septum being perfected in the crocodile, but leaving an opening between the two aortæ, causing the venous blood to flow through the body during submergence, when, by reason of defective respiration, the blood tends to accumulate at the right side, and but for these safety-valves, life would be impossible; at the same time, it should promote the nutritive processes, for the reasons already given (pp. 366–369). The anatomical peculiarities in the heart of the crocodile are succinctly stated in the following excerpt:

"In the Crocodilian order a marked advance is made in the structure of the heart. The blood from the general system is poured by the veins into a sinus (Fig. 180, *S*), whence it passes into a right auricle (*o*) by the usual bivalved aperture. The auricle has a more distinct 'appendix,' and its muscular walls are thicker than in lower reptiles. The auriculo-ventricular orifice is defended not only by the ordinary valve on its left side, which is attacbed to the base of the auricular septum, but by a similar though smaller fold on the opposite, or right side; this fold becomes the fleshy auriculo-ventricular valve in birds. To the junction of the two valves at their lower angle a fleshy column is attached. The ventricular cavity (*R*), which receives the venous blood, propels it to the left aorta (*A*) and to the pulmonary artery (*P*); the origin of each is guarded by a pair of semilunar valves. Immediately above the larger of those of the left aorta is an orifice leading into the right aorta; in Fig. 180,* a bristle is passed from the left aorta through this orifice into the right axillary branch (*a*) of the right or brachio-cephalic aorta. In the figure, the valve is drawn down to show the orifice; in its natural state it conceals and would cover the orifice, as the blood flowed from the ventricle into the left aorta. Some openings lead from the pulmonic cavity of the ventricle into a spongy structure, which has been defined as a particular cavity (*spatium interventriculare*) of the ventricle; but it is essentially a part of the pulmonic chamber; bristles are passed through the orifices or intercolumnar spaces leading from *R* to this structure. The left auricle (Fig. 18, 1, *M*†), when distended, is smaller than the right, and of a more transverse form; its muscular part is produced into an appendage, which almost meets that of the right auricle in front of

* *Ibid*, 339. † *Ibid*, 340.

the 'conus arteriosus,' embracing the 'sulcus coronalis' of the heart. There is a small pulmonary sinus receiving the short trunks of the pulmonary veins (*l*, *l*). The left auriculo-ventricular aperture is defended by a broad membranous fold continued into the ventricle from the middle of the base of the interauricular septum; to its margin are attached a few

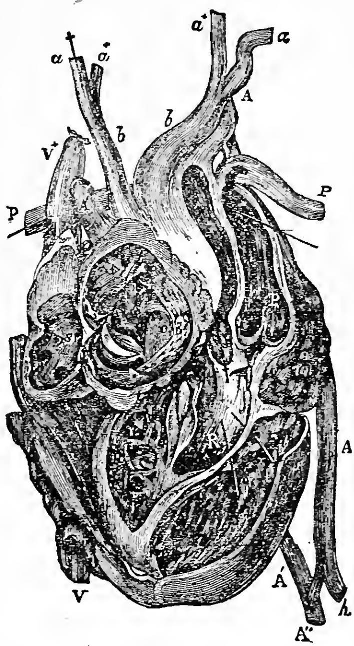


Fig. 180.—Right Auricle and Ventricle, *Crocodilus Acutus*.—Owen. *P*, *P*, right and left pulmonary arteries laid open at the root, so as to expose the semilunar valves (*P*), a bristle passed thence through right pulmonary artery: *Ah*, left aorta; *A'*, right aorta; *A''*, intercommunicating channel; v^{x}, superior vena cava; *v*, inferior vena cava; *s*, sinus; *o*, right auricle; *R*, right ventricular cavity; a^{x}, a^{x}, right and left carotid arteries; *a*, *a*, right and left subclavian.

chordæ tendineæ; the cavity into which it opens (*L*) is distinct from the pulmonic cavity, the septum being complete; its walls are smooth, or less broken by columnæ corneæ than in other reptiles; and the free walls of this ventricle are more compactly muscular. The ventricle is produced in a sub-conical form, from its base to the origin of the right or brachio-cephalic aorta; the auriculor ventricular valve is slit, to show the course of the ventricle to the origin of that aorta; this has a pair of semilunar valves, above which is the intercommunicating orifice with the left aorta. Thus, the heart in Crocodilia consists of two auricles and two ventricles, corresponding to the 'right' and 'left' auricles and ventricles of mammals. But, through the origin of an aorta from the right as well as from the left ventricle, and their intercommunication, it follows that whenever, from an impeded state of the pulmonary circulation, the right ventricle and its arteries become over distended, the venous blood flows through the inter-aortic orifice into the arterial trunk, which, after supplying the head and forelimbs, bends, at *A′*, over the right bronchus, and effects a union at *A″* (Fig. 180) with the left aorta, *A*, *h*. Such a state of the circulation coincides with and facilitates the long submersion of the crocodile. When the animal is on land, and breathing the air directly, the arterialized blood flows freely into the ventricle (181, *L*), and the synchronous currents from this and the opposite ventricle throw forward the valves at the respective origins of the two aortæ and close the inter-aortal orifice. The arterial and venous streams flow on unmixed: the former to the brain and other parts of the head and forelimbs; the latter, by the branch, *h* (Fig. 180), chiefly to the liver and contiguous viscera; a small part mixing with the arterial blood in *A′*, to be transmitted by *A″* to the other abdominal viscera, hind limbs and tail. To convert the heart of the crocodile into that of the bird, it needs only to obliterate the left aorta, to appropriate the right or pulmonic ventricle (Fig. 180, *R*) exclusively to the service of the pulmonary artery; and the 'left' or systemic ventricle to the service of the aorta, which, in *Hæmototherma* (warm-blooded animals) is the exclusive distributer of arterial blood, in an unmixed state, to the general system."

Coming to the birds, keeping in mind the cardinal circumstance in evolution, or the struggle with gravitation, together with the means for evolving force in the organism or by respiration, inclusive of the actions in the heart and vessels, since the whole forms a connected movement, as before remarked, we have only to regard the mechanics from that stand-point, and the whole is at once made intelligible. Thus, the animal is lifted off the ground in place of lying at full length upon it, and supported by two chains of bones forming the crura, which compel eternal vigilance and a tremendous struggle with gravitation in order to effect it, the animal literally living upon its feet, the body at greater or less elevation off the ground, tending to fall to the earth all the time, and with every movement to topple over in the direction of propelling

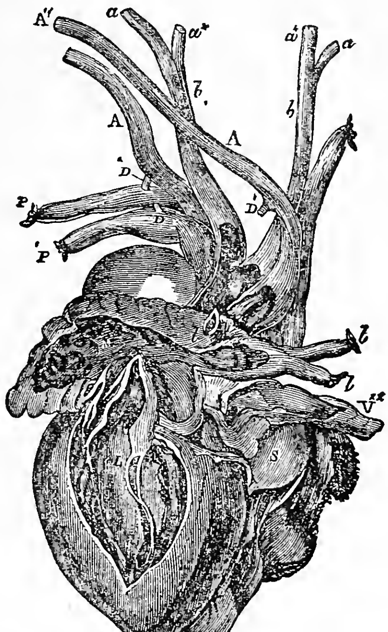


Fig. 181.—Left Auricle and Ventricle, *Crocodilus Acutus.*—Owen. *M*, left auricular cavity ; *L*, left ventricular cavity ; V^{xx}, inferior vena cava ; *S*, sinus formed at the junction of upper and lower cava ; *l*, *l*, short trunks of pulmonary veins ; *P*, *P*, pulmonary arteries ; *D*, *D′*, *D′*, intercommunicating channel between pulmonary arteries and aortæ ; a^x, a^x, carotid arteries ; *a*, *a*, subclavian arteries ; *b*, *b*, the two innominata. The pulmouary arteries, veins and upper cava are ligated.

force. Marvelous adjustments with gravitation obtain in it, but for obvious reasons we shall at present only consider the effect upon cardiac development.

For evolving the requisite amount of force in the bird, most extensive respiratory arrangements obtain in the lungs (Fig. 182) and air-bladders, with which the lungs communicate by means of openings (*a*, *e*) carried through the lung-substance, the air penetrating the very bones themselves by means of an extensive canalicular system, and in birds of vigorous flight passing into sacs between the muscles of the chest and neck; while for increasing the action during flight a special arrangement obtains in the costal framework by the formation of elbows (Fig. 23), by means of cartilages in the mid-costal region, dividing the ribs into "superior" and "inferior" (*i*, *j*), whereby the action in the chest is greatly facilitated, at the same time firmness and strength are imparted to the dorsal portions; while by means of the muscles of the abdomen, which are inserted into them and the sternum, the chest is rhythmically expanded and contracted by the action in the abdomen during respiration; while during flight the chest is rhythmically expanded and contracted by the alternate extension and retraction of the wings (p. 79), so that respiration is necessarily compelled to be in correspondence with the activities during the time of greatest exertion, in order to evolve the additional amount of force thereby expended. Such, in brief, is the ample provision for generating force, but which calls for corresponding provision in the circulatory organs in order to make it effective. Accordingly, we have the heart and blood-vessels completely developed; at the same time, the number of the muscles and nerves are increased correspondingly in both, while in the arterial system we have high blood-pressure for speeding the blood in the capillaries for energizing the local actions, while this, in turn, calls for the thick, strong elastic coat in the arteries in order to produce this increased pressure in the arterial system; while the whole relates to the generation of force in the organism commensurate with the amount expended in producing the activities.

Say what you will of life! *The evolution of force* in the organism by means of respiration and circulation, which are *based upon rhythmical changes in pressure*, invoked in the measure of the requirements, *is the law regulating the vital phenomena, anatomical and physiological*, in animal life. It is needless to extend the matter.

The following illustration (Fig. 183) exhibits the mode of termination of the great venous trunks at the heart in reptiles and warm-blooded animals, and the changes with progress in development.

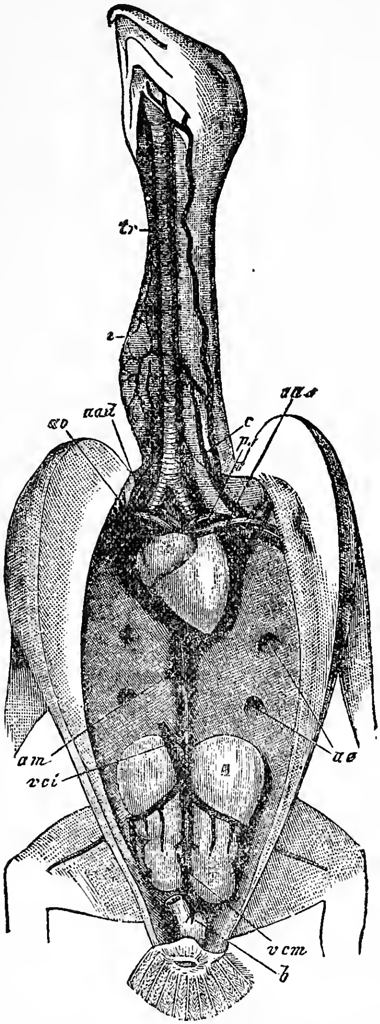


Fig. 182.—Heart and Great Vessels of *Buteo Vulgaris*.—Gegenbaur. *tr*, Trachea ; *i*, crop ; *ae*, communication between the air-sacs and the lungs ; *b*, Bursa Fabricii ; *ao*, aortic arch ; *aad*, right anonymous artery ; *aas*, left anonymous artery ; *ps*, left pulmonary artery ; *c*, carotid ; *am*, visceral artery ; *vci*, commencement of the inferior vena cava ; *vcm*, artery to coccygeal and mesenteric regions.

In Fig. 184, we have the different stages in development of the proximal arterial vessels in embryological evolution, to be read from left to right, beginning by the formation of the *truncus arteriosus* with one vascular loop only, the ones immediately succeeding this being shaded in, then the upper ones; making five pairs of vascular loops in all, as in the fishes (2); fol-

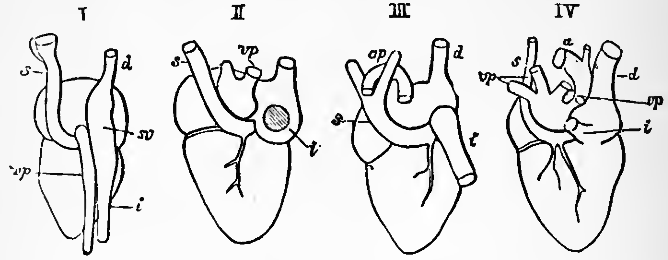


Fig. 183.—Showing Mode of Termination of the Great Venous Trunks in Different Stages in Development, viewed from behind.—Gegenbaur. I, Reptile (Python); II, Bird (Larcorhamphus); III, Marsupial (Halmaturus); IV, Pig; *i*, Vena cava inferior; *s*, vena cava superior sinistra; *d*, vena cava superior dextra; *ap*, pulmonary artery; *sv*, sinus venosus.

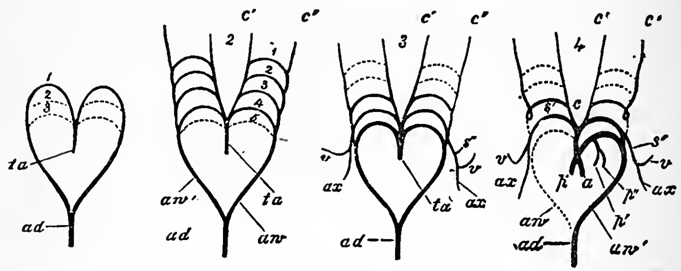


Fig. 184.—Showing the Different Stages in Development of the Proximal Arterial Vessels in Embryological Evolution.—Carpenter. 1, *Truncus arteriosus* with one pair of aortic arches, and dotted outlines indicating the future position of the second and third pairs; 2, *truncus arteriosus* with four pairs of aortic arches and indications of the fifth; 3, *truncus arteriosus* with the three posterior pairs of aortic arches, from which the permanent vessels of the embryo are developed, with dotted outlines showing the position of the two (now) obliterated anterior arches; 4, permanent arterial trunks in their primitive form, the obliterated portions still shown in dotted outline; 1–5, primitive aortic arches; *ta*, truncus arteriosus; *a*, aorta; *p*, pulmonary artery; *p'*, *p''*, branches to the lungs; *aw'*, root of thoracic aorta (*ad*) on left side; *aw*, obliterated root springing from right side; *s'*, *s''*, subclavian artery; *v*, vertebral; *ax*, axillary; *c*, common carotid; *c'*, external carotid; *c''*, internal carotid.

lowed by the gradual obliteration which sets in after a certain stage in development is reached; till, finally, we have the condition in 4, representing the permanent vessels or aorta, pulmonary, carotid, subclavian and vertebral arteries.

In the first two pairs, or highest arches, certain portions are obliterated, leaving three pairs; of these, the lowest pair is entirely obliterated on the right side; on the left, it gives off the pulmonary artery, and remains throughout fœtal life the channel of communication with the aorta, or *ductus arteriosus;* the *bulbus aorticus* is subdivided by adhesion of its walls, thereby forming two tubes, one of which is the nascent aorta, the other pulmonary artery; while of the second pairs, the right arch forms the innominate and first portion of right subclavian; the left becomes the arch of the aorta, and contributes to form the left subclavian. The third pair contributes, with portions of the two highest pairs, to the formation of the internal and external carotid arteries.

The following beautiful illustration (Fig. 185), by an English naturalist,† affords a bird's-eye view of the vascular changes which accompany the transition from intra-uterine to extra-uterine life, while the mechanical principle which underlies these changes in the mechanics of circulation is fully set forth in the chapter upon the embryonic circulation (pp. 338, 341).

Before leaving this subject, I desire to call attention to a deeply suggestive fact connected with circulation in the fœtus, notably, the very small amount comparatively of arterialized blood which actually reaches the heart of the embryo, which may be roughly estimated at one-fourth only of the blood in the umbilical vein, the great bulk of the blood passing through the liver parenchyma for effecting assimilation and promoting hæmatosis; the liver, undoubtedly, being concerned in both, is also relatively larger than at any other period of life; and since this would necessarily consume the oxygen, it follows that the supply would have to be by the route of the ductus venosus (7); while the small size of the canal is of itself eloquent

† "Outlines of Comparative Anatomy: Presenting a sketch of the present state of knowledge, and of the progress of discovery, in that science; and designed to serve as an introduction to animal physiology, and to the principles of classification in zoölogy." By Robert E. Grant, M.D., F.R.S., Lond. & Ed., F.L.S., F.G.S., F.Z.S., M.W.S., etc.; Fellow of the Royal College of Physicians of Edinburgh; late Professor of Physiology in the Royal Institution of Great Britain, and Professor of Comparative Anatomy and Zoölogy in University College, London. 1841.

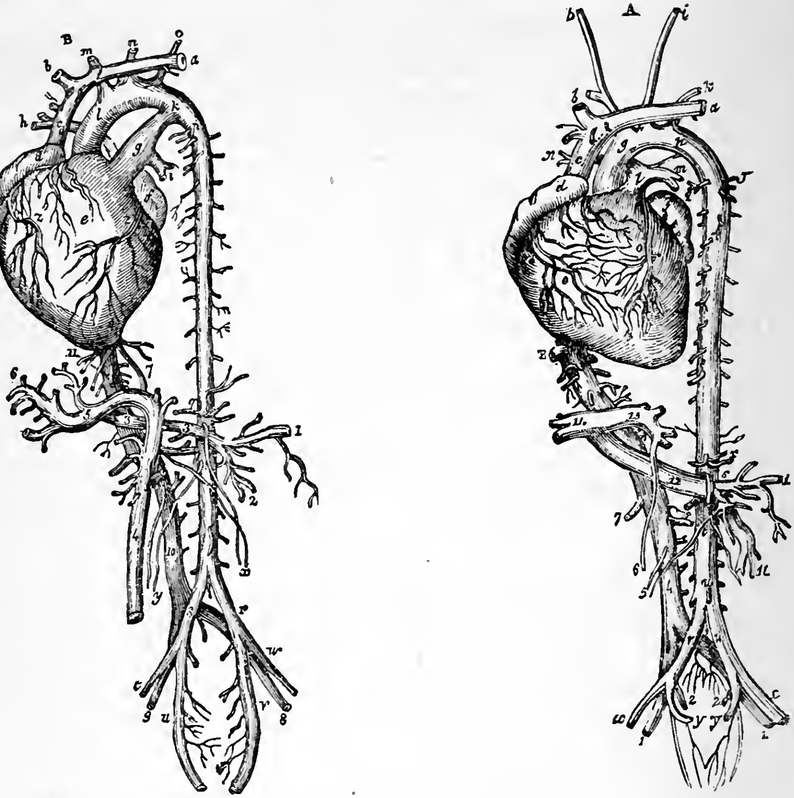


Fig. 185.—Circulation in Intra and Extra Uterine Life, showing the vascular changes.—Grant. B, intra uterine circulation in the matured embryo ; A, extra uterine B, 4, umbilical vein ; 5, sinus formed by junction of umbilical vein with vena portæ ; 1, 2, 3, vena portæ ; 6, hepatic veins (principally right lobe, unmarked vessel indicating left lobe of liver) ; 7, ductus venosus ; 10, 11, inferior vena cava ; *d*, right auricle ; *e*, right ventricle ; *g*, ductus arteriosus ; *k*, junction with first portion of descending aorta, pulmonary artery dividing into right and left pulmonary arteries (*h*, *i*) beyond ductus arteriosus ; *f*, left auricle ; *l*, ascending arch of aorta ; *m*, arteria innominata giving off carotid and subclavian of right side ; *n*, left carotid ; *o*, left subclavian artery ; *s*, right common iliac ; *r*, left common iliac artery ; *u*, *v*, umbilical arteries, continuation of internal iliac ; *t*, right external iliac artery ; *w*, left external iliac ; 8, 9, right and left external iliac veins ; *a*, *b*, brachio-cephalic trunks ; *c*, superior vena cava ; *h*, right pulmonary artery ; *i*, left pulmonary artery. A, *l*, pulmonary artery ; *m*, left branch ; *n*, right branch ; *p*, atrophied remains of ductus arteriosus ; *f*, left auricle ; *g*, ascending aorta ; *h*, right carotid from innominata ; *i*, left carotid ; *k*, left subclavian artery ; *r*, *s*, diaphragmatic, cœliac, and superior mesenteric arteries ; *t*, inferior mesenteric artery ; *u*, spermatic artery ; *w*, *r*, common iliac arteries ; *e*, *x*, external iliac ; *y*, *y*, internal iliac arteries; 1, 1, external iliac ; 2, 2, internal iliac veins ; 3, 3, common iliac veins ; 4, inferior vena cava ; 5, right spermatic vein ; 6, inferior mesenteric vein ; 7, right renal vein ; 10, 11, 12, venæ portæ ; 13, 14, divisions of same which ramify in right and left lobes of the liver ; 8, 9, terminations of the hepatic veins in the vena cava (the portal vessels being moved down in order to show this circumstance).

proof that but a relatively small proportion of oxygen is consumed in embryonic evolution. Now, then, for the question: Why should the embryo call for the minimum of arterial blood? This also is readily answered, notably: 1. Oxygen is the force-producer for evolving heat and producing motion in animal organisms; but since the maternal tissues are sufficient for maintaining temperature, temperature in the abdomen being the highest in the body, the embryo would not need oxygen for this purpose any more than the chick in incubation. 2. The nutritive processes *per se* do not require much oxygen, the amount consumed in the liver being simply by way of preparation, so to speak, in blood-making, the production of cells and albuminoid compounds, etc.; while the crystallizations in tissue-structure, as is the case in plants, would call for but slight expenditures in order to effect them; in proof of which, we have only to refer to circulation *below* the diaphragm.

The structures *below* the diaphragm in actual weight exceed those above it, and by universal admission *no* arterial blood is ever sent into this portion; nevertheless, nutrition is *very* active. Furthermore, when you take into consideration the hepatic circulation and the small amount of arterial blood reaching the lower cava; that this is first sent to the brain and upper portions of the body before reaching the heart again through the upper cava, thence through the ductus arteriosus to the lower portions, that in the very nature of things it cannot contain much oxygen; on the contrary, is highly venous.

Facts are stubborn things; none more so than anatomy. And who would read them aright, must regard them from the stand-point furnished in the organic laws and the history in development. It comes to this, then, that nutrition may be very active without much oxygen, the importance of which it would be difficult to overèstimate, since it would establish kindred processes in the nutrition of animals and plants, for which we have been contending. Look into it well, please; it is no hasty generalization, based upon insufficient data, but a sober fact, proven upon the anatomy of the fœtus, therefore incontrovertible.

3. But for producing *motion*, this would call for oxygen

sufficient only to keep up the action in the cardiac and vascular centres, as respiration proper does not go on, and there is no occasion for expenditure of force, save in the heart and blood-vessels; and should any other movements occur, notably the reflex actions in the spinal cord, as when the fœtus is said "to be active," we may depend upon it that the ductus arteriosus is unusually large. It is a mistake to fancy that the brain needs oxygen for effecting growth; the facts established by daily experience prove the contrary, notably the phenomena in sleep, especially in cases in which sleep is induced artificially by full doses of morphia and hydrate of chloral, in which the respirations are nearly suspended, the patient coming out of this condition, nevertheless, vastly improved (p. 367). Yes, it is an error to refer the nutritive processes in the brain or any other tissue to the presence of oxygen in the blood. On the contrary, everything goes to establish that the animal tissues, in common with vegetal, are best nourished in fluids saturated with carbonic acid gas, and there is no controverting that fact. Why seek to controvert it? Nay, keep this in mind when you do so: Force *one* thing, nutrition *another*, and quite the *opposite*.

The former effects *re*-distribution, disintegrates and disperses matter; the latter masses it, brings it together in methodical order, effecting increase in size. Oxygen is the agent for effecting the one, carbonic acid the other, at least is the principal agent in plants; while nitrogen is added in greater or less proportion in all, but greatest in animal tissue.

The head downward (which is the usual position), with the force in the umbilical vein and the suction-force in the heart, the blood from the ductus venosus, liver and lower cava are readily drawn into the heart, passing through the right to the left auricle and ventricle, guided by the Eustachian valve, and undergoing admixture along the route and in the ventricle, is sent thence to the cardiac structures and brain, the small amount of oxygen it contains being sufficient for evolving the requisite force in the cardiac and vaso-motor centres, which are the principal ones in habitual action.

The coronary arteries springing from the root of the aorta, immediately above the valves, insure prompt supply to the cardiac muscles and nervous ganglia, while the carotid and vertebral arteries maintain the activities in the vaso-motor centre, so that nervous force is readily evolved for producing the pumping actions in the heart and vessels, making this commensurate with the nutritive processes. All which is plain enough from the stand-point furnished in the organic laws underlying the organism; otherwise, are utterly inexplicable. And with the great respiratory movement in abeyance, the body-temperature maintained by the maternal tissues, volition and the voluntary movements wrapped in profoundest slumber and made impossible from the absence of the force-producer, oxygen, the action in the heart and vessels only, inclusive, of course, of the action in the cell-brood, the nutritive processes are more closely approximated to the floral than at any other period. The principle in nutrition is in the ascendency, while the one for evolving force by respiration must wait till all things are ready and the change in environment comes. How small the ductus arteriosus (Fig. 185, 7) contrasted with the size of the umbilical (4) and hepatic veins! (6)—but taking the shortest and most direct route to reach the heart and central nervous system, the life of the embryo depending upon it. The following illustration will serve for impressing the matter. The arrows indicate the course of the blood stream. Only, the diagram is misleading in several essential points, which I am compelled to notice, but it grieves me to have it to do; notably: 1. The ductus arteriosus (6) is nearly as large as the umbilical vein itself (3), creating the impression that the greater portion of the umbilical blood continues directly on into the vena cava, whereas fully three-fourths is diverted into the liver; therefore tending to misdirection, doing harm to the medical pupil, and retarding physiological progress as well. 2. The portal vein (7) is too large in proportion—is larger than the combined umbilical and portal streams (4, 4), and is made to appear as though it debouches in the umbilical vein with the right hepatic vein, thence through the ductus venosus into the lower cava; whereas, it blends with the umbilical stream at the portal gate, divides and subdivides in the liver parenchyma as an artery, the umbilical and the portal blood forming the common stream,

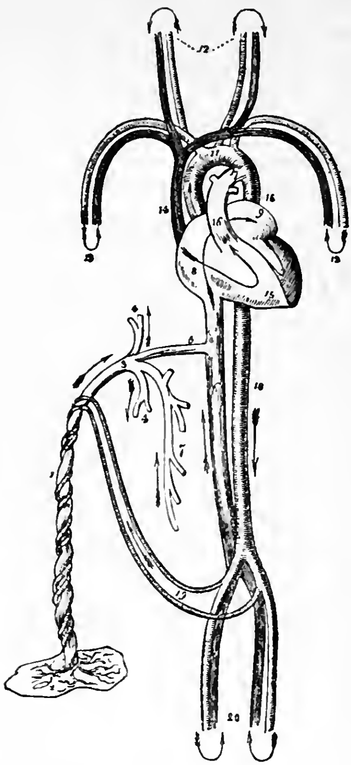


Fig. 186.—Diagram of the *Fœtal Circulation.* 1, The umbilical cord, consisting of the umbilical vein and two umbilical arteries, proceeding from the placenta (2) ; 3, the umbilical vein dividing into three branches ; two (4, 4) to be distributed to the liver, and one (5), the ductus venosus, which enters the inferior vena cava (6) ; 7, the portal vein, returning the blood from the intestines, and uniting with the right hepatic branch ; 8, the right auricle ; the course of the blood is denoted by the arrow proceeding from 8 to 9, the left auricle ; 10, the left ventricle ; the blood following the arrow to the arch of the aorta (11), to be distributed through the branches given off by the arch to the head and upper extremities. The arrows 12 and 13 represent the return of the blood from the head and upper extremities through the jugular and subclavian veins, to the superior vena cava (14), to the right auricle (8), and in the course of the arrow through the right ventricle (15), to the pulmonary artery (16) ; 17, the ductus arteriosus, which appears to be a proper continuation of the pulmonary artery ; the offsets at each side are the right and left pulmonary arteries cut off. The ductus arteriosus joins the descending aorta (18, 18), which divides into the common iliacs, and these into the internal iliacs, which become the umbilical arteries (19), and return the blood along the umbilical cord to the placenta, and the external iliacs (20), which are continued into the lower extremities. The arrows at the termination of these vessels mark the return of the venous blood by the veins to the inferior cava.

while the ductus venosus conveys the *unmixed* arterial blood to the lower cava. But the principal objection, that *the hepatic blood is not delivered into the vena cava at all, the hepatic veins not being represented by any circumstance in the diagram.* And to call this "the fœtal circulation," with fully three-fourths of the blood cut off, is simply absurd. It is like knocking the bottom out of the boat to give it a neat appearance; or, rather, constructing a boat without a "bottom," everything *taut* and ship-shape *but* the *bottom*, which is absent. If physiology is to advance, it will never be over that line. The anxiety to show the wonderful double spiral twist in the blood stream within the fœtal heart, by means of which the blood from the lower cava is transferred to the ascending aorta (8, 9,) through the foramen ovale, etc., and that from the upper to the descending aorta through the ductus venosus (16, 17), I conceive to be the explanation of the great blunder. What is needed, above *all* things, are *the anatomical facts*, and the special law which applies in the case; and by regarding anatomy from the stand-point in the organic laws, physiology is placed upon firm ground and the dismal morass made fertile soil.

CHAPTER XVIII.

DUALISM IN MUSCLES AND NERVOUS FORCE.

Nature of Vital Force—Principle in Expansion and Contraction—Molecular Changes in the Cell-Contents Involved in both Movements; Illustrated by the Action in Protoplasm and in Muscle Cells during Contraction, as Seen in the Field of the Polarizing Microscope—Dualism in Nervous Force Essential to the Production of both Movements—Extraordinary Hardness Produced in the Muscles by Nervous Force—Explanation Therefor—Hardness a Measure of Work—Mode of Demonstrating This Circumstance—An Easy Method of Proving Dualism in Muscles, and by Implication Nervous Force—Lessons Taught by the Phenomena in the Leech—Ditto, Tongue of the Frog—Ditto, Tortoise; the Action in the Head, Neck and Tail Demonstrating Dualism in Muscles and Nervous Force—Ditto, Conchifera, for Opening and Closing the Valves; Together with Physiological Experiment Demonstrating the Circumstance—Ditto, Inferior Maxilla in the Dog, showing the Masseter and Temporalis Muscles are Operated in the Same Way, the Mouth being Opened and Closed by Means of Expansion and Contraction in these Muscles—Physiological Experiment upon the Nerves to the Ciliary Ganglion Proving Dualism in Nervous Force upon the Nerves—The Circumstance Applied to the Oral Muscles and the Action in all the Sphincters, all of Them in Common Possessing Circular and Radiating Muscles, the Same as the Iris—Action in Erectile Tissue Readily Explained; Elucidated by the Action in the Tongue of the Chameleon, Penis, etc.—The Special Rôle in Nerves with Respect to Nervous Currents, Nervous Centres, Separators and Delimitators of Electrical Fluids Generated in the Tissues and Carried to the Centres for this Purpose—Reasons Therefor.

In order to complete the argument, it will now be necessary to enter a little more fully into the mechanics for producing expansion and contraction in the tissues and organs, bringing into prominence the principle in animal movement, making this also clear and easily understood. Nor will it be necessary to unduly expand the argument, exceeding the limits allotted to this work, since we are dealing with principles, and a few illustrative cases will be sufficient for the purpose, at the same time maintaining continuity throughout, the whole resting upon the action in the polar forces intensified by electrical currents. Thus, we have seen (p. 6) that there is but one means known to science for suspending matter in space and producing movements in it contrary to gravitation, which is by the action of electricity and polar forces which electricity serves to intensify, as illustrated by the rubbed glass and silver leaflet (Fig. 2). Vital Force! Never mind about vital force; one thing at a time; vital force has had its day. What we positively know is, that heat and electricity produce movements in matter contrary to gravitation, and that polar force is the guiding principle, serving also to lock the molecules in the positions which they occupy in the structures, animate or inanimate, as the case may be; at the same time maintaining mobility so as to produce the requisite changes among the molecules involved in the varied animal movements, having its acme in the muscular and nervous structures, while this in turn has its culminating point in warm-blooded animals in which body-temperature is highest. Accepting this, which is incontrovertible, all we have to do, then, is to make inspection of the special molecular physics, since it is by means of the changes effected in the relative positions of the molecules in the cell-contents that the changes of *form* are produced in the cells and in the mass composing the muscles, etc., whereby the movements, voluntary and involuntary, are produced, the whole resting upon molecular physics and the action of the polar forces, which heat and electricity serve to intensify. And that this is also true, is fully proven by the circumstance that by simply reducing temperature, the movements are promptly arrested, while heat undergoes metamorphosis into electrical force for energizing the polar forces, the same as in air and water, producing the vital phenomena. There! *that* is your Vital Force.

Commencing at the bottom, so to speak, of this problem, we have, then, the action in protoplasm to begin with. In undifferentiated protoplasm no form-elements present; nevertheless, this animal (Moneron) is highly sensitive, responds quickly to irritants, performs voluntary movements, eats, respires, circulates its fluids, and reproduces itself, the form-elements (first nucleus) in the subsequent stages, or amœboid development, the muscles and nerves in the compound organisms for energizing the local actions and effecting coördination, that the whole may perform as but a single individual only, the vascular system, respiratory apparatus and the other organs undergoing commensurate changes with the stage in development, there being a progressive onward movement in this direction ; while the whole relates to perfection of mechanical work for evolving the force which is expended in them in producing the varied movements, while this in turn relates to the struggle with gravitation, which is pivotal in development; but coexistent with this, the law of pressure, which is being incessantly invoked by means of the rhythmical expansions and contractions taking place in the organs and tissues for compelling circulation in the measure of the physiological requirements, which is also produced by means of heat and electricity, the same as for producing the voluntary movements and the actions in air and water. And if you would find Vital Force, you would have to seek for it in heat-metamorphosis, with the sun as the common source of supply. The "Fire-Worshiper" had instinctively sought out this circumstance long since. And "he laughs best who laughs last." Notwithstanding, the evidence of an *all-pervading* Intelligence is incontrovertible.

For impressing the circumstance of molecular action, we first bring before the reader the following forcible illustration (Fig. 187), by the famous biologist at Jena, representing eight presentations of the same animal (blood-cell of a snail), at as many moments during feeding. For example, beginning with *a*, we have the spherical and more or less translucent condition the cell at first presents, then an extension of the branched processes (*b*) for pumping the fluids into the body, else flowing over them and so engulfing the food particles, then the conditions at *c*, *d*, *e*, *f*, *g*, *h*, all the while becoming more and more opaque from absorption of the food, till at last the condition is reached when no more food can be taken, the animal being full, as in the case of the sucking leech (Figs. 15–17), and for every stage in development, the corresponding increase in size being alike visible in all; notably *h* is much larger than *a*, the full leech (Fig. 17) than the empty (Fig. 15). Now, then, in order to produce these varied changes of form in the cell, it is manifest that the cell-contents, the molecules equally with the masses, would have to change their relative positions, even to the nucleus (*a*, *o*), which occupies the root of a large branched process in *g*; while in the subsequent condition (*h*), in which the animal is fully contracted, restoring the original spheroidal condition (*a*), the nucleus occupies a nearly central position. In other words, we have definite actions and limitations in the protoplasmic substance, the movements directed to special objects, whether it relate to feeding or locomotion, in the entire absence of muscles or nerves, or any form-elements for producing them. Now, then, by looking from this to the actions taking place in the cells of compound organisms, in which muscles and nerves are developed, it will at once be seen that the same principle for producing motion is maintained, and must be so in the very nature of things. In the

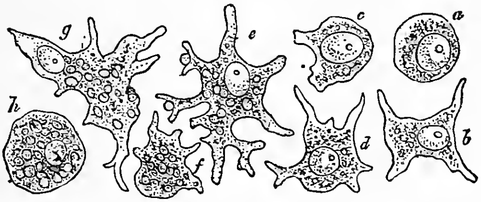


Fig. 187.—Devouring Blood-Cells of a Naked Sea-Snail (*Thetis*) very much magnified. In connection with the blood-cells of this snail, I was the first to observe the important fact that "the blood-cells of invertebrate animals are uncovered lumps of protoplasm, and, like the Amœbæ, by means of their peculiar movements can absorb matter," can, therefore, "eat." When at Naples (on the 10th of May, 1859) I had injected the blood-vessels of one of these snails with pulverized indigo dissolved in water. I was much astonished to find after a few hours that the blood-cells themselves were more or less filled with fine particles of indigo. By repeated experimental injections, I was able to watch the absorption of the coloring matter into the blood-cells, which was accomplished exactly as by Amœbæ. (See "Monograph of Radiolaria," 1862, pp. 104, 105.)—Haeckel.

muscles, for example, in which *changes of form* in the muscle cells, produced by the molecular movements in the cell-walls and cell-contents, are referable the expansile and contractile actions in the muscles, in response to nervous force; while the very fact that nervous force exerts this effect upon the molecules, shows at once it is also electrical, thereby producing the changes in polarity in the molecules, which is foundation and source of all the movements in animate as well as in inanimate nature. In fine, work is produced in muscles and animal tissues by means of heat metamorphosis and the action of electrical force, or the same as obtains in *any* mechanism in motion, only that in animal life it is automatic; nevertheless, *every* movement must have its equivalent in force, be paid for at the time, *there* and *then*, else there could be no movement, consequently no life.

Furthermore, we can readily understand why the pumping actions for increasing circulation should correspond with the activities, rising and falling with these, as everything is paid for by circulation, and this could not be made commensurate in *any other way*, pressure being invoked by the organs in the measure of the requirements for compelling prompt response, while for producing this it also calls for heat and electrical force, so that the principle is at once seen to be all-pervading. By reducing temperature simply, the action is promptly arrested in both animal and floral life. Thus, water (which is chief constituent of the tissues, and may be roughly estimated at three-fourths, the gray substance of the brain 80.5 decimals in the 100) freezes at a temperature of 30 degrees Fahr., which would at once put an end to circulation, therefore of life; but long before this reduction in temperature is produced in the tissues, all visible phenomena have arrest, which establishes beyond question that heat is the agent for effecting the actions. Not that heat is actually life itself, but that life is product of heat metamorphosis, and the interaction of the polar forces in special forms of matter, as embraced in air and water, out of which the living organism is evolved.

Finally, continuity (which undoubtedly exists) *implies* similarity in force, so that in every aspect of the case we see necessity for proceeding upon this basis, in order to make the matter intelligible. And since force connects through and through in order to produce the actions for sustaining life, nowhere more visible than in animal life, for producing the movements in respiration, circulation and the voluntary actions, it follows that there should be some common principle, applicable alike to all, for effecting the molecular actions involved in them, and which we find to be the polar forces, or the same as for producing the actions in air and water; otherwise is inexplicable. In furtherance of this view, we have submitted the action in protoplasm, showing it is molecular; but we would now contrast this with the action taking place in muscle cells during contraction, showing it is equally applicable to this also, as the following forcible excerpt, by a distinguished German microscopist, clearly establishes:*

"An important question still remains, which can be solved by the help of the polarizing microscope: Are the sarcous elements to be regarded as single and individual elementary bodies, or as groups of solid bodies, capable of being variously disposed? If the muscles contract, the fibres are seen to become thicker, and the transverse striæ to approximate. Each sarcous element must consequently change its form and become shorter and thicker. If such a change of form result from any force acting in an elementary solid body, the operation of the force must extend as far as the individual molecules, the optic constants must be changed, and it is not conceivable that they should be so changed that the ordinary and the extraordinary ray, after they have traversed equal thicknesses in the same direction, should present again the same difference in velocity that they offered under similar circumstances before the change of form. But it is quite a different matter if the sarcous elements are groups of solid, doubly refracting bodies, of which each individual remains unchanged in form in the act of contraction. The form of the whole group—that is, of the sarcous element—is here changed by an alteration in the arrangement of the several corpuscles, just as in a company of soldiers, groups of various breadths and depths are produced by changes in the position of the several individuals. In the latter case, the optic constants are not altered in the act of contraction, and the rays, on this account, if they have traversed equal thicknesses in the same direction, must constantly exhibit the same differences in velocity, whether the muscles be in the relaxed or in the contracted condition. Since we have a measure of the difference of velocity in the colors which appear under the polarizing microscope, we are enabled to answer the question experimentally whether the optic constants of the contractile substance change during contraction to any considerable extent or not. All the investigations I have directed to this point have had a negative result—*i. e.*, I have never seen any alteration of color that

* The Behavior of Muscular Fibres when Examined by Polarized Light. By E. Brücke. Stricker's Manual of Histology.

could not be entirely referred either to changes in the thickness of the layer traversed, or in the angle which the rays undergoing interference make with the optic axis. As, therefore, I have in vain sought after a change of the optic constants, I must maintain that the sarcous elements are not elementary and simple solid bodies, but groups of smaller, doubly refractile bodies."

This brings the molecular physics within the range of thought and distinct mental presentation. But then, the distinguished author, it would seem to us, has omitted one-half of the mechanics, namely, expansion; for expansion and contraction are correlated forces. And keeping expansion for the time in view only, is it not as easy to perceive that it may be made the *primary* movement, the individual molecules going from the *middle* to the *ends* of the column, in order to effect it, then, by simply reversing the movement, produce contraction?

In point of fact, it necessitates as much discipline among the molecules in reversing the action as for producing the primary movement; this, whether it relates to contraction or expansion. In short, that the molecules may go through either evolution with equal ease and celerity, in obedience to special nervous stimulus which applies for effecting it. There would seem to be no reason why this may not be the case. Given that the molecules are held in their relative positions by the interaction of the polar forces (of which there is no room for doubt, since it applies to everything), it follows that *dualism* inheres in the mechanics, while movement is product of a change in polarity among the molecules. Furthermore, this principle in the mechanics would afford a ready explanation for a number of phenomena otherwise inexplicable, notably:

a. How simultaneous action may be produced in opposite sets of muscles—*e. g.*, flexors and extensors with the obviation of friction and a waste of force, to the end that each should perform an *active* part in the work to be accomplished, and not hindering but *aiding* each other. But at present one set is made to pull the other into extension, which is unscientific, since it involves destruction or loss of equilibrium upon which the mechanics is based, not to mention rude friction and waste of force thereby made inevitable. In place of this, however, we have *both* sets of muscles acting simultaneously and in perfect concert with each other, while equilibrium is maintained in this manner at *any* angle in flexion or extension, at the same time obviating strain and friction to the histological elements as well as the articular cartilages in the joints, otherwise inevitable. In regard to the latter, for example, we may take the action in the hand. Spread it open widely, then tightly close it as a fist. How swiftly this is done! Well, is the enormous extension of the flexors in the first due to contraction in the opposing extensor muscles? and in the second is the prodigious extension of the extensors due to contraction in the flexors? In this mechanics we would have the ends of the fingers in which the tendons are inserted as the *point d'appui* from which force would have to be exerted in either case, and during closing of the hand the articular cartilages would have to endure rude friction from the rubbing of the opposing tendons over them, increasing *pari passu* with the movement, so that when the hand is tightly closed the pressure upon the articular ends of the bones would necessarily be enormous, painful even to contemplate ; the same remark applying, of course, for extension, as the strain would have to fall upon *the articular cartilages* in either case. On the contrary, however, we are not conscious of any strain or friction whatever, either in the *ends* of the digits or the articular ends of the bones, which shows conclusively that one set of muscles is *not* pulled into extension by the other, but that *both act together and simultaneously*, the one expanding as the other is contracting, and *vice versa*.

b. But we have now to mention another important factor connected with musculation, which is also needing explanation, notably the *extraordinary hardness and firmness* produced in the muscles by nervous force during musculation, and increasing with the energy in expansion and contraction, since it applies equally to both sets of muscles, to flexors as well as extensors, which are simultaneously affected. The following illustration (Fig. 188) will serve for impressing the matter. And with the weight in the body thus resting upon the metatarsal bones, the foot fully extended, *both* sets of muscles to palpation seem as hard as iron, so great is the hardness. Furthermore, the hardness is in the *ratio of the weight sustained.* For example, if the foot is extended when sitting or lying down, the muscles show only an amount of hardness; but if a portion of the body-weight be then placed upon it, at once there is greater hardness, while this increases in the ratio of the weight, till finally the maximum is reached, when

Fig. 188.—Showing the great *hardness* which is produced in the muscles by nervous force when in energetic action, and which applies to *both flexor* and *extensor muscles*, proving the dualism in nervous force, or the power of producing simultaneous contraction and expansion in opposite sets of muscles, coördination being perfect.

the whole weight in the body is thrown upon it; provided, of course, the party can endure no more than this; otherwise it will continue to swell till the end of his physical powers is reached, for the *hardness* will *correspond* with the amount of work the muscles are performing.

Taking *work*, then, as the condition for producing hardness, it follows that *both* sets of muscles, flexors with extensors perform work during musculation. The great advantage of this is, that while it maintains equilibrium, thereby reducing friction and conserving force and structure, it imparts great firmness to the articulations, the tendons acting as "splints" upon the joints, since the hardness extends to them as well. It is, therefore, obvious that one may not speak of "relaxation" at all in connection with musculation, being as wide apart as the "poles"—antipodes.

In short, "relaxation" is a state of rest, the very opposite to work; at the same time, *it* also involves dualism, which is essential to equilibrium, for which purpose the limbs are placed at an angle between flexion and extension, therefore involving action in both sets of muscles in order to effect it; hence, the monistic theory of muscular force will not apply here either. Moreover, the crucial test of a theory is its power of absorbing *all* the phenomena. It comes to this, that the nervous apparatus itself is *based* upon the molecular or polar actions, its special office being to energize the polar forces for increasing the action in the organs commensurate with the exigencies in the functions, and for effecting coördination, to the end that a balance may be maintained in the organism, the whole performing as but a single individual.

In Reference to the Cause of the Hardness in the Muscles, which is Produced by Nervous Force, and Increasing in the Measure of This.

In casting about for a natural solution of the deeply interesting problem in musculation—notably, the great hardness and firmness produced in the muscles by nervous force—we are struck with the remarkable experience of Faraday with the electro-magnet, which, for several reasons, would seem to us to afford a natural and easy solution of the phenomenon; moreover, it is in entire accordance with the fundamental principle in the mechanics—*i. e.*, the interaction of the polar forces, *intensified* by electrical currents. For example, he discovered when the current was on in an electro-magnetic machine, that "a weight of several pounds of copper, when made to move through the magnetic field, though nothing is visible, appears to move through a viscous fluid; while, when a flat piece of the metal is caused to pass to and fro like a saw between the poles, the sawing of the magnetic field resembles the cutting through of cheese or butter." And by connecting this deeply suggestive fact with that more recently ascertained in physiology (Helmholtz, Holmgren, Burdon-Sanderson), namely, that *electrical change precedes mechanical change in the sarcous elements*, the hardness in the muscles which accompanies musculation *increasing with the afflux of nervous force* in the parts, would seem to us to be due to a similar cause, or the *interaction of the polar forces intensified by electrical currents.* In other words, that the hardness represents magnetic tension, produced by electrical force, and that the *nervous current* is but a *form* of electricity, of which there can be but little doubt, continuity in force for producing molecular action calling for this. Furthermore, it would afford an explanation of other phenomena, otherwise inexplicable; notably: *a.* How the worms can *erect* their soft, tubular bodies almost *perpendicularly* with the *utmost ease and celerity*, when climbing and locomoting. *b.* It would afford an explanation for the extraordinary feats of strength displayed during periods of excitement sufficient to tear the muscles apart when out of the body, since the increase in magnetic tension in the sarcous elements should increase cohesive power correspondingly; in this way subserving the highest uses in the organism by reducing strain, thereby conserving structure and increasing function at one and the same time. For the muscle elements, being thus sustained by electrical force, and operated by electrical force, friction and strain during musculation are made impossible, a perpetual balance in force, which it necessarily involves, making it impossible. And, what is of equal importance, action is thereby unified, all the parts moving together in perfect order under electrical force, which pervades the mechanics through and through, producing the utmost concert in action.

Having thus gone briefly over the mechanical principles in musculation, we are now prepared to take up special vital phenomena appertaining to musculation and circulation, hitherto inexplicable, the first in order being the demonstration of dualism in the muscles, which is readily done.

An Easy Mode of Demonstrating Dualism in the Muscles.—For this purpose we make selection from the worms, since there is no occasion for isolating the muscular fibres in them, the special arrangements which obtain making this unnecessary, for the muscles being disposed in circular and longitudinal layers, the changes of *form* which the *body* undergoes is sufficient in itself to indicate the action in the muscles, while it gives us the actual facts in musculation, which the isolated fibre, removed from the cycle of organic forces and the volition of the animal, cannot possibly do.

Furthermore, to reproduce the phenomena in musculation requires perfect knowledge of the special mechanics and the power on the part of the operator to isolate the positive and negative electricities ; at the same time, to so regulate the currents as not to exceed the normal limits, which, it is needless to add, is difficult of attainment ; nevertheless, the power on the part of the animal to do this may not be doubted for a single moment, since the matter is fully proven by its ability to produce simultaneous expansion in opposite sets of muscles, and even in different portions of the individual muscle and muscular fibre, of which we shall give ample proof before we are done, commencing with the worms, notably the leech (Fig. 189), and ending with the higher animals. Here, of course, we must begin with the anatomy as means to ends, being the arrangements for producing *work*, while the special actions or movements observable, together with the laws of pressure and gravitation which apply, and the dual principle in nervous force for producing the molecular movements, will give us the *method* of doing this, which is what we wish to get at in the case. In short, whether there *is* actually *dualism* in muscles.

Anatomy.—Fundamentally, the body of the worms is a hollow cylinder, composed of circular and longitudinal muscular layers, the former external, the latter internal. In Annelides, the longitudinal fibres are increased, forming two dorsal and two ventral layers, leaving a lateral groove. In addition to this, a layer of transverse fibres, generally in the form of distinct bundles, passes from the ventral median line to the lateral grooves, which enables the animal to flatten its body when swimming, passing through the water by graceful undulations of the body, which is flattened out, ribbon-like. The suckers are special differentiations of the dermo-muscular tube, which agree with one another in all the essential points of their structure.

The great relative thickness of the muscular cylinder is seen in the following illustration (Fig. 13, *A*, *B*, *m*).

During feeding and locomotion the muscular layers are affected differently, the one directly the opposite of the other,

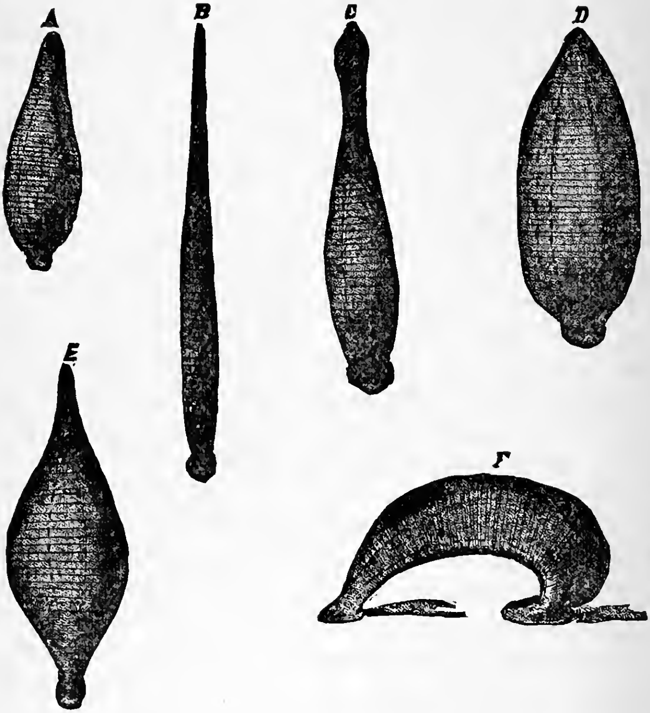


Fig. 189.—Six Cuts of the Leech, showing as many changes of form, assumed within a few minutes, allowing for the time occupied in filling itself with blood, and necessarily involving *simultaneous* expansion and contraction in the circular and longitudinal muscles. *A*, *before* feeding; *B*, when extending itself; *C*, when feeding; *D*, when gorged with blood; *E*, when freeing his "feet" for locomotion, driving the blood to the central portions; *F*, when locomoting.

but acting harmoniously and in utmost concert, their joint action being essential for effecting the movements. Now, then, and taking the state of rest as more nearly representing the condition of equilibration where motion is reduced to a minimum, we have presented to us the following appearance (Fig. 189, *A*), in which the animal is very small, nearly round or ovoidal in form. But when locomotion sets in, all this is changed (*B*), and from a short, globular body he assumes a long rod-like shape, extending himself to more than double the length he had when resting, while the anterior portions are drawn out to the dimensions of a bodkin or even less, so very attenuated they become.

Now, then, in order to effect this action, the *circular* muscles *must contract* and the *longitudinal elongate simultaneously;* otherwise it were utterly impossible to effect extension, since the one is greatly reduced in length, the other proportionately increased; hence, the former must contract and the latter expand. No? Please explain, then, and make us understand how it is done.

The short muscles contract and *pull out* the long muscles! Nothing of the kind. Nay, impossible and preposterous. Look at the anatomy, and put a little thought into the matter. In the first place, the long muscles in the leech are more numerous, therefore more powerful than the short; the weaker force, then, would have to overcome the stronger, which is not reasonable. 1. It would involve prodigious strain to the sarcous elements in the long muscles by being thus forcibly pulled to such extreme limits; it could not be otherwise, in the very nature of things. Moreover, muscles will not admit of much forcible extension, resisting it promptly, and the greater the force applied the more they contract, tearing in twain when the limit is reached. 2. It would involve enormous waste of force, which is antagonistic to conservation of energy and of structure, which is fundamental in the organism. Hence this rude mechanics, born of the monistic theory of muscular function, cannot possibly be correct. Fortunately, however, an easy method obtains for disproving it by actual demonstration, notably, by *feeding* the animal, when it becomes five or six times the size it had in the empty condition (*A*, *D*). Now, then, by looking from *A* to *D*, it is at once perceived that important changes in the muscles have taken place, notably that *D* is much larger than *A*, it is much longer than *A*—indeed, nearly twice its length, while in circumference it is *a number of times larger*. Hence *both* sets of muscles, the *transverse* as well as the *longitudinal*, are *elon-*

gated. Which set, then, pulled out the other set? The "pulling-out business" will not answer at all; one might as well try to lift himself by his boot-straps. Last, but not least, *beneath* muscular movement itself lies the law of *fluid equilibrium,* which *compels expansion* in order to produce low pressure *within* the animal; otherwise the fluids would *not* flow into the internal parts

So then, we have both the law for compelling movement in the fluids and the fact in this enlargement itself, as indisputable proofs of muscular expansion. And how can it matter whether we are able to *re*produce expansion in muscles *artificially* or not? The bald fact remains that the *animal,* of its own volition, *does it readily* enough, and must do so in the very nature of things; *that* ends the matter *there:* this, however, that when the operator shall have produced expansion as readily as contraction in the muscles with the method of coördinating the movements, the mystery in vital force itself will have been solved, and the cause of these innumerable "eddies" in the boundless ocean of Force laid bare to the investigator, for Life will then have been seen through and through. But since it involves metamorphosis in force, his investigations will be brought to a sudden stand-still on the threshold of that awesome fact—the heart of Nature's God, the unfathomable and unnamable All.

The animal not only produces expansion as readily as contraction, but the two actions are coördinated in producing circulation and the voluntary movements, since the method for increasing circulation by rhythmical changes in pressure involves alternate expansions and contractions in the muscles of the heart, vessels, and hollow viscera for compelling movement in the contents, the whole having adjustment with pressure, and which applies to the mouth as well as any other portion. Thus, in the case of the sucking leech (*C*), the oral sucker is first expanded over the cutaneous surface (*F*), then gradually contracted for pulling up the artificial nipple, the pharynx at the same time expanding for drawing it into the chamber (*c*), where it is incised by the to-and-fro motion of the three serrated teeth in the pharynx by the alternate expansions and contractions in the muscles connecting with the cartilages, the enlargement forming the cupping-apparatus (*c*), at the same time working energetically for aspirating and pumping the fluids into the canal; thence propelled along the tube by alternating expansions and contractions contiguous to each other, as in deglutition, of which it is archetypal.* Finally, when gorged with blood, so that no more can be introduced (*D*), the suction-action must cease, for the limit in expansion is reached; at the same time, however, this necessitates the power to maintain expansion for producing equilibrium in pressure, otherwise contraction, by increasing pressure, would compel reflux through the oral orifice, else the blood would escape by the anus, as when the animal is compressed between the fingers for the purpose of "stripping" him, which is by reflux action through the oral orifice, the terminal end of the gut being very small. Hence, all these movements involve dualism in the muscles, the notable circumstances being the *energy* in expansion, and the *power of maintaining a balance*, whether it relate to *expansion* or *contraction*, and which applies for the voluntary movements, as well as for circulation. For forcible evidence of this circumstance, and the facility with which the action is reversed, compare *D* with *E*, in which the animal is getting ready for locomoting, by first compelling the blood from the terminal ends toward the *central* portions of the body, or behind the more central diaphragms, which are *expanded* for *detaining* it, so as to allow the feet to be used as in *F*. Here contraction is made as energetic as expansion had previously been, which is again as suddenly reversed for *expanding* the *feet*, which are widely expanded to function as the basis of support in locomotion; while to this again must be added the expansion which takes place in the posterior portions of the body, contiguous to the hind foot, for bringing the blood over the centre of gravity (*F*), thereby relieving the anterior portions correspondingly for assisting locomotion, enabling the animal to more readily elevate these portions in locomotion, the ends being raised and lowered alternately. But by reason of coagulation of the blood, which soon sets in, and the diversion of nervous force to the alimentary canal

*In this case, gravitation aids muscular action, the fluids in consequence passing more rapidly to the distal end of the stomach.

and contiguous parts, this cannot readily be done; hence the ineffectual efforts of the gorged leech to locomote, for the glutton is too heavily handicapped. In this position, however (F), it is easy to perceive that the *dorsal* muscles are greatly *expanded*, while the *ventral* are proportionately *contracted*, in order to produce the *incurvated* condition of the body. So, then, to begin with, we have first, the general *body-expansion* (D), which must be maintained for retaining the fluids. In the second place, we have the *central portions* still *more widely expanded* for receiving the fluids in the terminal ends (E). Finally, we have the *feet expanded* and the body incurvated by expanding the dorsal and contracting the ventral muscles (F). Hence, there can be no earthly doubt that *expansion* as well as contraction are alike subject to *voluntary control;* otherwise it were utterly impossible to produce the above phenomena. The amount of nervous force absorbed in the digestive functions, and for producing circulation and maintaining equilibrium in pressure in the condition of repletion, should act as an enormous drain upon the central nervous system, and diminish in proportion the voluntary movements; in consequence, he would become inanimate and sluggish to a degree—a condition quite common to gluttons; and in the cold-blooded animal, in which respiration and circulation are at the minimum, of course, it would be more marked, inducing prolonged torpor.

We now pass to other phenomena in which expansile action in the muscles is made more energetic, notably the action in the tongue of the frog.

The remarkable rapidity with which expansion and contraction may be effected in the muscles has forceful illustration in the tongue of the frog. Anatomy: The tongue of the frog is composed principally of two muscles, the genio-glossus connected with the mandible (Fig. 190, *d*, *a*), and the hyo-glossus (*c*) proceeding from the posterior cornua of the hyoid bone, together with the cartilaginous plate (*b*) which is projected from the body of the hyoid bone as a supporting style, around the anterior end of which the hyo-glossus (*c*) curves to get upon the dorsal surface; so that the tongue is bent upon itself, the terminal end presenting toward the fauces.

At the point where the hyo-glossus curves over the end of the plate it forms a tendon, which facilitates the gliding action over the cartilage when the organ is extended and retracted. When forcibly extended in the dead animal, the organ reaches to the edge of the mandible. Such, in brief, is the visible mechanics, which will answer the purpose of description. Now, then, the animal has the power to *project* the tongue out of the mouth beyond the mandible with the *rapidity* of lightning, extending it fully two-thirds *the length of the body* for hooking the prey and compelling it into the mouth, doing it so rapidly that the eye cannot follow it, the speed in extension and retraction being so great. And how is it possible to explain this phenomenon by the monistic theory of muscular action? Thus, contraction in the genio-glossus (*d*, *a*) could only pull the end of the organ to the *edge* of the mandible; and with

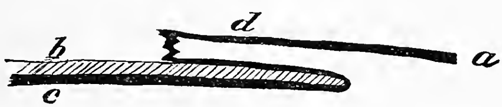


Fig. 190.—Diagrammatic Representation of the Tongue of a Frog. *d*, Tongue, reverted upon the cartilaginous plate (*b*) of the hyoid bone; *a*, *d*, genio-glossus; *c*, hyo-glossus muscle.

both muscles acting simultaneously, it must pull the reverted end of the tongue forward upon a line corresponding with the insertion of the muscle in the mandible, or straighten it simply, and, of course, holding it in this position during the period of contraction, which is *all* this action in the muscle can possibly do, but which *only puts the organ in a position to be suddenly projected from the mouth*, which requires *elongation in both muscles* in order to effect it; otherwise is utterly impossible, as must appear obvious. The special electrical current for producing expansion is determined into the parts under the volition of the animal, similar to what occurs in the electrical organ of fishes, the principle being the same, projecting and retracting the organ with the rapidity of lightning by reason of this action of the electrical current; otherwise is inexplicable. Fortunately, however, we have a means of studying the action in the muscles ready to our hand, in which the movements are more slowly performed, but which is equally conclusive of dualism in muscles and nervous force, notably in the tortoise, to which attention is now directed.

Concerning the Movements in the Head, Neck and Tail of the Tortoise, with Reference to the Principle in Musculation.

Dualism in muscles and nervous force has striking illustration in the muscular actions for producing the movements in the head, neck and tail of the tortoise; but in order to place the matter fully before the student, it will be necessary to make brief reference to the special anatomy in the parts or the bones and muscles concerned in the movements, beginning with the cervical vertebræ.

Cervical Vertebræ.—In chelonia the cervical vertebræ are elongated, eight in all, the last one (Fig. 191, 8), articulating with the first dorsal, is short and broad, with the anterior surface of the body divided into two transversely elongated convexities, the posterior forming a single convex surface, divided into two lateral facets, corresponding with opposite depressions and elevations in the first dorsal, forming the cervico-dorsal articulation; the fourth (*D*) is elongated and convex at both ends, fitting into shallow depressions in the adjacent vertebræ so as to admit of the bending and folding up of the cervical chain within the excavation, the whole forming a figure very similar to the letter S reversed, the upper leg at the carapace, the lower (*D*) at the plastron.

Cervical Muscles.—For producing the movements in the cervical vertebræ, beginning with the short and small segmental muscles in immediate contact with the bones, we have first, on the dorsal region, the *longus colli* (*t*), short fasciculi extending from the under part of the first and second costal plates and first dorsal vertebra, inclining forward and inward, to be inserted into the next adjacent vertebra, rising from one to be inserted in the other, the whole chain of short muscular links thus formed receiving this name; the "*biventer cervicis*" (*e*), from the neural plate and first dorsal to be inserted into the crest and fossæ of the occipital bone, and from the fifth to the third cervical vertebræ, to be inserted into the crests of the occipital and temporal bones; upon the sides seven short fasciculi, commencing with the eighth and ending with the second cervical vertebræ, known as "*inter-*

transversarii colli," with other fasciculi more obliquely disposed, corresponding with the fourth, third, second and first, known as the "*intertransversarii obliqui*"; upon the under surface "*scalenus*," proceeding from the lower three-fourths of the scapula, to be inserted into each cervical vertebra from the eighth to the second (*s*), "*sternomastoideus*," proceeding from the sternum to be inserted into the mastoid process; finally, the powerful "*retrahens capitis collique*" (*M*) from the neural arches and spines of the eighth to fifth dorsal vertebræ, inclusive, to be inserted by four tendinous attachments, the longest and strongest into the basi-occipital fossa, the other three into the fourth, fifth and sixth cervical vertebræ; and over all of them the great cervical muscular sheath, "*latissimus colli*" (Fig. 172, 21, 25), inclosing the cervical muscles for retaining them in position, and assisting the action by compelling the articular surfaces to glide over each other; this will serve the purpose of description. And it will not be necessary to name the muscles at the base of the skull connecting it with the proximal vertebræ, since they could do no work in effecting extension and retraction of the organs in the excavation The same applies for the muscles connected with the hyoidean apparatus.

Now, then, the question, How are the head and neck of the tortoise retracted and folded up in the excavation (Fig. 191), thence extended again (Fig. 192), seeing that muscles act between the points of origin and insertion only? And since there is but *one* muscle—namely, the powerful "*retrahens capitis collique*" (*M*), whose points of origin are *posterior* to the cervical flexure, it follows that this is the muscle for effecting retraction; which is obvious enough. But the animal cannot live by retracting the head and neck; hence this cannot be the chief function of this muscle, which is concerned in extending as well as retracting the organs. It would scarcely be contended that the small fasciculi connecting the chain of bones with each other are able to forcibly pull into extension the great muscular bundles in the retrahens, with all the advantage of leverage against them in addition. Nay, it cannot be entertained for a single moment, even. On the contrary, all the muscles are in harmonious concert in order to effect these actions, the short fasciculi being the fine adjustments for compelling the articular surfaces to glide over each other, as force is being applied by the powerful muscles for effecting extension and retraction, all acting together and *simultaneously*, the muscular sheath at the same time facilitating extension and retraction by contracting and expanding around the parts. But when the organs are being extended, the muscles connected with the sternum and scapulæ (*scaleni, sternomastodei*) serve to guide the head and determine it in

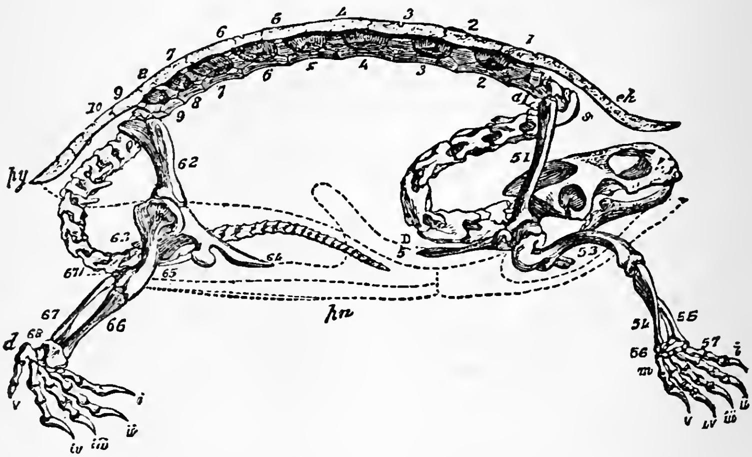


Fig. 191.—Skeleton of Tortoise (*Emys Europœa*) (Owen), showing the manner in which the neck and head are folded up in the excavation, forming a figure similar to the letter S reversed, the upper leg (*a*) at the carapace, the lower (*D*) at the plastron.

the direction desired, the other muscles connecting with the vertebræ and head, at the same time assisting. And the movements not only involve consentaneous action in the muscles, but opposite action in opposing sets of muscles; those upon the dorsal surface of the vertebræ undergoing elongation as those upon the ventral or lower aspect are undergoing contraction, and *vice versa;* otherwise, extension and retraction of the parts could not be accomplished. Finally, since nervous force produces hardness in the muscles, we can readily understand how the great muscular bundles, by becoming more and more rigid as they elongate, should have the effect of pushing the head and neck out of the excavation for effecting extension, the principle being the same as in the worms, for extending and erecting the soft tubular body ; one set of muscles undergoing elongation, another and opposing set undergoing contraction, both sets increasing in hardness with

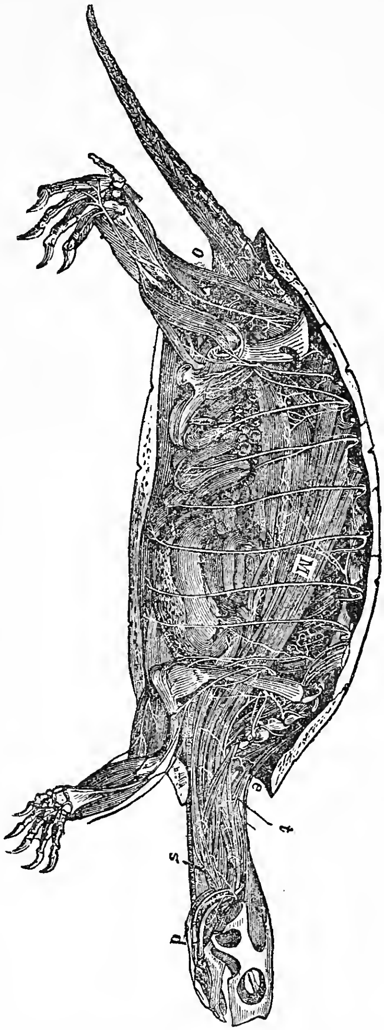


Fig. 192.—Nervous System of Tortoise (*Emys Europæa*), reduced; the letters added, showing the muscles for operating head, neck, tail and limbs.—Bojanus. *M*, *retrahens capitis collique*, chief muscle for operating head and neck ; *s*, the upper insertions of *scalenus* in second cervical vertebra, extending thence to the eighth, inclusive ; *e*, *biventer cervicis*, from neural plate and first dorsal vertebra to crest and fossæ of occipital bone ; *t*, *t*, *longus colli*, short muscular fasciculi from first and second costal plates and first dorsal vertebra, inclining forward and inward, to be inserted in the next adjacent cervical vertebra in a succession of muscular links the whole length of the neck, springing from one vertebra to be inserted in the next adjacent vertebra ; *c*, showing chief muscles in the tail ; *d*, rib-like processes of hyoid bone.

the energy in the movements. It follows that the muscles and nerves possess a dual function, or the power of producing expansion and contraction under the volition of the animal. In the tortoise we have a ready means of demonstrating this circumstance, by turning the animal upon its back simply, then watching the result. Remember, it may be the *first* time it was ever upon its back, so that it would have to bring into action special muscles for the first time, making them perform the work it desires, which is to throw itself back again into the normal position, or upon the plastron. Now, then, the animal will not only extend the head and neck to the full limit, but *curve them backward over the edge of the carapace*, stiff and rod-like, the head against the ground, to function as a lever, which is used vigorously for the purpose; at the same time, the tail also is extended and curved backward in a similar manner over the carapace; while the limbs in contact with the ground work vigorously, catching at any resisting surface. In this manner all the parts are employed, till at last the work is ac-

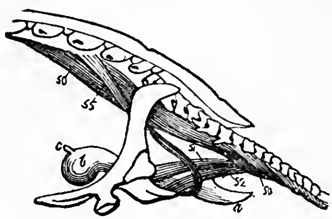


Fig. 193.—The Deep Muscles in the Tail of the Tortoise.—Bojanus.

complished, the ground favorable, performed quickly and deftly enough. Pausing to inspect the muscles of the tail, we find that here also the powerful muscles are below or upon the ventral surface (192, *c;* 193, 50, 51, 52, 55), the short fasciculi upon the lateral aspect being removed in order to fully expose these muscles. With all the advantage of leverage against them, it is simply impossible for the short fasciculi to pull into such forcible extension the powerful muscles in the tail, as must appear obvious.

And in the face of this overwhelming evidence to assert that the muscles do *not* possess dualism (not to mention the law in the organs of circulation compelling this circumstance, in order to produce the rhythmical changes in pressure), that they cannot expand as well as contract, exceeds the limits in reason and fair intelligence, blindfold though he be, seeing but dimly through the veil wrought by tradition and prejudice; but easily accounted for in the absence of the law underlying the organism and the fact that it cannot be produced artificially, tending to confirm and perpetuate the error. But we now see that the animal *itself* can make the muscles act in this manner readily enough, nay, must do so, in the very nature of things; while the molecular actions it involves, admit of distinct mental presentation, and are natural enough, so that recourse to the supernatural is not at all necessary any more than for the phenomena in the physical sciences. But the evidence may be still more simplified, and with the object of bringing out in clear relief this fundamental principle in animal mechanics, and laying bare the complicate arrangements that obtain in the structures and organs as adjustments with the special functions, we again have recourse to the lower animals, this time the conchifera, which will subserve the purpose admirably.

The Action in Conchifers.—The species of Mollusk known as conchifers, or bivalves, also lamellibranchiates, from the lamellar branchiæ or gills (Fig. 194, *b*, *g*), of which the oyster and scallop are the most common examples, have all the soft parts inclosed within two concave discs (or valves, as they are commonly called), which are opened and closed by means of a hinge-joint, and powerful muscles (*c*) connecting with the valves immediately in front of the joint, which is situated posteriorly; some of them possess two such muscles widely removed from each other, which induced conchologists to form the conchifera into two sub-classes, or Monomyoria* and Dimyoria,† the latter the more numerous class, embracing the mussel tribe and many others. But for simplicity, we shall take examples from the first class only—namely, scallop and oyster. It is the common impression, born of the monistic idea of muscular function (forced to it from this circumstance), that conchifera open the valves by relaxing the muscles simply, closing them again by contracting the muscles, the resistance in the spring, serving to open them when the muscles are relaxed, thereby making the so-called "*adductor muscle*" the *antagonist* of the wonderful elastic spring, of which

* μόνος, single ; μῦς, a muscle.

† δίς, twice ; μῦς, a muscle—having two muscles.

we have heard so much; hence the name to this muscle. Now, then, in order to probe this matter to the bottom, I made selection of the oyster, which has more elastic substance in the joint than any other, and applying a trephine over the insertion of the adductor muscle, succeeded in detaching it. Well, the valves did *not* open, but *remained closed.* Of course, they were no longer firmly held together, the muscle being detached, but the valves did *not expand* as they should have done according to the theory. The theory broke down *then* and *there.*

The explanation is obvious. Thus, when the adductor expands, it forces the valves open; reversing the action contracts them; while the special arrangement in the compressibly elastic ligament facilitates the action simply, making it more effective, using the force which is stored in it during contraction for assisting expansion, thereby relieving the action in the adductor to this extent. And that this is the principle in the mechanics, is fully shown by the following circumstances, notably: 1. The valves are air-tight; the water they contain will not run out of them when inverted, so that the muscle would have to expand in order to open the valves; which is announced by the noise they make when fed, the in-rush of air producing the characteristic sound. 2. The action in the adductor in the common scallop during locomotion, for by *energetically expanding and contracting the adductor*, the animal propels itself through the water, effecting a retrogressive movement, the valves *widely expanding* and violently beating the water by contracting against it, forcing the animal backward through the water by this means, the expansile action removing the valves *beyond the point where they could be influenced by the ligament.* The wide divarication in the valves when found upon the beach, the soft parts all out of them, is due to the drying of the external ligaments, and the shortening this produces in them causes the valves to revert upon the beveled edges, so that when fully dried the valves are nearly at right angles. But nothing of the kind ever takes place when the ligaments are kept moist, as in the living animal. So, then, there can be no doubt whatever of the existence of a dual force in the adductor, or the power to expand and contract under the volition of the animal. And turning from this, again, to the more complex movements in the higher stages in development—notably, the action in the jaws—and the same circumstance is readily proven on these muscles also, the stage in development, for obvious reasons, making no difference in this respect.

The Principle in Musculation Applied to the Action in the Jaws.—Briefly, the muscles for opening and closing the mouth are the masseter (Fig. 195, 1) and temporalis (Figs. 196, 2, 195, 3), and internal pterygoid (Fig. 197), one for each side,

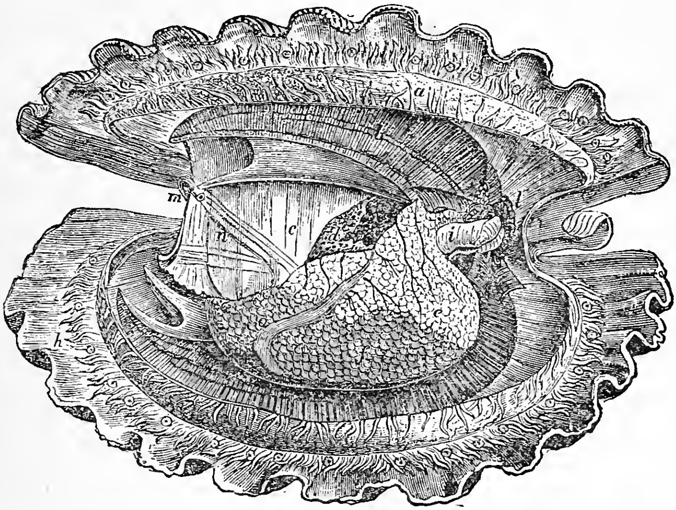


Fig. 194.—Common Scallop (*Pecten Jacobœa*).—Jones. *a, h,* Lobes of the mantle ; *b, g,* branchial lamellæ ; *l,* mouth ; *k,* lips ; *c,* adductor muscle ; *i,* "foot" ; *d, e, f,* visceral mass, principally filled with ova ; *n, o,* convolutions of intestine, seen through the transparent tegumentary membrane ; *m,* anal orifice.

which expand and contract for the purpose, the principle being the same as in the so-called "adductor" in bivalves; and there are *no* muscles for *opening* the mouth by *contracting* for the purpose, barring the small floating muscles in the infra-maxillary region connected with the hyoid bone and tongue for operating these organs in connection with deglutition, sucking, speech, etc., in deglutition serving to approximate the base of the tongue against the epiglottis, so as to close the glottis and prevent intrusion in the air-passages, which is the principal function of the genio-hyo-glossus, genio-hyoid, mylo-hyoid, stylo-hyoid and digastric muscles; the genio-hyo-glossus, in sucking by curving the tongue in the longitudinal axis so as to form a trough, the mylo-hyoid compressing it against the hard palate, forcing the aliment into the pharynx in deglutition, the other muscles acting in *concert*, the jaws closed for making the inferior maxilla the point of resistance. In other words, these muscles relate to the actions in the tongue and hyoid bone, and *not* to the jaws; therefore, cannot be regarded as opponents to the massetal and temporal muscles, which assist their action by keeping the jaws approximated during deglutition and sucking, granting, for sake of the argument, they were strong enough to antagonize the great muscles in the jaws, which can by no means be done. But to remove every possible excuse for contrariety of opinion, I resolved to probe this matter to the bottom also; and for the purpose made selection of a Spitz, and, placing it under chloroform, I swept the scalpel around the base of the lower jaw to the bone, and, twisting the bleeding vessels with torsion forceps, deflected the cutaneous flap, together with the platysma myoides, fully exposing the infra-maxillary regions, dividing first the anterior portion of the digastric near the insertion, then the genio-hyoid (dividing the muscles upon both sides), the mylo-hyoid at the attachment to the hyoid bone, not otherwise interfering with the floor of the mouth, finally snipping some of the fibres of the genio-hyo-glossus connecting with the hyoid bone, which completed the sections, not venturing to divide the muscle at the tubercles for fear of retraction of the tongue, producing suffocation; nor was it necessary, since these fibres could exert no influence in divaricating the jaws. The flap was then carefully replaced and secured by means of interrupted sutures. And the animal soon returning to consciousness, I punched him with a stick, which he bit viciously. That settled the matter *there*, showing conclusively that the masseters, pterygoids and temporals effect the movements in the jaws, or divaricate and close them by means of their action upon the inferior maxilla, which is done, of course, by means of expansion and contraction.* In this manner, then, the

* The animal took no nourishment for over three days, but the fourth morning the milk had disappeared from the basin, he having drunk it some time during the night; but he made a good recovery, the wound healing rapidly.

mechanics in the jaws are laid bare, and it is at once perceived that the principle is the same precisely as obtains in bivalves, through the action in the so-called "adductor muscle." Thus, the masseters, pterygoids and temporals open the mouth by expanding, reversing the action for closing it, the orbicularis oris expanding and contracting simultaneously, all the parts acting in concert, while coördination is readily effected by means of the fifth and seventh pairs of nerves, which are correlated in the medulla oblongata, the fibres being also distinctly traced into it.

The great relative size of the masseter (Fig. 195, 1), its ad-

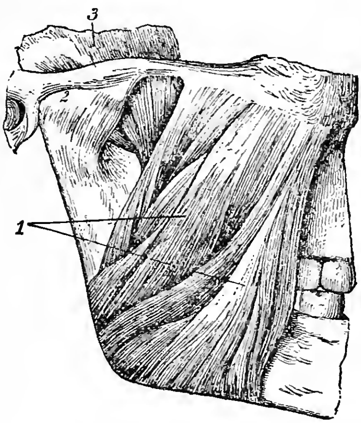


Fig. 195.—Section of the Upper and Lower Jaw, showing position and volume of the masseter muscle; reduced.—Bougery, etc.

vanced position in front of the hinge (2), closely embracing the angle of the jaw and much of the body of the bone, together with the number and disposition of the muscular bundles, stamp it at once as the chief force for opening and closing the jaws, the upper one being fixed. It is also manifest that by contracting the bundles connecting with the malar bone the angle and ramus of the jaw would have the effect of advancing the jaw, while the deep portions connected with the zygomatic arch and the body of the bone (not shown in the cut), would have the opposite effect, or retract the jaw; thus opening and closing the jaw, and upon occasion moving it forward and backward for triturating the food. It is also obvious that the position of the muscles is most advantageous for economizing force, since it gives the greatest leverage, which is much in excess of the temporal (3) inserted in the coronoid process, about an inch only in front of the hinge, or the width of the ramus itself (Fig. 196, 1, 3). The obvious purpose of this muscle is to assist the masseter in opening and closing the mouth and imparting greater force to the bite, being well developed in carnivora. Finally, to this force in the jaw we must add the action in the pterygoids (Fig. 197). It will be seen that the internal pterygoid is also a powerful muscle, resembling the masseter in form and the direction of its fibres; only that they are from *within* outward, connecting the bone with the base of the skull, tending to pull the bone during contraction toward the median line, while the action, alternating with the opposite muscle, rocks it from side to side for effecting the grinding action in the jaw. The volume of the muscle, and its extensive points of origin from the pterygoid fossa, the pterygoid plate (external) and palate bone, and the great expanse of the attachments in the ramus, angle and body of the jaw, will give some idea of the force in this muscle. The pterygoids expanding simultaneously would exert great force for divaricating the jaws; reversing the action would close them with corresponding energy, contracting between the points of insertion compelling this circumstance. In short, the pterygoids and masseters effect the grinding action in the jaws, moving the lower one upon the upper, which is stationary; while the temporals increase the action for divaricating and closing the jaws.

Such, in brief, is the tremendous force for *closing* the jaws by contraction, while there are *no* opposing muscles for *opening it by contraction*, the small floating muscles in the infra-maxillary region already referred to, with the hyoid bone fixed by means of the long, slender muscles (sterno-hyoid, sterno-thyroid, and omo-hyoid) connected with the sternum and scapulæ, may have some influence in opening the mouth, but that they are not important muscles in this respect, is now fully proven to demonstration. The mouth is opened with great energy and celerity—opened as quickly as it is closed, and with considerable force. In proof of this latter circumstance, let the student place his hand under the jaw with the object of arresting the action, and he will be at once convinced; he will also produce pain at the head of the bone from strain to the ligaments, produced by the action of the muscles tend-

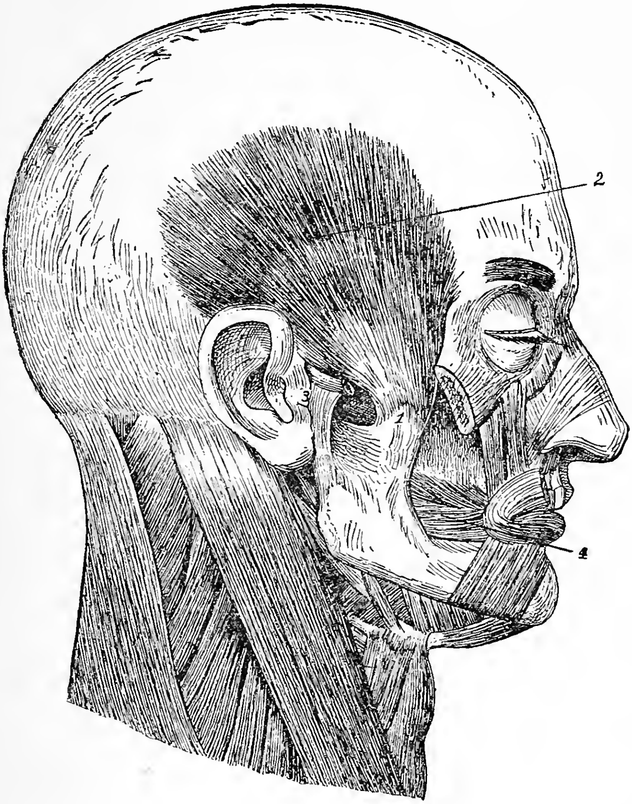


Fig. 196.—Excision of the Zygomatic Arch, showing attachment of the temporal muscle (2); in the coronoid process (1); reduced.—Bougery, etc.

ing to force it downward and backward, the anterior portions being immovable. Furthermore, he will find by palpating the masseters that there is *increasing hardness, or the same as with divarication in the jaw*, and when fully opened the muscles seem as hard as iron, from afflux of nervous force in them; and when making the experiment upon himself, a painful tension in the joint itself, as though enduring great strain, when the mouth is opened to its widest extent.

Finally, this action in the muscles would explain dislocation in the jaw from muscular action, and the special arrangements that obtain in the parts for obviating it, otherwise inexplicable; notably the existence and disposition of the external pterygoid muscles, one upon either side, for obviating displacement; otherwise inevitable. For example, the muscle extends almost *horizontally* between the zygomatic fossa and

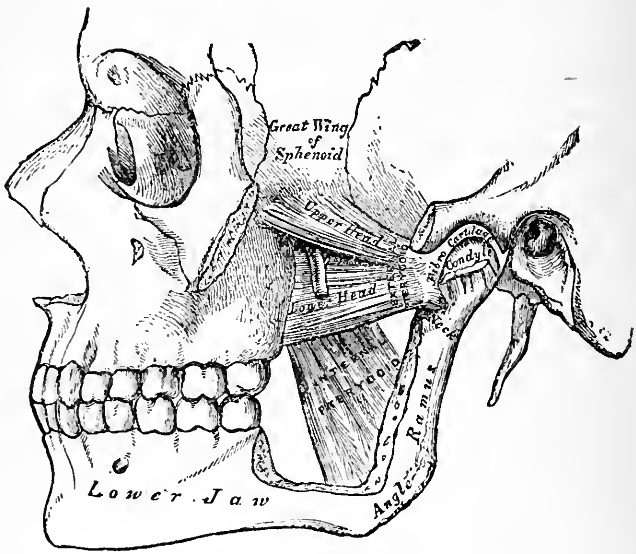


Fig. 197.—The Zygomatic Arch and a Portion of the Ramus of the Jaw Removed, showing position of the pterygoid muscles.—Gray.

the condyle of the jaw (Fig. 197)—a short, thick, powerful muscle, connecting the condyle with the superior maxillary, palate, and sphenoid bones, and spreading out widely over them, so that it is conical in shape, the small end being inserted into a depression in *front* of the neck of the condyle, and adjacent part of the *inter-articular fibro-cartilage*, the large end by two separate and broad insertions into the sphenoid and superior maxillary bones, inclusive of the palate bone, so that an effective counter-force applies for retaining the head of the bone in position in the downward and backward movements, which is the *direction of the force* in the muscles for opening the mouth, and but for the action of the external pterygoids, strain and dislocation would be inevitable in every widely opened mouth. The strong counter-force, supplied by means of these muscles, applied *close to the articular ends*, obviates this. Occasionally, however, the action in the divaricating muscles is excessive, forcing the body of the bone downward and backward so suddenly and forcibly as to dislocate the head, throwing it out of the articulating fossa, the action in the external pterygoid, which contracts simultaneously, pulling it forward over the crest of the fossa, where it is locked, the mouth open to the utmost limit, produced by yawning.

This concentration of force at the head of the bone from widely diverging points in the base of the skull, effected by the two heads of the external pterygoid, corresponds with the plane of divarication through all its angles as the counter-force for maintaining the head of the bone in position; otherwise the occasion for so large an amount of muscular force in this locality is inexplicable. At the same time, the insertion into the inter-articular fibro-cartilage would tend to give increased capacity to the articular cavity for effecting extensive motion in the head of the bone which is involved in the grinding action, showing also there must be action in the cartilage. In this manner, then, the special action in the parts is readily explained, while the adaptations of means to ends would seem to be absolutely perfect.

Passing from this as being sufficiently animadverted upon, we next take up the action in the circular and orbicular muscles, to note how readily the special phenomena appertaining to them are also readily accounted for and explained by the theory of a dual force in the muscles; otherwise are inexplicable.

Concerning the Action in Orbicular Muscles.—In order to illustrate the action in orbicular muscles, our first example shall be taken from the iris, for the reason that rude force may not be spoken of here, where everything is exquisitely organized and action is perfect; at the same time, there is a wide arc of movement in the muscles. But in order to make the matter fully intelligible, it will first be necessary to make a brief survey of the special anatomy in the iris.

Anatomy of the iris: Briefly, the iris is composed of two muscles, the circular and longitudinal, the muscular layers or lamellæ, and a delicate stroma of fibrous tissue, in which the pigment cells, vessels and nerves are contained, the posterior surface covered by a thin layer of connective tissue and the uvea.

*"The nerves of the iris are branches of the ciliary nerves of the choroid. After they arrive at the iris, they divide dichotomously in its external zone, form loops, and are finally resolved into a plexus consisting of nerve-trunks of medium size. In this plexus may be remarked an interchange of the fibres of the nerve-trunks, thus calling to mind the arrangement of the fibres in the chiasma nerv. opticorum.

"From these points of intersection three kinds of nerve-fibrils take their origin: *a*, pale fibres, in all probability belonging to the sympatheticus, which take their course toward the posterior surface of the iris (consequently toward the dilator), and upon it form an exceedingly fine plexus; *b*, medullated fibres, which advance to the anterior surface, and these are resolved into a compact network of fine fibres—these are the sensitive fibres of the iris; *c*, finally, a third plexus is distributed within the sphincter; its delicate fibres are for the most part motor."

"The circular muscle (Fig. 198, *a*) occupies the pupillary zone, extending outward for a distance of 0.09-1.3 mm. It is thinnest at the pupillary margin (0.10 mm.), becomes thicker externally, and near the outer border attains a thickness of 0.25 mm." According to Professor Iwanhoff, "the radiating fibres (*b*) are developed from the bundles of the sphincter as an *uninterrupted continuation of the same.* Its beginning is formed by a series of arched interlacing bundles, which lie partly within the sphincter (*b*, *a*), and partly on its posterior surface, between it and the pigment layer. These

* A Manual of Histology, by Prof. S. Stricker, of Vienna, Austria, in co-operation with Th. Meynert, F. von Recklinghausen, Max Schultze, W. Waldeyer and others. English translation. Art. The Organ of Vision. II. Tunica Vasculosa, by Prof. A. Iwanhoff, p. 856.

isolated bundles, after they have passed the boundary of the sphincter, unite to form a continuous layer, which spreads over the entire posterior surface of the iris; all its fibres lie regularly parallel to one another, and all are arranged in lines radiating from the pupillary to the ciliary margin. . . ." The dilator pupillæ (Fig. 198, *b*) is developed from the bundles of the sphincter as an *uninterrupted continuation of the same.* At the point of insertion of the radiating fibres into the ciliary muscles (Fig. 199, *b*, *c*) they bend suddenly upon themselves and return to the pupillary or circular muscle, some of the loops larger than others and lying in close contact with the ciliary muscles, others bending higher up the

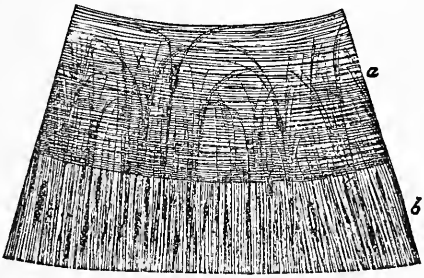


Fig. 198.—Segment of the Iris, viewed from the surface.—Jeropheef. *a*, Sphincter; *b*, dilator.

central portions in contact only (*c*, *c*), forming themselves into two layers (*a*, *a'*). Italics are added. From this it transpires that the sphincter is the chief muscle in the iris, while the radiating fibres serve for assisting the action simply. Indeed, the eminent author in the same connection uses the following forcible language: "The literature on the dilator pupillæ (radiating fibres) leads us unwillingly to the belief that until the time of Henle the existence of this muscle was presupposed on the ground of absolute physiological necessity, rather than actually demonstrated," referring to the prevalent belief that muscles cannot expand, consequently that there must be opposing muscles for pulling the sphincters into extension, but which we positively know to be erroneous. Nay, more than this, one portion of the same muscles may expand or elongate as another is contracting and shortening, both taking place simultaneously; a fact which is fully demonstrated in the leech during imbibition (Fig. 16); indeed, is seen in every visible movement (Fig. 175). The former, however, will suffice. Thus at the oral orifice the sphincter and radiating fibres (which answer to the muscles in the iris) expand and contract together and simultaneously, the same applying for the bulb-like expansion (1), the longitudinal and circular muscles expanding and contracting simultaneously, in the part adjacent the circular fibres are contracted only, in the next adjacent portion (2) both sets are again expanded, then another contraction of the circular less than the first; finally both sets of fibres are simultaneously expanded, and *continue to expand until the utmost limit is reached* (Fig. 17); so that there can be no doubt whatever that both actions may go on simultaneously and in utmost concert.

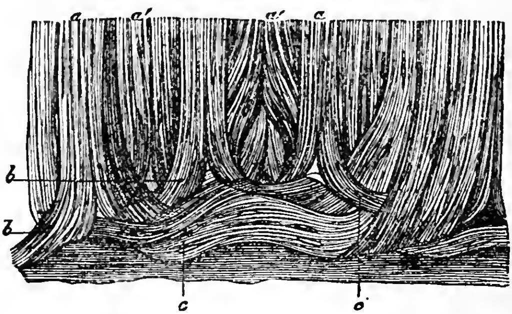


Fig. 199.—Arrangement of Muscular Bundles in the Iris.—*Ib.* *a*, *a′*, The two muscular layers formed by the radiating fibres; *b*, *b*, the same suddenly bending upon themselves before attachment to the ciliary muscle; *c*, *c*, same fibres, showing degree of approximation to the ciliary muscle represented in subjacent border ground, or dark horizontal shading.

Making the same deduction upon the muscles in the iris, the special phenomena in the expansion and contraction of the pupil are at once made intelligible, the two sets of fibres, circular and longitudinal, expanding and contracting together and simultaneously under the action of the nervous forces in the parts, both coöperating to this end, the one assisting the other. Thus, for expanding the pupil the portions of the veil contiguous to the sphincter are gently pulled aside by the action in the radiating fibres, thereby facilitating the action in the sphincter; while, for contracting the pupil, the circular fibres, by pulling upon the veil, would facilitate the action in the radiating fibres, so that the action is reciprocal. Nothing could be more perfect than the action in these muscles, but dualism is essential to it, and must be so in the very nature of things, as in no other way could a balance be maintained. And that there is such balance in nervous force to the muscles is susceptible of demonstration. For example, when the short root from the third pair (motor oculi) to the ciliary ganglion is divided, the pupil is *at once closed;* but when the long root from the ophthalmic branch of the fifth pair is divided, the action is the very opposite; the pupil as suddenly expands to the utmost limits, which shows undoubtedly opposite character in the two sets of nerve fibres, one producing contraction, the other expansion; otherwise is inexplicable. In other words, dualism in nervous force.

Then, again, either condition of the iris involves opposite action, so that the nerve-trunks must contain nerve-fibres to both circular and radiating muscles. This action in the circular muscles brings to mind the action upon the blood vessels to the salivary glands (p. 284), produced by irritation of the special nerves, stimulation of the chorda tympani (Fig. 1 5, *c*) causing the vascular walls to expand, producing a rush of blood into them, while stimulation of the sympathetic fibres causing them to contract, thereby diminishing the blood in proportion. In the one case, nervous force regulates the amount of light in the eye; in the other, the amount of blood in the glands; the principle the same. And if it be, as alleged, "that the radiating fibres are an uninterrupted continuation of the circular," it would only show, as in the case of the leech and worms, that a given portion of a muscular fibre may be undergoing expansion, while a contiguous portion is passing through the opposite movement. Moreover, there can be very little doubt but that the *undulations passing along the muscles* when stimulated, involve this circumstance, the two being inseparable in musculation. Finally, since the changes of form in the muscle-cells involve opposite movements in the molecular elements, it follows that the nervous apparatus for producing and energizing the actions should be in correspondence or be also dual, which would include the power of coördinating them in the functions, whether it relate to circulation, the voluntary movements, or the action in the iris, etc., the principle being the same in all. And since it depends upon opposite polarities in the molecular elements, we can readily understand why electrical force should precede mechanical change in the muscles. All this, then, is at once made intelligible by dualism in muscles and nervous force; otherwise is utterly inexplicable. We proceed to other phenomena

Concerning the Action in the Oral Muscles —By easy mental process, we transfer the action from the orbicular and radiating muscles in the iris to the orbicular and radiating muscles in the mouth, in which the latter fibres are gathered into muscular bundles under special names, in place of being spread out in a uniform layer as in the iris. Indeed, according to some, the radiating muscles of the iris in the white rabbit (Fig. 200, *b*, *b*) are gathered into bundles, but acting simultaneously for effecting the action in the pupil, whereas in the radiating muscles connecting with the orbicularis oris (Fig. 201, 7, 8, 9, 10, 11, 12, 13, 14) the action may be confined to several muscles at a time, which gives the power of expressing the moral feelings and the great variety of movements characteristic of the parts; at the same time, however, it involves the same principle in musculation and nervous force for producing them, related muscles expanding and contracting simultaneously in order to effect the actions; otherwise impossible. In other words, the orbicular muscle is not forcibly pulled into extension by the radiating muscles when the mouth is opened, but expands *pari passu* and simultaneously with contraction in the straight muscles, and *vice versa* when the mouth is closed, all the parts acting in concert by means of the special nerves for producing and coördinating the actions. Furthermore, this is in correspondence with the action in the powerful masseters, etc., for opening and closing the maxillæ, already referred to, and which involves corresponding expansion and contraction in the orbicularis oris; while the radiating muscles, by pulling upon the labiæ during divarication, facilitate the action in the orbicularis, as in the case of the iris, the principle being the same;

while by means of the fifth and seventh pairs of nerves running into every portion, the actions are readily produced and coördinated. It is all plain enough. For effecting the variety of movements in the parts, it calls for the special anatomical dispositions that obtain, which are simply perfect. In some animals the oral slit extends very far back, so that when the jaws are widely divaricated it reaches almost "from ear to ear." It is the case in carnivora, and when the lion yawns it sends a quiver through the flesh. But critically examine that energetic action in the muscles of the jaws and mouth, and the marvelous concert that obtains in the multitudinous parts is suitable preparation for the less impressive but more extensive movements which are similarly produced and coördinated in the medulla oblongata, or the respiratory, circulatory and locomotory movements, together forming a connected whole, as has already been fully considered; so that there can be no doubt whatever on the part of Nature to effect these actions in the muscles of the mouth and jaws. For example, when the jaws are divaricated by the expansile action in the masseters, temporales and pterygoids, the orbicularis oris expands simultaneously and *pari passu* with this action in these muscles, at the same time the zygomatici (10, 11) and buccinator (18) *contract* for pulling the angles of the mouth toward the masseters (15), the whole moving together and simultaneously the same as in the muscles of the iris under the action of the nervous apparatus, which produces and coördinates the movements, the more complicate arrangements in the muscles making no difference in this respect; while for closing the mouth the action is simply reversed, the utmost concert being maintained in the parts. With progressive increase of expansile action in the muscles of the jaws, there is corresponding increase of contractile action in the retractors at the angles of the mouth, so that the overlying integument is thrown into the characteristic folds in front of the masseters. For producing the innumerable local actions connected with the lips, the numerous radiating bundles and fasciculi apply. But in these cases the action is limited to the special localities, in which a given portion of the orbicularis, in conjunction with the muscle proceeding from it, is affected. And since we know that nervous action may be limited to a part of a muscle only, the comprehensive arrangement which obtains here is something beautiful to look upon. The great mobility in the lips is undoubtedly due to the number and variety of the local actions, which are swiftly changed and blended upon occasion by means of the nerves for operating and coördinating the structures. In the simple act of nursing, for example, it requires great mobility in the lips for effecting coaptation with the nipple and producing the movements concerned in sucking; also, as organs of prehension in taking solid food. While to this, again, must be added the functions connected with oral sounds,

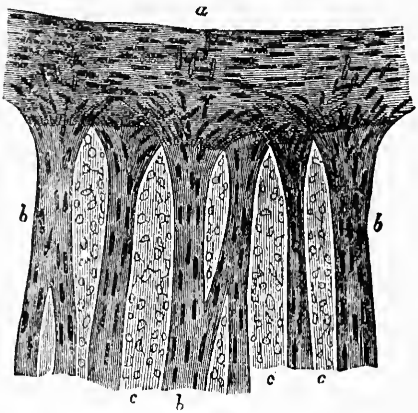


Fig. 200.—Muscular Structure of the Iris of a White Rabbit.—Carpenter. *a*, Sphincter of the pupil ; *b*, *b*, radiating fasciculi of dilator muscle ; *c*, *c*, connective tissue with its corpuscles.

and as channels for announcing the emotions. Varied as are the uses, then, the numerous adjustments which obtain in the lips would not seem excessive ; nor the grouping of the radiating fibres into separate muscular bundles be deemed strange, the matter being altogether different from the simpler action in the iris, in which the radiating fibres form a uniform layer for producing the action in the screen concerned in opening and closing the pupil. At the same time, it is equally manifest that the same mechanical principle applies for producing the movements.

We pass rapidly over this anatomy, the object being to show the principle in the mechanics simply, leaving the student to follow it at his leisure. By beginning with a principle upon which to base the mechanics, and proceeding from the simpler to the more complex forms, the comprehensive arrangements which obtain in the organs are seen to be but as many beautiful adaptations of means to ends, while order and method are made inevitable. In the orbicularis palpebræ (4) we have another adaptation of the mechanics in the orbic-

Fig. 201.—Muscles of the Head and Face.—Wilson and Buchanan. 1, Frontal portion of the occipito-frontalis ; 2, its occipital portion ; 3, its aponeurosis ; 4, orbicularis palpebrarum, which conceals the corrugator supercilii and tensor tarsi ; 5, pyramidalis nasi ; 6, compressor naris ; 7, orbicularis oris ; 8, levator labii superioris alæque nasi—the adjoining fasciculus between ciphers 8 and 9 is the labial portion of the muscle ; 9, levator labii superioris proprius—the lower part of the levator anguli oris is seen between the muscles 10 and 11 ; 10, zygomaticus minor ; 11, zygomaticus major ; 12, depressor labii inferioris ; 13, depressor anguli oris ; 14, levator labii inferioris ; 15, superficial portion of the masseter ; 16, part of its deep portion ; 17, attrahens aurem ; 18, buccinator ; 19, attollens aurem ; 20, temporal fascia covering the temporal muscle ; 21, retrahens aurem ; 22, anterior belly of the digastricus—the tendon is seen passing through its aponeurotic pulley ; 23, stylohyoid muscle pierced by the posterior belly of the digastricus ; 24, mylo-hyoideus ; 25, upper part of the sterno-mastoid ; 26, upper part of the trapezius. The muscle between 25 and 26 is the splenius.

ular muscles. By reason of the form of the orbital excavation, the eye occupying the cavity, with a deep depression round it, together with the convexity in the upper lid, which is in close contact with the ball, a special arrangement in the muscles for opening and closing the eye is made inevitable, as the ordinary sphincter would not answer. Accordingly, we have comparatively but few circular fibres in the upper lid, while the radiating or straight fibres form a broad triangular muscle (levator palpebræ), which joins the tarsal cartilage through its whole length, proceeding thence to the middle line of the upper portion of the orbit, to be attached to the optic foramen and sheath of the optic nerve at the very bottom of the excavation. Now, then, for producing the wide arc of movement in the upper lid is the explanation for the great length in this muscle, since it is the provision for effecting extensive contraction and expansion, for elevating and depressing the lid, while the breadth of the attachment in the tarsal cartilage makes the action simultaneous over the whole lid; at the same time, the circular fibres serve for assisting the action, increasing the force for closing the lids, and by expanding facilitate retraction. But here, as elsewhere, the two sets of fibres are in utmost concert, expanding and contracting simultaneously.

And so we might proceed from sphincter to sphincter through all the hollow viscera, in illustration of the antagonism subsisting between the circular and the radiating or longitudinal muscles and the principle which obtains in the mechanics, but further extension is unnecessary, for it is all simple enough, and we cannot be misapprehended. Moreover, the action in the sphincters has already been sufficiently considered in connection with the special functions in the viscera, in which it was shown that the sphincters expand as the sides and fundus of the organ contracts and *vice versa*, the principle being the same precisely as obtains in the iris and oral muscles.

Concerning the Action in Erectile Tissue.—Finally, we come to the action in erectile tissue, in which we have a different order of phenomena, but which flow out of the properties in the muscles and in nervous force, before referred to; notably, we have enormous *expansion* with *hardness* in the structures, which, after a short duration, again pass off, leaving them in a flaccid and shrunken condition, in striking contrast to what they had lately been when erect and fully expanded. Furthermore, the action is rapidly produced. And being a product of nervous force, of course, it is susceptible of explanation; but the ineffectual efforts to do so by the monistic theory of muscular and nervous action, shows necessity for introducing a new principle in animal mechanics, in order to make it intelligible. Physiologists, in seeking an explanation, have recourse to the action in the penis, in which it was thought to be due to obstructed venous return from the organ; but that this is not the true explanation is sufficiently obvious from the action in the tongue of the chameleon, where it cannot apply, and which we shall now briefly consider.

Action in the Tongue of the Chameleon.—Anatomy: Briefly, the organ consists of two sheaths, an internal and an external sheath, in form of two cylinders, the one fitting in the other. The internal is formed of dense, fibrous and elastic tissue, the fibres decussating at right angles and inclosing a stile or supporting cartilage, projected from the body of the hyoid bone, which is closely invested by it, especially in the lower portions of the sheath, where the attachment is very intimate; but in the anterior portions the connecting fibres are larger and longer, and admitting of considerable movement of the membrane upon the stile, permitting the organ in the relaxed condition to be folded up upon it much "like the seam of a dress upon a bodkin" (*C*, *c*), the end of the stile presenting in the lower lip of the bulb (*A*, *a*). And when thus folded within the mouth, the organ measures about one and one-half inches; but when extended, however, it is from six to seven inches in length, and projecting far beyond the end of the stile (*B*, *b*). But there is no canal, the elastic tissue fibres filling up and occupying the portion corresponding with the canal, the stile making its way through the interlacements when the organ is being folded up upon it. The large bulb forming the head of the organ is furnished with a short upper and a long lower lip (*B*, *c*, *b*), which are approximated in the relaxed condition, so as to form a transverse fissure, but in erection they are expanded, presenting a funnel-shaped opening (Fig. 203), with the lower lip extended and curving a little upward. The opening is also supplied with an orbicular muscle, which would explain the opening and closing of the lips for seizing the insect, while the glutinous secretions for lubricating the parts would cause it to adhere. Finally, a thin, muscular layer (hyo-glossus), composed of longitudinal fibres, extends the whole length of the organ upon the lateral aspects (one on either side); while a large nerve courses on top of it to reach the head of the organ.

The sheath corresponding with the mucous membrane is formed of white fibrous tissue, the fibres also decussating at various angles, some running transversely, others longitudinally. (There is a difference of opinion in regard to the histological character of some of these fibres, which are believed, on the

Fig. 202.—Tongue of Chameleon.—Cyclopædia of Anatomy; Art. Tongue. H. Hyde Salter. A, retracted; B, elongated; C, seen from beneath, *in situ*, by incision and separation of the integument; *a*, anterior portion, dome shaped; *b*, posterior portion; *c*, upper lip of tongue; *b*, lower lip of tongue; *e*, genio-hyoid muscle; *f*, cerato-maxillary muscle; *g*, sterno-hyoid muscle; *h*, cerato-sternal muscle; *i*, omo-hyoid muscle; *k*, apex of greater cornua of hyoid bone.

part of some, to be unstriped muscle elements; but since nervous force is not limited in its action to the muscles, it need not concern us.) Thus constituted, the organ is made to ride to and fro, forward and backward, by the action in the genio-hyoid (*A*, *e*) and omo-hyoid (*g*) muscles, while it is raised or lowered by means of guy-muscles (*h*, *f*) attached to the cornua (*k*) of the hyoid bone for aiming it at the object —much in the manner of a cannon upon the carriage. For effecting the movements in the opposing sets of muscles, of course, it requires dual action, the one expanding as the other is contracting, and *vice versa;* in this manner materially assisting each other. Thus, as the genio-hyoid (*A*, *e*) contracts for pulling the hyoid carriage toward the oral orifice, the omo-hyoid (*g*) elongates for pushing it along, and *vice versa* for running it back after erection. The same remarks apply for the guy-muscles, which are also made tense in this manner for regulating the point of elevation. Finally, when projected, it *leaps off the stile* in energetic action, going straight to the object as though shot out of a pistol, and, striking the target, is as rapidly returned upon the stile in the folded condition, as previously. For effecting the former action, the circular fibres are suddenly contracted upon the network of elastic fibres occupying the canal, while the longitudinal fibres elongate, and the hardening this produces pushes it off the stile in the erect position, and serving *to hold it, rod-like, from the end of the supporting staff* (203); otherwise it would fall and the end of the staff be caught in the fibres. Again, there is no central canal, for the circular fibres contract upon the network so as to convert the whole into a solid, stiff mass, and greatly reduced in size in consequence (Fig. 203), with the head contracted and elongated; while for effecting retraction the action is simply reversed, the longitudinal fibres contracting and the circular expanding, and which would include, of course, the central network, for nervous force pervades the whole of it; while the hardening this produces in the structures, as in example of the soft body of the worms, enables the actions to be produced; otherwise is inexplicable. The tremulous action in the organ previous to launching is produced by the guy-muscles (*B*, *h*, *f*) for aiming the organ, while the bolt itself is suggestive of the discharge of electric currents through the organ by means of the large lateral nerves. But the partial and more deliberate protrusion which precedes the final discharge is due to the action of the muscles on the hyoid bone, or the genio-hyoid and omo-hyoid muscles; but with the remainder of the phenomenon they can have but little to do, save for running the carriage back again at the end of the performance to the place it occupies in a state of rest. Finally, it should be borne in mind, in this connection, that when the organ is thus projected to the extremest limit in extension, it still retains perfect control of all its parts, else the movements in the end of the organ could not be produced for seizing the insect, nor the sheaths be returned and folded up upon the stile; so that in no sense can the action be regarded as a passive one, or the product of a single force simply; on the contrary, it is product of a dual force subject to the volition of the animal, and involving perfect coördination in all the parts for effecting it.

Concerning the Action in the Penis.—This power in nervous force for producing expansion in the muscles, elastic and fibrous tissues would explain the phenomena in the penis,

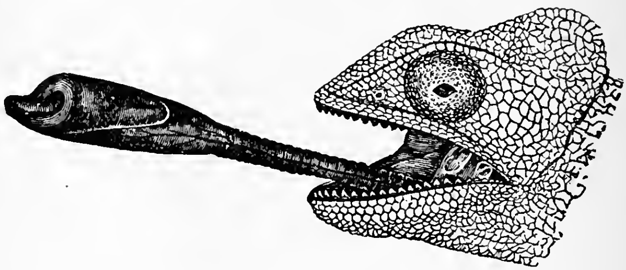


Fig. 203.—Tongue of Chameleon, when in action.—Jones.

hitherto inexplicable, making this also plain and easily understood, the means to ends being very perfect.

Anatomy: Briefly, the penile organ is composed of a mass of erectile tissue, in form of three cylindrical compartments, known as corpora cavernosa (which occupy the upper surface) and corpus spongiosum (containing the urethra), the lower surface, occupying the central groove formed by the corpora cavernosa, expanding over the ends to form the glans penis, which is firmly secured in position by means of connective-tissue fibres. The several bodies are contained in a separate sheath, composed of elastic and fibrous tissue similar to the elastic coat in the arteries (Fig. 204, *h*), dense and thick, and closely bound together from the intermingling of the fibres along the sides, while within this outer tunic is a muscular cylinder, the two intimately interblending to form the common wall (*h*). From the interior of this sheath (*tunica albuginia*) proceed numerous bands and cords (*trabeculæ*), which intersect, dividing and subdividing the interior into numerous separate compartments (*d, d*), lined by laminated epithelium—a continuation, in short, of the endothelial lining of the veins, with which they freely communicate; and so free and intimate is this communication with the veins that they were at first taken to be mere venous dilatations, but are vascular spaces simply, formed by the trabeculæ, into which the endothelial lining of the vessels is projected, or similar to what

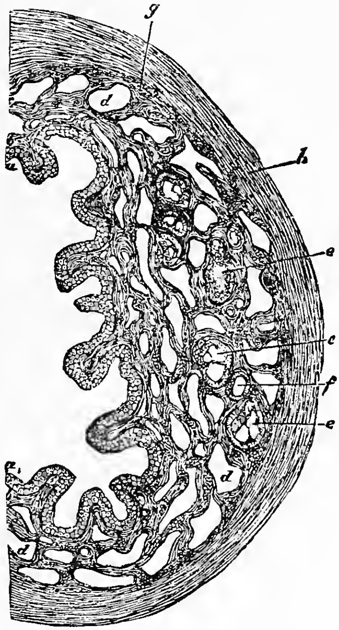


Fig. 204.—Transverse Section through the Spongy Portion of the Urethra (*corpus spongiosum urethræ*).—Klein. *a*, Epithelium; *b*, tunica mucosa; *c*, muscular cords; *d*, vascular spaces of the corpus cavernosum; *e*, glands; *f*, excretory duct of gland; *g*, longitudinal muscles; *h*, tunica albuginia.

occurs in the uterine and placental sinuses (Fig. 137, *c*, *c*). Finally, we have large arterial capillaries emptying into these vascular spaces by funnel-shaped openings, for producing rapid afflux of blood in the parts, and embossed by dense nervous plexuses connecting with the nerves and structures in the penis, on the one hand, and with the hypogastric plexus on the other, by means of which the expansile action in the organ and the requisite blood-supply for filling and distending the vascular spaces during the sexual orgasm are readily produced;

the blood serving to give *volume* to the organ; otherwise it would be needle-like; hence these vascular arrangements

This will serve the purpose of description. In the flaccid condition the organ is comparatively small, the dense fibrous and elastic sheath and muscular trabeculæ contracted, the organ less than one-third the size in the state of erection. Now, then, the question: How is this wonderful transformation effected? Well, the only explanation that present physiology can offer (forced to it by the monistic theory of muscular and nervous force) is the one of *venous obstruction* produced by *contraction of the muscles at the root of the organ, compressing the veins*, thereby causing the blood to dam back in the vascular spaces; this, together with similar obstruction at the venous outlets of the vascular spaces produced by distension (as suggested by others, not feeling sure that the former would be sufficient). But the following incontrovertible facts show conclusively that neither is correct, nor can it be in the very nature of things. Notably:

a. The walls of the veins, in common with the universal rule, are very distensible, yielding readily under pressure; hence, it were utterly impossible to force open the sinuses by this means or choking the veins, since it would involve the forcible distension and pulling of the thick trabeculæ and the dense fibrous sheaths inclosing the organ to fully double their length (not to mention the extraordinary hardness which accompanies it, and which, of course, would require corrresponding force for producing it, involving a degree of strain to the vessels, painful even to contemplate), the veins as the point of resistance, the absurdity of the proposition is too obvious for controversy. The veins would burst under the force. Hence, it cannot be entertained for a single moment even.

b. It would involve *arrest* of circulation in the parts, which cannot be thought of, for it would *at once put the organ in peril*, since this is simply *strangulation*—can be nothing else; hence, in prolonged priapism, incidental to specific disease and abnormal irritation, would inevitably produce necrosis or death of the organ, which *never* takes place from this cause. Moreover, it has been demonstrated (Eckhard) that in place of arrest, or even partial arrest, circulation is *vastly increased* in the organ during erection, the arteries being greatly expanded and the veins discharging an *unusual amount of blood.*

c. Pressure in the sinuses could not exceed pressure in the arterial system, else reflux should inevitably occur, the blood escaping in this direction, and so relieving the structures; and since pressure in the sinuses could not exceed pressure in the arterial system, this would not be competent to force open the fibrous sheaths and trabeculæ, and produce the characteristic hardness; granting, for sake of the argument, the veins could offer sufficient resistance, which can by no means be done. Hence the phenomena could not be produced by damming the blood in the sinuses.

d. It would not account for decline of erectile power with advancing years and the waning of general muscular force (they go together), for circulation is unimpaired in the parts, and secretion is abundant. Nevertheless, erectile power in the organ corresponds with the waxing and waning of muscular force, the minimum in extreme age.

e. It would not explain the *sudden* flaccidity and collapse of the organ when in the state of erection from *mental* causes, disgust, fear, etc., since *it would be utterly impossible for the blood to escape so rapidly* in order to effect it.

f. Last, but not least, it is utterly *incompetent to explain* the *anatomy in the organ*, notably the number of the *muscles* traversing the erectile tissue and forming the walls of the sinuses, together with a *muscular cylinder for inclosing them* beneath the containing sheath of fibrous and elastic tissue. Nor why the arterial capillaries should terminate in the sinuses by *funnel-shaped* openings.

The explanation is easy, embracing *all* the phenomena, as a matter of course: notably, 1. The containing sheath and trabeculæ *expand* under afflux of nervous force in the parts, the *amount* of this *determining the degree in hardness.* 2. Simultaneous with this expansile action in the erectile tissue, the arterial capillaries and trunks *expand* correspondingly for *filling* the sinuses or vascular interspaces, the suction force in the latter, together with the pressure in the arterial system, *compelling them to be filled instantaneously*, thereby producing enormous afflux of blood in the sinuses, the veins serving to carry off the excess, so as to produce a *current through the organ* and prevent reflux into the arterial system; at the same time maintaining a flow of arterial blood through the structures for evolving the force in the muscles, which is essential to their action, in this manner obviating strain and preserving vitality, and *which cannot be done in any other way;* while all the circumstances in the anatomy of the organ, *inclusive of the funnel-shaped openings of the arterial capillaries*, fall readily into line at the proper time and place, leaving no outstanding quantity refusing absorption, thereby proving the correctness of the premises. It is needless to extend the matter.

From this we proceed to other portions of the genital apparatus, making a brief survey of them also, for completing the description so far as it appertains to the special mechanics which we wish to elucidate. It will not detain us.

Concerning the Action in the Vas Deferens and the Principle it Involves.—There is no hollow organ in the body more muscular, comparatively, than the vas deferens (Fig. 205), not excepting the heart itself, the cavitary space (Fig. 39) being relatively larger, comparing part with part. Thus, the vas deferens has three great muscular layers, the inner (*c*), middle (*d*) and outer layer (*e*); the inner and outer layers composed of longitudinal, the middle of circular fibres, the muscles being thus systematically arranged. Now, then, since muscles relate to work, why all this force for the vas deferens? This also is easily answered; notably, the spermatic fluid is highly albuminous and very tenacious; moreover, has to ascend the tube *perpendicularly* (Fig. 206); hence, this degree of force for *compelling circulation.* But how compel? By contracting from below up! Very well. But this involves several important circumstances for which we have been contending, notably: 1. The fact of "automatism in the organs," which is absolutely essential to the performance of their functions; also involving local mind centres for coördinating the movements, or the same as obtains for the separate independent organism, living and sustaining existence by itself. 2. It involves the principle for producing movements in the contents by means

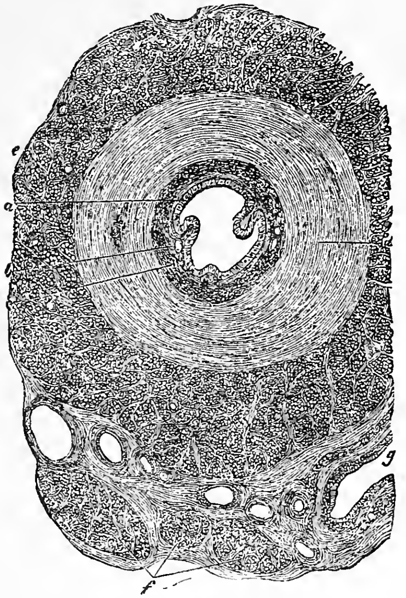


Fig. 205.—Transverse Section through the Commencing Portion of the Vas Deferens.—Klein. *a*, Epithelium ; *b*, tunica mucosa ; *c*, inner ; *d*, middle ; *e*, outer muscular layer ; *f*, bundles of the cremaster internus ; *g*, vein containing muscles in its walls.

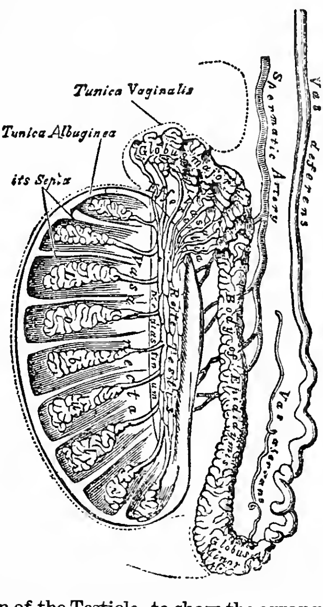


Fig. 206.—Vertical Section of the Testicle, to show the arrangement of the ducts.—Gray.

of "rhythmical changes in pressure"; therefore, is based upon pressure, which is fundamental in the organism for compelling circulation in the measure of the physiological requirements, this whether it relate to the blood itself, the juices in the structures, or the secretions in the organs.

3. It involves dualism in muscles and nervous force in order to effect the actions, or the power to produce expansion and low pressure in one portion, with simultaneous contraction and high pressure in a contiguous portion, whereby rapid movement in the contents, with obviation of friction and strain, are readily effected. A most notable circumstance in the vas deferens is the absence of valves for sustaining the fluids and obviating reflux; this, notwithstanding the ascent is perpendicular, in order to reach the vesiculæ seminales or seminal reservoirs at the base of the bladder (Fig. 207), where the fluid is stored for favorable opportunity. But the mucous membrane is in longitudinal folds, that increase in number in the ampulla, the dilated lower extremity (Fig. 206), in which the muscles are also increased, and which, of course, have relation to and correspond with the amount of work that is involved for lifting the fluid up the tube. In other words, the arrangements which obtain are similar to what occurs in the bronchial tubes, œsophagus, and stomach, for compelling movement in the contents, the folds in the mucous membrane, as in the other cases, being necessary adjustments with the action in the muscles, permitting them to expand and contract upon the contents in the measure of the requirements. A circumstance which strengthens this conclusion is the extension of the muscles into the mucous membrane, the fibres traversing it to the epithelium, so that simultaneous action in all the parts is thereby made inevitable. It will not be necessary to the argument to enter into the minutia of the beautiful and wonderful anatomy in the testis, the number, variety, and extent of the tubes (the totality said to approximate a mile in length); suffice it to say, that we have this delicate structure, the problem being to remove the secretions as fast as they are formed. And it is not to be supposed, for a single moment even, that the powerful ampulla, into which they are previously discharged (passing through a narrow muscular

portion to reach it), is forcibly distended by the tubules by compelling the fluid into it; but, on the contrary, that this expands from the sensory impressions in the mucous surface produced by the fluid, the same as the gall-bladder, urinary bladder, or the pelvis of the kidney and ureter, to which the structures are more closely approximated; till finally, the limit being reached, the receptacle contracts for compelling it out, driving it up the tube, contraction beginning from below and continuing on up the canal in a series of rhythmical expansions and contractions, similar to what occurs in the œsophagus and the body of the worms, with which the structures are homologous, the same law applying alike to all, and necessarily involving similar arrangements in the structures for producing the work. In the present case we have the great abundance of longitudinal muscles (Fig. 205, *c*, *e*) for effecting shortening in the tube, thereby diminishing the distance and reducing work in proportion, while the circular muscles (*d*) effect the rhythmical changes in pressure for compelling movement, the fluids here, as elsewhere, flowing from high to low pressure in conformity with organic law. In other words, the special adaptations relate to *work*, while force is applied in the measure of the requirements (and widely removed in function as is the local vein (*g*) coursing through the structures, can it be doubted, for a single moment, that the *muscles* in *its* walls also relate to work, contracting from below up for forcing the blood to the heart and lungs, the same law applying to both?).

The nerves are situated in the tunica adventitia, and form a pretty dense plexus—the plexus spermaticus—in a portion distant from the cremaster internus, and are derived from the spermatic and sympathetic. From the plexus spermaticus issue several smaller nerve-trunks, which *penetrate the muscular and mucous layers of the vas deferens*, where they are observed to have medullated fibres (Klein).* "In the upper portions of the vas deferens small ganglion cells are scattered in the nerve-trunks of this plexus, and also in those trunks lying more externally and running separately. In the neighborhood of the ampullæ, however, there are some quite feebly-

* Stricker's Manual of Histology. Art., Male and Female External Genital Organs; together with their Glandular Appendages, p. 584. By E. Klein.

developed ganglion cells." It will thus be seen the nervous supply to the organ for producing and coördinating the movements spoken of is abundant.

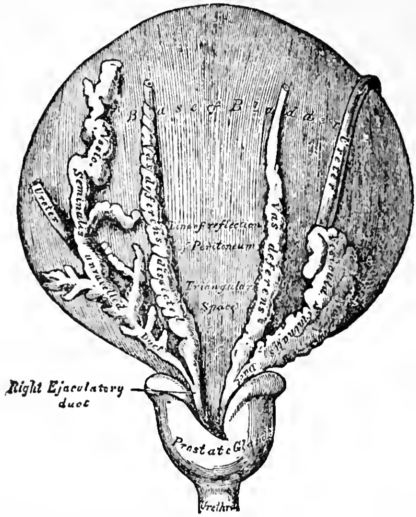


Fig. 207.—Base of the Bladder with the Vasa Deferentia and Vesiculæ Seminales.—Gray.

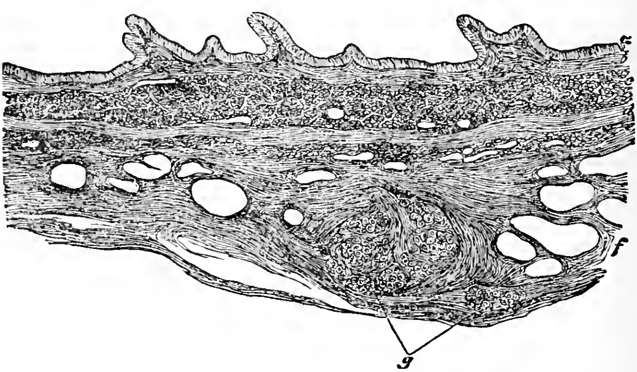


Fig. 208.—Transverse Section through the Wall of a Seminal Vesicle.—Klein. *a*, Epithelium ; *b*, mucous layer ; *c*, internal ; *d*, middle, and *e*, outer muscular coat ; *f*, adventitial tunic ; *g*, ganglia. From a child.

After the fluid has reached the seminal reservoir, it is still within the embrace of muscular and nervous force, the arrangements which obtain in the parts being fundamentally the same as in the vas deferens, only that the cavitary space is larger and the rugæ in the mucous lining more extensive (Fig. 208, *a*), the muscles (*c*, *d*, *e*) not quite so numerous, comparatively. Thence it is compelled into the urethra within the grasp of the ejaculatory muscles during the sexual orgasm, whence it is driven out of the body with great energy under the action of the special nerves. The large nervous ganglia (*g*) in the adventitia (*f*) very probably serve for coördinating the vas deferens with the action in the walls of the reservoir, as also for compelling emission, in this manner holding similar relations to the ganglia of the renal plexus for producing and coördinating the actions in the kidney, pelvis and ureter for compelling movement in the contents, the matter being one of variety simply. For present purposes it is needless to extend the matter.

Striation and Fibrillation.—There can be very little doubt that striation and fibrillation relate to electrical tension and increase of power in the muscles for producing energetic action. In the slow-moving snail, for example, there are no striated muscle fibres; but in the earthworm and leech, which possess considerable energy, the striated are freely interspersed with the non-striated muscle fibres. In the tongue of the frog, in which the action is very energetic, the muscles are strongly striated (Fig. 209).

In the slow-moving tortoise, it might be urged, the muscles are also striated! Very true; but it is no exception, and admits of easy explanation.

Thus for lifting and transporting the heavy house-like body it calls for the expenditure of considerable force, hence the striated muscles for operating the bony levers, cervical and caudal vertebræ; while the slow movements in the body result from the defective and embarrassed respiration, preventing that degree of oxygenation of the blood which is essential for rapid locomotion, the whole forming a connected movement in the very nature of things, for evolving the force which is expended in the activities, as has already been fully set forth; hence this circumstance. But in the individual members action may be made very energetic, notably, the retraction of the head and limbs when the parts are irritated, the animal doing this quickly enough. The fishes move rapidly and possess great muscular power; the muscles are striated.

In short, striation in muscles corresponds with the degrees of energy and force. This circumstance has striking illustration in the hollow viscera of the warm-blooded animals, notably the heart, terminal portions of the rectum, the ejaculatory muscles in the urethra, and the paunch of the ruminant, in which the muscles are striated, whereas in all the other viscera the muscles are of the non-striated variety, for the reason that *rapid action is not called for.* Finally, in embryognesis,

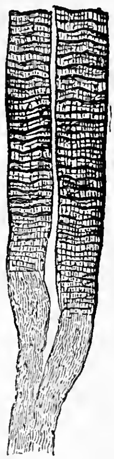


Fig. 209.—Isolated Muscular Fibre with Transverse Striæ from an Oblique Section of the Tongue of a Frog Colored with Chloride of Gold. The muscle cells are distinctly shown, and three are visible, each containing several nuclei. P. 61 (Oc., 3 ; obj. 8). Klein.

in which development repeats itself, we have the transitional stages in muscle evolution also manifesting itself, the fusiform cells of non-striated muscle fibres inosculating and undergoing progressive striation (Fig. 210). Then, again, we have experimental evidence showing electrical phenomena in the muscles during musculation, notably: 1. Every cross-section of a striated muscle represents a negative pole of an electric current, and every longitudinal section a positive pole; and it is immaterial whether the section be made with a knife or corrosive substance; while muscles which are rigid, or which have been killed without "rigor" being induced, exhibit no current. Du Bois-Reymond (Hermann). 2. That during the passing of a wave of contraction along the bundle of fibres, produced by stimulating the end, that the different spots in

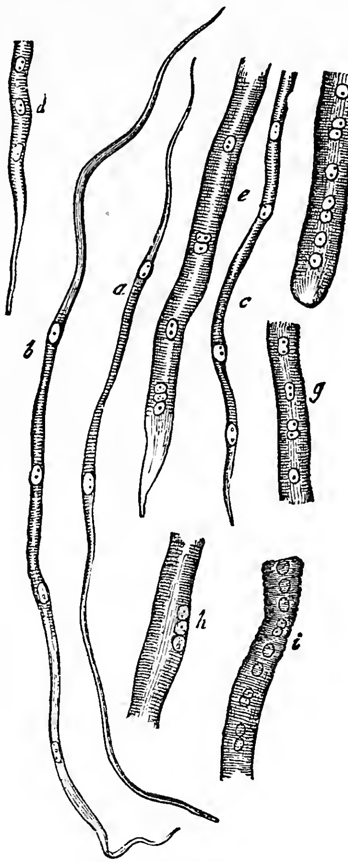


Fig. 210.—Muscular Fibres from a Fœtal Sheep in Process of Striation.—Frey. *a*, *b*, Very long fusiform cells, two or three nuclei and commencing striations ; *c*, *d*, portion of a somewhat more mature fibre, with numerous nuclei and considerable diameter ; *e*, *f*, *g*, fibres still further developed, with nuclei in the axis ; *h*, nuclei beneath the envelope ; *i*, a fibre breaking up into thick disks.

succession on the longitudinal surface become negative in reference to other spots, there being a negative wave, as it were, which travels along at the same rate as the wave of contraction, viz., about three metres per second (Bernstein*)† "At each point the negative state, which first increases and then decreases, lasts about $\frac{1}{300}$ of a second; it is entirely gone by the end of the 'latent period,' which lasts $\frac{1}{100}$ of a second. Every point in a fibre must therefore first of all undergo electrical changes before contracting (Helmholtz, Holmgren); or, in other words, the wave of muscular contraction is *immediately preceded by a negative wave*. . . . The statement that this negative wave diminishes in intensity as it travels on (Bernstein) appears only to apply to the case of muscle which is dying (Du Bois-Reymond)." Italics are added. It will thus be seen that dualism in muscles and nervous force is further corroborated by the electrical phenomena occurring in the muscles during musculation, the difference in the currents answers to the opposite molecular changes in the sarcous elements corresponding with expansion and contraction; otherwise are inexplicable. But the most striking circumstance, the fact that *the negative wave, which answers to expansion, precedes the positive*, which answers to contraction, in the muscles; the importance of which it would be difficult to overestimate, since it underlies the mechanics for effecting circulation, so that diastole in the heart, vessels, and hollow viscera is not only in conformity with the law underlying the movement in the fluids, but is further made inevitable from the very nature of the mechanics in musculation; and the two being correlated forces in nature, are readily coördinated in the animal functions by means of the nervous apparatus, which, as it were, separates and limits the two forms of electrical force, pouring one or the other into parts, so as to produce rapid expansion or contraction in the organs, as the case may be, in the exigencies in the functions; which would explain the special phenomena, while nothing else would. In short, the nervous system controls the electrical currents in the muscles; at the same time, they may be induced artificially, to wit:

* Bernstein, *Untersuchungen über d. Erregungsvorgang im Nerven und Muskelsysteme*. Heidelberg. 1871.

† Human Physiology, pp. 291–292. By L. Hermann, Professor of Physiology in the University of Zürich.

* "*In a perfectly uninjured, unskinned animal the muscles, which are in a state of rest, are entirely free from electrical currents* (Hermann†); the currents originate during the preparation of the muscle, in consequence of injurious influences acting upon their surfaces. In frogs, for instance, among other such influences, is to be mentioned the action of traces of the caustic secretion of the skin. The more these injurious influences are avoided, the greater the freedom of the muscle from electrical currents. In muscles which are at rest there are, therefore, no currents except those which are brought about by the negative electric tension of the artificial cross-section in reference to the longitudinal section" (Hermann).

Then, again: ‡In the electrical stimulation of muscles, the same laws hold as in that of nerves. Here, also, *it is only variations in currents* that produce stimulation, which, as before, proceeds, on closing, from the cathode, and, on opening, from the anode (von Bezold).

As changes take place more slowly in muscle than in nerve (as evidenced, for example, by the different degrees of rapidity with which they transmit impressions), length of duration of the stimulating current is more necessary in the former than in the latter for the production of stimulation. Hence, all induction-currents, and the more transitory constant currents, are unable to stimulate to contraction muscle deprived of its nervous connections by curare, while they are able to cause contractions in a muscle by acting upon its motor nerves (Brücke). This fact was early known to be the case with muscles, the nervous organs of which were rendered incapable of performing their functions by exhaustion, local death, pathological paralysis, etc. (von Bezold, Fick, Neumann)" The above brief excerpts will be sufficient to show the *nature* of the mechanics in musculation and nervous force. Last, but not least, we have to mention the suggestive fact in the "striæ" themselves (Figs. 211, 212), which differ essentially from each other, and placed one above the

* Hermann, *Weitere Untersuchungen über den Stoffwechsel in Muskel.* Berlin, *Verlag* v. A. Hirschwald. 1867.

† Hermann's Physiology, pp. 285–286.

‡ Ibid., pp. 339–340.

other alternately, sustain striking resemblance to what obtains in a Voltaic pile (Fig. 212, *a*, *b*), the sarcolemma inclosing them; also, that during musculation the muscle juices give an acid reaction, which corresponds with the conditions in an electric pile. Furthermore, the force which is manifested in

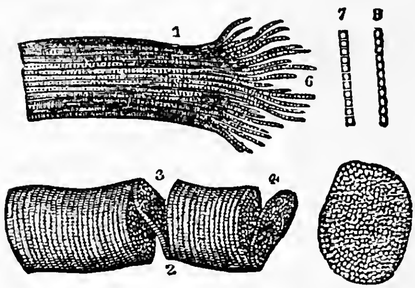


Fig. 211.—Fragments of Striped Elementary Fibres, showing a cleavage in opposite directions; magnified 300 diameters.—Todd and Bowman. *A*, longitudinal cleavage—the longitudinal and transverse lines are both seen; *c*, fibrillæ separated from one another by violence at the broken end of the fibre, and marked by transverse lines equal in width to those on the fibre; *e′*, *e″*, represent two appearances commonly presented by the separated single fibrillæ (more highly magnified); at *e′* the borders and transverse lines are all perfectly rectilinear, and the included spaces perfectly rectangular; at *e″*, the borders are scalloped, the spaces bead-like—when most distinct and definite, the fibrilla presents the former of these appearances. *B*, transverse cleavage—the longitudinal lines are scarcely visible; *a*, incomplete fracture following the opposite surfaces of a disk, which stretches across the interval and retains the two surfaces in connection—the edge and surface of this disk are seen to be minutely granular, the granules corresponding in size to the thickness of the disk, and to the distance between the faint longitudinal lines; *b*, another disk nearly detached; *b′*, detached disk, more highly magnified, showing the sarcous elements.

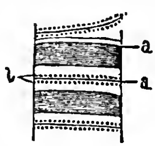


Fig. 212.—Piece of Dead Muscular Filament from the Fly.—Engelmann. *a*, *a*, Transverse disks; *b*, accessory disks.

the muscles during energetic action, sufficient to rend them asunder, is not explicable by any other theory than the one of polar action, which should increase cohesive power with afflux of electrical force; while the *progressive increase in hardness* is also not explicable by any other theory. From what has preceded, it follows: 1. That striation and fibrillation relate to increase of energy in the muscles. 2. That *two* forms of nervous force exist, which answer to the two poles in the electric current, or positive and negative; while the principle for producing motion in muscles is by changing polarity in the molecular elements, which is the function of the nervous apparatus.

The regular intervals and correspondence between the striations, the transverse markings in all the fibres occurring at the same intervals (Fig. 211), should facilitate the passage of the nervous currents and effect concert of action. The mode of nerve-terminations also throws some light upon it. Thus, the wall or sheath of the nerve-tubes (Fig. 213, *B*, 1, 1) blends with the sarcolemma (3, 3), with which it is continuous, the terminal nerve-plates (5, 5) being within the sheath of the muscle-plates, in *immediate contact with them*, the medullary substance of the nerve-tubes (4) ceasing abruptly at the site of the nerve-plate, whence electrical force is diffused through the muscle-plates by means of the granular substance which forms the principal part of the nerve-plate, and which may be regarded as distributors of electrical force, which is not by sharp points, but blunt or spherical bodies, so as to more uniformly diffuse it through the fibre, taking from the medullary substance and transmitting it through the muscle-plates. But here again comes up an important question; notably: "What becomes of the force which is *generated in the muscles*, seeing that this is the principal seat of oxidation and source of body-temperature? And while heat rapidly diffuses itself through the tissues, and is removed by the passing blood, we know that considerable proportion must undergo metamorphosis into electrical force, or similar to what obtains in the external mechanics. The importance of this question will at once be seen when contrasted with the amount of work performed by the muscles, which must have its equivalent in electrical force derived from some source, and paid for *there* and *then*.

Take a medium-sized man, or one of one hundred and fifty pounds, for example, during locomotion. He rises to the erect position and steps out—first one, then the other lėg, following each other in rapid succession in locomotion; the force which does this emanates in the brain, but having started the mechanics fairly and well, the thing runs itself from the spinal cord by what is known as "reflex action," propagated through the spinal medulla, the brain itself having little to do with it. Nor can it be imagined for a single moment even that the force for producing all this work is generated in the cord itself, the special nervous centres involved being far too inadequate for this, admitting even that the principle was right, which, for obvious reasons, can by no means be done. On the con-

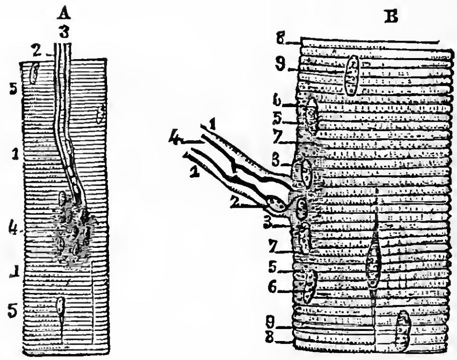


Fig. 213.—Mode of Nerve Terminations in Striated Muscles.—Rouget. A, primitive fasciculus of the thyro-hyoid muscle of the human subject, and its nerve tube ; 1, 1, primitive muscular fasciculus ; 2, nerve-tube ; 3, medullary substance of the tube, which is seen extending to the terminal plate, where it disappears ; 4, terminal plate situated beneath the sarcolemma, that is to say, between it and the elementary fibrillæ ; 5, 5, sarcolemma. B, primitive fasciculus of the intercostal muscle of the lizard, in which a nerve-tube terminates ; 1, 1, sheath of the nerve-tube ; 2, nucleus of the sheath ; 3, 3, sarcolemma becoming continuous with the sheath ; 4, medullary substance of the nerve-tube ceasing abruptly at the site of the terminal plate ; 5, 5, terminal plate ; 6, 6, nuclei of the plate ; 7, 7, granular substance which forms the principal element of the terminal plate, and which is continuous with the axis-cylinder ; 8, 8, undulations of the sarcolemma reproducing those of the fibrillæ ; 9, 9, nuclei of the sarcolemma.

trary, the work involved in transporting the body is paid for by means of oxidation of fresh materials brought into the muscles by means of respiration and circulation, which are in correspondence with the activities, so that the *force is necessarily generated in the muscles themselves;* but since the nervous apparatus produces and regulates the muscular movements, it follows that the force so generated would have to *pass into the nerves* to the spinal cord, thence *out* again into the muscles, the nerves serving to conduct it to and fro between the muscles and the ganglia, under guidance and direction of the ganglia, which determine the movements. In short, it would seem to us that the electric force generated in the tissues passes up one set of nerves, notably the so-called "sensory nerves," to the posterior columns of the cord (Fig. 214, 13), thence through the gray matter of the cornua, and out again through the anterior roots or "motor nerves" (11, 11, 11) from the anterior columns to the muscles, the nervous ganglia in the cord serving to *separate* and *limit* the currents, so as to

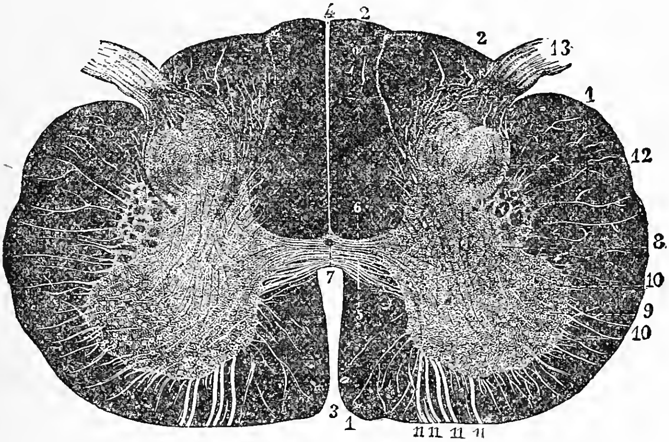


Fig. 214.—Transverse Section of the Spinal Cord at the Origin of the Fifth Pair of Cervical Nerves.—Stilling. In this figure, the white substance of the cord is represented in black, to show more clearly the limits of the gray matter ; 1, 1, antero-lateral columns ; 2, 2, posterior white columns ; 3, anterior median fissure ; 4, posterior median fissure ; 5, white commissure ; 6, gray commissure ; 7, central canal ; 8, 9, anterior cornua of gray matter ; 10, 10, group of large multipolar cells ; 11, 11, 11, anterior roots of the spinal nerves ; 12, posterior cornua of gray matter ; 13, posterior roots of the spinal nerves.

specialize, at the same time regulating, the energy of the movements in the muscles, and so as to produce expansion or contraction, as the case may be, in the exigencies in the functions; otherwise impossible. We know, too, that the nervous apparatus regulates respiration and circulation for evolving the force; that it regulates temperature by means of the vaso-motor centre, compelling the blood to the skin surface for cooling it, which would involve control of the whole mechanics, and by implication the force generated in the muscles; otherwise it would be utterly impossible to produce, regulate and coördinate the movements in the muscles, as must appear obvious. Hence, we must conclude that the force generated in the muscles passes up to the cord through one set of nerves and down again through the other set. This principle in the mechanics has further corroboration in what occurs in the case of the sympathetic ganglia (Fig. 215), in which there is similar arrangement, the nerves passing into the nerve knot through one of the converging trunks, to pass out again at another portion of the knot. Nay, further, the primitive fibrils pass into the separate cells and out again

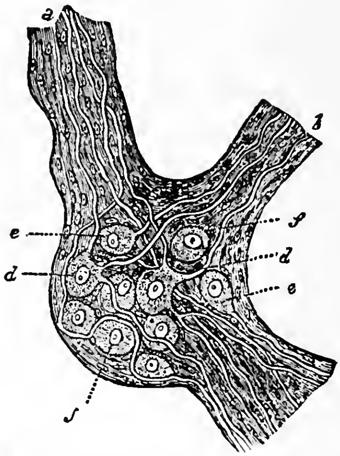


Fig. 215.—Sketch of a Mammalian Sympathetic Ganglion.—Frey. *a*, *b*, *c*, Nervous trunks; *d*, multipolar cells; *d*, some of the latter with a dividing nerve-fibre; *e*, unipolar, and *f*, apolar cells.

from the opposite side, forming multipolar cells (*d*), some of the latter (*d**) with a dividing nerve fibre. Why some cells (*e*) have only one fibre is explicable only by the hypothesis of a special form of nervous force; while the apolar cells (*f*) would refer to separating and disuniting the fluids, which are transferred to the muscles through the adjacent cells and nerves. This would explain the presence of the ganglion on the posterior root of the spinal nerves (Fig. 113, *A*), with the fibres running into and out of the cells, thereby relieving the ganglia in the spinal cord to that extent, and all sensory nerves are thus intersected by a ganglion knot. *The more numerous the fibres, the larger the ganglion;* notably the fifth and the eighth pairs, the latter possessing actually two such ganglia. And being the universal rule, it cannot be doubted for a single moment that they have important functions: in short, that they effect some change upon the nervous fluid; otherwise are meaningless. This circumstance has forcible illustration in disease of the posterior columns of the cord, notably "progressive locomotor ataxia," in which this transference of electric fluid through the nervous arc in the cord is arrested, and every movement is made directly from the brain, and necessitating the concentrated attention and volition of the patient in order to effect locomotion, which is extremely difficult, showing conclusively that the main source of force for effecting it is in the muscles themselves and the changes effected upon the fluid in the cord itself. In short, it underlies the principle in "reflex action," which means specialization in force; *not* transformation, but rather elective action, separating the two forms of electric force; otherwise, this also would be meaningless. Finally, that there is such transference of force—electric force—from the muscles and all the organs to the appellate nervous centres, would seem inevitable, from the very nature of things. Otherwise, the comprehensive arrangements for generating force would not be effective, and the maintenance of a balance utterly impossible, since every movement involves expenditure of force for producing it. One other thing in this connection, and we will bring the matter to a close; namely, the very intimate relation which the terminal nerve trunks sustain to each other in the tissues (Fig. 216), which is *not* by inosculation, as Sir Charles Bell thought (the finer work attained by means of the microscope since then making this known), but the fibres overlapping simply, which has the effect of completely separating the currents, enabling the outgoing current to pass up the sensory nerves and the in-going down the other or motor nerves, without interference, passing readily in and out of the open end of the nerves through the terminal plates for collecting it. And it must not be supposed for an instant that the brain generates the nervous force expended in the organism, though undoubtedly it contributes greatly to it; but as in the case of the spinal centres, its principal rôle is the separator and regulator of the nervous supply, and as a great reservoir, giving it out in the measure of the requirements. But if constantly drawn upon for producing the voluntary actions, as, for example, in walking over uneven ground, where every move-

Fig. 216.—Nerves of the Face, fifth and seventh pairs.—Sir Charles Bell. *A*, facial nerve ; *B*, trunk of same, dissected off and pinned out ; *C*, branch of third division of fifth nerve joining the plexus of the facial ; *D*, masseteric branch of fifth nerve ; *E*, bucco-labial branch of fifth ; *F*, branch of fifth to muscles of lower jaw ; *G*, infra-orbital nerve ; *H*, mental nerve ; *I*, infra-trochlear nerve.

ment is voluntary, or made directly from the brain, it speedily induces exhaustion, though the amount of work actually performed falls far short of that done upon even ground, where the movements are simply reflex, the brain itself but slightly involved. In fine, the generation of force involves the evolution of heat; hence we must conclude that the main source of force in the organism must be in the muscles; nor is it reasonable that the furnace should be in the brain, since nervous substance can endure less heat than any other tissue, a few degrees of blood temperature above the normal amount promptly arresting its functions, inducing prostration, insensibility and death. But the nerves terminating in the muscles as they do, the neurilemma blending with the sarcolemma, the nerve-plates in contact with the muscle-plates, we can readily understand how force may be rapidly generated without heating the brain, which is far removed. The nerve cells being the most highly organized, we can readily understand the special arrangements that obtain respecting them and their relations to the rest of the organism. The matter needs looking into. But we may rest assured that everything is as it should be for conserving the central nervous system, at once the seat of government and throne of the cell-brood.

The question which obtrudes itself, Can force be evolved by oxidation in the tissues *without* producing *corresponding* heat? has deepest import, but by reason of the nature of the problem is difficult of solution. In nerve cells heat metamorphosis into electrical force is probably instantaneous and more or less complete, else active mental processes would be fraught with peril, speedily bringing life to an end from destructive changes it would necessarily superinduce; hence, we must conclude that heat metamorphosis is more or less complete and instantaneous. But in muscle cells, etc., it is different; here an amount of heat is evolved, which cannot be regulated in any other way than by bringing the blood rapidly to the body-surface for cooling, and promoting radiation and conduction by means of diaphoresis and evaporation, at the same time reducing respiration and circulation for diminishing the importations, as has already been fully set forth; otherwise, all these arrangements would be meaningless. Moreover, it is susceptible of easy demonstration by simply inhibiting the due escape of heat from the body for maintaining a balance, which is promptly followed by fever and constitutional disturbance, and, if not relieved, would undoubtedly terminate fatally.

Indeed, one may be speedily aroused from deepest sleep by increasing the covering upon him simply, the sensations distressful in the extreme, the imperious necessity and dominant thought *to cool the blood*, disrobing with all impetuosity. So, then, we must conclude that oxidation in the body-tissues necessarily involves evolution of heat, and that the arrangements spoken of for regulating temperature are the only means for maintaining a balance; the only question being whether there is exception in nerve cells. For the reasons given, I think such is the case. While life is an "eddy" in force, the central nervous system is the heart of the eddy where force culminates, both generated in itself, and rushing into it through the nerves from every portion of the body, for evolving the movements and producing the psychical phenomena, while the rapidity of THOUGHT would of itself show that *metamorphosis is instantaneous.*

THE END.

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