In fishes the heart is single, or consists only of two compartments instead of four, and hence the circulation is single also. The gills in this class answer the intention of lungs, and the blood is sent to them for this purpose from the heart, in order to be deprived of its excess of carbon, and supplied with its deficiency of oxygen. It is not returned to the heart, as in the case of the superior animals, but is immedatiely distributed over the body by an aorta or large artery issuing from the organ of the gills. The oxygen in these animals is separated from the water instead of from the air; and for this purpose the water usually passes through the mouth before it reaches the gills: yet in the ray-tribe there is a conducting aperture on each side of the head, through which the water travels instead of through the mouth. In the lamprey it is received by seven apertures opening on each side of the head into bags, which perform the office of gills, and passes out by the same orifices, and not, as has been supposed, by a different opening said to constitute its nostril.

In the common leech there are sixteen of these orifices on each side of the belly, which answer the same purpose. In the sea-mouse (aphrodita *aculeata*) "the water passes through the lateral openings between the feet into the cavity under the muscles of the back."*

The siren possesses a singular construction, and exhibits both gills and lungs;† thus uniting the class of fishes with that of amphibials. Linnæus did not know how to arrange this curious animal, and shortly before his death formed a new order of amphibials, which he called MEANTES, for the purpose of receiving it. It ranks usually in the class of fishes.

The only air-vessels of the winged insects have a resmblance to the apertures of the lamprey, and are called stigmata. In most instances these are placed on each side of the body; and each is regarded as a distinct trachea, conducting the air, as M. Cuvier elegantly expresses it, in search of the blood, as the blood has no means of travelling in search of the air.‡ They are of various shapes and number, and are sometimes round, sometimes oval, but more generally elongated like a button-hole. In the grasshopper they are twenty-four, disposed in four distinct rows.

The membranous tube that runs along the back of insects is called by Cuvier the dorsal vessel. It discovers an alternate dilatation and contraction: and is supposed by many naturalists to be a heart, or to answer the purpose of a heart. Cuvier regards it as a mere vestige of a heart, without contractions from its own exertion, and without ramifications of any kind: the contractions being chiefly produced by the action of the muscles running along the back and sides, as also by the nerves and tracheæ, or stigmata. Scorpions and spiders have a proper heart; and as the term *insects* is now confined by M. Cuvier and M. Marcel de Serres to those that have only this dorsal vessel, or imperfect heart, the two former genera are struck out of the list of insects as given by Linnæus.§

This organ differs very considerably in its structure and degree of simplicity in moluscous animals. The heart of the teredo has two auricles and two ventricles; that of the oyster one auricle and one ventricle. In the muscle the heart is not, strictly speaking, divided into an auricle and ventricle, but rather consists of an oval bag, through the middle of which the lower portion of the intestine passes. Two veins from the gills open into the heart, one on each side, which may be considered as the auricles.

In several of the crustaceous insects of Linnæus, as, for example, the monoculus and craw-fish, the stigmata converge into a cluster, so as to form gills; which in some species are found seated in the claws, and in other species under the tail. These have for the most part a small single heart, and

* Sir E. Home, Phil. Trans. 1815, p. 260.

† Home's Life of Hunter, prefixed to Hunter's Treatise on the Blood, Inflammation, &c. p. xli.

‡ En un mot, le sang ne pouvant aller chercher l'air, c'est l'air qui va chercher le sang. Leçons d'Anat. Comp. i. 23, Sect. 2, Art. 5.

§ See M. Marcel de Serres' Statement, Tilloch's Journal, vol. xliv. p. 148; and especially Thomson's Annals of Phil. No. xxiii. p. 347, 348. 350. 354.

consequently a single circulation, the course of which, however, is directly the reverse of that pursued in fishes; for the heart in the present instance propels the blood through the body, and the gills receive it, and propel it to the heart. This is also the case in the snail, slug, and many other soft-bodied worms, which possess a gill in the neck, consisting of a single aperture, which it can open and shut at pleasure. Yet with a singular kind of apparent sportiveness, the cuttle-fish is possessed of three distinct hearts, which is one more than is allotted to mankind, in whom this organ is only double.

In zoophytes we are in great ignorance both as to their sanguineous and respiratory functions. That they stand in need of oxygen, and even of nitrogen, has been sufficiently determined by Sir H. Davy; as it has also that they absorb their oxygen and nitrogen, as fishes do, from the water which holds these gases in solution. Their nutrition appears to be effected by an immediate derivation of the nutritive fluid from their interior cavity into the gelatinous substance of their body.*

Hence then the respiratory organs of the animal kingdom may be divided into three classes; lungs, gills, and holes or stigmata: each of the three classes exhibits a great variety in its form, but the office in which they are employed is the same. Animals of every kind must be supplied with air, or rather with oxygen, however they may differ in other respects in tenacity of life; for a vacuum, or a medium deprived of oxygen, kills them equally. Snails and slugs corked up in small bottles have been found to live till they had exhausted the air of every particle of oxygen, and to die immediately afterward: and frogs and land-turtles, which are well known to survive the loss of the spinal marrow for months, and that of the head or heart for several days, die almost instantly on exposure to a vacuum.†

Connected with this general subject, there is still an important question to be resolved, and which has greatly occupied the attention of physiologists for the last fifty years.

Mediately or immediately, almost all animal nutriment, and, consequently, almost all animal organization, is derived from a vegetable source. The blade of grass becomes a muscular fibre, and the root of a yam or a potato a human brain. What, then, is that wonderful process which assimilates substances in themselves so unlike; that converts the vegetable into an animal form, and endows it with animal powers?

Now to be able to reply succinctly to this question, it is necessary first of all to inquire into the chief feature in which animal and vegetable substances agree, and the chief feature in which they differ.

Animals and vegetables, then, agree in their equal necessity of extracting a certain sweet and saccharine fluid, as the basis of their support, from whatever substances may for this purpose be applied to their respective organs of digestion. Animal chyle and vegetable sap make a very close approach to each other in their constituent principles as well as in their external appearance. In this respect plants and animals agree. They disagree, inasmuch as animal substances possess a very large proportion of azote, with a small comparative proportion of carbon; while vegetable substances, on the contrary, possess a very large proportion of carbon, with a small comparative proportion of azote. And it is hence obvious, that vegetable matter can only be assimilated to animal by parting with its excess of carbon, and filling up its deficiency of azote.

Vegetable substances, then, part first of all with a considerable portion of their excess of carbon in the stomach and intestinal canal, during the process of digestion; a certain quantity of the carbon detaching a certain quantity of the oxygen existing in these organs, as an elementary part of the air or water they contain, in consequence of its closer affinity to oxygen, and producing carbonic acid gas; a fact which has been clearly ascertained by a variety of experiments by M. Jurine of Geneva. A surplus of carbon, however, still enters the animal system through the medium of the lacteals, and continues

* Blumenbach, § 167.

† See Encyclop. Brit. art. Physiol. p. 679.

to circulate with the chyle, or the blood, till it reaches the lungs. Here again a certain portion of carbon is perpetually parted with upon every expiration, in the form of carbonic vapour, according to Mr. Ellis, but according to Sir H. Davy and others, in that of carbonic gas, in consequence of its union with a part of the oxygen introduced into the lungs with every returning inspiration;* while the excess that yet remains is carried off by the skin, in consequence of its contact with atmospheric air: a fact put beyond all doubt by the experiments and observations of M. Jurine, although on a superficial view, opposed by a few experiments of Mr. Ingenhouz,† and obvious to every one, from the well-known circumstance that the purest linen, upon the purest skin, in the purest atmosphere, soon becomes discoloured.

In this way, then, and by this triple co-operation of the stomach, the lungs, and the skin, vegetable matter, in its conversion into animal, parts with the whole of its excess of carbon.

Its deficiency of azote becomes supplied in a twofold method: first, at the lungs; also, by the process of respiration, as should appear from the concurrent experiments of Dr. Priestley and Sir H. Davy,‡ which agree in showing that a larger portion of azote is inhaled upon every inspiration than is returned by every succeeding expiration; in consequence of which the portion retained in the lungs seems to enter into the system, in the same manner as the retained oxygen, and perhaps in conjunction with it; while, in union with this economy of the lungs, the skin also absorbs a considerable quantity of azote, and thus completes the supply that is necessary for the animalization of vegetable food:§ evincing hereby a double consent of action in these two organs, and giving us some insight into the mode by which insects and worms, which are totally destitute of lungs, are capable of employing the skin as a substitute for lungs, by breathing through the spiracles existing in the skin for this purpose, or merely through the common pores of the skin, without any such additional mechanism. It is by this mode, also, that respiration takes place through the whole vegetable world, offering us another instance of resemblance to many parts of the animal; in consequence of which, insects, worms, and the leaves of vegetables equally perish by being smeared over with oil, or any other viscous fluid that obstructs their cutaneous orifices.

But to complete the great circle of universal action, and to preserve the important balance of nature in a state of equipoise, it is necessary, also, to inquire by what means animal matter is reconverted into vegetable, so as to afford to plants the same basis of nutriment which plants have previously afforded to animals?

Now this is for the most part obtained by the process of PUTREFACTION, or a return of the constituent principles of animal matter to their original affinities, from which they have been inflected by the superior control of the vital principle, so long as it inhabited the animal frame, and coerced into other combinations and productions.‖ Putrefaction is, therefore, to be regarded as a very important link in the great chain of universal life and harmony.

The constituent principles of animal matter we have already enumerated: they are most of them compound substances, and fall back into their respective primordia as the putrefactive process sets them at liberty. This process commences among the constituent gases; and it is only necessary to notice the respective changes that take place in this quarter, as every other change is an induced result.

* See Sir H. Davy's Researches Chemical and Philosophical, &c.; and Mémoire sur la Chaleur, par MM. Lavoisier et De la Place. Mem. de l'Acad. De la Combustion, &c.

† Essaie de Théorie sur l'Animalization et l'Assimilation des Alimens, &c. Annales de Chimie, tom. ii.

‡ See Davy's Researches Chemical and Philosophical, &c.; and Priestley's Experiments and Observations on different Kinds of Air, vol. iii.

§ M. Jurine is chiefly entitled to the honour of this discovery: his experiments coincide with several of Dr. Priestley's results, and have been since confirmed by other experiments of MM. Lavoisier and Fourcroy. See Premier Mémoire sur la Transpiration des Animaux, par A. Seguin et Lavoisier, 1792; and compare with M. Hassenfratz's Mémoire sur la Combinaison de l'Oxygen, &c. Acad. des Scien. 1791.

‖ It should hence appear, that putrefaction is the only positive criterion of death, or the total cessation of the principle of life. Galvanism has, indeed, been advanced as a decisive proof of the same by Behrends and Crevę; but Humboldt has sufficiently shown its insecurity as an infallible test.

Of these gases I have already observed, that azote or nitrogen is by far the largest in respect of quantity, and it appears also to be by far the most active. Hence, on the cessation of the vital principle, the azotic corpuscles very speedily make an advance towards those of oxygen, and generally in the softer and more fluid parts of the system; the control of the vital principle being here looser and less powerfully exerted. A union readily takes place between the two, and thus combined they fly off in the form of nitric acid; while at the same time another portion of azote combines with some portion of hydrogen, and escapes in the form of ammonia or volatile alkali. A spontaneous decomposition having thus commenced, all the other component parts of the lifeless machine are set at liberty, and fly off either separately or in different combinations; during which series of actions, from the union of hydrogen with carbon, and especially if conjoined at the same time with some portion of phosphorus or sulphur, is thrown forth that offensive aura which is the peculiar characteristic of the putrefactive process, and which, according to the particular mode in which the different elementary substances combine, constitutes the fetor that escapes from putrid fishes, rotten eggs, or any other decomposing animal substances.

In this manner, then, by simple, binary, or ternary attractions and combinations, the whole of the substance constituting the animal system, when destitute of its vital principle, flies off progressively to convey new pabulum to the world of vegetation; and nothing is left behind but lime or the earth of bones, and soil or the earth of vegetables: the former furnishing plants with a perpetual stimulus by the eagerness with which it imbibes oxygen, and the latter offering them a food ready prepared for their digestive organs.

In order, however, that putrefaction should take place, it is necessary that certain accessaries to such a process should be present, without which putrefaction will never follow. Of these the chief are rest, air, moisture, and heat.

Without REST the putrefactive process in no instance takes place readily, and in some instances does not take place at all: for animal flesh, when exposed to the perpetual action of running water, is often found converted into one common mass of fat or spermaceti, as I shall presently have occasion to observe more minutely.

AIR must necessarily coexist, for putrefaction can never be induced in a vacuum. Yet we must not only have air, but genuine atmospheric air; or, in other words, the surrounding medium must be compounded of the gases which constitute the air of the atmosphere, and in their just proportions. To prove this, it is sufficient to mention that dead animal substance has been exposed by M. Morveau,* and other chemists, for five or six years in confined vessels, to the action of simple nitrogen, hydrogen, carbon, and various other gases, without any change that can be entitled to the appellation of putrefaction.

There must also be MOISTURE; for as I have already observed, putrefaction commences in the softer and more fluid parts of the animal system. On this account it rarely occurs during a sere harmattan or drying wind of any kind, and never in a frost so severe as to destroy all moisture whatsoever; the power of frost exercising quite as effectual a control over the elements of animal matter as the living principle itself.

For the same reason there must be HEAT; since in the total absence of heat frost must necessarily take place, together with an entire privation of moisture. On this last account, again, the heat made use of must only be to a certain extent, as about 65½° of Fahrenheit; for, if carried much higher, the rarefaction which takes place in the surrounding atmosphere will induce an ascent of all the fluids in the animal substance towards its surface; whence they will fly off in the form of vapour, before the putrefying process can have had time to commence, and leave nothing behind but dry indurated materials, incapable of putrefaction because destitute of all moisture. Our dinner-

* See Mémoire sur la Nature des Fluides élastiques aëriformes, qui se dégagent de quelques Matières animales, &c. par M. Lavoisier, Mém. de l'Acad. 1782; as also, M. Brugnatelli's paper in Crell's Chemical Annals for 1708, Ueber die Faulung thierischer theile in verschieden Luftarten.

tables too often supply us with instances of this fact, in dishes of roast or boiled meat too long exposed to the action of the fire, and hence reduced to juiceless and ragged fibres, totally devoid of nutriment, and capable of keeping for weeks or months, without betraying any putrefactive indication.

In like manner, when bodies are buried beneath the hot and arid sands of Egypt or Arabia, with a sultry sun shining, almost without ceasing, upon the sandy surface, the heat hereby produced is so considerable as to raise the whole of the fluids of the animal system to the cuticle, whence they are immediately and voraciously drunk up by the bibulous sands that surround it; or, piercing their interstices, are thrown off into the atmosphere in the form of insensible vapour. In consequence of which, when a body thus buried is dug up a few weeks after its interment, instead of being converted into its original elements, it is found changed into a natural mummy, altogether as hard, and as capable of preservation as any artificial mummy, prepared with the costliest septics employed on such occasions.

When dead animal organs are deposited in situations in which only a very small portion of atmospheric air is capable of having access to them, a change indeed takes place, but of a very different description from that of putrefaction, and which is of a most curious and extraordinary nature. For in such cases the animal organs, instead of being converted into their original elements, are transmuted into fat, wax, or spermaceti; or rather into a substance *sui generis*, and possessing a middle nature between that of the two former, whence the French chemists have given it the appellation of ADIPOCIRE; a term not strictly classical, but for which the chemists of our own country have not hitherto substituted any other.

This result is observed, not unfrequently, in bodies that are drowned, and rendered incapable of rising to the surface of the water; for in such a situation but very little air, and, consequently, very little oxygen, can reach them from the external atmosphere. And it is to these circumstances we ought, perhaps, to resolve the singular appearance in the body of Colonel Pollen, who was wrecked a few years ago in the Baltic Sea, near Memel, and within sight of the coast; and whose corpse was six months afterward thrown on shore, with the features of the face so little varied, that every one of his acquaintance recognised him at the first glance. The body had probably been entangled in the submarine sands on first sinking, and been retained in this situation for months, cut off from that exposure to external air which is absolutely necessary in all cases of putrefaction properly so called. A similar conversion into wax-fat was observed also in 1786 and 1787, on opening the *fosses communes*, or common burial pits in the churchyards of the Innocents at Paris, for the purpose of laying the foundation of a new pile of buildings. For the bodies that on this occasion were dug up, instead of being dissolved into their elementary corpuscles, were found for the most part converted into this very substance of waxy fat or adipocire. The populace were alarmed at the phenomenon, and the chemists were applied to for an explanation. M. Fourcroy, among others, attended upon this occasion; and his solution, which will apply to all cases of a similar kind, referred the whole to the extreme difficulty with which external air had obtained any communication with the inhumed bodies, in consequence of the close adaptation of coffin to coffin, and the compactness with which every pit had been filled up. Difficult, however, as this communication must have been, he conceived that, from the natural elasticity of atmospheric air, some small portion of it had still entered, conveying, perhaps, just oxygen enough to excite the new action of decomposition. This having commenced, the constituent oxygen of the dead animal organs would itself be progressively disengaged, and rapaciously laid hold of by all the other constituent principles, from their strong and general affinity to it. During this gradual evolution, there can be little doubt that the greater part of it would be seized by the predominant azote, a very considerable part by the carbon, and the rest by the hydrogen; and the result would be, upon the total but very slow escape of the constituent and disengaged oxygen, that the whole or nearly the whole of the azote, a considerable portion of the carbon, and a certain quantity of the hydrogen, would escape also —leaving behind the remainder of the carbon and the hydrogen, now incapable of escape from the want of oxygen to give wings to their flight, together with the residual earth of the animal machine.

But hydrogen and carbon, though in this case incapable of sublimation for want of oxygen, would still, from their mutual attraction and juxtaposition, enter into a new union and produce a new result, and this result must necessarily be fat; for fat is nothing else than a combination, in given proportions, of carbon and hydrogen. And hence, whatever the respective animal organs of the bodies deposited in these burial caverns may have antecedently consisted of, whether muscles, ligament, tendon, skin, or cellular substance, when thus deprived of their oxygen and azote, the whole must of necessity be converted into fat. Pure and genuine fat it would have been, provided there had been nothing left behind but mere carbon and hydrogen, and in their respective proportions for the formation of fat; but as we can scarcely conceive such proportions could take place, or that every corpuscle of the azote could be carried off before the total escape of the oxygen, many parts of it must necessarily have assumed a flaky, soapy, or waxy appearance, from the union of the azote left behind with some portion of the hydrogen, and the consequent production of ammonia or volatile alkali; since, by an intermixture of alkali with fat, every one knows that soap or a saponaceous substance is uniformly produced.

But, excepting in situations of this kind, in reality, in every situation in which dead animal matter, destitute of its living principle, is exposed to the usual auxiliaries of putrefaction, putrefaction will necessarily ensue, and the balance will be fairly maintained:—the common elements of vital organization will be set at liberty to commence a new career, and the animal world will restore to the vegetable the whole which it has antecedently derived from it.

In this manner is it, then, that nature, or rather that the GOD of nature, is for ever unfolding that simple but beautiful round of action, that circle of eternal motion, in which every link maintains its relative importance, and the happiness of every part flows from the harmony of the whole. Can we, then, do better than conclude with the correct and spirited apostrophe of one of our most celebrated poets?—

Look round the world! behold the chain of love
Combining all below and all above.
See plastic nature working to this end;
Atoms to atoms—clods to crystals tend.*
See dying vegetables life sustain;
See life, dissolving, vegetate again.—
All serv'd, all serving, nothing stands alone,
The chain holds on, and where it ends unknown.

LECTURE XIV.

ON THE PROCESSES OF ASSIMILATION AND NUTRITION; AND THE CURIOUS EFFECTS TO WHICH THEY LEAD.

WE have traced out in our preceding studies something of the means by which form, and magnitude, and motion are produced in the inorganized world:—how the various substances that surround us combine and separate, vanish from us and reappear, and, in the multifarious processes they undergo, give rise to new products by new and perpetually shifting involutions. We have farther traced an outline of the means by which organized matter is capable of building up the curious structures of plants and animals; how the chief func-

* This line is altered to answer the present purpose in a better manner.