THE

CHEMICAL AND PHYSIOLOGICAL BALANCE

OF

ORGANIC NATURE.

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ORGANIC NATURE:

AN ESSAY,

BY

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PREFACE.

There have been in Chemistry and all experimental sciences, epochs in which the accumulating facts of many years have led to great discoveries. Such were the periods of the separation of the atmospheric gasses, the synthesis of water, the establishment of a chemical nomenclature, the analysis of alkaline and earthy bodies, the process of organic analysis by Liebig. These events are important to the progress of science by interesting large numbers of persons not devoted to its cultivation. For a time scientific facts intrude even into the discussions of fashionable assemblies, because of their novelty ; but hitherto they have made little permanent impression.

A new epoch has arrived in Chemistry. The functions of organized bodies, the laws of life, are the subjects of investigation. It is destined to be far more brilliant and important than any which has gone before. It does not promise to satisfy the curiosity of the people only, but to unfold truths of the most serious consequence to our species. Medicine, Agriculture, Political Economy, will *per force* be illustrated by Chemistry. Hitherto the mass of mankind have been amused by remarkable discoveries ; we have now reached a period when they are to be controlled by them.

Liebig's Animal and Vegetable Chemistry have awakened the attention of many ; they are the earliest of a series of publications for which the labors of Dumas and Boussingault have furnished the most valuable materials. In this little work those philosophers have expressed their own doctrines, prefatory to a more detailed practical treatise.

In the words of M. Dumas, this essay " presents a variety of new views, calculated to supply general physiology, medicine, and agriculture, with grounds upon which the study of the chemical phenomena that take place in organized beings may be advantageously pursued.

" We feel intimately persuaded that the considerations embraced in this Essay may henceforth be made to bear upon many of the most important questions of public economy.—Not that we have given such development to our principles as makes them always obviously applicable to matters of detail,—time alone will admit our doing this ; but we apprehend that our views, generally speaking, are so stated, as to show conclusions interesting to the legislator and public economist in connexion with agriculture in general, and in particular with the growth of corn, and of sugar, the feeding of cattle, and above all, with that question,—of such vital importance,—

the maintenance of the laboring classes of mankind."

The opinion of scientific Europe has been freely canvassed and expressed in respect to the views of the authors. They were first pronounced by M. Dumas in the Ecole de Mêdécine, where their value was at once recognized. The leading journals printed them with applause, and although but four years have elapsed, the essay has passed to a third edition, and been translated from the French into English, German, Spanish and Italian.

To attempt to exalt the reputation of Dumas and Boussingault is supererogatory. The greatest liberty taken with the work is the omission of their preface, part of which is incorporated herein. All additions bear the editor's initials.

D. P. Gardner.

New York, May 15*th*, 1844.

PROGRAMME OF THE DISCOURSE.

AN ANIMAL is AN APPARATUS OF COMBUSTION;	A VEGETABLE is AN APPARATUS OF REDUCTION;
Possesses the faculty of Locomotion;	Is fixed;
Burns Carbon, Hydrogen, Ammonium;	Reduces Carbon, Hydrogen, Ammonium;
Exhales Carbonic Acid, Water, Oxyde of Ammonium, Azote;	Fixes Carbonic Acid, Water, Oxide of Ammonium, Azote;
Consumes Oxygen, Neutral Azotised matters, Fatty matters, Amylaceous matters, sugars, gums;	Produces Oxygen, Neutral Azotised matters, Fatty matters, Amylaceous matters, sugars, gums;
Produces Heat, Electricity;	Absorbs Heat, Abstracts Electricity;
Restores its elements to the air or to the earth;	Derives its elements from the air or from the earth;
Transforms organized matters into mineral matters.	Transforms mineral matters into organic matters.

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ORGANIC NATURE:

A LECTURE DELIVERED BY M. DUMAS,

On concluding his Course, at the Ecole de Medecine.

GENTLEMEN,

AMONG the phenomena of life, whose deepest mysteries you are called upon to fathom, there are some which obviously connect themselves with the forces that material nature herself brings into play, others which emanate from a source higher and less accessible to even the boldest flights of thought.

It is not among my duties with you to scan with curious eyes that part of your studies which has reference to the due or jarring exercise of the instincts of life. Still less have I had occasion to speak of those noble faculties by which the human mind, mastering all that surrounds it, breaking down all barriers, bending all the forces of nature to its wants, has, by degrees, made empire of the earth, of the ocean, of the whole globe which we inhabit,—a vast domain, in sooth, yet one which our aspirations, our presentiments, perchance, still lead us often to regard but as a prison.

To others, more fortunate, the pleasing task of initiating you in studies so grave as these, of unfolding to you the noble thoughts to which such subjects lead; my task, more humble, is limited to the field that embraces the physical phenomena of life; and even among these there are many for which we have been able to find no place in our Course.

We have, in fact, had our attention mainly directed to the part which matter plays in the production and growth of organized beings, in the accomplishment of the phenomena of their daily existence, in the changes which their bodies undergo after their death; and we have found these subjects amply sufficient to engage us through the present year.

I.

Vegetables, animals, man, contain matter in their composition. Whence comes it? What part does it play in their tissues and in the fluids which bathe them? What becomes of it when death breaks the chain by which its various parts and forms were so closely conjoined?

Such are the questions which we approached with so much diffidence at first, inasmuch as to answer them might have been beyond the powers of modern chemistry; but, by and by, with greater confidence, when we felt, by the silent and secret accord of our minds, that our footing was sure, and as we saw that the wished-for goal was gradually approached in spite of every obstacle. If, from this labor, at which you have been spectators,—in which, I should rather say, you have lent your aid,—if from this scientific effort some general views have arisen, some simple and comprehensive formulæ have appeared, I feel that I ought to make myself the historian of these:—but allow me the pleasure of adding that they also belong to you, that they belong to our school, the spirit of which has, of late, been unfolding itself upon this new ground. It is the zeal, indeed, with which you have followed me in this career that has given me the strength to pursue it; it is the lively interest you have taken that has sustained me, your curiosity which has awakened mine, your confidence which has made me see,—which assures me at this moment, that we are in the path of truth.

These words will bring to your minds with what amazement we discovered together, that of all the elements of modern chemistry, organic nature made use of but three or four; that of those vegetable and animal substances which are now multiplied almost to infinity, general physiology requires no more than some ten or twelve species; and that all the phenomena of life, so complex in appearance, may be referred in their essence to a single general formula, so simple, that in a few words everything seems stated, everything having been recalled to mind, every thing foreseen.

Have we not, in fact, found, by a multitude of results, that an animal, in a chemical point of view, constitutes a true apparatus of combustion, by which carbonaceous matters, burnt incessantly, are returned to the atmosphere in the shape of carbonic acid; in which hydrogen, burnt incessantly, is returned as water; whence, in fine, free azote is ceaselessly exhaled in the breath, and, in the state of oxide of ammonium, is thrown off in the urine?

From the animal kingdom, therefore, as a whole, carbonic acid, watery vapor, and azote or oxide of ammonium, are continually escaping,—simple substances, and few in number, the formation of which is intimately connected with the history of the atmosphere itself.

Have we not, on the other hand, found that vegetables, in their natural and healthy state, decompose carbonic acid incessantly, fixing the carbon, and setting free the oxygen; that they decompose water, seizing on its hydrogen, and disengaging its oxygen as before; lastly, that they either abstract azote directly from the air, or take it indirectly from oxide of ammonium, or nitric acid; thus acting, in every particular, inversely or in opposition to animals? If the animal kingdom constitute an immense apparatus of combustion, the vegetable kingdom, in its turn, constitutes an immense apparatus of reduction, where carbonic acid decompounded leaves its carbon, water its hydrogen, and oxide of ammonium and nitric acid their ammonium or their azote.

If animals incessantly produce carbonic acid, water, azote, and oxide of ammonium, vegetables consequently consume, without cessation, oxide of ammonium, azote, water, and carbonic acid. What the one gives to the atmosphere, that the other takes from it; so that, surveying these facts from the loftiest point of view, and in connection with the physics of the globe, it would be imperative on us to say that, in so far as their truly organic elements are concerned, plants and animals are the OFFSPRING OF THE AIR; that they are but condensed or consolidated air; and that, to form a true and accurate idea of the constitution of the atmosphere at the epochs which preceded the birth of organized beings, it would be necessary to restore to it, by calculation, the whole of the carbonic acid and azote, the elements of which were appropriated by vegetables and animals when they appeared.

Vegetables and animals, therefore, come from the atmosphere, and return to it again; they are true dependants of the air.

Vegetables, then, assume from the atmosphere the elements which animals exhale into it; viz. carbon, hydrogen, and azote, or rather carbonic acid, water, and ammonia.

But how do animals procure the elements which they give to the atmosphere? Let us inquire particularly into this point. Now it is impossible to contemplate, without admiration, the sublime simplicity of the laws of nature here, as everywhere! Animals always derive their elements primarily from vegetables.

We have found, in fact, by results beyond the reach of question, that animals do not create any of the truly organic substances, but that they consume or destroy them; that vegetables, on the contrary, habitually create these substances, and that they destroy but few, and this only for particular and determinate ends.

It is in the vegetable kingdom, therefore, that the great elaboratory of organic life is found; it is there that both vegetable and animal substances are compounded: and they are all alike formed at the cost of the atmosphere.

From vegetables these substances pass ready-formed into the bodies of herbivorous animals, which destroy one portion of them, and store up another in their tissues.

From herbivorous animals they pass ready-formed into the bodies of carnivorous animals, which destroy or lay them up, according to their wants.

Finally, during the life of these animals, or after their death, the organic substances in question return to the atmosphere from whence they originally came, in proportion as they are destroyed.

Thus is the mysterious circle of organic life upon the surface of the globe completed and maintained! The air contains or engenders the oxidized substances required,—carbonic acid, water, nitric acid, and ammonia. Vegetables, true-reducing apparatus, seize upon the radicals of these, carbon, hydrogen, azote, ammonium; and with them, they fashion all the variety of organic or organizable matters which they supply to animals. Animals, again, true apparatus of combustion, reproduce from them carbonic acid, water, oxide of ammonium, and azotic or nitric acid, which return to the air to reproduce the same phenomena to the end of time.

And if, to this picture, already so striking by its simplicity and grandeur, we add the indubitable part performed by the solar light, which is alone possessed of power to bring into play this immense, this unparalleled apparatus, constituted by the vegetable kingdom, in which the oxidized products of the atmosphere are subjected to reduction, it is impossible not to be struck with the import of these words of Lavoisier: "Organization, sensation, voluntary motion, life, only exist on the surface of the earth and in places exposed to light. It might be said, indeed, that the fable of Prometheus was the expression of a philosophical truth, which had not escaped the penetration of the ancients. Without light, nature were without life and without soul: a beneficent God, in shedding light over creation, strewed the surface of the earth with organization, with sensation, and with thought!"

These words are as true as they are eloquent. If sensation and thought, if the noblest faculties of the soul and the understanding require a material vesture for their manifestation, vegetables are the laborers charged with the task of building it up, and from elements which they derive from the air, and elaborate under the influence of the light which the sun, its inexhaustible fountain, pours in ceaseless floods upon the earth.

And as if all in these grand phenomena were destined to be associated with causes which should appear the most remote, we may here observe upon the sources whence the oxide of ammonium and azotic acid, from which vegetables derive a portion of their food, are themselves derived. They are, in fact, produced upon the grand scale by the action of those magnificent electric sparks that dart from the storm-cloud, and, furrowing vast fields of air, engender in their course the nitrate of ammonia, which analysis discovers in the thunder-shower.

As it is from the mouths of volcanoes, then, whose convulsions so often make the crust of our globe to tremble, that the principal food of plants, carbonic acid, is incessantly poured out; so is it from the atmosphere on fire with lightnings, from the bosom of the tempest, that the second and scarcely less indispensable aliment of plants, nitrate of ammonia, is showered down for their behoof.

Might it not be said, that we have here a remembrancer of that chaos mentioned in the Bible, of those periods of tumults and disorders which preceded the appearance of order and organization upon earth?

For, scarcely are carbonic acid and nitrate of ammonia formed, than a calmer, though not less energetic force begins to act upon them for new purposes: this force is LIGHT. By the agency of light, carbonic acid yields up its carbon, water its hydrogen, nitrate of ammonia its nitrogen. These elements combine, organic matters are formed, and the earth is clothed with verdure.

It is, in fact, from absorbing incessantly a true force, the light and heat of the sun, that vegetables perform their functions, and produce the vast quantities of organized or organic matter which are the destined food of the animal creation.

And then, if we add that on their side animals engender heat and elicit force in consuming that which vegetables have produced and slowly accumulated, would it not seem that the ultimate intent of all these phenomena, that their most general or comprehensive formula was laid open to our view?

The atmosphere presents itself to us as including the primary material of all organization. Volcanoes and thunder-storms meet us as the laboratories in which are compounded the carbonic acid and nitrate of ammonia which life requires for its manifestation and extension.

Light arrives, and with the concurrence of carbonic acid and nitrate of ammonia, the vegetable world, the grand producer of organic matter, is developed. Plants farther absorb the chemical force which reaches them from the sun, and enables them to decompose carbonic acid, water and ammonia; plants are embodiments of a reducing power, of greater virtue than any other that is known, for no other will decompose carbonic acid in the cold.

Then come animals, consumers of matter, and producers of heat and of force, true instruments of combustion. It is in them, unquestionably, that organized matter acquires what may be called its highest expression. But it is not without detriment to itself that it becomes the instrument of sensation and of thought. In this new capacity organized matter is burnt; and in giving out the heat, or electricity, which constitutes and is a measure of our force, it is destroyed and returned to the atmosphere, from whence it had originally come.

The atmosphere, therefore, is the mysterious link that connects the animal with the vegetable, the vegetable with the animal kingdom.

Vegetables absorb caloric, and store up the matter which they have had the power to fashion; Animals, again, through which, it may be said, that organic matter merely passes, burn or consume it, to produce by its means the heat and various forces which their motions turn to profit.

Allow me here, borrowing a simile from modern science, of grandeur somewhat commensurate with these grand phenomena, to liken the vegetable world of the present age, the true store-house whence animal life is fed, to that other magazine of carbon which we possess in our primeval beds of coal, and which, burnt under the genius of Papin and of Watt, produces carbonic acid, water, heat, motion,—we might almost add, life and intelligence.

In our eyes, therefore, the vegetable world constitutes an immense magazine of combustible matter, destined to be consumed by the animal world, and in which this last finds the source of the heat and locomotive powers which it turns to account.

A common link between the two organic kingdoms, then—the atmosphere ; four elements in vegetables and in animals—carbon, hydrogen, azote, and oxygen ; a very limited number of forms under which vegetables lay these up, under which animals consume them ; a few laws of great simplicity, which their enchainment simplifies still more : such is the picture of organic chemistry in the abstract, which results from our studies of the present session.

You, doubtless, felt as I did myself, that, before finally separating, it would be well for us to fall back upon ourselves, as it were, to make sure of our data, and to contrast and review our opinions, in which are involved the explanation and development of the grand principles which we have announced; finally, that it would be advantageous to you in your future studies, to have in writing, and in precise terms, the expression of views which have been engendered in part under the stimulus of your regards, and therefore presented with the hesitation which so frequently accompanies the first cast of our thoughts.

II.

Inasmuch as all the phenomena of life are carried on upon substances having for their basis carbon, hydrogen, nitrogen, and oxygen; inasmuch as these substances pass from the animal to the vegetable kingdom, through intermediate forms—carbonic acid, water, and oxide of ammonium; since, in fine, the air is the source whence the vegetable world is nourished, is the reservoir within whose bosom the animal world is annihilated, we are naturally led to study these different bodies from the particular point of view of general physiology.

Composition of Water (1).—Water is incessantly formed and decomposed in the bodies of animals and vegetables. With a view to the due appreciation of what is to follow, let us inquire into its composition. Direct experiments,—the combustion of hydrogen in oxygen gas,—in which I have produced more than a quart of artificial water, render it extremely probable that water is composed by weight, of

1 part Hydrogen, and
8 parts Oxygen,

and that these simple and round numbers express the prime relations in which these two elements combine to constitute water.

As substances are always represented in the eyes of the chemist by atoms or molecules, as he always seeks to connect in thought, with every substance, the weight of its atom, the simplicity of the relation just stated is not without importance. Each atom of water, in fact, being a compound of one atom of hydrogen and one atom of oxygen, we arrive at those simple numbers, which are not readily forgotten. An atom of hydrogen weighs 1, an atom of oxygen weighs 8, and an atom, or molecule of water, weighs 9.

Composition of Carbonic Acid (2).—Carbonic acid is produced incessantly by animals, and decomposed incessantly by plants; its composition, therefore, merits especial attention on our part.

Now carbonic acid, like water, is represented by the most simple numbers.

Experiments in which the diamond was burnt directly, and converted into carbonic acid, have satisfied me that this acid is formed by the combination of 6 parts, by weight, of carbon, with 16 parts, by weight, of oxygen.*

We are, therefore, led to represent carbonic acid as formed of 1 atom of carbon weighing 6, and two atoms of oxygen weighing 16, which together constitute 1 atom of carbonic acid weighing 22.

Composition of Ammonia (3).—Finally, ammonia would appear, in its turn, to be formed, in round numbers, of 3 parts of hydrogen and 14 of azote, which may be represented by 3 atoms of hydrogen weighing 3, and 1 atom of azote weighing 14.

Thus, as if to show her infinite resources, Nature does not bring into play, in connection with organization, more than a very small number of elements, combined in the simplest relations.

The whole atomic system of the physiologist, in fact, revolves upon these four numbers, 1, 6, 7, 8:

1 is the atom of hydrogen,
6 is that of carbon,
7, or twice 7=14, is that of azote, and
8 is that of oxygen.

Let him always attach these numbers to these names; because to the chemist no such things as abstract hydrogen, carbon, azote, or oxygen, exist. They are always true entities which he has in

* See Appendix A.

view; it is of their atoms that he invariably speaks, and for him the word hydrogen signifies an atom which weighs 1, the word carbon an atom which weighs 6, and the word oxygen an atom which weighs 8.

Composition of the Air (4).—Has the atmosphere which plays so important a part in organic nature, as simple a constitution as water, carbonic acid, and ammonia? Such is the question which M. Boussingault and I have lately studied attentively. And we have found, in conformity with the opinions of the majority of chemists, and in opposition to the views of Dr. Prout, to whom chemistry is indebted for so many ingenious inquiries, that air is a mixture, a true mixture.

The air of the atmosphere contains, by weight, 2300 of oxygen to 7700 of azote; by volume, 208 of the former to 792 of the latter.

The air contains, in addition, from $\frac{4}{10000}$ths to $\frac{6}{10000}$ths, by volume, of carbonic acid, whether it be taken in the midst of a great city such as Paris, or in the country. (5) In general it contains about $\frac{4}{10000}$ths of carbonic acid.

The air, moreover, contains an almost inappreciable quantity of the carburetted hydrogen gas, which is incessantly evolved by stagnant waters and marshes. (6)*

We do not here speak of the watery vapor, the

* See Appendix. B.

quantity of which varies so much at different times, nor yet of the oxide of ammonium and nitric acid, which can only exist momentarily in the atmosphere, by reason of their great solubility in water.

The air of the atmosphere, therefore, is a mixture of oxygen, nitrogen or azote, carbonic acid, and carburetted hydrogen, or marsh-gas.

The quantity of carbonic acid in the atmosphere varies, and that even considerably, inasmuch as the difference extends from $\frac{4}{10000}$ths to $\frac{6}{10000}$ths. Might not this fact be cited as a proof that plants abstract carbonic acid from the air, whilst animals exhale it? is it not an assurance that the equilibrium in the elements of the air is rightly ascribed to the inverse action of animals and of vegetables upon it?

It is long, indeed, since it was observed, that animals rob the air of its oxygen,* and exhale into it carbonic acid; and that plants, in their turn, decompose this carbonic acid, fixing its carbon, and restoring its oxygen to the air.

As animals go on breathing incessantly, and as plants only respire under the influence of the solar light; as in winter, the earth is stripped and naked, whilst in summer it is clothed with verdure; it was believed that the air ought to bear witness in its constitution to these varying states or influences. The carbonic acid, it was imagined

* See Appendix C.

must increase in the night and diminish in the day; the oxygen, on the contrary, diminish in the night and increase in the day.

The carbonic acid and the oxygen, it was also conceived, must follow the course of the seasons, augmenting inversely in one, falling off inversely in the other. (7)

All this is true, undoubtedly, and perfectly sensible in regard to small portions of air confined under a bell-glass; but in the mass of the atmosphere all local and temporary differences are lost and confounded. A long succession of ages would be requisite to bring into play and render manifest any preponderance in either of the two realms of nature, with reference to the composition of the atmosphere. We are, therefore, far—very far from experiencing those daily or annual variations which philosophers and the vulgar were at one time alike disposed to regard as equally easy to observe and to foresee. (8)

With regard to the oxygen, calculation shows that, even in exaggerating all the data, not less than 800,000 years must elapse before the animals living on the surface of the earth could consume it entirely.

If it be supposed, therefore, that an accurate analysis of the air was made in the year 1800; and that through the whole of the succeeding century, plants had ceased from their functions over the entire surface of the earth, all the animals, nevertheless, being conceived to go on, living and breathing as usual, an analysis undertaken in 1900 would not show the oxygen of the air diminished to any greater extent than $\frac{1}{8000}$th part of its weight, a quantity which is altogether inappreciable to the most delicate means of investigation we possess at the present day, and which, very certainly, would have no influence on the life of animals.

Nevertheless we do not deceive ourselves as to the fact; the oxygen of the air *is* consumed by animals, which convert it into water and carbonic acid; and it *is* restored by vegetables, which decompose these two substances.

But nature has so arranged matters that the magazine of the atmosphere, in reference to its consumption by animals, is such, that the necessity for the intervention of vegetables for its purification could only become apparent after the lapse of centuries.

The atmosphere which surrounds us weighs as much as 581,000 cubes of copper, one kilometre in the side; its oxygen alone weighs as much as 134,000 of these cubes. Now, supposing the earth to be peopled by 1,000,000,000 of men, and its animal denizens to be equivalent to 3,000,000,000 of men, it may be shown that these together do not consume a weight of oxygen equal to 15 or 16 cubic kilometres of copper in the course of a year, whilst the air, as we have seen, contains 134,000 of such kilometres.

It would require no less a period than 10,000 years before all the men on the face of the globe could produce any effect that should be sensible to Volta's eudiometer, even supposing vegetable life to be extinct during the whole of this time.

With regard to the question of permanence in the composition of the atmosphere, therefore, we may say, with a perfect assurance of accuracy, that the proportion of oxygen which it contains is secured for a long succession of ages, even supposing the influence of the vegetable world to be *nil;* and that plants, nevertheless, go on incessantly restoring to it oxygen in quantity at least equal, and perhaps even superior, to that which it loses; for vegetables live at the expense of the carbonic acid that is emitted by volcanoes, as well as of that which is exhaled by animals.

It is not, therefore, as purifiers of the air that plants are so immediately and especially necessary to animals; it is rather as supplying them, and that incessantly, with organic matter ready prepared for assimilation, which they may burn or otherwise consume to their advantage.

The service which vegetables render us in purifying the air we breathe is necessary, without doubt, but it is so remote that our gratitude is little. There is another service, so immediate, so intimate, that did it fail but for a single year, the earth would be depopulated; it is that which these same vegetables confer in preparing food for us, and for the whole animal creation. It is here especially that the connection of the two kingdoms of nature is remarkable. Annihilate vegetation, and forthwith animals perish of hunger; the entire realm of organization must necessarily disappear with that of vegetation.

Yet we have said that the carbonic acid of the atmosphere varies from $\frac{4}{10000}$ths to $\frac{6}{10000}$ths of its bulk. These variations are easy to observe, and they occur very frequently. May not this be a phenomenon proclaiming the influence of animals which introduce this acid into the air, and that of plants which abstract it?

No; you are aware of the fact that the phenomenon in question is simply meteorological. It is with carbonic acid as with watery vapor, which is formed at the surface of the ocean to be condensed elsewhere, to fall back as rain or dew, and to be raised again in the form of vapor.

This water, which is condensed and falls, dissolves and precipitates the carbonic acid; the water which evaporates, raises and abandons the same gas to the air.

It would, consequently, be of great interest, meteorologically, to contrast the variations of the hygrometer with those of the seasons, and the state of the heavens with variations in the quantity of carbonic acid contained in the air; but hitherto all tends to prove that the rapid variations observed constitute simple meteorological incidents, and by no means, as was once supposed, physiological incidents, which, isolatedly considered, would very certainly produce variations vastly more slow than those that are actually noted, whether in cities or the country.

The air is, therefore, a mighty magazine whence plants for a long time may draw all the carbonic acid they require for their wants, and where animals, for a still longer period, will find all the oxygen they can consume.

The atmosphere, we conclude, then, is a mixture which incessantly receives and incessantly furnishes oxygen, nitrogen, and carbonic acid, by a thousand exchanges, of the nature of which it is now easy to form a right conception, and of which a rapid sketch will enable us to appreciate the most remarkable circumstances.

III.

Let a seed be thrown into the earth; let it germinate and grow; let the new plant be followed until it have borne flowers and fruit in its turn, and it will be seen by proper analyses, that the original seed in producing the new being has fixed carbon, hydrogen, oxygen, nitrogen, and certain earthy particles or ashes.

Carbon.—The carbon of vegetables is mainly derived from carbonic acid, whether it be taken from that of the air, or from that which the spontaneous decomposition of manure evolves incessantly in contact with their roots.

But it is from the air especially that plants derive their carbon; how can this be otherwise, indeed, when the enormous quantities of carbon which trees, the growth of a century, for example, have laid up, are contrasted with the very limited extent to which their roots extend? Very certainly, when the acorn whence sprang the oak, which is now our admiration, germinated a hundred years ago, the soil where it fell and struck root did not contain the millionth part of the charcoal which the oak now encloses. It is the carbonic acid of the atmosphere which has furnished all the rest; that is to say, almost the whole mass of the noble tree. (9)

But what can be more clear or conclusive upon this subject than that experiment of M. Boussingault, in which peas sown in sand, watered with distilled water, and fed by the air alone, nevertheless found in this air all the carbon necessary to their developement, flowering, and fructification?

All plants fix carbon, and all obtain it from carbonic acid, whether this be derived directly from the air by the leaves, or be obtained by the roots from the ground, watered with rains impregnated with carbonic acid from the sky, or supplied by the gradual decomposition of organic particles and manures in the soil.

These facts are proved without difficulty. M. Boussingault observed the leaves of a vine, included in a glass flask, to take the whole of the carcarbonic acid from a stream of air that was sent through the vessel, however rapid the current. And M. Boucherie, on his part, observed enormous quantities of carbonic acid, which had certainly been taken up from the soil by the roots, to escape from the trunks of trees cut across when they were in full sap.

But if the roots derive this carbonic acid from the soil—if it passes into the trunk, and from thence into the leaves, it ends by being exhaled, without change, into the atmosphere, if no new force intervenes.

Such is the case with plants vegetating in the shade and during the night season; the carbonic acid of the soil permeates their tissues and is diffused in the air. Plants are commonly said to produce carbonic acid during the night: this is incorrect: plants only then transmit unchanged the carbonic acid which their roots have pumped up from the soil.

But, suppose this carbonic acid, whether derived from the soil or from the atmosphere, to be in contact with the leaves and green parts, and the light of the sun to fall on these, immediately the whole scene is changed: the carbonic acid disappears; minute bubbles of oxygen are evolved from every point of the leaves, and the carbon is fixed in the tissues of the plant.

And it is a point most worthy of remark and fitted to arouse reflection, that these green parts of vegetables, the only ones that have been found capable of exhibiting this wonderful phenomenon, the decomposition of carbonic acid, are also possessed of another property not less peculiar, not less mysterious.

If we attempt to transfer their images to a prepared plate in the apparatus of M. Daguerre, the green parts are found not to be reproduced, not to be figured; it is as if the whole of the chemical rays, essential to the photographic phenomenon, had disappeared, had been absorbed and retained by the leaf.

It would seem, therefore, that the chemical rays of light vanish entirely in the green parts of plants, — an extraordinary absorption, without doubt, but easily explicable when the enormous expenditure of chemical force necessary to the decomposition of a substance so stable as carbonic acid is considered.*

Let us next inquire concerning the part played by the carbon thus wonderfully fixed by vegetables. What is its business—what its destination? For the major part, unquestionably, it combines with water or its elements, and thus gives origin to substances of the highest consequence in the economy of plants.

Twelve atoms of carbonic acid being decomposed, and abandoning their oxygen, there will result 12 atoms of carbon, which, with 10 atoms of water, will compose either the cellular or the ligneous tissue of plants, or the starch and the dextrine which are their derivatives.

In every plant, consequently, almost the whole of its framework, formed as it is of cellular tissue, ligneous tissue, and starch or gummy substances, is represented by 12 atoms of carbon combined with 10 atoms of water. (10)

Woody fibre, which is insoluble in water; starch, which, with boiling water, forms a jelly; and dextrine, which dissolves so readily both in cold and boiling water, therefore, constitute, as M. Payen has so excellently shown, three bodies having precisely the same composition, but diversified by a different atomic arrangement.

* See Appendix D.

With the same elements, consequently, in the same proportions, the vegetable world elaborates the insoluble walls of cells, cellular tissue and vessels, as well as the starch which it stores up as aliment around its buds and embryos, and the soluble dextrine which the sap transports from one part to another to supply the various wants of the plant.

Admirable fecundity, which can fashion from the same elements three different substances, and has power, in addition, to transmute them one into another, with the least possible expenditure of power, as often as occasion requires the change!

It is still by means of carbon, combined with water, that the saccharine substances are produced, which are so frequently deposited in the organs of plants, for the special ends which we shall speak of by and by. Twelve atoms of carbon and 11 atoms of water form cane-sugar; 12 atoms of carbon and 14 atoms of water form grape-sugar.

These ligneous, amylaceous, gummy, and saccharine matters, which carbon, in the nascent state, can produce by combining with water, play so great and essential a part in the life of plants that, taking them into consideration, it is not difficult to explain the important part performed by the decomposition of carbonic acid in the vegetable world.

Hydrogen.—In the same way as plants decompose carbonic acid, appropriating its carbon, and with this forming the several neutral substances which constitute almost their entire mass, so do they also decompose water and fix its hydrogen, in order that they may form certain compounds in which this element predominates. This fact follows clearly from the experiments of M. Boussingault upon the vegetation of peas in close vessels. It is even proclaimed more strikingly in the production of the fat and volatile oils which are so frequently met with in different parts of vegetables. and are well known to be so rich in hydrogen. This can only come from water, inasmuch as vegetables have no other hydrogenous compound to feed on save water. (11)*

The hydrogenous substances, to which the fixation of the hydrogen derived from water gives rise, are employed by plants for various subordinate purposes. Volatile oils serve to defend them, or their parts, from the attacks of insects; the grease, or fat oils with which seeds are so commonly surrounded or impregnated, serve as materials for combustion, and produce heat at the period of germination; the wax with which the leaves and the fruit are covered, renders them impermeable to water, &c.

But these various purposes are evidently no

* See Appendix F.

more than adventitious, or accidental, in the life of plants: hydrogenous compounds are therefore much less necessary, much less frequent in the vegetable kingdom than the neutral compounds of carbon and water.

Nitrogen or Azote.—Every plant fixes nitrogen during its life, whether it obtains this element from the atmosphere, or from manures added to the soil. In either case, it seems probable that the azote only enters the plant, is only consumed, under the form of ammonia or nitric acid.

The experiments of M. Boussingault have shown that certain plants—the Jerusalem artichoke among the number—abstract large quantities of azote from the air; and that others, on the contrary, such as wheat, depend upon manure for the supplies of this element which they require. What an important distinction is this for agriculture! Is it not obvious that we must begin by raising plants that assimilate the azote of the atmosphere, with these feed animals which shall furnish us with manure, and then apply this to the culture of those vegetables that are dependent on manure for their nitrogen?

One of the first problems in agriculture is to procure supplies of nitrogen at a cheap rate.* With regard to carbon, there is no cause for solicitude,—nature has provided that in ample

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* See Appendix F.

abundance; the air and every shower of rain are charged with it. But it is otherwise with reference to nitrogen; the azote of the air may be unassimilable, and the ammoniacal and nitrogenous salts which rain-water contains may not be in sufficent quantity. It is indispensable, therefore, to surround the roots of almost every plant whose culture is of importance to mankind with manures rich in azote, as enduring sources of ammonia or of nitric acid, which the plants appropriate in proportion as they are produced. To do this, as is well known to all, is one of the grand causes of expense in agriculture, one of the grand obstacles to its progress; for we are generally dependent upon, and have only access to, the manure which we can severally produce. But chemistry is so far advanced in this direction, that the problem requiring the production of a purely nitrogenous manure cannot long remain unresolved.

M. Shattenmann, the able director of the manufactories of Bouxvillers in Alsace, M. Boussingault, and M. Liebig, have directed attention particularly to the part played by ammonia in nitrogenised manures; and recent inquiries have shown that the nitric or azotic acid of the nitrates also deserves especial consideration. (12)

But what may be the use of this nitrogen which plants seem to require so imperiously? The researches of M. Payen answer this question in part, for they show us that all the organs of vegetables, without exception, begin to be formed out of a nitrogenised matter analogous to fibrine, with which the cellular tissue, the woody tissue, and the amylaceous tissue itself, are associated at a later period. This azotised matter, the true source of all the parts of plants, is never destroyed; it is always to be found, however abundant the non-azotised matters, which have been subsequently interposed between its proper particles, may be.

The azote that is fixed by vegetables, therefore, serves for the production of a concrete fibrinous substance, which forms the rudiments of every one of their organs.

It serves, moreover, for the formation of the liquid albumen, dissolved in all the coagulable juices of plants, and of the caseum, frequently confounded with albumen, but so easily distinguishable from it, which forms so important a principle in many vegetables.

Fibrine, albumen, caseum exist, then, in plants. (13) These three principles, which are further identical in their elementary composition, as M. Vogel showed long ago, present a singular analogy to the ligneous tissue, starch, and dextrine.

Fibrine, in effect, is insoluble, as is the woody fibre; albumen coagulates with heat like starch; caseum is soluble, like dextrine.

These azotised matters are further neutral, as well as the three parallel non-azotised matters; and we shall find that they are as abundant, and play the same parts in the animal kingdom, as these last do in the vegetable world.

Moreover, in the same way as it is necessary, in the formation of non-azotised neutral substances, to have carbon combined with water, or its elements; so, to form the neutral azotised matters in question, it is sufficient to combine carbon and ammonium with the elements of water: 48 atoms of carbon, 6 of ammonium, and 15 of water, constitute fibrine, albumen, and caseum.

Thus, in either case, the substances that are reduced, carbon and ammonium, added to the elements of water, suffice to form the matters which engage us, and their production enters naturally into the circle of reactions which vegetable nature appears above all fitted to produce.

The office of the azote in plants is therefore worthy of the most serious attention, inasmuch as it is this element which serves for the formation of fibrine—a principle that is found as the matrix of every organ, and for the formation of albumen and caseum, substances that occur so extensively distributed throughout the bodies of all plants, and that animals assimilate or modify to meet their peculiar wants.

It is in plants, consequently that the true laboratory of organic chemistry resides; carbon, hydrogen, ammonium, and water, are the elements they work upon; and woody fibre, starch, gums, and sugars, on the one hand, fibrine, albumen, caseum and gluten, on the other, are the products that present themselves as fundamental in either organic kingdom of nature — products, however, which are formed in plants, and in plants only, and merely transferred by digestion to the bodies of animals.

Ashes.—An immense quantity of water passes through a plant during the term of its existence. This water evaporates from the surface of the leaves and necessarily deposits, as residue, the salts which it held in solution. These salts constitute the ashes of plants, products evidently derived from the soil, and restored to it again by vegetables after their death.

As to the form in which these mineral products are deposited in the tissues of plants, there is nothing more variable. Let us only remark, in this place, that one of the most frequent and abundant consists of the pectinate of lime, which M. Jacquelain detected in the ligneous tissues of the great majority of plants. (14)

IV.

If plants in the shade act as simple filters, which water and carbonic acid gas permeate; if under the influence of solar light, they take upon themselves the office of reducing apparatus which decompose water, carbonic acid, and oxide of ammonium; there are still certain epochs and certain organs in which plants perform another, and entirely opposite part.

If the business be to have an embryo produced, a bud evolved, a flower fecundated, the plant which has hitherto absorbed solar light, which has decomposed carbonic acid and water, changes immediately in its procedure; it begins to burn carbon and hydrogen; it produces heat; in other words, it manifests some of the principal characters of animality.*

But, here, a remarkable circumstance presents itself. In the process of germination of wheat, barley, &c., there is a great evolution of heat, carbonic acid, and water. The starch of the grain changes first into gum, then into sugar, and then it disappears, producing the carbonic acid in question. Does a potato sprout, it is still the starch of the tuber that changes into dextrine, then into sugar; and this in its turn, in the process of its decomposition into carbonic acid, evolves caloric; sugar

* See Appendix G.

would, therefore, seem to be the immediate means by which vegetables evolve heat, when it is required.

How is it possible not to be struck with the coincidence of the following facts? Fecundation is always accompanied by an evolution of heat; flowers respire by producing carbonic acid; they, therefore, consume carbon; and, if it now be asked whence this carbon proceeds, we find that the sugar which has been accumulated in the plant—the stem of the sugar-cane, to choose a single and very remarkable instance,—has disappeared entirely, when the flowering and fructuation have been accomplished. In the beet-root, in the same way, the quantity of sugar goes on increasing up to the time of flowering; from this time it decreases; and when the plant is in full seed, not a trace of sugar can be shown in the root. In the parsnip, carrot, turnip, &c., precisely similar phenomena are observed.

At certain epochs then, in certain organs, a plant becomes an animal—like this, it becomes an apparatus of combustion; it burns carbon and hydrogen; it produces heat.

At these periods, however, it destroys an abundance of saccharine matter, which it had previously engendered slowly and stored up. Sugar, or starch converted into sugar, is therefore the primary substance by means of which vegetables evolve the heat that is necessary to the performance of some of their functions.

And, if we now observe with what instinct animals, and man himself, proceed to select as food the very parts of vegetables in which they had laid up their stores of sugar and starch as means for the evolution of caloric, to meet their own wants, does it not become infinitely probable that sugar and starch are also destined to play the same part in the animal economy, to be burnt in the process of respiration, and to develope the heat which accompanies the act?

To resume: so long as the plant preserves its habitual character, it derives from the sun heat, light, and chemical rays, which it stores up. It receives carbon from the air, takes hydrogen from water, nitrogen or ammonium from ammonia or nitric acid, and various salts from the soil. With these elementary or mineral substances it fashions organic substances, which accumulate in its tissues.

The substances so fashioned and accumulated are either ternary compounds, lignen, starch, gum, sugar, oils or fats; or they are quaternary compounds, fibrine, albumen, caseum, gluten.

So far, the vegetable is therefore a constant producer; but if at particular times, and in order to accomplish certain functions, it become a consumer, it exhibits precisely the same phenomena as the animal is about to present us withal. (15)

V.

An animal does, in fact, constitute an instrument of combustion, whence carbonic acid is incessantly disengaged, and where, consequently, carbon is incessantly consumed. (16)

You are aware that we have not been arrested by the phrase, *cold-blooded animals*, which would seem to imply that there were animals devoid of the power of producing heat. The rod of iron, which is burnt in oxygen gas, produces a heat which no one will deny; but it requires reflection and some science to perceive that the iron which rusts slowly in the air disengages just as much heat, although its temperature never varies sensibly from that of the surrounding atmosphere. Phosphorus alight burns brilliantly, and produces abundance of heat; phosphorus in the cold still burns, but it is with little lustre, and the heat which it evolves was for a long time denied.

Now, there are some animals which burn a large quantity of carbon in a short time, and preserve a sensible and considerable excess of heat above surrounding bodies,—these are what are called warm-blooded animals. There are other animals again, which burn a much smaller quantity of carbon in a given interval of time; and they have so slight an excess of temperature above surrounding objects, that it is difficult or impossible to perceive it.

Nevertheless reason leads us to see the most constant character of animality in this combustion of carbon, with formation of carbonic acid and evolution of heat, which are its necessary consequences.

It matters not whether the question be of superior or inferior animals, whether the carbonic acid be exhaled from the lungs, gills, or the skin, the phenomenon is the same, the end and influence are identical.

At the same time that they burn carbon, animals also consume hydrogen; this is a fact, proved by the constant disappearance of oxygen which occurs in the course of their respiration.

Animals, further, constantly exhale azote. I insist particularly upon this point, with an especial view to getting rid of one of the illusions which I hold most inimical to your progress. Some observers have admitted an absorption of azote in the course of respiration; but this never occurs save in connection with circumstances which render it more than doubtful. The constant phenomenon is the exhalation of this gas, as M. Despretz has very well observed. (17)

We must conclude then, and with a full assurance of the fact, that we never derive nitrogen from the air; that the air is never an aliment for us; that all we do, is to take from it the oxygen which is requisite with our carbon to form carbonic acid, with our hydrogen to form water.

The nitrogen we exhale, then, proceeds from our food, and from our food only. The nitrogen of the atmosphere might, in the general economy of nature, be absorbed in the course of thousands of ages by plants, which, like the Jerusalem artichoke, derive their azote immediately from the air.

But this is not all the azote which animals throw off. Each of us here assembled excretes, on an average, according to the estimate of M. Lecanu, 15 grammes, or nearly 4 drachms of azote, with his urine every day. The azote here is obviously derived from our food, as are the carbon and hydrogen which we burn. (18)

Under what form does the nitrogen escape? Under that of ammonia. And here we have another of those wonderful arrangements which never fail to fill the mind with admiration of the simplicity of the means which Nature brings into play in working out her very greatest ends. If, in the general economy of things, we render to the air its constituent azote which certain plants may one day appropriate, it might have been anticipated that we should also be bound to restore the ammonia we have received, seeing that this is a compound so necessary to the existence, to the perfect evolution of the greater number of plants.

Now, this is precisely what is effected by the urinary secretion; which is neither more nor less than a solution of ammonia restored to the earth or the atmosphere.

But, need I observe, that the urinary organs would have been affected in their functions, in their vitality, by the contact of so caustic a substance as ammonia, or even carbonate of ammonia? provident Nature has, therefore, caused us to excrete urea.

But urea is still a carbonate of ammonia; that is to say, it is a compound of carbonic acid, such as we expire, and ammonia, in the shape in which it is craved by plants. But the carbonate of ammonia has here lost, or is without hydrogen and oxygen in the proportions that would form 2 atoms of water; deprived of which it constitutes urea, a neutral (19) and inert substance, which can pass through the delicate structure of the kidneys, the ureters, and the bladder, without irritating or inflaming them.

Brought into contact with the air, however, urea speedily undergoes a true fermentation which restores to it the 2 atoms of water and turns it into ordinary carbonate of ammonia,—an extremely volatile substance, apt to exhale into the air; very soluble, also, and ready to be caught and precipitated in dews and rains; evidently destined, therefore, to travel from the earth to the atmosphere, from the atmosphere to the earth, until, seized upon by the roots of a plant, and elaborated there, it is converted anew into organic matter.

Let us add one touch more to this picture. In the urine, Nature has placed side by side with the urea, traces of an albuminous or mucous substance, so slight that they almost escape detection by analysis. Nevertheless, this infinitely minute quantity of matter undergoes a change when it comes into contact with the air, becomes one of those ferments which are found distributed over the whole of organic nature, and determines the conversion of the urea into ordinary carbonate of ammonia. (20)

These ferments which have so frequently attracted our attention, and which preside over the most remarkable metamorphoses of organic chemistry, will furnish us with a theme for our lectures of another session.

We excrete urea, then, accompanied with this ferment, with this contrivance, which, coming into play at the proper moment, will convert the urea into carbonate of ammonia.

If we refer the carbonic acid of the urea to the general phenomenon of animal combustion, to which, indeed, it belongs of right, we shall have ammonia remaining as the characteristic product of the renal secretion.

With reference to the lungs and skin, then, we have carbonic acid, water, and azote ;

To the urine, ammonia.

Such are the constant and necessary excretions of the animal body.

And these are precisely the elements which vegetables require and turn to use, just as the plant, in its turn, restores to the air the oxygen which the animal had consumed.

Whence have the carbon and the hydrogen burnt by an animal, the azote, free or converted into carbonate of ammonia, which he exhales, been derived ? Unquestionably from his food.

In studying the function of digestion from this point of view, we have been led to regard it in a manner much more simple than is usually done, and which we shall now recapitulate in a few words.

When, in fact, we have had it demonstrated to us that an animal creates no organic matter ; that he is limited to assimilating it, or to expend by burning it, there was no longer any reason to search for all those mysteries in digestion which are very certainly not to be found there.

Digestion, in a word, is a simple process of absorption. Soluble substances pass into the blood, for the major part without alteration; insoluble substances make their way into the chyle, having been sufficiently comminuted to be imbibed by the lacteal vessels.

Moreover, the object of digestion is evidently to restore to the blood a material fitted to supply our respiration with the $2\frac{1}{2}$ or $3\frac{3}{4}$ drachms of carbon, or an equivalent quantity of hydrogen, which each of us burns in the course of an hour (21), and also to purvey the 15 grains of azote per hour which are exhaled by the lungs, the skin, or the kidney.

Amylaceous matters are, therefore, changed into gum and sugar, and these substances are absorbed.

Fatty matters are subdivided, formed into an emulsion, and in this way pass into the vessels, subsequently to form deposits, which the blood resumes for the purpose of combustion, as they are required. (22)

The neutral azotised substances, fibrine, albumen, and caseum, dissolved at first, and then precipitated, find their way into the chyle in a state of extreme subdivision, or dissolved anew. (23)

Animals would, therefore, seem to receive, and to assimilate almost unchanged the neutral azotised substances which they find ready-formed in the vegetables or other animals upon which they feed:

they receive fatty substances from the same sources; they receive amylaceous, or saccharine substances, which are in the same predicament. (24)

These three grand orders of substances, the origin of which must always be referred to vegetables, are divided into assimilable products,—fibrine, albumen, caseum, fat, which serve for the growth or renovation of organs; and into combustible products, sugar and fats, which are consumed or burnt in respiration.

An animal consequently assimilates, or he destroys, organic substances ready formed; he creates or forms none.

Digestion introduces these already prepared organic matters into the blood; assimilation appropriates those that are azotised; respiration burns the rest.

If animals, then, possess no special power of producing organic substances, have they not, at least, the special and wonderful power of producing caloric without expenditure of matter, which has been ascribed to them?

You have seen, in our discussion of the experiments of Messrs. Dulong and Despretz—you have seen positively that they have not. These excellent experimenters have supposed that an animal, inclosed in a calorimeter and surrounded with ice, or ice-cold water, quits the machine with precisely the same temperature as he entered it,—a thing impossible, and well known now. It is the cooling of the animal, of which they took no note, that expresses in their tables the excess of heat ascribed by them and the generality of physiologists after them, to a calorific power peculiar to the animal, and independent of respiration. (25)

It is a matter of demonstration to me that all the heat which an animal engenders proceeds from the respiration, and that its amount is exactly measured by the quantity of carbon and of hydrogen consumed. It is matter of demonstration, in a word, that the poetic likening of an animal to a locomotive steam-engine, rests upon more serious grounds than has been generally supposed. In one, as well as the other, there are combustion, heat, and motion, three phenomena connected and in relation.

Considered in this way, the animal machine comes to be much more easily understood; it is the medium between the vegetable world and the atmosphere; it derives all its elements from the former, it throws out all its excretions, and, finally, is itself decomposed into the latter.

Shall I recall to your recollection in what manner we have regarded respiration; a process more complex than it was held to be by Laplace and Lavoisier and Lagrange, but which every addition to its complexity tends to bring more and more into the category of the laws which govern inanimate nature?

You have seen that the venous blood dissolves oxygen and disengages carbonic acid; that it becomes arterial, without any trace of a rise of temperature. It is not, therefore, in becoming arterial merely that the blood produces heat.

But under the influence of the oxygen absorbed, the soluble principles of the blood are converted into lactic acid, as was perceived by M. Mitscherlich, and by Messrs. Bourton, Charlard, and Frémy; the lactic acid formed, is itself converted into lactate of soda, and this by a true process of combustion is turned into carbonate of soda, which is immediately seized upon by a fresh portion of lactic acid, and so on.

This slow and ceaseless succession of phenomena constitutes the true essence of respiration; it exhibits to us a remarkable instance of those slow processes of combustion, upon which M. Chevreul fixed the attention of chemists so long ago.

The blood is oxygenated in the lungs; it actually respires in the capillaries of all the other organs, in which the combustion of carbon and the production of heat are especially accomplished. (26)

One other reflection. To reach the summit of Mont-Blanc, a man spends two days of twelve hours each. In this time he burns, on an average, 300 grammes (about $9\frac{1}{2}$ oz. avoirdupois), of carbon, or an equivalent quantity of hydrogen. Were a steam-engine employed to carry him thither, it would consume from 1000 to 1200 grammes (2lb. 8 oz. to 3lb. 2 oz. avoirdupoise) of carbon in the service.

Considered as a machine, then, deriving the whole of its power from the carbon it consumes, the body of man is at least three or four times more perfect in its mechanism than the most perfect steam-engine.

Our artificers and engineers have, consequently, much still to accomplish; and yet these numbers are of a nature calculated to prove that there is community of principle between the living engine and the other; because, if we take an account of all the losses inevitable in fire-machines, and so carefully and admirably guarded against in the human fabric, the identity of principle in their respective forces stands out clear and manifest to the eyes. (27)

But we have gone far enough in a course in which your own reflections already take the lead of me, and where your recollections leave me nothing to add.

If we recapitulate, we shall see that the primitive atmosphere of our globe has formed itself into three great parts or masses:

One, constituting the atmospheric air of the present time; a second, represented by plants; a third, by animals.

Between these three masses continual changes are effected; matter descends from the air into vegetables, penetrates in this way into animals, and returns to the air in proportion as they consume or apply it to their purposes.

Green vegetables constitute the grand laboratory of organic chemistry. They are the agents which, with carbon, hydrogen, azote, water, and oxide of ammonium, slowly form the most complex organic substances.

Under the form of heat, or of chemical rays, they receive from the sun the force which enables them to accomplish this great work. (28)

Animals assimilate or absorb the organic substances which plants have formed. They alter them by degrees; they destroy or decompound them. New organic substances may arise in their tissues, in their vessels; but these are always substances of greater simplicity, more akin to the elementary state than those they have received.

They decompose, then, by degrees, the organic matters created by plants. They bring them back by degrees towards the state of carbonic acid, water, azote, and ammonia, a state which admits of their ready restoration to the air.

In burning or destroying these organic substances, animals always produce caloric, which, radiating from their bodies into space, goes to supply that which vegetables had absorbed and fixed.

Thus all that the atmosphere yields to plants, plants yield to animals, animals restore to the air. Eternal round, in which death is quickened and life appears, but in which matter merely changes its place and its form!

The crude and formless mass of the air, gradually organized in vegetables, passes, without change, into animals, and becomes the instrument of sensation and thought; then, vanquished by this effort, and, as it were, broken, it returns as crude matter to the source from whence it had come.

Allow me, in concluding this discourse, briefly to recapitulate the opinions which, to my mind, present themselves but as consequences and necessary developments of the grand route which Lavoisier marked out for modern chemistry (29); allow me to speak as he spoke of his fellow-laborers and friends.

If in my course—if in the foregoing summary I have been led to adopt, without quoting his name, the opinions or experiments of M. Boussingault, it is only because the habit of freely communicating our ideas, our observations, our modes of viewing every subject that interests us, has engendered a community of opinion between us, in which it would be difficult for each to specify what belongs to him in particular.

In strengthening with his name, with his authority, these opinions and their consequences, in stating to you that we labor zealously, now together, now severally, to give precision to all these facts, to illustrate by experiment all these results, it is to show you how anxious I am to bear you out in the interest you have taken in the labors of the session that now ends.

I thank you heartily. Your countenance gave me the courage needful to undertake long series of researches, and if aught useful to the progress of humanity result from the labor, to you, and to that intelligent kindness with which you have always upheld me, and for which I shall ever feel most grateful, be all the honor.

DOCUMENTS.

The principal data upon which the various considerations developed in the preceding discourse are grounded, have been united in the following notes.

I. *Composition of Carbonic Acid.*—In assuming, with Prout, the composition of carbonic acid to be 16 of oxygen and 6 of carbon, or 8 of the former and 3 of the latter of these substances, I rely upon experiments performed by burning pure graphite and the diamond in oxygen gas.

Here are the numbers obtained in the experiments which I performed along with M. Stas, Professor in the Military School of Brussels:—

Combustion of the Natural Graphite of Ceylon.

Graphite consumed.	Carbonic Acid obtained.	Relations between the Oxygen and the Carbon.
1.000	3.671	8 : 2.995
0.998	3.660	8 : 3.005
0.994	3.655	8 : 2.999
1.216	4.461	8 : 2.998
1.471	5.395	8 : 2.999
	Mean - -	2.9990

Combustion of the Artificial Graphite of the Smelting Furnace.

Graphite consumed.	Carbonic Acid obtained.	Relations between the Oxygen and the Carbon.
0.992	3.642	8 : 2.995
0.998	3.662	8 : 2.997
1.160	6.085	8 : 8.003
1.465	5.365	8 : 3.005
	Mean - -	8 : 2.9993

Combustion of the Diamond.

Diamond consumed.	Carbonic Acid obtained.	Relations between the Oxygen and the Carbon.
0.708	2.598	8 : 2.997
0.864	3.165	8 : 3.000
1.219	4.465	8 : 3.004
1.232	4.517	8 : 3.000
1.375	5.041	8 : 3.000
	Mean - -	8 : 3.0002

These experiments, repeated in Germany by two excellent and practised chemists, Messrs. Erdmann and Marchand, having given exactly the same results, I hold it as established that oxygen and carbon combine in the simple relations of 8 : 3, or 16 : 6, to form carbonic acid.

II. *Composition of Water.*—We know of no process by which we can weigh a few grammes of hydrogen, and having burned them, proceed to weigh the water which they might form in their combustion,—the sole means of attaining, with reference to the composition of water, the same high degree of precision to which we arrive in burning the diamond, when the composition of carbonic acid is the question.

The experiments which I performed with M. Stas were based upon the reduction of oxyde of copper by means of an undetermined quantity of hydrogen. The oxygen furnished by the oxyde was weighed, and again, the water which was formed was weighed. Here are the numbers obtained :—

Oxygen given off by the Oxide of Copper.	Water obtained.	Relations between the Oxygen and the Hydrogen.
13.179	14.827	8 : 1.0004
20.362	22.905	8 : 0.9992
20.495	23.053	8 : 0.9998
57.004	64.044	8 : 1.0004
76.364	85.960	8 : 1.0049
43.571	49.047	8 : 1.0050
34.811	39.178	8 : 1.0036
45.887	51.623	8 : 1.0000
60.031	67.586	8 : 1.0066
51.838	58.322	8 : 1.0003
52.508	59.078	8 : 1.0009
59.789	67.282	8 : 1.0026
62.090	69.899	8 : 1.0061
51.838	58.390	8 : 1.0068
56.483	63.517	8 : 1.0046
36.789	41.390	8 : 1.0005
34.162	38.458	8 : 1.0058
32.133	36.175	8 : 1.0060
30.827	34.677	8 : 0.9993
Sum 841.161	945.441	Mean 8 : 1.002

From the mean of these experiments, water would, therefore, appear to be composed of 8 of oxygen and 1 of hydrogen. In publishing them with all the details necessary to their repetition, we expressed the wish that they might speedily be controlled by methods of still greater delicacy. Both in a philosophical and practical point of view, it is of the greatest consequence that the composition of water should be definitely fixed by procedures of irreproachable precision—a consummation which cannot be obtained without performing several series of syntheses analogous to those that have been reported above.

III. *Composition of Oxide of Ammonium.*—M. Ampère has proposed to consider all ammoniacal products, as formed by a species of compound metal, ammonium. This is one of the happiest thoughts which this illustrious individual has left to chemistry.

Combined with 1 atom of oxygen, ammonium forms the oxyde of ammonium, which, when free, always undergoes transformation into one atom of water and 1 atom of ammoniacal gas.

The composition of water being known, we have only to determine that of ammonia, in order to have that of every ammoniacal compound, and even of ammonium itself.

Now, ammonia is evidently formed by 3 volumes of hydrogen and 1 volume of azote. M. Boussingault and I have ascertained that the density of azote is 0.972, and that of hydrogen 0.0693. It follows that ammoniacal gas must contain

Hydrogen - -	$3 \times 0.0693 =$	0.2079 say	3
Azote - - -	$1 \times 0.9720 =$	09.720 or	14.02
Ammoniacal gas - - - -		1.1799	17

Consequently 3 of hydrogen and 14 of azote constitute ammoniacal gas. Whence we have

4 hydrogen and 14 azote = 18 ammonium
8 oxygen, 4 hydrogen and 14 azote = 26 oxide of ammonium

a result which fixes at 14, or at $\frac{14}{2} = 7$, the weight of the atom of azote.

IV. *Composition of the Air.*—By the process which M. Boussingault and I have lately employed, we have been enabled to subject atmospherical air to a very rigorous analysis. The process alluded to consists in fixing the oxygen of the air by means of metallic copper, and weighing it, whilst its azote passes into a flask in which it is also weighed.

Here are the numbers obtained in our several experiments:—

1000 *Parts of Air contained by Weight :*

		Oxygen.	Azote.	
April 27.	Weather fine - -	229.2	770.8	Paris.
	Ditto - - - -	229.2	770.8	—
April 28.	Weather fine - -	230.3	769.7	Paris.
	Ditto - - - -	230.9	769.1	—
29.	Weather fine - -	230-3	769.7	—
	Ditto - - - -	230.4	769.6	—
May 29.	Rain - - - - - -	230.1	769.9	—
July 20.	Noon, Rain - - -	230.5	769.5	—
21.	Midnight, sky clear	230.0	770.0	—
24.	Mid-day - - -	230.7	769.3	—
	Mean - - - -	230.2	769.8	—

From the nature of the procedure, possible errors tend to diminish the proportion of oxygen. We can therefore say that, at Paris, there are at least 230.2 parts of oxygen in 1000 parts of air by weight.

Analysis shows no difference in regard to air taken from a height of upwards of 9000 feet.

As it is customary to consider the composition of the air by the volume, it is proper to add to these particulars, that from the numbers given, and having regard to the densities of oxygen and nitrogen, the air of our atmosphere must consist of

208 oxygen, and
792 azote,

1000 air.

V. *Composition of the principal Ternary Compounds of Vegetables.*—The woody fibre, starch or dextrine, and sugar, comprise the chief substances which belong to this head.

The elegant researches of M. Payen on the cellular and woody tissue have led him to a result of the highest physiological importance. Once freed from the matters deposited after its formation within the cells and vessels which it constitutes, it always presents the same composition. In the state of purity, it consists of

12 atoms carbon	=	72
10 atoms hydrogen	=	10
10 atoms oxygen	=	80
		162

Or otherwise, 100 parts of this tissue, which I have designated *cellulose*, contain,

Carbon - - - - - - - -	44·4
Water - - - - - - - -	55·6
	100·0

Such, then, is the composition of the general frame-work of vegetables; and such, also, is the composition of pure starch, and of dextrine or starch become soluble.

Cane-sugar, in the state of sugar-candy, contains an additional atom of water. The analyses of Gay-Lussac and Thénard show it, in fact, to consist of

12 atoms carbon - - - - - -	72
11 atoms hydrogen - - - - -	11
11 atoms oxygen - - - - - -	88
	171

or 100 parts of the same sugar consists of

Carbon - - - - - - - -	42·1
Water - - - - - - - -	57·9
	100·0

Grape sugar, better known at the present time under the name of sugar of starch, and which I have called *glucose*, contains three additional atoms of water, thus :—

12 atoms carbon - - - -	72
14 atoms hydrogen - - - -	14
14 atoms oxygen - - - -	112
	198

or referring this composition to 100 parts of this sugar, it consists of—

Carbon - - - - - - - -	36·3
Water - - - - - - - -	63·7
	100·0

With 72 parts of carbon, proceeding from the reduction of carbonic acid, then, plants are able to form the following products, by merely combining it with different proportions of water :

72 carbon	and	90 water	form	the cellular and ligneous tissue
72	——	90	———	starch and dextrine
72	——	99	———	cane-sugar
72	——	108	———	sugar of milk
72	——	128	———	sugar of grapes, or of starch.

Without entering into any consideration of the arrangement of these elements, we see, therefore, that with a single radical, CARBON, and water, plants can produce the whole of these substances, so generally contained in their organs.

VI. *Composition of the Neutral Quaternary Organic Substances.*—Under this head we have fibrine, albumen, caseine, gluten, proteine, vitelline, legumine, gelatine, and chondrine.

Gay-Lussac and Thénard, and Mulder at a later period, have paid particular attention to the analysis of these substances, and have arrived at conclusions which are generally correct. The particulars which follow are extracted from a paper, which I published in conjunction with M. Cahours (*Annales de Chimie*, &c. 3^{me} Serie T. vi. p. 385).

It has been assumed in the body of the preceding lecture, that animals receive albuminous substances ready formed from plants: nothing is more conclusive in regard to this fact than the analysis of wheaten flour. As is well known, it separates by careful washing into two portions—gluten and fecula; but, besides these, it also contains albumen. The starch is, by and by, deposited, and the clear liquid, which floats above it, contains, in solution, the albumen, which is easily recognizable, and coagulates at a temperature of about 75° C. (167° F.)

The gluten, which remains in the hand of the operator, is a complex substance, which contains not fewer than four distinct products; 1st, fibrine, which remains when it is treated with dilute boiling alcohol; 2d, caseine, which precipitates from the alcoholic solution when it cools; 3d, glutine, which is obtained as a residue on evaporating the alcohol; 4th, an aggregate of fatty matters, mixed with the three preceding substances.

Fibrine.—It had, for some time, been generally allowed, that fibrine was a substance identical with albumen in point of composition. The repeated analyses of Mulder, and of Liebig and his pupils, all tend to this conclusion.

The analysis of different kinds of fibrine has led us to another and a different inference. To prepare the fibrine destined for analysis, it was first purified by long washing with cold water; it was then treated, first, with hot alcohol, and then with hot ether. The fibrine thus handled was dried and reduced to powder; it was then subjected to renewed digestions in boiling alcohol and ether; finally, it was dried in vacuo, at a temperature of 140° C. (316° F.)

As for the fibrine of wheaten flour, or that obtained from crude gluten, it had to be subjected to particular treatment, in order to be freed from the starch, which it includes mechanically, or the caseine, or the glutine, which blend with it obstinately.

Mean of Analyses of Fibrine.

	Of the Blood of the Sheep.	Of the Blood of the Calf.	Of the Blood of the Ox.	Of the Blood of the Horse.	Of the Blood of the Dog.	Of the Dog, fed for two months and a half on Flesh.	Of the Dog, fed for two months and a half on Bread.	Of the Blood of Man.	Of Wheaten Flour.
Carbon....	52·8	52·5	52·7	52·67	52·74	52·77	52·57	52·78	53 13
Hydrogen.	7·0	7·0	7·0	7·00	6·92	6·95	7·07	6·96	7·01
Azote.....	16·5	16·5	16·6	16·63	16·72	16·54	16·55	16·78	16·41
Ox'gen,&c	23·7	24·0	23·7	22·70	23·62	23·77	23·81	23·48	23·35
	100·0	100·0	100·0	100·00	100 00	180·00	100 ·00	100·00	100·00

Fibrine, exhausted by boiling water, has exactly the same composition as albumen; it consists, in fact, of

Carbon	53·49
Hydrogen	7·09
Azote	15·88
Oxygen, &c.	23·54
	100·00

Fibrine, thus treated, yields a particular substance to the water, and loses ammonia by the boiling. The substance dissolved by the water differs from albuminous substances, both in point of composition and of properties; it also differs from gelatine, to which it has been likened, in this, that it does not set into a jelly; it precipitates with tannin, however, and with nitric acid. Its composition is as follows:—

Carbon	47·91
Hydrogen	6·87
Azote	14·96
Oxygen	30·26
	100·00

It may be represented by the following formulæ:—

$$C^{48}\ H^{42}\ Az^{12}\ O^{22}$$
$$C^{48}\ H^{40}\ Az^{13}\ O^{22}$$

Gelatine.—Gelatine differs from the substance last mentioned in point of composition. It consists of—

Carbon - - - - - - - -	50·99
Hydrogen - - - - - - -	7·07
Azote - - - - - - - -	18·72
Oxygen - - - - - - - -	23·22
	100·00

Chondrine.—Chondrine, or the gelatinous substance which cartilege yields to boiling water, approaches closely in its composition to the soluble substance which fibrine yields under similar treatment. According to Mulder, it contains,

Carbon, - - - - - - -	50·61
Hydrogen, - - - - - -	6·58
Azote, - - - - - - -	14·44
Oxygen, - - - - - -	28·37
	100·00

Albumine.—To procure the albumine, which was made the subject of the following analysis, blood-serum or white of egg was precipitated by alcohol; the precipitate was exhausted by alcohol and by water. It was then dried, pulverised and digested anew, with alcohol and ether; finally, it was dried at a heat of 140° C. (316° F.) in vacuo.

Mean of Analysis of Albumine.

	From Serum of the Sheep.	From Serum of the Ox.	From Serum of the Calf.	From Serum of Man.	Of white of Egg.	Of wheaten Flour.
Carbon	53.54	53·40	53 49	53·32	53·37	53 74
Hydrogen.....	7·08	7·20	7·27	7·29	7·10	7·11
Azote	15·82	15·70	15·72	15·70	15·77	15·66
Oxygen.......	23·56	23·70	23·52	23·69	23·76	23·50
	100·00	100·00	100 00	100 00	100·00	100·00

Caseine.—The caseine used for analysis was prepared from milk. It was precipitated by means of acetic acid, purified and dried in the same way as the albumine and fibrine.

The caseine of the blood was procured by treating a quantity of the clot with dilute boiling alcohol, which dissolves it, but lets it fall on cooling. The caseine of wheat is obtained by treating gluten in the same way.

Mean of Analysis of Caseine.

	Of Cow's Milk.	Of Goat's Milk.	Of Asses Milk.	Of Ewe's Milk.	Of woman's Milk.	Of Blood.	Of Flour.
Carbon	53·50	53·60	53·69	53·52	53·47	53·47	53·46
Hydrogen	7·05	7·11	7·14	7·07	7·13	7·09	7·13
Azote	15·77	15·78	16·00	15·80	15·83	15·87	16·04
Oxygen, &c.......	23·68	23·51	23·20	23·61	23·57	23·29	23·37
	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Glutine.—This name has been given to the substance which alcohol dissolves when crude gluten is treated with this menstruum, and which does not precipitate on the cooling of the fluid. To obtain it pure, the alcoholic solution is evaporated to dryness: it is then carefully dried, powdered, and washed with boiling ether. Desiccated in vacuo at 140° C. (316° F.) it has the same composition as caseine and albumine.

Mean of Analysis of Glutine.

Carbon, - - - - - - - -	53·27
Hydrogen, - - - - - - -	7·17
Azote, - - - - - - - -	15·97
Oxygen, - - - - - - -	23·62
	100·00

Proteine.—The name of Proteine was applied by Mulder to the pure animal matter, which enters into the composition of albumine and caseine, and is combined with sulphur or with phosphorus, bodies which have been confounded with oxygen in the preceding analysis. The proteine which was employed in the analysis which M. Cahours and I performed was procured from caseine and albumine.

Mean of Analysis of Proteine.

Carbon, - - - - - - - -	54·37
Hydrogen, - - - - - - -	7·12
Azote, - - - - - - - -	15·93
Oxygen, - - - - - - -	22·58
	100·00

The formula C^{48}, H^{37}, Az^{12}, O^{15}, represents with great accuracy the composition of this substance; it, in fact, gives in 100 parts,

C^{48} - - - - - - - - -	54·44
H^{37} - - - - - - - - -	6·99
Az^{12} - - - - - - - -	15·88
O^{15} - - - - - - - - -	22·69
	100·00

Vitelline.—Vitelline constitutes the albuminous matter of the yolk of the egg.

Mean of the Analysis of Vitelline.

Carbon, - - - - - - - -	51·60
Hydrogen, - - - - - -	7·22
Azote, - - - - - - - -	15·02
Oxygen, - - - - - - -	26·16
	100·00

Whence is deduced the formula

$$C^{48}\ H^{37}\ Az^{12}\ O^{15} + 3\ HO.$$

Which gives:—

C^{48} - - - - - - - - -	51·8
H^{37} - - - - - - - - -	7·1
Az^{12} - - - - - - - - -	15·1
O^{18} - - - - - - - - -	26·0
	100·0

Legumine.—M. Branconnot has so entitled an azotised substance which he extracted from peas, haricot beans, and lentils. There is an analogous matter, amandine, which is found in almonds and some other seeds. The substance which served for the following analysis was prepared by digesting the seeds which contain it with tepid water; the solution was precipitated by dilute acetic acid, the precipitate was dried, pulverized, exhausted by ether, and dried in vacuo at 140° C.

Mean of Analyses of Amandine of different Seeds.

	From Sweet Al-monds.	From ditto.	From ditto.	From Kernels of Plums.	From Kernels of Apri-cots.	From White Mustard Seed.	From Hazel Nuts.
Carbon	50·90	50·93	50·80	50·93	50·72	50·83	50·73
Hydrogen ..	6·72	6·70	6·71	6·73	6·65	6·72	6·95
Azote	18·93	18·77	18·80	18·64	18·78	18·58	18·76
Oxygen	23·45	23·60	23·69	23·70	23·85	23·87	23·56
	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Mean of Analysis of Legumine of the Leguminosæ.

	Of Peas.	Of Lentils.	Of Haricot Beans.
Carbon	50·53	50·46	50·69
Hydrogen..............	6·91	6·65	6·81
Azote	18·15	18·19	17·58
Oxygen, &c...........	24·41	24·70	24·92
	100·00	100·00	100·00

The formula which would best represent the composition of amandine would be this :—

C^{48} - - - - - - - - - -	50·9
H^{37} - - - - - - - - - -	6·5
Az^{15} - - - - - - - - - -	18·5
O^{17} - - - - - - - - - -	24·1
	100·0

VII. *Principal Chemical Effects of Germination.* —The following experiments of M. Boussingault show in what way plants behave at different periods of their germination, and what elements they abstract from the air or from water, and also what elements they themselves lose.

1. *Germination and Cultivation of Trefoil (Trefolium pratense.)*—In determining the composition of the seed and of the produce, M. Boussingault made use of the ordinary methods of organic analysis; here are the results he obtained :—

Dry Trefoil Seed.

	1.	2.	3.	Mean.
Carbon,	0·4165	0·4930	0·4910	0·494
Hydrogen,	0·0583	0·0600	0·0549	0·058
Azote,	0·0699	0·0699	0·0699	0·069
Oxygen,	0·3468	0·3486	0·3557	0·350
Ashes,	0·0285	0·0285	0·0285	0·028

Trefoil Seed freed from Ash.

	1.	2.	3.	Mean
Carbon,	0·511	0·507	0·505	0·508
Hydrogen,	0·061	0·062	0·062	0·062
Azote,	0·072	0·072	0·072	0·072
Oxygen,	0·356	0·359	0·361	0·360
	1000	1000	1000	1000

2. *Germination of Trefoil—First Period.*—The seed was made to sprout upon a porcelain dish; when the radicle of each several seed had attained the length of from ½ to 1 centimetre (the 40th to the 20th of an English inch), it was carried to a stove heated to 100° C. (212° F.); the complete desiccation was then secured in the usual way. The seeds which had not germinated were collected and dried apart from the rest.

The sprung seed dried and subjected to analysis yielded:—

	1.	2.	Mean.
Carbon,	0·497	0·501	0·499
Hydrogen,	0·064	0·060	0·062
Azote,	0·078	0·078	0·078
Oxygen,	0·331	0·331	0·331
Ashes,	0·030	0·030	0·030
	1000	1000	1000

The sprung seed freed from ashes gave :—

	1.	2.	Mean.
Carbon,	0·513	0·517	0·545
Hydrogen,	0·066	0·061	0·063
Azote,	0·080	0·080	0·080
Oxygen,	0·341	0·342	0·342
	1000	1000	1000

From these analyses it results that

	Car.	Hydr.	Oxyg.	Az.
1 of trefoil seed containing	0·508	0·060	0·360	0·072
Yielded 0·932 of germinated seed containing	0·480	0·059	0·319	0·074
Difference	0.023	0·001	0·041	0·002

The analysis therefore shows that during the first period of germination, trefoil seed lost carbon and oxygen.

3. *Germination of Trefoil—Second Period.*—M. Boussingault has designated as the second stage in the germination of trefoil the epoch at which the green parts make their appearance. Each grain was transferred to the drying stone so soon as the seminal leaves were evolved. The shell of each seed was preserved and added to the sprung grain.

The sprung grain dried and analysed at the second stage yielded :—

	1.	2.	Mean.
Carbon,	0·458	0·457	0·458
Hydrogen,	0·060	0·055	0·058
Azote,	0·084	0·084	0·084
Oxygen,	0·364	0·364	0·364
Ashes,	0·034	0·030	0·036
	1000	1000	1000

And freed from ashes :—

	1.	2.	Mean.
Carbon,	0·474	0·472	0·472
Hydrogen,	0·062	0·058	0·060
Azote,	0·087	0·087	C·087
Oxygen,	0·377	0·383	0·381
	1000	1000	1000

Whence it follows that

	Carb.	Hyd.	Oxy.	Az.
1 of trefoil-seed, containing......	0·508	0·060	0·360	0·072
Yielded at the second stage of germination 0·833, containing....	0·394	0·050	0.317	0·072
Difference........	0·144	0·010	0·043	0·000

To reach this stage the trefoil-seed lost carbon and oxygen, as in the preceding experiment; but here the loss in carbon surpassed that in oxygen. Farther, an unequivocal loss of hydrogen is apparent. Finally, the azote which existed in the seed before germination is found in it after it has sprung.

These analyses of germinated and ungerminated trefoil-seed seem to show that the phenomenon of germination is not so simple as it is generally believed to be. We know from the elegant researches of M. de Saussure, that seeds in germinating change oxygen into carbonic acid. It has been further ascertained, that the acid gas formed has the same volume in the majority of cases as that of the oxygen which has contributed to its formation ; whence the conclusion has been drawn that seeds in germinating lose a portion of their carbon without either absorbing or emitting oxygen. Even from the beginning of his experiments on the subject, however, M. de Saussure observed, that the total loss suffered by a seed which had germinated, always exceeded that which can be ascribed to the carbon which combines with oxygen to form carbonic acid. This learned chemist explained the excess of loss by the disengagement of a certain quantity of water, which, becoming free, is thrown off during the drying of the germinated grain.

Analysis does not bear out this explanation. It indicates a very notable loss of oxygen during the germination of trefoil-seed, and shows, moreover, that, during the first stage, the loss cannot be due to water disengaged, inasmuch as there has been no sensible change in the hydrogen of the seed. During the second period, indeed, there is an elimination of hydrogen ; but the quantity evolved is still not in proportion to the disappearance of oxygen ; it is too small to change the whole of the oxygen that is lost into water. And then, it has lately been found, that germinating seed has a considerably varied action upon the surrounding air. Some seeds, in germinating, change the oxygen of the air into exactly the same bulk of carbonic acid; but there are others which furnish sometimes less, sometimes more carbonic acid than there is oxygen consumed. These results even vary with reference to the same species of seed, according to the stage more or less advanced of the germination.

Analysis satisfactorily explains these varieties, which seem to depend on the phases through which a seed that germinates passes successively. It is enough, for example, to compare ungerminated trefoil-seed with the product of the first period, and this with that of the second. We then discover that the loss of carbon is common to the two periods; but we see at the same time, that the loss of oxygen seems to be stayed during the interval which separates the first from the second period.

On comparing these two stages we have

		Carb.	Hydr.	Oxyg.	
1 of seed		0·508	0·060	0·360	
Which in the first stage becomes..	0·993, and contains	0·480	0·059	0·319	differ. 0·041
And in the second...	0·833.....	0·394	0·050	0·317	differ. 0·002

Experiments upon Wheat.—The grain which was used in the following experiments had been grown in a good garden soil—a circumstance which ought to be noted, inasmuch as analysis proves the influence of manure on the quantity of azotised substance contained in the cerealia. The same wheat gathered from the best open-field wheat lands contains no more than 0·025 of azote, whilst that which we have under consideration here, from the mere circumstance of having grown in a more fertile soil, contains as much as 0·035 of the same element.

1. *Composition of Wheat.*

	Dry.			
	1.	2.	3.	Mean.
Carbon.............	0·453	0·455	0·458	0·455
Hydrogen...........	0·059	0·055	0·056	0·057
Azote..............	0·034	0·034	0·034	0·034
Oxygen.............	0.431	0·433	0·429	0·431
Ashes	0·023	0·023	0·023	0·023
	1000	1000	1000	1000

	Freed from Ashes.			
	1.	2.	3.	Mean.
Carbon.............	0·464	0·465	0·469	0·466
Hydrogen...........	0·060	0·056	0·058	0·058
Azote..............	0·045	0·0345	0·0345	0·0345
Oxygen	0·4315	0·4145	0·4385	0·4415
Ashes..............	..	..	..	..
	10005	10000	10000	10000

2. *Germination of Wheat—First Stage.*—The germination was arrested immediately after the appearance of the radicles; the young stems were scarcely visible.

Composition of Germinated Wheat.

	Dry.			Freed from Ashes.		
	1.	2.	Mean.	1.	2.	Mean.
Carbon......	0·457	0·460	0·459	0·467	0·472	0·470
Hydrogen....	0·057	0·058	0·057	0·059	0·059	0·059
Azote.......	0·036	0·036	0·036	0·036	0·037	0·037
Oxygen......	0·426	0·422	0·422	0·436	0·437	0·437
Ashes.......	0·024	0·024	0·024	..	..	..
	1000	1000	1000	1000	1000	1000

Summary:—

	Carb.	Hydr.	Oxyg.	Azote.
1 of wheat, containing.......	0·466	0·058	0·441	0 035
Yielded of germinated wheat 0 974.................	0 458	0 057	0 423	0 036
Difference......	..0 008	..0 001	..0 018	..0 001

During the first stage of the germination, the wheat appeared therefore to have gained a certain quantity of azote; but the amount is so small, that the gain is even doubtful. The loss experienced by the wheat is almost entirely referable to the carbon and the oxygen. As in the first stage of the germination of trefoil-seed, the weight of the oxygen lost is much greater than that of the carbon. The loss of hydrogen is within the limits of the possible errors of analysis. The elements lost during this first stage may be represented by water and oxide of carbon.

3. *Germination of Wheat—Second Stage.*—The sprouting was not arrested until the young stems had acquired the length of the seeds.

Composition of Germinated Wheat—Second Stage.

	Dry.			Freed from Ashes.		
	1.	2.	Mean.	1.	2	Mean.
Carbon......	0 4456	0 4390	0 4123	0 4569	0 4489	0 4329
Hydrogen....	0 0583	0 0576	0 0580	0 0593	0 0590	0 0592
Azote	0 0356	0 0356	0 0356	0 0354	0 0354	0 0354
Oxygen......	0 4418	0 4441	0 1404	0 4494	0 4557	0 4515
Ashes.......	0 0237	0 0237	0 0237	..	..	..
	10000	10000	10000	10000	10000	10000

Recapitulation :

	Carb.	Hydrog.	Oxyg.	Azote.
1 of wheat, containing....	0·466	0 058	0 441	0·035
Yields 0 966, containing..	0 439	0 057	0 334	0 036
Difference........	–0 027	–0 001	–0 007	+0 001

In the course of this second stage, the wheat in germinating, consequently, lost the same elements as during the first; but the relations between these elements are different. The hydrogen and azote did not vary sensibly; the quantity of carbon lost was five and a half times as great as that of the oxygen. The loss is, consequently, almost entirely at the cost of the carbon; there is, nevertheless, a slight loss of oxygen.

When we contrast the analysis of the germinated wheat at each period, however, we perceive that in the passage from one to the other, there was a fixation of oxygen.

	Ger. gr.	Carb.	Hyd.	Oxyg.	Azote.
1st Period—1 of grain gives............	0 974	0 458	0 057	0 423	0 036
2d Period..........	0 966	0 439	0·057	0 434	0 036
Difference....	–0 008	–0 019	–0 000	+0 011	–0 000

4. *Germination of Wheat—Third Period.*—The germination was only stayed when the green parts predominated in the sprung grain. The stems had then a length of from three to five centimetres (1·18 to 1·96 of an English inch). After drying, the several grains were very much wrinkled, almost empty, and on being crushed, showed scarcely any traces of starch.

Composition of Germinated Wheat—Third Stage.

	1.	2.	Mean.	1.	2.	Mean.
Carbon......	0 461	0 457	0 459	0 474	0 470	0 472
Hydrogen....	0 060	0 060	0 060	0 061	0 061	0 061
Azote.......	0·041	0 041	0 041	0 042	0 042	0 042
Oxygen	0 410	0 414	0 412	0 423	0 427	0·425
Ashes.......	0 028	0 028	0 028	..	..	..
	1000	1000	1000	1000	1000	1000

Summary :

	Carb.	Hydr.	Oxyg.	Azote.
1 of wheat, containing.....	0 466	0 058	0·441	0 035
In germinating, becomes 0·841, containing......	0 397	0 051	0 357	0 036
Difference........	–0 069	–0 007	–0 084	+0 001

To attain this advanced stage of germination, we see that the wheat lost 16 per cent; having yielded to the atmosphere carbon, hydrogen, and oxygen. Analysis does not yet exhibit more than a very trifling change in the quantity of azote, which has increased rather than diminished.

VIII. *Principal Chemical Phenomena of Vegetation.*—It is still by the method of organic analysis that M. Boussingault has demonstrated that plants in full growth always take CARBON from the carbonic acid of the air, HYDROGEN from the water which bathes them, and frequently AZOTE from the air.

The soil he used for the growth of his plants, the subjects of experiment, was a siliceous sand, which was first sifted, then kept at a red heat for some time, in order to destroy every trace of organic matter within it. It was then moistened with distilled water, and the seeds sown ; after the interval of a few days, the seeds which did not germinate were removed. The porcelain dishes which contained the sand thus sown were placed in a chamber situated at the extremity of a large garden. The windows of the chamber were kept shut through the whole term of the experiment, but the sunlight entered it freely during the day. In order to gather the harvest, the dishes, with their contents, were dried by means of a gentle heat. The plants were then easily pulled up from among the sand ; and to free their roots from adhering particles of sand, they were gently shaken in water. The whole plants were then dried in a stove, and the desiccation was subsequently completed by means of an oil-bath in vacuo.

By determining the weight of the sand, and of the ashes, that of the harvest, dried and freed from ash, was known; this weight was compared with that of the grain sown, deduction being, of course, made of the grain which had not sprung.

The sand in which the experiment had been carried on was sifted anew, which permitted certain fragments of the plants, and particularly the husks of the grain, to be collected. The sand was elutriated, and the water evaporated to dryness; but, with the exception of saline matter, the origin of which could not be accounted for, no residue was obtained of sufficient consequence to be weighed.

1. *Growth of Trefoil.*—The trefoil which was gathered two months after it had been sown in the sand, was of a fine green color; but, contrasting it with what it would have been had it been grown in a well-manured soil, it was dwarfish; on an average, the length of the stalks did not exceed 2 inches; its roots, of great tenuity, were a little more than 2 inches long.

Composition of the produce obtained.

	1.	2.	Mean.
Carbon - -	0·508	0·504	0·506
Hydrogen -	0·057	0·058	0·058
Azote - - -	0·047	0·047	0·047
Oxygen - -	0·388	0·391	0·389
	1000	1000	1000

Summary of the experiment :—

	Carb.	Hydr.	Oxy.	Azote.
1 of seed, containing....	0 508	0 060	0 360	0 072
Yielded a crop of 1 649, containing	0 834	0 095	0 641	0 079
Difference....	+0 326	+0 035	+1·281	+0 007

In the course of two months, consequently, the trefoil had acquired azote; the quantity gained is too large to be attributable to any ordinary error in analysis.

Further, the seed, or rather, the plant which was its product, acquired carbon, hydrogen, and oxygen, from water and from the atmosphere. It is to be observed, that the relations in which the two latter elements occur are those precisely in which they constitute water.

The produce after three months had a pretty good appearance, the trefoil having from 2½ to 3 inches in height. The warmth of the month of August had brought this crop rapidly forward: a few withered leaves were observed. The largest leaves could be inclosed within a circle about 2 inches in diameter; the length of the roots varied between 2 and about 4 inches, but they were very slender. The produce, dried and powdered, was of a deep green color.

Composition of the produce.

	1.	2.	Mean.
Carbon - -	0·506	0·508	0·507
Hydrogen -	0 066	0·065	0·066
Azote - - -	0·038	0·038	0·038
Oxygen - -	0·390	0·389	0·389
	1000	1000	1000

Recapitulation of the experiment:

	Carb.	Hydr.	Oxy.	Azote.
1 of seed containing......	0 508	0 060	0 360	0 072
Yielded in produce 2 589, containing...........	1 313	0·171	1 007	0 098
Difference........	+0·805	+0 111	+0 647	+0 026

In the course of three months, consequently, the seed, become vegetable, acquired about $\frac{1}{5}$th by weight of azote, in addition to that which it contained before it was sowed; the carbon again increased in the ratio of 5 to 8; and the hydrogen and oxygen were very nearly doubled; but here these two substances do not present themselves in the proportions required to form water. The hydrogen is in excess, and the excess is such that it cannot be ascribed to an error of analysis.

From the experiments on trefoil it follows, that, during the germination of the seed, there is no azote fixed; but, during the growth of the plant, it appears that there is a certain quantity of this element assumed from the air.

Among the various objections which might be raised to the precision of the experiments that have now been described, there is only one that appears of any importance, and it has been raised as often as the attempt has been made to fix the weight of the elements which the growing plants take from the air and water: it is that which ascribes a portion of the elements acquired by the plants to particles of dust floating in the air. It is impossible to deny the presence of dust in the atmosphere, so that it might be maintained that this influences the result in the manner of manures; and as it is indubitable that a part of the dust which floats in the air is of animal origin, it might even be said, until the contrary was demonstrated, that this is the source of the azote which the plants had assimilated during their growth.

To remove all doubt upon this point, M. Boussingault contrived an apparatus in which he could make trefoil germinate and grow, and yet be all the while completely protected from the dust that floats in the air. He still obtained precisely the same results as formerly. In germinating in a close vessel as well as in the open air, trefoil absorbs no notable quantity of azote; but, during its growth, it gains a very sensible quantity of this element.

2. *Wheat grown during the months of September and October.*—Thirty-seven grains or particles of wheat were sown in sand: they all sprung. The

stems, when the plants were gathered, were from 8 to 10 inches long. They were extremely slender, bending under their own weight. Some of the leaves near the bottoms of the stalks were completely discolored; the roots were of excessive length, but thin and capillary.

The produce contained

Carbon - - - - - -	0·495
Hydrogen - - - -	0·064
Azote - - - - - -	0·022
Oxygen - - - - - -	0·419
	1000

Thus:—

	Carb.	Hydr.	Oxy.	Azote
1 of wheat containing....	0 466	0 058	0 441	0 035
Produced 1·462, containing	0 724	0 094	0 612	0·032
Difference........	+0 258	+0 036	+0 171	-0 003

During the two months of vegetation, therefore, at the sole expense of the air and distilled water, the weight of the wheat increased in the ratio of $1\frac{1}{2}$. The increase took place by an assimilation of carbon, hydrogen, and oxygen; analysis, moreover, shows a slight loss of azote.

Wheat grown during the months of August, September, and October.—Forty-six grains or particles of wheat were sown in sand: all sprung. When the plants were gathered, the stalks were from 14 to 15 inches long; the greater number of the lower leaves were yellow: the roots were of considerable length, and by matting together, formed a sort of tissue, which made washing very difficult.

Composition of the produce.

	1.	2.	Mean.
Carbon - -	0·482	0·482	0·482
Hydrogen -	0·057	0·052	0·058
Azote - - -	0·020	0·020	0·020
Oxygen - -	0·441	0·439	0·440
	1000	1000	1000

Thus :—

	Carb.	Hydr.	Oxy.	Azote.
1 of wheat, containing....	0 460	0 058	0 441	0 035
Produces 1 838, containing	0 880	0 105	0 810	0 037
Difference........	+0 420	+0 047	+0 369	+0 002

After three months' vegetation, consequently, the weight of the grain was, so to say, doubled; the carbon, hydrogen, and oxygen, appear in almost a twofold proportion in the produce. Analysis shows an increase of azote that is altogether insignificant.

The results obtained with wheat, in reference to germination, were analogous to those come to with trefoil. It appears constant that during this proof there is neither gain nor loss of azote.

3. *Growth of Peas.*—In cultivating peas under the same conditions, precisely similar results were obtained; but an additional and unexpected fact was also brought to light; it is this: that peas, under the influence of the regimen followed, having no sustenance save air and water, blossomed and brought seed to perfect maturity.

Composition of the Peas, the Subjects of Observation.

	Ashes included.	Ashes deducted.
Carbon - - - -	46·5	48·0
Hydrogen - - -	6·1	6·4
Oxygen - - -	40·1	41·3
Azote - - - -	4·2	4·3
Ashes - - - -	3·1	„
	100·0	100·0

Five peas, weighing together about 18 grains, and as nearly as possible of the same weight, were sown on the 9th of May, in baked earth, or clay calcined at a red heat, and then moistened with distilled water.

On the 16th of July, these peas, which looked extremely well and healthy, were in bloom; each pea had furnished one stalk, and on each stalk there was one flower. On the 15th of August the pods were ripe; no more water was supplied, and by the end of the month the plants were dry.

The length of the stalks varied from 3 feet 3 inches to 5 feet, but they were very slender, and the leaves were not more than one-third the superficial size of the leaves of peas grown in a manured soil. The pods were about 1-3 inch long, by from 0·3 to 0·4 of an inch broad.

Four of the pods inclosed two peas each, the fifth contained but one; but this pea was almost twice the size of any of the others.

Composition of the produce gathered.

	Ashes included.	Ashes deducted.
Carbon - - - -	53·5	54·9
Hydrogen - - -	6·6	6·8
Oxygen - - -	33·8	34·7
Azote - - - -	3·5	3·5
Ashes - - - -	2·6	”
	100·0	100·0

Composition of the Stalks and Pods, Ashes deducted.

Carbon - - - - - -	52·8
Hydrogen - - - - -	6·2
Oxygen - - - - -	39.4
Azote - - - - - -	1·6
	100·0

Summary of the experiment :—

	Carb.	Hydr.	Oxy.	Azote.
Weight of peas sown, 1 072 containing......	0 515	0 059	0 440	0 046
Produce, 4 441, containing..	2 376	0 281	1 680	0·101
Difference........	+1 861	+0 215	+1.237	+0 055

It results from this experiment that 15½ grains of peas gained 51½ grains of organic matter in 99 days of vegetation, during the hottest period of the year, and that the weight of azote originally contained in the seed was more than doubled in the produce.

The rest of the elementary matter, assimilated during the growth of the plant, is not represented exactly by water and carbon ; there is such an excess of hydrogen as cannot be attributed to an error of analysis.

4. *Culture of Trefoil in a Barren Soil.*—From a field of trefoil, sown in spring, several plants of the same height were chosen. Three of these, weighing 103 grains in the green state, were put aside and preserved for analysis; three others, which weighed 104 grains, were immediately transplanted to a bed of sand, recently calcined, and moistened with distilled water. This was done on the 28th of May, and the plants were forthwith protected from the dust of the atmosphere. The plants drooped during the first few days, but, by and by, they became remarkably vigorous. At the end of a month the plants had doubled in height; their leaves were of a fine green, and they appeared altogether as strong as those which had been left growing in their original places in the open field. The flowers began to appear about the 8th of July; on the 15th the flowers were of a fine carnation red, on the 1st of August no more water was supplied and the plants were suffered to die.

The roots were found to be very little developed: the extremities were very bushy, but the spindle or tap, which constitutes the body of the trefoil-root, had made no progress.

Analysis of the Trefoil before the Experiment.—The three plants of trefoil reserved afforded—

Carbon - - - - - -	43·42
Hydrogen - - - - -	5·40
Oxygen - - - - - -	47·43
Azote - - - - - -	3·75
	100·00

Composition of the Trefoil, the subject of the Experiment in Flower.—Dried in vacuo, at a temperature of 110° C. (266° F.) this trefoil weighed 2·754 grammes (about 41 grains), and yielded,—

Carbon - - - -	53·00
Hydrogen - - -	6·41
Oygen - - - -	38·14
Azote - - - -	2·45
	100·00

Recapitulation:—

The trefoil, at the moment of transplantation, freed from ashes, weighed	0 884 of a gramme, or about 14 grains.
After 63 days of cultivation, it weighed	2 264 grammes, or about 33 grains.
It had therefore gained in this time	1 380 grammes, or about 19 grains.

	Carb.	Hydr.	Oxy.	Azote.
Before the experiment, the trefoil contained	0 384	0·048	0·419	0·933
After the experiment......	1·200	0·145	0·863	0·056
Difference........	+0 816	+0·097	+0 544	+0 023

So that in the course of two months trefoil, living at the sole cost of air and of water, is found, in round numbers, to have tripled the weight of its elementary matter; the azote, for its part, being very nearly doubled.

Growth of Oats in pure Water.—On the 20th of June, three plants were taken from a field of oats, and having been found to weigh 158 grains were set aside for analysis. Four other plants, destined for experiment, and weighing 220 grains, were secured from dust, with their roots plunged in distilled water. About the middle of July the stalks had nearly doubled in length, and, at this time, presented the appearance of those which had been left in the open field. At the end of July the plants were in flower. Towards the 10th of August, the grain seemed ripe, and the whole of the plants were dried in the stove.

Composition of the young Oat Plants reserved for Analysis.

Carbon - - - - -	53·0
Hydrogen - - - -	6·8
Oxygen - - - -	36·4
Azote - - - - -	3·8
	100·0

Composition of the ripe Oat Plants, the subject of Experiment.

Carbon - - - - -	48·1
Hydrogen - - - -	6·2
Oxygen - - - - -	44·0
Azote - - - -	1·7
	100·0

Summary :—

The young plants weighed	1·560 grammes, or about 23 grains			
The plants experimented on weighed	3 418 grammes, or about 52 grains			
Gain, during the experiment................	1 158 grammes, or about 16½ grains.			
	Carb.	Hydr.	Oxy.	Azote.
Before the experiment, the plants contained	0·827	0 106	0 568	0·059
After 41 days' vegetation..	1·500	0·193	1·373	0·058
Dfference........	+9·671	+0·087	+0·804	-0·006

In this experiment, analysis shows, that far from there being any gain of azote, there was, on the contrary, a slight loss of this principle.

The experiments which have been detailed thus far demonstrate :—

1st. That in germinating, trefoil or clover, and wheat, neither gain nor lose a quantity of azote that is appreciable by analysis.

2d. That during germination these seeds lose carbon, hydrogen, and oxygen ; and that the absolute loss of each of these elements, as well as the ratios in which the losses take place, vary at different epochs of the germination.

3d. That during the growth of trefoil in a soil absolutely void of organic matter, and under the sole influence of the air and distilled water, this plant assumes carbon, hydrogen, oxygen, and a quantity of azote appreciable to analysis.

4th. That wheat cultivated under precisely the same circumstances also abstracts from the air and from water carbon, hydrogen, and oxygen; but that after the complete growth of the plant analysis detects neither gain nor loss of azote.

5th. That peas, planted in a soil absolutely barren and watered with pure water, may attain to complete maturity, passing through all the phases of their natural growth, and bearing flowers and ripe seeds. During this process they fix a large quantity of azote, which they must derive either from the air dissolved in the water which they absorb by their roots, or from the air that surrounds their stalks and leaves.

6th. That trefoil grown at first in a fertile soil, but cultivated subsequently without the concurrence of organic matters, also fixes azote.

7th. That the oat-plant, raised at first in a manured soil, and then placed in the same circumstances as the trefoil, abstracts carbon, hydrogen, and oxygen from the air and water, but assimilates no azote; analysis, on the contrary, showing a slight decrease of this element.

From all of which it may be inferred that in certain conditions various plants have the power of deriving azote from the air. But under what circumstances, in what state does the azote become fixed in plants? These are questions which the present state of our knowledge does not allow us to answer satisfactorily.

Azote, in fact, may enter the organism of plants directly, if their green parts be possessed of the aptitude to fix it; or the element may be carried into the bodies of the plants dissolved in the water which is aspired by the roots. Finally, it is possible, as some natural philosophers believe, that an infinitely small quantity of ammoniacal vapor constantly exists diffused in the atmosphere.—Extracted from the Memoirs of M. Boussingault, in the *Annales de Chemie et de Physique*, tomes 57 et 59.

IX. *Respiration of Man.*—From experiments of which I was myself the subject, I find that at each inspiration I introduce about a third of a litre* of air into my lungs; I make from fifteen to seventeen inspirations per minute; the air expired contains from 3 to 5 per cent of carbonic acid; and it has lost from 4 to 6 per cent of oxygen.†

* A litre is 1·760, or very nearly 1¾ of an English pint.—Ed.

† These experiments were performed at Geneva, in 1820, when I was twenty years of age, and were undertaken in connection with a complete work on Respiration which M. Prevost and I had then in view. I have since that time quoted them regularly in my courses. It will be seen by and by that as we advance in years the consumption of carbon increases.—J. D.

These data give for each day of 24 hours :—

16 inspirations per minute of $\frac{1}{3}$ of a litre, or 0 533 of an Eng. pint..	=	5 3 litres (about 9 3 pints) of air expired per minute.
——		31 8 (57 8 pints) ditto per hour.
——		763 2 (1387 2 pints) ditto per diem.

Assuming that the expired air contains on an average 4 per cent of carbonic acid, we should have,

12 7 litres of carbonic acid per hour.
305 8 —— per diem.

Reduced to weight these data furnish us with :

$166\frac{2}{3}$ grammes (about 5 ounces 40 grains) of carbon consumed per diem.

$55\frac{5}{9}$ grammes of carbon to represent the hydrogen consumed in the same time.

$212\frac{2}{9}$ grammes or about 9 ounces of carbon burned in 24 hours,

which is at the rate of about 9 grammes (or 140 grains) per hour, whether of carbon or its equivalent in hydrogen.

Some of the older observers estimated the quantity of carbon consumed at 340 grammes (or 11 ounces, 1 drachm, 15 grains), per diem, which would bring the consumption up to about 14 grammes (or about 3 drachms, 35 grains) per hour.

In assuming the consumption at from 10 to 15 grammes (or $2\frac{1}{2}$ to $3\frac{2}{3}$ drachms) per hour, we shall be within the limits of the truth. But I hold that the consumption of so many as 15 grammes can only be regarded as the exception, and as applicable to individuals of great stature, of very ample chest, large eaters, &c. Ten grammes (or $2\frac{1}{2}$ drachms) per hour is probably as near an approximation to the truth as can be made in regard to the generality of men in adult age.

The high importance of this question, with which indeed is connected the very serious one of what may be held sufficient sustenance in the shape of food for man, requires that it should be studied with greater attention to accuracy of results, and upon a greater number of individuals than have yet been employed. We are at this time engaged in the study.

The experiments which were thus announced in the preceding edition of this Essay have been performed by Messrs. Andral and Gavarret with great care. We give an abstract of their paper in this place:—

"We have had it in view," say these two physiologists, "to determine the quantity of carbonic acid which escapes in a given time from the lungs of man as well in the state of health as in the state of disease.

"To accomplish our object we made use of the following apparatus, the first conception of which belongs to Messrs. Dumas and Boussingault.

"Through a mask made of impermeable materials, of sufficient capacity to contain an entire expiration, and carefully fitted to the face, we established a current of atmospherical air by means of glass balloons, in which a vacuum had previously been made. It was in this continual current that the subject lived during the course of the experiment. The force or rapidity of the current was readily controlled by means of a graduated stopcock, in such wise that the respiration was always performed freely, without effort either in aspiring or in expiring the air incessantly attracted by the draught of the balloons. Every precaution was further taken to guard against loss of expired gas; and the draught was so regulated that the same portion of air could never be subjected oftener than once to the action of the lungs.

"In analysing the gases thus collected, we made use of the processes employed by Messrs. Dumas and Boussingault, with the modifications introduced by M. Leblanc in his work on the analysis of confined air.

"Before inquiring to what extent the quantity of carbonic acid exhaled by the lungs may vary in different forms of disease, we felt bound to ascertain by experiments more numerous and consequent than any that had yet been undertaken, the quantity eliminated in the physiological or healthy state. Our first endeavor was to make out the influence of the three grand physiological circumstances of age, sex, and constitution, upon the exhalation of carbonic acid by the lungs. It was also important to ascertain the influence of rest and of motion, of watching and of sleep, of fasting and repletion, of light and of darkness, &c.

"All our experiments were performed as nearly as possible under the same circumstances, on subjects in good health, at the same time of the day—viz. between one and two o'clock, at the same interval after eating, and in conditions as nearly similar as might be in regard to the quantity and quality of the food, of muscular exertion, of moral state, &c.

"And then, to give the greater value to our conclusions, we took care to repeat every experiment several times—as often as six times—on the same subject; the agreement in the results was found in every case as great as could be expected in a physiological inquiry.

"We collected almost invariably 130 litres (about 217 pints) of gas in each experiment, which lasted between eight and thirteen minutes. The products collected were therefore of quantity sufficient on the one hand to render even minimum differences very apparent; and on the other, the trial was continued for a sufficient length of time to admit of a pretty rigorous conclusion from the fact observed, with reference to what would happen in the course of an hour or any longer period. We have not, however, made use of our results to calculate the quantity of carbonic acid which each individual exhales in the course of twenty-four hours, inasmuch as we are still without the assurance that the intensity of the pulmonic function continues the same at every period of the day, and especially of the night.

" Let us only further add, that in the statement of our experiments we have generally represented in grammes the quantity of carbon contained in the carbonic acid exhaled, inasmuch as by this means we obtain numbers that are more easily remembered, and especially because definitively it is the quantity of carbon that is thus burnt which it imports us to know.

" Seventy-five experiments were made with all the precautions indicated on seventy-two different subjects, of whom thirty-six were of the male and thirty-six of the female sex.

" These experiments satisfied us, that from the age of eight years on to extreme old age, the quantity of carbonic acid exhaled from the lungs in a given time, varies notably according to the age, sex, and constitution of the individual observed.

" At every age, from eight years upwards, the exhalation of carbonic acid from the lungs is greater in males than in females. Here are the differences presented by the two sexes :

" In the male the quantity of carbonic acid exhaled goes on increasing continually from the age of eight to thirty years ; from thirty to forty it is stationary, or even tends to diminish a little ; from forty to fifty the tendency to decrease is more decided ; lastly, from fifty to extreme old age, the exhalation of carbonic acid diminishes more and more, until, in men arrived at the last term of existence, it returns to nearly the same amount as it was at ten years of age.

" The following numbers indicate the quantity of carbon contained in the carbonic acid exhaled in an hour from the lungs of man at different ages.

" A male child, eight years of age, burns 5 grammes (77 grs.) of carbon in an hour ; the quantity was found to increase by regular degrees until the age of fifteen years was attained, when the quantity consumed amounted to 8·7 grammes (133 grs.)

" From the age of fifteen, the quantity of carbon consumed increases in the following manner :—

" At sixteen, the consumption is 10·8 gram. (166 grs.) per hour ; between eighteen and twenty years, it rises to 11·4 gram. (175 grs.) ; in the period of life comprised between twenty and thirty years, it remains very constantly at 12·2 gram.

(187½ grs.); and between thirty and forty years, the quantity continues very nearly the same.

"From forty to sixty, the measure of carbonic acid exhaled is represented by no more than 10·1 gram. (155 grs.) of carbon; from sixty to eighty, it is represented by 6·2 gram. (95¼ grs.) only; finally, in an old man, aged 102, it was represented by no more than 5·9 gram. (90⅜ grs.)

"In following the variations in the quantity of carbonic acid exhaled from the female lungs at different periods of life, we find in the female child, from the age of eight to the period of puberty, that the quantity goes on increasing continually, precisely as in the boy; but it always remains a little less than in him. At the age of puberty, a very remarkable phenomenon presents itself: it is the sudden cessation of any further increase in the quantity of carbonic acid exhaled from the moment the woman menstruates. Whilst in man the exhalation of carbonic acid augments considerably after the period of puberty, it, on the contrary, continues the same in woman as it was previously to this grand epoch in her life, and so it remains as long as she continues to be regular. When they are in all respects in perfect health, women do not consume more than about 6·4 gram. (98¼ grs.) of carbon per hour, estimating the consumption by the carbonic acid exhaled from the lungs; they are precisely like children of the female sex before puberty; whilst in males the mean of the carbon consumed per hour, which was 7·4 gram. (or 113½ grs.), between eight and fifteen years, after this period rises to 11·3 gram. (174 grs.), and so continues to forty.

"The period arrives, however, at which females cease to be regular; and, most remarkable, from this time the quantity of carbonic acid thrown off by the lungs immediately begins to increase; so that in females between thirty-eight and forty-nine years of age who have ceased to be regular, the quantity of carbon which represents that thrown off in the shape of carbonic acid from the lungs, increases from 6·4 to 8·4 gram. (98¾ to 129 grs.). But now, as years accumulate, the quantity begins to lessen, and henceforward follows the same laws as in the male subject, laws from the influence of which females at the critical age appeared to have temporarily escaped.

'Thus, whilst in females between forty and fifty years of age who have ceased to be regular, the quantity of carbonic acid exhaled in the course of an hour indicates 129 grains of carbon, this mean sinks between fifty and sixty years to 112 grains, and in females between sixty and eighty years, it amounts to no more than 104¾ grains, a quantity, which is nevertheless higher than we found it in women quite regular and only twenty-five years of age. Finally, in a female of eighty-two, we found the consumption of carbon to amount to no more than $92\frac{1}{4}$ grains per hour, a figure which very nearly corresponds with that of the old man of 102.

"Another remarkable fact is this: that if, in a young woman, the periodical discharge ceases accidentally at any time, the exhalation of carbonic acid from the lungs is forthwith suddenly increased, precisely as it is at the critical age. Thus, then, whatever the time of life, the existence of the periodical discharge regularly coincides with a diminution in the exhalation of carbonic acid from the lungs.

"If such be the influence of menstruation on the exhalation of carbonic acid from the lungs, it was only natural that we should inquire into the state of affairs when pregnancy came to interfere with the process. We, therefore, instituted observations on four females at different periods of pregnancy, and in them we found that the mean quantity of carbonic consumed amounted, on an average, to about 123 grains per hour, varying in different instances between 115 and 129 grains; in pregnant women, therefore, the exhalation of carbonic acid obeys the same laws as in those who have passed the critical period of life.

"In individuals of different ages and different sexes, the general strength of constitution, especially as this is indicated by the development of the muscular system, exerts a notable influence upon the quantity of carbonic acid which is exhaled from the lungs in a given time; but there is still no violation of the laws already indicated, and age and sex always exert their empire. Thus, the most robust child never exhales so much carbonic acid as an adult; but a very sturdy old man may be found burning a quantity of carbon equal to that which is generally consumed at a less advanced age. The most robust female, particularly if she be regular, never exhales so much carbonic acid as the most weakly male of the same age.

"The maximum quantity of carbonic acid exhaled was observed in a young man, twenty-six years of age, and of athletic constitution; in two successive trials, he burnt upon each occasion at the rate of 217 grains of carbon per hour. In another man, sixty years of age, and whose constitution was at least as strong as that of the preceding subject, the quantity of carbonic acid exhaled indicated a consumption of 209 grains of carbon per hour. In a third, sixty-three years of age, and built like the two former subjects, the consumption was still 190½ grains per hour. Lastly, in an old man, who, at ninety-two, preserved a singular degree of energy, and who, in his younger days, had boasted of uncommon muscular powers, the quantity consumed was still over 9·8 grammes, or about 151 grains per hour. By way of contrast to this last instance, we may mention that the same quantity was indicated in four successive experiments upon a man of only forty-five years of age, whose muscular system was extremely slender, although in other respects he was in the enjoyment of perfect health.

"These facts are sufficient to show the influence of individual constitution upon the exhalation of carbonic acid from the lungs; and they also show to what extent this influence may counterbalance, without, however, destroying that which belongs to age and to sex.

"Is it necessary to add, in the face of the various facts that have now been stated, that the weight of the individual, although not entirely without effect, still plays but a very secondary part in connection with the differences noted in regard to the quantity of carbonic acid exhaled? To prove this circumstance, it may be enough to say, that a female between twenty and thirty exhales no more carbonic acid than a young girl of twelve years; that this female eliminates about one half less than a man of the same age,—a difference which very certainly is not explained by any difference in the weight of the body ; and, finally, that a man, upwards of a century old, and still in good health, is found throwing off no more carbonic acid than a child ten years of age.

"And here another and final question of great importance presents itself: may not the differences in the quantities of carbonic acid exhaled from the lungs in a given time, which have been indicated, be due to a simple difference in the capacity of the chest, in the extent of the respiratory motions, and consequently in the volume of the gases expired? The examination of this difficulty would lead us to speak of facts which fall under our pathological category; this we shall not do at present, but merely state, that the limits within which such influences oscillate are extremely restricted, and lay it down as a law that—

"The very considerable differences which correspond with age, sex, menstruation, and constitution, do really indicate a modification in the activity of the forces which in the economy preside over the combustion of carbon.

"To sum up, then, we say that—

"1st. The quantity of carbonic acid exhaled by the lungs in a given time, varies by reason of the age, the sex, and the constitution of the subject.

"2d. That the quantity exhaled is modified by age, independently of the weight or stature of the individual who is the subject of experiment.

"3d. That in every period of their lives included between eight years and extreme old age, males and females are distinguished by the difference in point of quantity of carbonic acid which is exhaled from their lungs in a given time. All things else being equal, man always exhales more than woman. This difference is particularly well marked between sixteen and forty years—an interval during the whole of which a man gives off nearly twice as much carbonic acid from his lungs as a woman.

"4th. In man, the quantity of carbonic acid exhaled goes on increasing incessantly from eight to thirty years of age, and this continual increase becomes suddenly very great at the period of puberty. From thirty years, the exhalation of carbonic acid begins to decrease, and the decrement takes place by degrees, which are by so much the more strongly marked as man approaches to extreme age, and finally goes so far, that at length the exhalation of carbonic acid from the lungs returns to that which it was about the tenth year.

"5th. In woman, the exhalation of carbonic acid increases from infancy and through youth up to puberty, according to the same laws as in man; but at puberty, and simultaneously with the appearance of the periodical discharge, the exhalation suffers an arrest, and continues stationary at the point to which it had attained, so long as this discharge persists. On its cessation, however, the exhalation of carbonic acid from the lungs increases in a very decided manner; and then it decreases in proportion as woman advances in years, precisely as in men.

"6th. The exhalation of carbonic acid from the lungs is increased during the whole term of pregnancy, attaining temporarily to the same amount as in women who have passed the critical age.

"7th. The quantity of carbonic acid exhaled from the lungs is at all ages by so much greater as the constitution is stronger and the muscular system more highly developed."

X. *Exhalation of Azote by Animals.* When respiration is studied in the human subject, it is extremely difficult to determine the exhalation of azote; we do not know the precise quantity of air inspired, and if we seek to ascertain it by an analysis of the expired air, we perceive that the exhalation of azote is confounded with the disappearance of the oxygen which corresponds with the quantity of hydrogen that is burned.

Thus, if we analyse a measure of air in which a man has breathed, we shall find, for example:

Azote - - - - - - -	798	
Carbonic acid - - - -	16	202
Oxygen - - - - - -	186	
	1000	

The sum of the carbonic acid and oxygen ought to produce 202; it only represents 200. Now the difference can be explained either in supposing that six parts of oxygen have disappeared to form water, or that thirty parts of azote have been disengaged. It is impossible to know precisely what has happened, and to say in what proportion each of these causes has contributed to the final result.

The exhalation of azote can only be determined by making an animal respire in a known quantity of air. This was the course pursued by Messrs. Dulong and Despretz in their experiments. Now, these experiments exhibit a notable and constant exhalation of azote; for in seventeen experiments, M. Dulong ascertained, upon fourteen occasions, a decided exhalation of azote; in the other two there was neither absorption nor exhalation of this principle.

On the other hand, M. Boussingault has shown, that there ought to be an exhalation of azote from the lungs, inasmuch as the whole of the azote consumed as food does not re-appear either in the urine or the excrements.

It may therefore be affirmed, that animals do not take azote from the air; all carefully conducted experiments, on the contrary, show that they rather exhale it.

Such is, in fact, the opinion adopted by Berthollet, Nysten, Dulong, and Despretz, from their individual experiments upon the respiration of animals. M. Despretz has, indeed, insisted upon this conclusion in a very particular manner; he even makes it a general law, inasmuch as he observed an exhalation of azote in at least two hundred experiments. As there is some reason to suspect that the quantity of azote exhaled from the lungs has been exaggerated, new experiments upon the subject seem desirable.

XI. *Excretion of Urea.*—I have assumed the following as the composition of urea:—

2 atoms of	carbon	- - -	12	20·0
2 —	oxygen	- - -	16	26·6
4 —	azote	- - - -	28	46·6
4 —	hydrogen	- -	4	6·6
			60	100·0

In examining the effect which the animal substances that accompany the urea in the urine produce upon it, we find that, becoming altered or modified by exposure to the air, they turn to true ferments; and that, under their influence, the urea fixes water in such proportions as convert it into carbonate of ammonia.

1 atom of urea	$= C^2 O^2 Az^4 H^4$
2 atoms of water	$= O^2 H^4$
2 atoms of carbonate of ammonia	$= C^2 O^4 Az^4 H^6$

Thus the constitution of urine is such, that the whole of the urea excreted by animals through the channel of the kidney, must be speedily turned into carbonate of ammonia.

By the side of urea we find two other excretions of the same order—the uric and the hippuric acids.

Uric acid contains—

10 atoms of	carbon	60	35·71
4 —	hydrogen	4	2·37
8 —	azote	56	33·33
6 —	oxygen	48	28·59
		168	100·00

Crystallised hippuric acid contains:—

18 atoms of	carbon	108	60.33
9 —	hydrogen	9	50·3
2 —	azote	14	7·82
5 —	oxygen	48	26·82
		177	100·00

XII. *Heat of Animals and of Vegetables.*—The animal heat was considered by Laplace and Lavoisier as entirely due to the slow combustion which goes on in the blood under the influence of respiration. We regard this view as the expression of the truth, although some recent experiments call in question its accuracy.

In their experiments, having for object the measure of animal heat in its relations with respiration, Messrs. Dulong and Despretz employed—

1st. A water calorimeter, in which the animal was placed; 2d, Two gasometers, contrived, the one to furnish, the other to receive, the air necessary to respiration.

Of 100 parts of heat absorbed by the calorimeter, M. Dulong found when he made use of water that the combustion of carbon or of hydrogen in the process of respiration accounted for 75 or 80 parts. The remaining 20 or 25 parts he ascribed to a cause unknown.

M. Despretz, who operated with mercury, collected the carbonic acid thrown off in respiration more completely than M. Dulong had done, and of 100 parts of heat collected by the calorimeter, he found from 80 to 90 parts due to respiration.

We must be convinced that the portion of heat absorbed by the water of the calorimeter, which exceeds that represented by the respiration, is due, in principal part, to a true cooling of the animal, when we observe that those animals whose proper temperature is the highest, and which cool most readily, are precisely those which present the greatest excesses. The experiments of M. Edwards have, in fact, shown that young animals lose a portion of their heat much more readily than adult animals of the same species, and it is necessary to remember this conclusion, in order to explain certain apparent anomalies which are encountered in such experiments.

Here is the table which M. Despretz has published of his experiments, experiments which, in other respects, deserve every confidence from the care with which they were performed:

		Caloric produced by Respiration.	Caloric collected by the Calorimeter.
Young animals.	2 little puppies of 5 weeks........	100	135
	1 bitch of 8 months	100	135
Temperature of the animal from 42° to 45° C (107° to 113° F.)	4 magpies........	100	133
	4 owls	100	133
	An adult great owl	100	129
	3 adult pigeons ...	100	126
	Adult duck.......	100	126
	Adult fowl (male).	100	125
Ditto, from 38° to 39° C. (100° to 103° F.)	Cat 2 years old ...	100	123
	Bitch 2 years old..	100	123
Ditto, from 35° to 36° C. (95° to 97° F.)	Male rabbit	100	115
	3 adult Guinea-pigs	100	112
	Adult doe rabbit ..	100	110

This table shows clearly that the excess of heat collected by the calorimeter is by so much greater as the animal is younger, and as its proper temperature is higher.

In other words, the heat which the animal lost to the water which surrounded it, renders a satisfactory account of the apparent excess of heat observed in these experiments. It is not proved, therefore, that there is any source of heat in animals, save respiration.

The theory of Laplace and Lavoisier, in conclusion, which ascribes the whole of the heat produced by animals t. their respiration, must still be held as the most probable.

XIII. *Of the Source of the Mineral Substances which are met with in Organized Beings.*—It has often been subject of debate, whether or not plants create any mineral substances in the course of their growth, and whether or not animals on their side produce them during their lives.

With regard to vegetables, the experiments of M. Laissaigne prove indisputably that they have no faculty of the kind.

And with reference to animals, so far back as the year 1822, I made some experiments in concert with my friend, Dr. Prevost, of Geneva, which lead to the same conclusion.

Eight fresh eggs, weighing together 428·55 grammes, yielded 40·10 grammes of ashes.

Nine incubated eggs, at the point of hatching, weighing together 426·53 grammes, yielded 51·87 grammes of ashes.

Twelve fresh eggs, weighing together 676·37 grammes, lost, during the period of incubation, a quantity equal to 92·75 grammes.

The following conclusions have been deduced with regard to the comparative composition of fresh eggs and eggs ready to hatch :—

	Fresh Eggs.	Eggs at the point of hatching.
Mineral substances - -	9·3	9.4
Organic substances - -	23·8	21.2
Water - - - - - - -	66·9	55·6
Loss during incubation -	. .	13·8
	100·0	100.0

Whence it follows, that there is an actual destruction of organic matter during the development of the chick, and that there is no production of mineral or inorganic substance.

XIV. *Theory of Digestion.*—We have recognized two distinct digestions: 1st, That of soluble articles, which takes place in the stomach ; 2d, That of fatty or insoluble substances, which must take place in the intestinal canal. M. Sandras and Bouchardat express themselves to the following effect on this subject :—

1st. In digestion the function of the stomach consists, with reference to albuminous substances—fibrine, albumen, caseine, gluten, in dissolving them by means of the hydrochloric acid.

2d. This acid suffices, when exceedingly diluted ($\frac{1}{2}$ part to the 1000?—*dilué au demi-millieme*), for the solution of the substances cited, so long as they are raw. If they have been boiled, or otherwise exposed to a high temperature, the dilute hydrochloric acid no longer suffices for their solution in our glass vessels; and as they are certainly dissolved in the living stomach, we must admit that something more than a simple digestion in dilute hydrochloric acid there takes place; only the presence of hydrochloric acid appears to us to be at all times indispensable.

3d. In regard to albuminous substances, digestion and absorption are performed almost exclusively in the stomach, the rest of the alimentary canal showing almost no trace of this solution in its contents, although it was found very abundant in the stomach.

4th. It is in the stomach, also, that the solution of fecula is accomplished. In the ordinary state this principle does not appear to us to be changed into sugar; neither do we hold it demonstrated that it passes into the state of soluble starch or dextrine; we look upon its conversion into lactic acid as ascertained.

5th. The absorption of this portion of the food has appeared to us less exclusively confined to the stomach than that of the albuminous matters which are dissolved there. This is in accordance with the particular characters of the intestines in non-carnivorous animals.

6th. Fat is not attacked in the stomach; it passes into the duodenum in the state of emulsion, to which it is brought by means of the alkalis furnished by the liver and pancreas. This emulsion is found in abundance, through the whole intestinal tracts.

7th. The chyle appeared to us similar in animals which were killed fasting, and in those that were killed shortly after being fed with albuminous substances and fecula. It never showed any marked difference, save in those that we fed with fatty substances, which were found in it in considerable proportion.

The action of water sharpened with hydrochloric acid, to which a few drops of rennet were added, was studied by M. Cahours and myself; and as the results we obtained are rather curious, I shall briefly mention them here.

When some fibrine, which has been washed, freed from grease and dried, is thrown into a flask, containing water, acidulated with hydrochloric acid, in the proportion of about 19 grains of acid to $1\frac{3}{4}$ pints of water, the substance is observed to swell, to become transparent, and then to acquire at least ten times its original bulk.* After a considerable interval of time, a part of the fibrine generally dissolves; but in some cases no solution whatever occurs. When, however, a few drops of rennet are added to the acid menstruum, solution is found to take place in from twenty to twenty-four hours, if the temperature be maintained at from 10° to 15° C. (50° to 60° F.), and in from four to five hours, if the temperature have been kept at between 35° and 40° C. (65° and 104° F.) The filtered fluid is colorless, transparent, and bears a strong resemblance to an albuminous liquid, such as serum. The addition of strong or dilute hydrochloric, nitric or sulphuric acid, determines the formation of an abundant white flocculent precipitate: a solution of alum has the same effect. Evaporated in vacuo over sulphuric acid, the liquid leaves a substance of a yellowish white color, which resembles dried albumen. This substance dissolves readily in warm water, and the solution is not coagulated by heat.

Coagulated albumen behaves in the same way with the acidulated liquor to which a few drops of rennet, or better, of gastric juice, have been added; but the solution is effected much more slowly.

* The analysis of this product satisfied us that the fibrine had suffered no change in its composition.

If the acidulated liquor be employed alone, the same results can be obtained by carrying the temperature to 100° C. (212° F.)

We have analysed the various products obtained, and have discovered numbers which seem to approximate this substance with chondrine in point of composition; but it differs from chondrine in its properties.

Chondrine, however, treated with water slightly acidulated with hydrochloric acid, furnishes a product which entirely resembles the substance just mentioned.

Our analysis satisfies us that the substance which arises under such circumstances may be considered as albumine, which has fixed water.

These analyses, in fact, afford this mean:—

Carbon, - - -	50·8
Hydrogen, - -	7·1
Azote, - - -	15·0
Oxygen, &c. -	27·1
	100·0

Whence the following formula may be deduced:—

$$C^{48} H^{36} Az^{12} O^{15} + 4H^{2} O.$$

C^{48} - - - -	288	51·06
H^{40} - - - -	40	7·09
Az^{12} - - -	84	14·88
O^{19} - - - -	152	26.97
	564	100·00

Formation of Fatty Substances.—I have agreed with Messrs. Boussingault and Payen, that oils or fats are produced by vegetables; that they pass ready formed from them into the bodies of animals, and that there they may either be burnt immediately, in order to supply the heat which the animal requires, or that they may be laid up in the tissues more or less modified, to serve as a reserve for respiration. With a view to verify this idea, we instituted many experiments, which all led us to recognize, in the food of the herbivorous animals subjected to experiment, quantities of fatty matter superior to those found in the milk of the milch-cows, for example, or stored up in the tissues of the ox put up to fatten. By keeping account of the fatty matter contained in the dung, and adding it to the quantity fixed, the sum obtained is still inferior to the quantity of fat which analysis discovers in the food of the animal. With these facts before us, it appeared to us natural to admit that animals assimilated directly the fatty substances of vegetables without modifying them at all, or modifying them but little.

M. Liebig, again, has published some speculations on this subject. In his opinion, fatty matters are formed in the herbivora at the cost of their food. He conceives that the neutral non-azotised substances,—starch, gum, sugar, by the elimination of a certain quantity of oxygen, may be converted into fat in the blood itself, under the influence of the most intimate forces of animal life.

We have not admitted that such conversions were indicated in reference to azotized substances; and with regard to starch and sugar, we have held that, if they undergo such a change, it must be in virtue of a true fermentation analogous to that whence is derived the fuesel oil, or fetid oil of potatoe spirit, which M. Stas and I have succeeded in changing into phocenic acid. Messrs. Pelouze and Gelis have since found that sugar, fermenting in a particular manner under the influence of cheese, produces butyric acid. Since the publication of these researches, M. Edwards and I have observed, as did Hubert half a century ago, that bees fed with sugar alone had still the power of producing wax.

If further experience shows that animals do actually possess the faculty of engendering fatty matters from sugar as bees produce wax from the same substance, we shall have to conclude that there is another point of resemblance between the fruits of plants and animals properly so called. In the same way as we see that fruit is the seat of certain metamorphoses, in which sugar disappears and becomes changed into fatty matter; so will animals be found laying up in reserve with the same purpose and by the same means, under the form of fat, the sugar which they have not consumed in their respiration.

The decomposition of sugar and its return to the state of carbonic acid and water would thus be accomplished by two very different means: 1st. A fermentation which, in fruit, and perhaps in some animals, converts it into carbonic acid and fatty matter, insoluble in water; 2d. A total combustion of the fatty matter so produced, whence result carbonic acid and water.

The formation of fatty principles and their deposition in certain tissues would, therefore, constitute a phenomenon intermediate to the creation of organic products, which take place by the respiration of plants, and their destruction, which is effected by the respiration of animals.

At all events, it is at this time certain that herbivorous animals make use of all the fatty substances which plants contain, and that these substances are more abundant than had been supposed. It is almost certain, also, that carnivorous animals do not produce any fat, so that the neutral azotised substances are necessarily excluded from the number of bodies capable of being converted into fat by the act of digestion.

To these general statements it must be added, that Messrs. Bouchardat and Sandras, on the one hand, and Messrs. Delafond and Gruby on the other, have found, by means the most unquestionable, that the fatty substances of our food pass by the intestinal villi into the lacteal vessels, and constitute the matter which gives the chyle its opacity and white color. When the food contains no fatty matter, the chyle is scarcely opalescent; it has none of its ordinary milkiness.

In digestion, therefore, there is an apparatus,—and this is the most characteristic element in this function—which, as we have seen, possesses the special faculty of absorbing fatty matters reduced to the state of emulsion, suffering very little to escape it where the function is vigorous.

There is, consequently, no reason to feel surprise that the fatty elements in the food of herbivorous animals, however small their quantity in appearance, should be almost completely assimilated in digestion.

The principal facts and conclusions which have been announced in this discourse, began to take shape in our mind so far back as the year 1837; but, convinced that it was necessary to build upon reiterated experience previously to coming before the public, we thought fit to expose them gradually, and only in proportion as it became possible to justify them by positive facts.

We have not been able, to our great regret, to persevere in this strict path. A publication of our personal opinions, premature in certain respects, at least, appeared to us to have become quite necessary in 1841; for we saw ourselves exposed to the risk of losing all our rights.

This necessity, which was a subject of much regret with us, will serve as our apology for having laid down certain propositions before having performed the experiments which would have served to control them. The historical notes which follow, will, in other respects, complete the references to the authorities upon which we have leaned in adopting the opinions we have advocated.

Organic chemistry has now entered upon a course of exploration, in which, balance in hand, it seeks to afford testimony to the truth of certain general views having reference to the physics of the globe.

To whom does the discovery of these views belong? To whom shall be assigned the first use of the balance as a general means of investigation in studying the phenomena of life? The answer to these queries is easy:—

Respiration and Animal Heat.—In the chemistry of Lavoisier we find the following passage:—

"This is not the place to enter into any detail in regard to organized beings. It is from design that I have passed them over in this work, and it is this that has prevented me from speaking of the phenomena of respiration, sanguification, and animal heat.

"I shall return some day to these subjects."*

This he did in fact; and in these terms, some few days only before his deplorable end, did he announce the general result of his experiments, so well combined and so precise:—

"Setting out from the knowledge we possess, and confining ourselves to such simple ideas as every one may appreciate, we shall say, in the first place, that respiration is nothing more than a slow combustion of carbon and hydrogen, resembling in all respects that which takes place in a lamp or candle which burns; and that, in this point of view, animals which réspire are true combustible bodies which burn and consume.

"In respiration, as in combustion, it is the air of the atmosphere which furnishes the oxygen and the caloric; but, as in respiration, it is the substance of the animal itself, as it is the blood which supplies the combustible matter; did not animals repair habitually by their food the loss they sustained by respiration, the lamp would soon be void of oil, and the animal would die as a lamp goes out when its oil is consumed.

"The proofs of this identity of effect between

* Elémens de Chimie.

respiration and the combustion of oil in a lamp, flow immediately from experiment. The air, in fact, which has served for respiration, no longer contains its original quantity of oxygen; it contains not only a quantity of carbonic acid gas, but much more water than it did before it was taken into the lungs. Now, as vital air can only become converted into carbonic acid gas by an addition of carbon; as it cannot be converted into water without an addition of hydrogen; as this two-fold combination cannot take place without the vital air losing a portion of its specific caloric, it follows, that the effect of respiration is to extract a portion of carbon and of hydrogen from the blood; and, in the place of this, to leave a portion of its specific heat, which, during the circulation of the blood, is distributed to all parts of the body, and there maintains that almost invariable temperature which is observed in every animal that breathes.

"We might imagine that this analogy between respiration and combustion had not escaped the poets, or rather the philosophers, of antiquity, of whom the poets were the organs and interpreters. This fire, stolen from heaven—this torch of Prometheus, does not only present us with an ingenious and poetic idea; it is much rather a faithful picture of the operations of nature. We may therefore say, with the ancients, that the torch of life is light-ed when the child begins to breathe, and that it is not extinguished until death.

" In reviewing an illustration so happy, we are almost tempted to believe, that the ancients had, in fact, penetrated more deeply than is generally imagined into the sanctuary of the sciences, and that their fables, as some writers have maintained, are but allegories under which they have concealed important truths in general physics and in medicine."*

It was not, therefore, without very sufficient reason that we, at the end of our discourse, ascribed to Lavoisier the discovery of the route which physiology now treads with so much security in matters of detail, but of which our great chemist had already seen the general course with his penetrating glance.

This restitution is not, however, a matter of circumstance. To prove this, it will suffice if I recall the following words delivered in 1837, three years before anything of recent date had been written on the relations that connect the air of the atmosphere and organized beings so intimately :—

" We begin to understand, it was said, the seduction which Lavoisier exerted on his age, when we see that, in attaching himself with singular perseverance to the study of the air, of water, of car-

* Mémoires, tom. iii.

bonic acid and of carbon, he had actually made choice of the four bodies,—discriminating them with wonderful sagacity from the host of others,—which serve especially for the accomplishment of all the phenomena in the life of plants and animals.

"Not only do these bodies play an important part in crude nature in the formation and alteration of the products that constitute the crust of our globe, but it may be boldly asserted that without them—without the wonderful relations they manifest, life would never have appeared upon the face of the earth; it would not have met with the plastic material which it fashions with so much art and facility.

"These are the four bodies, in fact, which, becoming animated at the fire of the sun, the true torch of Prometheus, approve themselves upon the earth the eternal agents of organization, of sensation, of motion, and of thought."*

"If nothing comes between me and my purpose," adds the writer, "I mean to devote a portion of my course next season to the simplest and most general explanation of what passes in organized bodies during their life and after their death, taking my stand upon the results of physiology and those of organic chemistry. I do not fear to say that

* Dumas, Leçons de Philosoyhie Chimique, p. 100. Paris, 1837.

here, too, we shall discover admirable laws—simple laws—harmonies worthy of the whole attention of enlightened minds."*

Use of the Balance—Fixation of Carbon and Hydrogen by Plants.—At the very same time, M. Boussingault began on his part the long series of inquiries to which he has dedicated himself for several years. These inquiries he imparted to the Institute in more than one successive memoir, which were received by agriculturalists at first with many misgivings, and which led to the following report made to the Academy of Sciences in 1839 by M. Dumas.

" Messrs. Thenard, Pelouze, and myself, have been charged by the Academy to render an account of the last memoir of M. Boussingault upon the chemical phenomena of vegetation and the theory of rotation.

" It is long since the author communicated the principal facts of this memoir to your Reporter, and the Academy will understand that this circumstance ought to be known, for it proves that M. Buossingault proceeds to the researches, the results of which he has communicated to the Academy for some time past, according to a system of ideas attained to a long time ago.

" In the rank of the conquests of modern philoso-

* Dumas, Leçons de Philosophie Chimique, p. 420.

phy must be placed those admirable laws which have fixed the parts severally played by water, air, and carbonic acid, in the development of plants and animals. Modern chemistry alone was in a condition to discover this series of marvellous reactions, the equilibrium of which assures the stability in point of composition of the atmosphere, and consequently of plants, and of animals, upon the surface of the earth.

"All that was known of this subject, however, had been learned by means of procedures employed of old, and without the use of the balance, the only method, nevertheless, which can, by possibility, lead to results of precision sufficient to dissipate every doubt.

"But the character of the researches of M. Boussingault is this: he has introduced the use of the balance into the study of the questions of general physiology which engaged his attention; he has striven to find an equation for each of them; and, placing on one hand all the substances employed, on the other all the matters produced, he is enabled to render an exact amount of the changes experienced by each element during the course of every experiment.

"Thus, when M. Boussingault would discover the influence of water, or of air, upon a plant, he places it in a closed vessel or chamber, in relation with these two bodies in a state of freedom from impurity, and he makes the elementary analysis of the plant before and after its introduction into the apparatus, which protects it against every foreign influence.

"In this way he has discovered that certain plants abstract azote largely from the air, whilst others take none; a very extraordinary fact, but singularly well calculated to shed light upon the part which manures play in rural economy.

"He has further ascertained that plants, independently of the water which they fix, also appropriate hydrogen; that is to say, he has determined a decomposition of water in the act of vegetation, in the same way as the decomposition of carbonic acid had already been discovered.

"Finally, he has verified the fixation of carbon derived from the carbonic acid of the air, having here confined himself to controlling by the balance, a fact which had been detected by other means.

"From the phenomena which take place when a plant, restricted to air and water by way of nourishment, vegetates under a bell-glass, to those that occur when the plant grows in the open field, there is a difficult step to take; the question involved is of no less significance than to determine the part played by manures.

The author has essayed the solution of this delicate question by the general method already indicated.

He forms an equation, the first member of which includes the elements of manure, those of the seed, and a third term, the value of which is unknown; whilst the second member comprises the elements of the crop or produce.

He then inquires what the air, or the water, must have furnished to complete the equilibrium; for the produce generally greatly exceeds the elements of the seed and manure in weight. The third term, of unknown value, represents what has been supplied by the water or the air; that is to say, by those manures, or aliments of plants which cost the farmer nothing; and all things else being equal, it is then easy to judge, according to its rise or fall, whether the crop have been favorable or burthensome.

The author, therefore, weighed the dung and the seed, and then, by varied analyses, he sought to render an account of the quantity and nature of the elements which these two bodies included.

On the other side, he likewise weighed the whole of the produce collected, and analysed it exactly.

He then arranged the results in such a way as to confront the various common elements, and came to the following conclusions:—

As a general rule, the crop contains twice as much carbon as the seed or the manure.

In a general way, also, the crop contains twice as much hydrogen as the seed and manure, a portion of the hydrogen having been fixed independently of the fixation of water.

In general, further, the crop contains about one-half more of azote than the seed or the manure could have furnished to the plant.

But when the Jerusalem artichoke is studied, the culture of which is so extensively practised in Alsace, where the author holds a large farm, it is found that the quantity of carbon is quintupled, and that of azote doubled, so that it may be said that of all the crops tried by the author, the Jerusalem artichoke is the most productive, inasmuch as it takes the largest quantity of carbon and of azote from the elements of the air, pabula that cost nothing. On the other hand, the cultivation of wheat upon a manured fallow is the least productive, inasmuch as in the crop little oı no larger a quantity of azote is discovered, than was already contained in the seed and manure expended.

It must be perfectly understood, that if the author admits that all the elements of the manure, or of the seed, pass into the produce, it is only to place himself in the case in which their effect would be carried to its maximum; the influence which he ascribes to the air and to water is, therefore, reckoned at the lowest amount; but it is still very great, as must be apparent, when it is seen that the Jerusalem artichoke upon a hectare (2·473 acres) of land takes more than 13,000 kilogrammes of carbon, and 130 kilogrammes of azote.*

The experiments of M. Boussingault, therefore, embracing, as they do, the action of vegetables on the air, on water, and on manures, and that of animals upon food and air, tend to base, on accurate analysis, the true DOCTRINE OF THE STATISTICS OF ANIMALS AND VEGETABLES—one, and not one of the least important or interesting of the services which the process of organic analysis, discovered more than thirty years ago by Gay-Lussac and Thénard, shall have rendered.

These researches of M. Boussingault accord with the known fact, that plants decompose carbonic acid, appropriating its carbon, and returning its oxygen to the air, whilst animals convert anew this carbon into carbonic acid;

That plants also decompose water, fixing its hydrogen, and unquestionably restoring its oxygen to the air, whilst herbivorous animals convert anew this hydrogen into water;

That certain plants appropriate the azote of the

* A kilogramme being equal to 2·205 lbs. avoirdupois, the equivalent English weights are about 28,000 lbs. carbon, and 286 lbs. azote.

air, whilst others derive none of this element from this source.

Of these consequences, the first had been already acquired for science ; but the second and the third are new, and of the very highest importance.*

By the side of this Report, and bearing the same date, the *Comptes-Rendus*, or Account of Proceedings of the Academy of Sciences, contains another upon a memoir of M. Payen. The reporter there makes it appear, that from the analyses of woody matters performed by M. Payen, it is imperative on us to admit a *cellulose* in every wood, formed of carbon and of water, and an *incrusting matter* in which hydrogen is in excess. He concludes from this, that water must have been decomposed to furnish the hydrogen.

A discussion having arisen in the Academy on the occasion of receiving these reports, and on the election of M. Boussingault, M. Dumas, giving utterance to the thoughts of the committee, showed that the whole of these late researches led necessarily to the conclusion, that if animals are apparatuses of combustion, plants, on their part, are as certainly a reducing apparatus. In his opinion, M. Boussingault, in proving that plants decompose water, had raised the particular fact of the decom-

* Comptes-Rendus de l'Academie des Sciences, tom. viii. p. 54. 1839.

position of carbonic acid by the green leaves of vegetables, into a general theorem of terrestrial physics.

Sennebier, therefore, had shown that plants decompose carbonic acid to fix the carbon.

M. Boussingault has shown that they decompose water to fix its hydrogen.

Lastly, a committee of the Academy of Sciences in 1839 contrasted the reducing office of plants with the destructive action of animals;

In showing that animals burn carbon to form carbonic acid, and that they burn hydrogen to form water;

Whilst plants decompose carbonic acid to seize upon its carbon, and decompose water to seize on its hydrogen.

It follows incontestably from these data, that, previously to the year 1839, the general physical principles upon which, in our discourse on the balance of organic nature, we summed up the parts severally played by vegetables, and by animals in the economy of nature, had already been laid down and discussed in printed works.

Source of the Azote of Plants.—Whilst in the preceding pages we have spoken continually of certain plants taking azote from the air, and of others deriving it from manures, there is no positive mention of ammoniacal compounds having any essential part to play in this phenomenon.

The reason is simple: it is, that though we saw ammoniacal compounds play the part of powerful manures, it was impossible to affirm that the azote of the air takes this form before becoming fixed in the substance of plants. In presence of the Academy we should, therefore, have had nothing to offer beyond an opinion upon the subject. But if we divide the question it becomes perfectly clear.

M. Boussingault shows us that certain plants fix the azote of the air. It is not known whether this azote passes into the state of ammonia before becoming fixed; ulterior experiments can alone determine the point.

What renders it probable that it does, is the fact that ammoniacal salts certainly play an important part in the manures of which they form a constituent. Let us see, then, to whom belongs the discovery of this duty, or, at all events, who first endeavored to give a practical demonstration of the fact.

In a journey which he took into Alsace, in 1836, in the course of which he visited the beautiful manufactory of Bouxwiller, in company with M. Peligot, M. Dumas received the following communication from M. Schattenmann:—

"Ammoniacal salts form very energetic manures.

In Switzerland it is the practice to drench the dungheaps, and to saturate the liquor obtained with sulphate of iron or sulphuric acid, by which means a liquid manure of great potency is obtained. The sulphate of ammonia in solution, distributed over a meadow with a watering-pot, enables us to repeat the celebrated experiment of Franklin."

Since this time, M. Dumas has always cited M. Schattenmann in his Course, as having discovered the part which ammonia plays in vegetation. But here is an abstract of a letter from this ingenious manufacturer on the subject :—

"I esteem it a proof of your kindness that you do me the honor to quote me upon various occasions in treating of the action of ammonia upon vegetation.

"The treatment of manures is still greatly neglected in France, and even in Alsace, where agriculture is nevertheless very far advanced. For a long time past the urine of the stable has been made use of in Switzerland; there they are in the habit of exhausting dunghills with water and collecting the liquor in ditches, in which, after fermentation, the ammonia is saturated and converted into sulphate of ammonia by means of sulphate of iron, sulphate of lime, or oil of vitriol. The liquor thus prepared, distributed over the fields, produces a luxuriant vegetation, which must be mainly ascribed to the sulphate of ammonia, which is not volatile like the carbonate, and is not dissipated and lost to the proprietor by the action of heat. Dung, like urine, contains ammonia, which it is of import to preserve, but which, under the usual modes of procedure, is generally lost.

"Horse-dung is held to be vastly inferior to that of horned cattle; but this appears to be entirely owing to the method of treating it, which in Alsace, Lorraine, and throughout France generally, consists sometimes in throwing it into a pit, where it is liable to be drowned with water, sometimes in heaping it up in a hillock, either leaving it dry, or watering it insufficiently. The prejudiced notion that horse-dung does not make good manure unless it be turned and mixed, leads to its being stirred once or twice at least. Now, the dung which is immersed in water does not ferment, and the straw does not undergo decomposition; and that, on the contrary, which is heaped up lightly, and is not sufficiently watered, heats up to the point that it moulds; the ammonia which has been formed is dissipated, and the most energetic portion of the manure is lost. The manure that remains is, in fact, light and little substantial, and vastly inferior to that derived from the dung of oxen and kine, which, as being naturally moist and fat, is little disposed to heat and perish.

"For my own part, I have always treated horse-dung with perfect success, upon a plan altogether different from that which is generally practised. I had a square shallow pit dug, 400 metres superficial measure (about 437½ yards), but divided into two compartments of 200 metres each. This pit is an inclined plane, sloping towards the middle, so that the liquid which oozes from the dung-hill collects in a reservoir there, which reservoir is furnished with a pump, for the purpose of returning the drainings as often as may be desired upon the dung-heap. By this arrangement I do not lose a drop of the saturated liquor that distils from the dunghill. This liquor, in fact, is at length entirely absorbed by the manure when it is ready for carting, unless it has been reserved for the purpose of being employed by itself.

"The two compartments are alternately piled with the dung from the stables, which is laid from three to four or five yards thick over the whole surface of the square, trodden down by the feet of the men who fetch it, and abundantly watered by the pumps.

"I thus obtain sufficient solidity and moistness, two conditions which I regard as necessary to keep under or subdue the violent fermentation to which stable dung is subject, and which causes the dissipation of its most active parts. I add to the saturated liquor sulphate of iron in solution, or I scatter over the dung-heap a quantity of sulphate of lime or plaster in powder, with a view to converting into a sulphate the ammonia which is evolved, and which would be dissipated and lost to me if not thus fixed. By these simple and little costly means, in the course of from two or three months I obtain a large quantity of manure perfectly made, as fat and pasty as the dung of neat cattle, and cf great strength, a fact which is abundantly manifested in the remarkable crops I have grown on my fields and meadows for a number of years past.

"Horse-dung piled up absorbs a very considerable quantity of water, which is explained both by its natural dryness, and by the heat it engenders, and the evaporation to which this gives rise. I am convinced that sufficient importance is not attached to this evaporation, and that stable-dung does not receive from the majority of our farmers nearly the quantity of water it requires.

"Urine and the drainings from heaps of fermented manure, the ammonia of which has been converted into a sulphate and retained, if distributed over grass-fields and meadows by a watering-cart, produces great luxuriance of vegetation, so that a name written or a figure described in watering a meadow is very distinguishable by the superior growth, *just as it was easy to form such figures* *by strewing plaster over the surface of the clover-fields in America, when there was an anxiety to extend the use of gypsum in that country.* Ammonia is an essential part of manure, for whatever purpose employed; and as my process tends to preserve the ammonia, and to prevent its loss by evaporation when the manure is spread, it is obvious that this manure must have a very superior effect.

"I do not imagine that I have made any discovery here; the practice of saturating the urine and drainings of dunghills, and of watering meadows with the liquor during damp weather, in the spring as well as after each successive cutting, is old in Switzerland. I only sought to know the nature of the action of sulphate of iron upon fermented urine, and of the powerful effect of the fluid to which it was added upon vegetation. I was naturally led to conclude, that the ammonia engendered, by decomposing the sulphate of iron, is itself converted into a sulphate, which, not being volatile, is not dissipated, and so becomes the principal cause of the great influence exerted by the prepared liquor upon vegetation. I was also led to perceive that horse-dung, by entering into too violent fermentation, by overheating, must cause a dissipation of its volatile ammoniacal parts, and I therefore bethought me of a means of mastering this fermentation as well as of fixing the ammonia.

"I have made these principles known upon all occasions. Various proprietors, fond of agriculture, have made use of sulphate of iron to saturate the drainings of their dung-hills, without attaching much importance to the result, with the exception of Baron de Gail, a landed proprietor at Mülhausen, who has made use of the sulphate of iron and plaster for several years in this direction, and who loudly vaunts the good effects he has obtained from the practice."

The preceding letter is accompanied with a document dated 12th July, 1835, which proves that the facts it contains were at that time publicly announced at the Agricultural Meeting of the Lower Rhine.

Source of the Carbon of Plants.—If it be quite evident that plants derive their hydrogen from water, their azote from the air or from ammonia, it is not quite so natural to suppose that their carbon is obtained exclusively from carbonic acid.

We have only adopted on this topic the opinion expressed so far back as 1828 by M. Ad. Brongniart, in a paper read at one of the public sittings of the Academy of Sciences. These are the terms in which he expresses himself:

"The study of the metamorphoses undergone by the vegetable kingdom, if I may be allowed to make use of such an expression, during the formation of the crust of the globe, appears, therefore, to inform us that the temperature and extent of the ocean have been diminishing incessantly from the first appearance of vegetables upon the earth to the present epoch.

"The comparison of the successive development of plants and animals is not one of the least remarkable points in the study of fossil organized bodies.

"We know, in fact, that in the strata of older date than, or of the same epoch as, the coal-formations, th re are no remains of any terrestrial animal, whilst at this epoch vegetation had already made great progress, and was composed of plants as remarkable for their forms as for their gigantic stature. At a later period terrestrial vegetation loses in a great measure the signal vigor which it formerly possessed, and cold-blooded vertebrate animals become extremely numerous: this is what is observed during the third period.

"Subsequently plants become more varied, more perfect; but the analogues of those that existed originally are reduced to a vastly smaller stature: this is the epoch of the appearance of the most perfect animals, of animals breathing air, of mammalia, and birds.

"Is there no means of discovering some cause adequate to explain in a natural way this vast development, this vigorous growth of plants breathing air, even from the most remote epochs in the formation of the globe? And, on the other hand, of the appearance of warm-blooded animals, that is to say, of animals whose aerial respiration is most active in the last periods of its formation only? May not this difference in the epoch of the appearance of these two classes of beings depend on the difference in their mode of respiration, and of the circumstances in the state of the atmosphere calculated to favor the development of one and to oppose that of the other?

"Under what form, at the epoch of the creation of organized beings, did the whole of the carbon exist which these beings subsequently absorbed, and which is now buried with their spoils in the bosom of the earth, or which is still met with distributed among the infinite multitude of organized beings, that actually cover the surface of the globe?

"It is obvious that animals derive carbon neither from the atmosphere nor the soil, but exclusively from their food.

"We cannot conceive how plants could have assimilated this carbon had it been in the solid state; and, moreover, in the formations older than those that include the first remains of vegetables, we scarcely encounter any traces of carbon.

"This carbon, then, which the vegetables of the primitive world, and those of the subsequent and present world, absorbed, must necessarily have existed in a shape proper to furnish them with nutriment; and we only know of two,—humus or vegetable mould, which resulting itself from the decomposition of other vegetables would lead us into a vicious circle, and carbonic acid, which, decomposed by the leaves of vegetables under the influence of solar light, deposites its carbon, and so serves for their growth.

"It appears to me impossible, therefore, to suppose that vegetables can have derived from any other source than the atmosphere, and in the state of carbonic acid, the carbon which is found in all existing species of plants and animals, as well as that, which after having served the vast primeval forests for sustenance, has been deposited under the form of coal, lignite, and bitumen, in the different sedimentary strata of the earth. If we suppose, then, that the whole of this carbon was diffused through the atmosphere in the shape of carbonic acid prior to the creation of organized beings, we shall see that the atmosphere, instead of containing less than the one thousandth part of its bulk of carbonic acid, as at present, must have contained a quantity which it is not easy to estimate exactly, but which was perhaps in the proportion of 3, 4, 5, 6, and even 8 per cent.

"We are well assured, by the experiments of M. Th. de Saussure, that carbonic acid, far from proving detrimental to vegetation, is positively favorable to it when plants are exposed to the sun's light. This highly probable difference in the constitution of the atmosphere may, therefore, be regarded as one of the causes influencing most powerfully the more active, and very remarkable vegetation of the organic period of our globe.

"But this same circumstance must, on the contrary, have interfered materially with the decomposition of the remains of dead vegetables and their transformation into soil; for this kind of decomposition is owing essentially to the abstraction of a portion of the carbon of the wood by the oxygen of the air; and if the atmosphere contained less oxygen and more carbonic acid, the decomposition in question must have been, without doubt, both more difficult and slower. Hence the accumulation of vegetable *debris* in extensive beds, even in circumstances and from vegetables which, in the actual state of the atmosphere, would give rise to no such layers of combustible material.

"On the other hand, this difference in the composition of the atmosphere, so favorable to the development, growth, and preservation, of vegetable matter, must have proved a bar to the existence of animals, particularly of warm-blooded animals, whose respiration, as it is more active, also requires a purer air: during this first period, consequently, not a single animal breathing air appears to have existed.

"During this period the atmosphere must have been purged of some portion of the excess of carbonic acid which it contained, by the vegetables which then existed; these assimilated it first, and subsequently buried it in the state of coal in the bowels of the earth. It is after this first period, in the course of our second and third periods, that this immense variety of monstrous reptiles makes its appearance, animals which, by the nature of their respiration, are capable of living in an atmosphere of much less purity than that which warm-blooded animals require, and were the heralds and precursors of these.

"Vegetables continued incessantly to abstract a portion of the carbon of the air, and thus rendered it every day more pure; but it was not till after the appearance of a vegetation altogether new, abounding in mighty trees, the source and origin of numerous deposits of lignite, a vegetation which seems to have covered the surface of the earth with vast forests, that a great number of mammiferous animals, analogous in all essential features of their organization to those that still exist in the world, appeared for the first time upon its surface.

"Would it not be fair to suppose from this that our atmosphere had now arrived at that degree of purity which could alone comport with the active respiration of warm-blooded animals, and prove alike favorable to the development of plants and animals, whilst the simultaneous existence of these two orders of beings, and the inverse influence of their respiratory actions, conduce to maintain our atmosphere in the state of stability, which is one of the remarkable characters of the present period?"

General Views in regard to the part played by Plants in the Economy of Nature.—It was from the whole of the preceding considerations and experimental conclusions, that we drew up the following heads as the basis of our researches, and as a kind of synopsis of our lectures upon the particular branch of our subject interested:

Plants are a Reducing Apparatus.

They decompose carbonic acid,
water and
oxide of ammonium or nitric acid

They fix carbon,
hydrogen, and
azote, or ammonium.

They disengage oxygen.

They absorb caloric, or light.

They produce sugar, starch, and gum,
fatty substances,
fibrine, albumen, and caseum.

In this list there are two opinions which, perhaps, are not sufficiently justified by the results previously announced.

The first is that which assumes as essential to plants the faculty of absorbing caloric or light; this opinion was derived from a paper presented to the Academy of Sciences by M. Boussingault, in 1837, in which the author, contrasting the meteorological circumstances, in which wheat, barley, Indian corn, and the potato, are developed at the equator and in temperate zones, arrives at the conclusion "That the same annual plant, everywhere, receives the same quantity of heat in the course of its existence." We have since then been accustomed to regard this heat as one of the principal agents, by means of which the phenomena of vegetation are accomplished.*

* "All the chemical changes that mark the course of nature, are attended with changes of temperature, from the slowest process of fermentation to the most rapid combustion; that is, all the decompositions and recombinations of matter are attended with the addition or subtraction of caloric. Without the continual agency of the solar beams, the vital air, the ocean and the solid, would become a motionless mass of inert and chaotic matter. Without the reception of caloric

The second of the opinions which we have to justify by facts, is the existence of fibrine, albumen, and caseum, in plants.

With regard to fibrine, it is generally known that M. Vauquelin was the first who, long ago, recognized the existence of this proximate principle in the sap of the *Carica papaya.* Messrs. Boussingault and Rivero, on their part, also admitted the existence of fibrine in the milk of the *Paolo de vacca*, or cow-tree. Their paper, published in 1823 ("Annales de Chimie," tom. xxiii. p. 222), contains the following passage :

"Thus obtained, the fibrous substance is brown, because it is undoubtedly slightly altered by the temperature of melting wax; it is tasteless; on hot iron it swells and twists about, melts, and is carbonised with the odor of broiled meat.

"Heated with dilute nitric acid, a gas was disengaged which was not nitrous acid gas. The fibrous substance was changed into a yellow and

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from the atmosphere by respiration, the wonderful mechanism of animal motion, sensation, and life, could not go on."—*On* CALORIC, *its Mechanical, Chemical, and Vital Agencies in the Phenomena of Nature*, by Samuel L. Metcalfe, M.D., London, 1843. An admirable work; full of original, grand, and comprehensive views; to chemistry at large, physiology, and general physics, all that Professor Dumas's elegant Discourse is to the vegetable and animal kingdoms of nature in particular.—EDITOR.

greasy mass, in the same way as muscular flesh, when nitrogen is prepared from it by the process of M. Berthollet.

"Alcohol does not take up this fibrous matter; and we made use of this fluid to procure it unchanged. By treating the extract of vegetable milk repeatedly with hot alcohol, and decanting the liquid, it is finally obtained in the form of white and flexible fibres; in this state it dissolves readily in dilute hydrochloric acid. The substance, therefore, possesses the same characters as animal fibrine.

"The presence in this vegetable milk of a substance which is not generally met with, save in the secretions of animals, is a very surprising fact, which we should not announce without much hesitation, had not one of our most distinguised chemists, M. Vauquelin, already discovered animal fibrine in the milky juice of the carica papaya."

M. Dumas, in his Course of 1839, admitted the identity with fibrine of the part of wheat gluten which alcohol refuses to dissolve.

With reference to albumen, every one has acknowledged its existence in vegetables; but it is imperative on us to mention M. Mulder in this place, this chemist having first proved that the composition of vegetable albumen was the same as that of animal albumen, and who deduced the important consequence, "that the great mass of animal substances is supplied by the vegetable kingdom."

Finally, when we quoted the existence of caseum in vegetables, we had in view the opinion of Proust, who looked on the azotised matter of almonds as caseum; that of Braconnot, who viewed the azotised substance of pease and beans as caseum, and that which M. Dumas had advanced in his course of 1839, touching the existence of caseum in the gluten of wheat. The opinions of Proust and Braconnot have not been borne out by subsequent researches, as appears from the paper of Messrs. Dumas and Cahours; but hitherto nothing has shaken M. Dumas's conclusions relative to the caseum of gluten.

All the opinions comprised in the foregoing syllabus were therefore publicly announced or actually published by us previously to 1839.

We imagined that it was competent for us in 1841, in the Discourse which has just been read, to give a general sketch of views which we had already published, which had taken five or six years to reduce themselves to shape in our mind, and which we had in every instance felt bound to connect with positive experiments before venturing to give them utterance in words.

We are equally satisfied that if the views which are associated in this discourse preserve in future times the importance which is assigned to them now, it will remain a matter of demonstration, that the principal labors upon which these views are founded have been performed in France,* and that their association as a general formula must be referred to Lavoisier, who gave the impulse to physiolgy which we have followed out.

If we deceive ourselves in this, the fact will be easily shown. It will only be necessary to prove that we were in error when we ascribed :

1st. To Lavoisier, the discovery of the theory of animal heat, that of the part which animals play as consumers of carbon and hydrogen, the function which characterizes their influx, and the first application of the balance to the study of the phenomena of life;

2d. To Sennebier, the discovery of the decomposition of carbonic acid by vegetables;

3d. To Boussingault, the discovery of the decomposition of water by vegetables ; the use of the balance in studying the phenomena of vegetation ;

4th. To Schattenmann and Davy, the discovery of the intervention of ammonia in the process of vegetation ;

* See Appendix, Note L.

5th. To Ad. Brongniart and Parrot, the first thought of assigning to the carbonic acid of the atmosphere the origin of all the carbon of organized beings;

6th. To Vauquelin, Boussingault, Mulder, Proust, and Braconnot, the discovery of fibrine, albumen, and caseum in vegetables;

7th. To Dumas and Boussingault, the discovery of the reducing faculty of the vegetable kingdom at large over the face of the earth;

8th. To Chevreul, the true theory of the respiration of animals

WORKS AND PAPERS

REFERRED TO.

(1) Mémoire sur la composition de l'Eau, Dumas et Stas, *Ann. de chim. et de phys.*, 3e série, juin 1843.

(2) Mémoire sur le poids atomique du Carbone, Dumas et Stas, *Ann. de chim. et de phys.*, 3e série, t. I. p. 5.

Idem, Erdmann et Marchand, *Ann. de chim. et de phys.*, 3e série, t. III. p. 500.

(3) Berthollet, *Ann. de chim. et de phys.*, t. XXII. p. 97.

(4) Recherches sur la véritable constitution de l'Air atmosphérique, Dumas et Boussingault, *Ann. de chim. et de phys.*, 3e série, t. III. p. 257.

(5) Recherches sur la variation de l'Acide Carbonique atmosphérique, Th. de Saussure, *Ann. de chim. et de phys.*, t. II. p. 199 ; et *Ann. de chim. et de phys.*, t. XLIV. p. 5.

Boussingault, *Comptes-rendus des séances de l'Académie des sciences*, 1840.

Brunner, *Ann. de chim. et de phys.*, 3e série, t. III. p. 312.

Gay-Lussac, *Ann. de chim. et de phys.*, t. II. p. 204.

(6) Boussingault, *Ann. de chim. et de phys.*, t. LVII. p. 448.

(7) Recherches sur les variations de l'Acide Carbonique avec les saisons, Th. de Saussure, *Ann. de chim. et de phys.*, t. XLIV. p. 5.

(8) Opinion de M. Gay-Lussac sur le travail précédent, Gay-Lussac, *Ann. de chim. et de phys.*, t. LII. p. 92.

(9) Considération sur la nature des Végétaux qui ont couvert la surface de la Terre aux diverses époques de sa Formation, Adolphe Brongniart, *Comptes-rendus des séances de l'Académie des sciences,* t. V. p. 409.

10) Recherches sur le Ligneux, l'Amidon et la Dextrine, Payen, *Ann. de chim. et de phys.*, t. LXV. p. 225.

Dumas, Rapport sur le Mémoire précédent. *Comptes-rendus des séances de l'Académie des sciences,* t. V. p. 898.

Dumas, Rapport sur un Mémoire de M. Payen relatif à la composition de la Matière Ligneuse. *Comptes-rendu des séances de l'Académie des sciences,* t. VIII. p. 5'

(11) Recherches chimiques sur la Végétation, Dumas, Rapport sur un Mémoire de M. Boussingault, relatif à des Recherches chimiques sur la Végétation. *Comptes-rendus des séances de l'Academie des sciences,* t. VIII. p. 54.

(12) Schattenmann, *v.* p. 134.

(13) Recherches sur les Matières Neutres Azotées de l'Organisation, Dumas et Cahours, *Ann. de chim. et de phys,.* 3e série, t. VI. p. 385.

(14) Recherches sur les Cendres des Végétaux, Boussingault, *Observations inédites.*

(15) Recherches sur la Végétation et la Germination, Boussingault, *Comptes-rendus des séances de l'Académie des sciences,* t. VI. p. 102.

(16) Opinion sur la Chaleur Animale, Dumas, *Leçons de philosophie chimique,* p. 79.

(17) Recherches sur la Chaleur Animale, Despretz, *Ann. de chim. et de phys.*, t. XXVI. p. 341.

(18) Recherches sur la Détermination de la Quantité d'Urée, contenue dans l'Urine, Lecanu, *Journal de pharmacie*, t. XVII. p. 649 et t. XXV. p. 681.

(19) Recherches sur la Composition de l'Urée, Dumas, *Ann. de chim. et de phys*, t. XLIV. p. 273.

(20) Recherches sur la Transformation de l'Urée en Carbonate d'Ammoniaque, Jacquemart, *Ann. de chim. et de phys.*, 3e série, t. VII. p. 449.

(21) Dumas, *Leçons de philosophie chimique.*

Andral et Gavarret, *Ann. de chim. et de phys.*, 3e série, t. VIII. p. 129.

(22) Recherches sur la Digestion des Matières Grasses Tiedemann et Gmelin, *Recherches sur la digestion*, t. I. p. 192.

(23) Recherches sur la Digestion, Bouchardat et Sandras, *Ann. de chim. et de phys.*, 3e série, t. V. p. 478.

(24) Dumas, Boussingault et Payen, *Ann. de chim. et de phys.*, 3e série, t. VIII. p. 63.

Dumas et Cahours, *Ann. de chim. et de phys.*, 3e série, t, VI. p. 385.

(25) Dumas, *Philosophie chimique*, 7e leçon.

(26) Recherches sur la Manière dont se comporte l'Acide Gallique en Présence des Alcalis, Chevreul.

(27) Thomas, *Note communicated to M. Dumas.*

(28) Recherches Chimiques sur la Végétation, Boussingault, *Comptes-rendus des séances de l'Academie des sciences.*

(29) Dumas, *Leçons de philosophie chimique*, t. II. p. 90

APPENDIX.

NOTE A.—Page 29.

It will be remembered that Dumas advocates the views of Dr. Thompson in respect to chemical equivalents.—D. P. G.

B.—Page 30.

From the same source sulphuretted, and a minute quantity of phosphuretted hydrogen are evolved.—(*See the Editor's paper, Am. Journal Med. Sciences, Apr.* 1843.)—D. P. G.

C.—Page. 31.

Liebig has made a general estimate of the proportion of ammonia at $\frac{1}{60000}$ in vol.—D. P. G.

D.—Page 40.

The rays of light which produce marked effects upon vegetation are not those which act on Daguerre's plate.—(*See the Editor's paper, London and Edinb. Phil. Mag., Jan.*, 1844.

E.—Page 42.

The hydrogen of ammonia decomposed by plants is retained.—D. P. G.

F.—Page 43.

This is effected in practice by turning in clover, a plant that absorbs nearly all its azote.—D. P. G.

G.—Page 48.

See the Editor's paper, London and Edinb. Phil. Mag., July, 1842.

H.—Page 49.

This is true also in the corn plant, which, when cultivated for sugar, should be hindered from developing the ears.—D. P. G.

I.—Page 52.

In the recent experiments of Brunner and Valentin, the difference of nitrogen between atmospheric air and expired air is not greater than may arise from errors of observation, and they consider it inactive. Liebig, admitting its occasional presence, refers it to the penetration of the nitrogen of atmospheric air taken into the stomach with saliva. In the same way the nitrogen dissolved in water could pass out by the skin and lungs.—D. P. G.

J.—Page 58.

The view here advocated that animals receive all their fat from vegetables has been abandoned in part by M. Dumas. Liebig had in his Animal Chemistry advanced the doctrine of the transformation of amylaceous substances into fat in the animal economy. He based it on the researches of Grundlach on bees. A difference of opinion having arisen MM. Dumas and Milne Edwards proceeded to determine the point experimentally. They selected a hive of 1988 bees, and placed them in a proper vessel where they received honey only as food for thirty-one days. One hundred and five bees were analyzed before the experiment—and one hundred and seventy-seven afterwards to determine the amount of fat they contained. The result of the experiment communicated to the Academy of Science, Sept. 18th, 1843, showed that there had been an actual transformation of honey into wax, amounting to 0·0742 gramme by each insect.

It will be understood, therefore, that animals receive fat from vegetables and are also able to transform starch, sugar, gum, &c., into that body.—D. P. G.

K.—Page 68.

The ammonium theory owes its existence to the discovery of the ammoniacal amalgam by Berzelius. In its formation one atom of ammonia and one atom of water are acted on by galvanism in the presence of mercury; a bulky pasty amalgam results at the negative, and one atom of oxygen is liberated at the positive pole. This body consists, therefore, of N. H.4—united with mercury. It has the general characters of sodium and potassium, and forms chlorides, iodides, &c. For the production of oxygen salts it is necessary that the ammonium be in the state of oxide or N. H.4+O., which contains the elements of one atom ammonia, and one atom water, and exists only in combination. We are under no necessity to consider ammonium a metal, but a compound radical similar to Ethyl, &c.—D. P. G.

L.—Page 167.

The Editor wishes to disavow the presumptuous assertion of M. Dumas that the principal labors tending to the present development of animal and vegetable physiology are of Parisian origin.—D. P. G.