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HODGKINS FUND.

AIR AND LIFE.

BY

HENRY DE VARIGNY, M. D., Sc. D.,

Member of the Société de Biologie, Demonstrator in the Institute of Comparative Pathology in the Paris Museum of Natural History.

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[Translation (by the author) of the essay on L'Air et la Vie, submitted by Dr. Henry de Varigny in the Hodgkins Fund Prize Competition of the Smithsonian Institution, and awarded "the third prize of $1,000, for the best popular treatise upon atmospheric air, its properties and relationships."]

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INTRODUCTION.

A great chemist, J. B. Dumas, once said that living organisms are nothing but "condensed air." He thus expressed, in terse terms, the result of the investigations pursued by himself and others into the relations of the atmosphere to living beings.

My purpose, in the following pages, is to show how closely Dumas's statement agrees with ascertained facts, even more closely than he himself supposed. It is also desirable to briefly instance and illustrate the varied ways in which air influences the general life of the globe. If the ordinary definition of the word were not an impediment to its use in the present case, I would say that I purpose making a general sketch of the "biology" of the atmosphere. More exactly and appropriately I may use a quite similar term, and say that the subject-matter of this essay is the "natural history" of the air—taking the term in the sense given to it by Geoffroy St. Hilaire—an essay upon the properties of air considered in its relations to living beings, upon its composition, its contents, its origin, its varied modes of action.

While I shall especially and particularly consider air in its relations to life, I shall also refer briefly to its relations to other subjects, pointing out those which it would be useful to investigate further in order to increase the scope of our knowledge.

The study of the atmosphere is truly one of great magnitude; its relations to the remainder of the universe are so varied and important, the subjects which it suggests are so numerous and take us through so many fields of inquiry, that a comparison suggests itself forcibly—just as the atmosphere surrounds our whole planet and forces itself into the clefts and fissures between its elements and rocks to the depths of the soil, in the same manner does the study of air pertain to all departments of science, to geology as well as astronomy, to physics no less than to chemistry, and to biology in the largest sense of the term.

While it would be a hazardous enterprise to undertake a complete review of so important a subject, it may prove useful to give a rapid sketch of some features, and that I shall endeavor to do, by showing what air is, physically and chemically considered, what is its origin, what it contains, and of what use it is to life. Doubtless this is but a small part of the subject, but this sketch may contribute to show how vast and varied is that chapter of science that goes under the name of the "study of the atmosphere."

I.—Air Considered from the Physical Point of View.

Vast as are the proportions of the atmosphere it is none the less invisible. It surrounds us on every side; we are bathed in it, and we do not see it; when it is not in motion we do not feel it. Although having material existence and creating material effects, for evil or for good, it is immaterial to our senses. This fluid, this gas, may, however, be weighed. Jean Rey[1] and Otto von Guericke[2] were the first who gave positive proof of this, and showed that a glass receiver in which a vacuum had been made—even imperfectly—weighed less than the same receiver in normal and free connection with the surrounding atmosphere—that is, full of air—and, on the other hand, a receiver into which air is forced and maintained under pressure weighs more than the same receiver full of air at the normal pressure *pro loco et tempore.* One liter of air, pure and dry, under the pressure of 760 millimeters, at 0° temperature, and at the latitude of Paris, weighs 1.293 grams (Regnault). It weighs more if the pressure is higher, less if it is lower; and hence a liter of air has more weight at the bottom of a shaft in a mine than at sea level, and less on top of a hill or mountain. The higher the altitude at which air is weighed the less it weighs, because it expands, the same weight of air occupying a larger space or volume. Air is more dense at low stations, less dense in the higher strata of the atmosphere, so that when the weight of air is mentioned it is always given with reference to a certain altitude, to a certain pressure, and also to a certain temperature and hygrometric state, because these different conditions exert a considerable influence upon the matter.

As in the case of other gases, air is made up of molecules, and these are considered as being in a state of perpetual motion. It has been reckoned that the number of impacts or collisions to which each molecule is subjected during each second, in the tremendous turmoil which takes place in the air, amounts to something like 4,700,000,000! These molecules are exceedingly small, and Sir William Thomson (Lord Kelvin), Clerk Maxwell, and Van de Waals give their dimensions as being less than a fraction of one-millionth of a millimeter, 1 cubic centimeter of air, at 0° and 760 millimeters pressure, containing, in round numbers, some 21,000,000,000,000,000,000 of these molecules.

I have referred to the fact that the weight of the air is not the same in all localities. It also varies in the same locality. The sum total of

[1] Jean Rey, French physician and physicist, said, in 1630, that if tin is burnt in contact with air, it increases in weight, and this increase is due to air which has been absorbed by the metal during the combustion.

[2] Otto von Guericke, born 1602, died 1686. He also demonstrated atmospheric pressure by means of the instrument called the Magdeburg hemispheres—two hollow hemispherical cups which it is very difficult to separate when a vacuum has been created in the interior.

the weight of the atmosphere, wherever considered, varies every day more or less, often appreciably within the limits of a few hours and even minutes. This could not happen, of course, if the weight of the strata of air did not vary also. The weight of the whole atmosphere increases or decreases because the weight of the air, considered at any region vertically above the point where the observation is made, increases or decreases. These variations of weight, or pressure, are indicated by the barometer—devised in 1643 by Torricelli, pupil and friend of Galileo—and the oscillations of that instrument are only indications of the differences of the weight or pressure of the air.

Now, as the pressure is increased at low stations, and diminished at high ones, and, as there is a very definite and regular connection between differences of altitude and barometrical indications, it is conceivable that the barometer may, to some extent, and with certain limitations, yield information as to the altitude at which an observer finds himself. It is sufficient to mention the fact; the methods by which it is established would require too long an exposition.

Since air is material and has a weight of its own, however variable, it must press upon all organisms. It is not difficult to estimate with some precision the weight of the superincumbent air. For each square centimeter of our skin, the pressure exerted is exactly that of a vertical column of mercury 1 square centimeter in section, and of the same height as the barometrical column at that moment. If the barometer stands at 760 millimeters, the pressure is exactly that of 76 cubic centimeters of mercury, and as each cubic centimeter weighs 13.6 grams, the sum total, per square centimeter, is 1 kilogram 33 grams, or about 15 pounds per square inch. Taking the skin surface of the average adult to be something like 1½ square meters (15,000 square centimeters), the weight with which the atmosphere presses on each of us amounts to 15,450 kilograms; but under ordinary circumstances we do not feel this enormous load, because the pressure is exerted in all directions; from within outward as well as from without inward, from below upward as well as from above downward. To perceive this pressure, it must be removed from one side, as when the hand is placed over the open end of a cylinder in which a vacuum is being formed; then one feels the strong pressure pushing the hand toward the opposite end of the cylinder. Of course the pressure exerted upon the body and all objects, is lessened as the altitude increases, or the barometer falls; and, reciprocally, if the barometer rises, or if the body be at a low station—in a mine for instance—the pressure is higher. The total weight of the atmosphere, at sea level, under normal circumstances, averages some 5,000,000,000,000,000,000 kilograms—that is, the millionth of the weight of our planet itself; or, to use other terms, the weight of a continuous stratum of mercury 76 centimeters high, and covering the entire surface of the globe, both sea and land. This is a fairly high figure for a substance so nearly immaterial that it escapes our vision. However, air is not always invisible; it may be seen very clearly; it may also be touched and handled, although no one would undertake to do so, or to recommend the feat. Whilst it is gaseous under normal pressure and circumstances, it may be made to assume the liquid form when subjected simultaneously to the influence of considerable cold and very high pressure. High pressure alone is not sufficient. Under a pressure of 3,000 atmospheres, 3,000 times that of ordinary sea-level pressure, oxygen and nitrogen remain gases (Natterer); but if at the same time the temperature is lowered, they immediately assume the liquid condition. MM. Cailletet and Pictet have obtained liquid air by means of pressures of 300, 500, or 1,000 atmospheres cooperating with intense cold, with the cold corresponding to 100° or 200° below zero (Celsius or centigrade). Under such circumstances air may even assume the solid form; the liquid air freezes into a solid block.[1]

No one could venture to touch this liquid or solid with the bare skin, for two reasons; one being that, of course, air can be kept liquid or solid only under the circumstances of its production, and instantly becomes a gas under normal pressure or temperature; the other, that, even if the transformation were not instantaneous, the intense absorption of heat (production of cold) which accompanies the passage from the liquid or solid to the gaseous state would be more than sufficient to kill instantly all living tissues in the vicinity.

It is enough for our present purpose to simply mention the importance of air as an elastic fluid, and the part played by this gas in luminous, thermic, acoustic, and electric phenomena, where it is an all-important medium. It is also sufficient to remind the reader of the temperature of the atmosphere and its varied movements, from the light breeze that cools the hot summer days to the cyclones and tornadoes which destroy buildings and tear up the strongest giants of the forests. Lastly, the atmosphere is very far from being unlimited. It ceases at some distance from our planet, becoming very thin and rare even at altitudes that are not exceedingly great, such as 5,000 meters (Mont Blanc, 4,813 meters; Gaurisankar 8,840 meters), and while we are not prepared to state the exact distance from the earth at which all traces of air disappear, it is generally admitted that above 320 or 350 kilometers (1 kilometer=1,000 meters) height, vertically, there is no atmosphere worth mentioning. Of course, at such altitudes, the air must be exceedingly thin and rarefied, as it is in the exhausted receiver of the air pump.

It is commonly said that air is tasteless and odorless. Pure air

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[1] The gas is first cooled down to 30° below zero, and then compressed under 200 or 300 atmospheres. It remains fluid; but if a small amount of it is then allowed to escape, the sudden expansion—which is accompanied by a production of cold, while compression causes heat to be evolved—cools down the remainder of the air, the temperature falls to 200° below zero, and the air immediately assumes the liquid condition. Lower down it freezes and becomes a solid block.

may be unable to affect the olfactory membrane; but this is not the case with the atmosphere generally. The air that surrounds us is full of scents and odors, but we are so accustomed to them that we take no notice thereof. But after we have spent some time in an atmosphere where most ordinary odors can not conveniently gain access, and then return to our ordinary surroundings, the case is altered, and we perceive a very powerful odor. This has been noticed by different observers after a considerable sojourn in deep caves, such as the Mammoth Cave in Kentucky. The air in these caves is nearly odorless, and when, after a few hours spent in this scentless environment, the visitor emerges again into the open, the atmosphere seems powerfully, even violently, scented or odoriferous, and some persons may even be temporarily affected by the intensity of the sensation. During the sojourn in the unscented air the olfactory cells have rested, but the renewal of their activity, generally unconscious, is accompanied by a very strong sensation which however soon fades.

The atmosphere does not stop at the surface of the seas, nor does it cease at the surface of the soil. It penetrates both, the former especially. In the latter the access of air is very soon arrested by the compactness of the rocks or strata, and, generally speaking, the proportion of air in the soil is very small in all cases where there are no clefts, fissures, or deep underground galleries. In the superficial layer, however, the case is different; air is always present in appreciable proportions in the less compact parts where plants push their roots and seek their nutriment; and in the deepest shafts, caverns, caves, and other natural or artificial excavations of the soil, air exists. It should not be expected to find there as pure a gas as that which surrounds the exterior of the planet. In the soil many slow but continuous chemical reactions are going on between the air and the solid constituents, and the result is an alteration of both sets of elements; some chemicals of the earth and rocks are transformed, and while the air loses some part of its constituents new elements are added to it, and thus its normal composition is soon altered. This is the reason why great care should always be exercised to ascertain the condition of air in all deep cavities, and even in normal excavations if they are rather secluded. The air may have been so much altered in its composition as to have become unfit for the maintenance of life, and cases are on record where it consisted almost entirely of carbonic acid. Among the investigators who have specially concerned themselves with the chemical composition of "ground" air, Boussingault has obtained interesting results, showing that while 1 cubic meter of normal atmosphere contains about 4 deciliters (or 0.216 gram) of carbon, 1 cubic meter of ground air contains 9 liters (or nearly 5 grams), which is twenty-two or twenty-three times more. In recently manured soil the proportion is much more considerable, and the amount of carbonic acid may be twenty-four times as great as in atmospheric air. This considerable amount of carbonic acid in ground air fully explains a number of accidents, inasmuch as while the proportion of this gas is considerably increased that of oxygen is greatly diminished.

Air penetrates to a great depth in water, whether fresh or salt. This is shown by the number of living forms found, not only at the surface or in its neighborhood, but at the greatest depths to which man has yet been able to lower his nets, dredges, and sounding apparatus. Since living organisms exist in the depths of the ocean, and since they are physiologically, in their most important features, constructed on the same principles as those which live near the surface, it is obvious that in the waters of the deep, air must be dissolved of which they take advantage for their respiratory functions. Direct and precise observation fully confirms this inductive reasoning. Many instruments have been devised for the purpose of obtaining water from different depths. One of the first was the bottle, which was used by the Kiel committee. This bottle, firmly stopped and empty, was lowered to the required depth, and a sudden pull was enough to cause it to open, the surrounding water filling it in a few seconds. Many similar implements have been since invented by Bunsen, Meyer, Mill, Buchanan (*Challenger*), Ellman, Sigsbee (*Blake*), Richard, Villegente, and Paul Regnard. The description of these instruments is given at length in many works—for instance, in T. Thoulet's Océanographie (Vol. I), Paris, 1890, and P. Regnard's La vie dans les eaux, Paris, 1891—where the reader who desires full information on the matter may find it, and it will suffice for our purpose to give a general summary of the results obtained, without detailing the methods by which water is brought to the surface from different depths, or those, familiar to all, by which the gases contained in water are extracted and submitted to chemical analysis. In short, the results of these experiments fully and completely confirm the opinion above expressed, that even at the greatest depths water does contain air; that the atmosphere extends down to the nearly unfathomable abysses of the ocean.

As to rivers and lakes, or other shallow waters, the demonstration is most easy. Their water contains oxygen, nitrogen, and carbonic acid. But it is a noteworthy fact that these gases are not to be found in the proportions in which they exist in the atmosphere. Strictly speaking, one can not say that there is any air in water. What we find are the elements of air, the latter being all present, but their proportions being different from those in the normal atmosphere. For instance, 1 liter of river water contains from 4 to 8 cubic centimeters of oxygen; from 12 to 18 cubic centimeters of nitrogen, and from 2 to 20 or 25 cubic centimeters of carbonic acid. These proportions differ greatly from those which these three constituents have in normal air, and it must be noted that the variations are different in different rivers or even in the same river when examined in different places. Take the Seine River, for instance. Each liter of water contains 32.1 cubic centimeters of gas, of which 3.9 are oxygen, 12 nitrogen, and 16.2 are carbonic acid. Take the Rhone River, on the other hand, and you find 34.8 cubic centimeters of gas, of which 8.4 are oxygen, 18.4 nitrogen, and 8 carbonic acid. These differences are less surprising after reflection. Each river may and does differ in chemical constitution from other rivers, and even from itself, at different times and places, because of the difference in the nature and quantity of the chemical operations going on in the water. The chemical composition of the banks varies, and the activity of living organisms within the waters also varies. Such differences must exert their influence upon the chemical composition of the latter, and we have abundant proof that they do so. If the water of the same river, taken at different places at the same moment, is tested chemically, differences are observed which are sometimes considerable. For instance, the Thames, above London, contains 7.4 oxygen, at Hammersmith 4.7, at Somerset House 1.5, at Woolwich 0.25. Whence arise these considerable variations? They are easily explained by the fact that the river receives a large quantity of organic débris, vegetables, dead animals, and a large number of dead or dying substances or organisms; the débris combines with oxygen, and thus the amount of this gas is greatly diminished. The consequence is that the fish often perish through asphyxia, the amount of oxygen being inadequate. The same occurs in Paris. After its passage through the city, the Seine is generally quite unfit to support the life of most aquatic animals. Many species are not to be seen in the river at Paris, nor below it for some distance, although found above, where the water is sufficiently pure and aerated, and some 10 or 20 miles below, where aeration has been sufficient to make up for the loss, the water having absorbed enough fresh oxygen from the atmosphere.

So much for one series of differences in aeration. But another series exists which is even of greater interest. The aeration of waters, or the absorption of gases by water, varies according to general external conditions, among which temperature and pressure rank highest—not only general pressure, but, so to speak, individual pressure, or, to put it in other terms, the proportion of any given gas in a mixture. Under identical conditions, each gas, moreover, has its own special coefficient of solubility. While nitrogen is feebly soluble, ammonia is highly so. This fact helps us to understand why it is that the gases which spontaneously dissolve in water in contact with the atmosphere do not, when extracted from the water, yield a mixture even distantly comparable to air: how it is that the elements of air are not found in water under the proportions they bear to each other in the atmosphere. While water contains the constituents of air, it contains such proportions of these constituents as are peculiar to it. However, the latter are provided in sufficient quantity, and normal river water is quite adequate to maintain the life of aquatic animals. This applies to fresh waters generally, for ponds and lakes have the same conditions as rivers.

Some special points are to be noted concerning salt water. Of course the constituents of atmospheric air are met with in sea water. But, generally speaking, the variations in the proportions of these constituents are less numerous and of less importance. The seas, generally considered, make up a more homogeneous whole than any river of large dimensions. Between the south Atlantic and the north Atlantic less differences are to be expected, and less found, than in the Thames or the Seine, below and above London or Paris. A priori it is obvious that there are less causes of difference in aeration in the two parts of the Atlantic than there are in any of the two rivers in two points, not 10 miles apart. It is quite obvious also that local differences, such as exist at the mouth of a great river that has just passed through a large town, as is the case with the Hudson, the Thames, or the Gironde, must be very soon dissipated in the enormous mass of the ocean through the agency of tides, currents, and winds. Upon the whole, generally speaking, none of those local differences are of any real importance. There are, however, differences which should be noticed, but their causes are quite different from those which obtain in the preceding case. The most important are observed when we compare specimens of water obtained from different depths. Carpenter noticed the fact and comparing specimens of water obtained in the same vertical line, at depths of 750, 800, and 862 fathoms, he observed the following composition of the air extracted:

	750 fathoms.	800 fathoms.	862 fathoms.
Oxygen	18.8	17.8	17.2
Nitrogen	49.3	48.5	34.5
Carbonic acid	31.9	33.7	48.3

While the proportion of oxygen decreases with increasing depth, that of carbonic acid increases in a marked manner. No very satifactory explanation of this fact has been yet provided.

We have now sufficiently dwelt upon this topic, and none will doubt that air—that is, the constituents of air, to put it in exact terms—intimately mingles with the waters that cover three-fourths of our planet. While waters do not contain atmospheric air as such, and while the gases dissolved in them do not make up normal air, they contain the elements of the latter, and the proportions are sufficient to maintain aquatic life. We may consider that these elements are found in water, even at the most considerable depths, although we have no positive proof of it.

Now, it is quite clear that since the mass of the waters contains organisms that breathe and live, and since life goes on notwithstanding the unceasing production of carbonic acid and the destruction of oxygen, both necessary consequences of their life and respiration, there must exist some unceasing agency by means of which new oxygen is added and carbonic acid carried away. Otherwise aquatic life would soon cease. In other terms, there must exist a perpetual exchange between the gases dissolved in the waters and those which make up the atmosphere, just as there goes on a perpetual exchange between the air of any place where the atmosphere is vitiated—a town, a manufactory, a room—and the air of the streets or surrounding country. And the exchanges which go on between air and water, and between the general atmosphere and those multitudinous centers, great or small, where the normal proportions of the gases of air are being constantly altered, must indeed be most nicely adjusted, since by no method have we yet been able to detect any alteration in the composition of the atmosphere. The equilibrium must be unceasingly maintained. That equilibrium is a very interesting matter. Interesting in two senses—practically, since life depends upon it, and from the scientific point of view, as it is the consequence of a general established law.

How, then, is that exchange effected between air and water, without which life would soon extinguish all life, without which the living organisms of water would soon render life impossible to themselves and to their congeners? By means of what may be termed "the breathing of the waters." The waters breathe—that is, expire obnoxious gases and inspire those that are useful; they expel carbonic acid and collect oxygen. Diffusion is the main agency of this grand function of waters, and it is enough that both air and water be in presence and contact to insure the operation. But diffusion is not alone at work; another agency cooperates. It does not at first seem that dust would have any influence, and few would suppose that it plays any part here. It does, however, and the enormous quantity of it which, imperceptibly in most cases, is carried from the land over the seas, where it falls and slowly sinks to settle at the bottom as a soft red or gray mud—the first stage of new strata of rocks—is a great help toward the respiration of the seas. As J. Thoulet has shown, every particle, however small and minute, carries some air which adheres to it and does not escape when submerged; this air slowly dissolves in the surrounding water. The experimental proof is easy. Bring some water to the boiling point, in order to expel the gases dissolved in it, and then add some potash and pyrogallic acid. This mixture turns black when in presence of oxygen by reason of the action of the latter on the acid. Under ordinary conditions, the experiment being thus prepared, what one witnesses is this: The surface of the water blackens and the black color extends slowly toward the bottom, according to the ratio of diffusion of atmospheric oxygen in the mixture. The rapidity, or rather slowness, of the change of color is the measure of the slowness of diffusion. Now, throw some fine dust into the vessel containing the water so prepared. What happens then is that each grain or particle, while falling through the liquid, leaves behind it a black line which marks its path exactly, and there are as many vertical streaks in the colorless solution as there were particles of dust thrown into it. Each particle's atmosphere of air acts upon the pyrogallic acid, and instantly causes the change of color. The experiment is a very elegant one, and provides a very convincing demonstration, and when one thinks of the number of dust particles (either of terrestrial origin or coming from the interplanetary spaces under the form of microscopical meteorites) which uninterruptedly pour down on the oceans like some paradoxical dry rain, it is conceivable that the importance of these infinitesimal particles to all aquatic organisms is great. From this point of view, a catastrophe like that of Krakatoa becomes a blessing, and each volcanic outbreak with its concomitant cloud of dust and cinders, which often spreads over hundreds of square miles, and gives forth a soft slow rain of solid particles which fall through the air to the water and thence to the underlying abysses, is doubtless a benefit to aquatic organisms. It may seem absurd to speak of the beneficial influence of volcanic catastrophes upon the denizens of the ocean; the fact is nevertheless incontestable. Nature abounds in such curious and unexpected interactions. Most of these, as yet, escape us, but some now and then become apparent, and go to show how difficult and complex is the study of life or biology, in its real sense, and how essential is the knowledge of circumstances and surroundings.

The experiment which has just been referred to suggested to Paul Regnard the means of measuring, so to speak, the rapidity of the ocean's respiration, the rapidity of diffusion of the aerial gases in water, and especially that of oxygen, which is the most important for organisms. The method is very simple. All that is required is a large glass tube, some 3 yards long, closed at the lower end, placed vertically, and filled with water holding Coupier blue in solution, saturated with hydrosulphide of soda. This solution, a pale yellow in color, turns blue under the influence of oxygen. The tube thus filled is left to itself and each day an observation is made of the point to which the blue layer has extended. The first day the mere surface only is blue, but by degrees the underlying strata also turn blue, according to the rapidity with which atmospheric oxygen diffuses and is absorbed. Under such circumstances, P. Regnard noted that in the course of three months oxygen diffused no farther than about a yard from the surface, and the rate of propagation is hardly a centimeter per day. If such is the normal ratio, air penetrates water at the rate of 4 meters per year, and if, "at the beginning"—of which so much is said, and so little known or knowable—the sea was entirely devoid of oxygen, no less than a thousand years were required to allow atmospheric oxygen to penetrate to the depth of 4,000 meters, a depth which we all know is not uncommon in the ocean.

It is thus seen that the respiration of waters is very slow—at least it is very slow so far as diffusion alone is concerned. But, as already noticed, diffusion is not the sole agency, and it is quite clear that the white crested waves, all foam and sparkling with air bubbles, that the winds, the currents, the tides, and lastly the dust particles have done and are doing much to hasten the process, and accelerate the execution of the great respiratory function of the deep. No method, unfortunately, has yet been devised for measuring the rapidity of this process; and before it can be done, some manner by which the approximate number of dust particles falling into the seas can be ascertained should of course be discovered. The problem is a difficult one, truly.

II.—Air from the Chemical Point of View.

Considered by the ancients, and even by modern philosophers till a very recent period, as one of the four initial elements (earth, air, water, and fire), air was unable to keep this position after the birth of modern chemistry. Like most other substances it has had to reduce considerably its pretensions. They were of no avail in presence of the methods of chemistry. Instead of being, as formerly supposed, an element, a homogeneous matter out of which no known method of reduction can obtain two or more differing substances, air has shown itself to be nothing more than a mixture of different elements. A mixture, a mechanical mixture; not a compound. Air is not like water, in which two gases, oxygen and hydrogen, are combined and make up a third body exceedingly different in properties from those out of which it is made, nor like the enormous number of compounds known to chemistry in which two or more elementary substances are combined in definite proportions and form new substances more or less peculiar, but invariable, and possessing properties which neither of the elements possesses; it is a mixture only. This may be demonstrated in various ways. When nitrogen and oxygen, the fundamental elements of the air, are mixed together, no heat is evolved, no heat is absorbed, as is the case in the preparation of most compounds. Again, the refringency of air is equal to the mean of the refringency of oxygen and nitrogen when experimentally mixed in the proportions in which they occur in the atmosphere; and the ratio of oxygen to nitrogen is not a simple one; lastly, when in presence of air, water dissolves different proportions of the different constituents of the former; it dissolves each gas according to its own proper coefficient of solubility.

These four proofs are considered as more than sufficient to show that air is a mixture, not a compound. It may be added, moreover, that while the composition of the atmosphere is fairly uniform as a whole, it is not absolutely so; the one or the other constituent is more or less abundant according to circumstances. No chemical compound offers such variability in composition; its constituents are constant, always the same, and in the same ratios, while in a mixture every variation is possible, and may be expected.

And now, what are the constituents of this mixture? Our knowledge of these elements, as well as that of air itself, considered as a whole, is of recent date. While it would require more space than we can spare to give a full historical account of the chemistry of air, the principal facts may be briefly summarized.

As has been previously stated, a French physician, Jean Rey, was the first who proved the materiality of air, and his experiment was repeated and confirmed by Galileo in 1640, and by Otto von Guericke in 1650. Jean Mayow, in 1669, was the first to prove that air is not an element, a homogeneous substance. He suspected the fact that air contains two different gases, of which the one, which he called "nitro-aerial," maintains combustion or fire and respiration, while the other does nothing of the sort. In short, he suspected the presence of the two different gases which are now named oxygen and nitrogen. Had he lived longer, Mayow might have discovered the facts which are the basis of Lavoisier's fame.

In 1774 Priestly[1] made a great step in the right direction when he succeeded in obtaining the separation of the two principal gases which make up air, and on the same date Scheele[2] did the same, going somewhat further, as he discovered the ratio of what he called "dephlogisticated air" (or oxygen) to "phlogisticated air" (or nitrogen). Both, however, fell into the same error. Both considered the two gases as identical, but possessing different properties. No doubt the properties are different, but the differences are inherent to the gases themselves; the one is not a form of the other and can not be transformed into the other, and the differences are much more numerous than these two pioneers of chemistry perceived.

To Lavoisier was reserved the honor of providing precise and unassailable knowledge concerning the nature and composition of air. To prove that air, as already demonstrated, is made up of two elements, the one adequate the other inadequate to maintain combustion and respiration, was no difficult task. But he went farther on his road by means of the following experiment, one that is fundamental in the history of chemistry: He placed a known amount of mercury, carefully weighed, in a retort whose long curved neck opened into an inverted glass tube placed on a mercury trough. By means of a curved pipette he sucked out part of the air in the tube, and consequently the mercury rose within it to some height. The point to which the mercury rose was carefully marked, and then the retort was submitted to the influence of heat. The temperature was 360° C., and on the second day he perceived that small red pellicles were forming at the surface of the mercury. During a week, the heating being continued, the pellicles kept forming, and then no more appeared. He kept up his fire during four days more and then put it out. When the apparatus was cooled

[1] Born in England in 1733; died in Pennsylvania, 1804.

[2] Born in Sweden in 1742; died 1786.

down, he saw that in the glass tube the mercury rose higher than before the experiment, and he observed that the remaining gas was unable to maintain respiration and combustion. In it small animals died and a light went out. He then collected the red pellicles, weighed them, put them in a retort whose neck opened under a glass tube filled with mercury, and heated the retort to 400° C. The pellicles melted away; they yielded a certain amount of mercury which was deposited in the neck of the retort, while in the glass tube some cubic inches of a peculiar gas had accumulated at the top. The volume of this gas corresponded exactly with the volume of air which had disappeared in the preceding experiment, and this gas was fully able to maintain combustion.

Thus was performed the first analysis of air, and Lavoisier came to the conclusion that that fluid contains two gases—one which forms one sixth of the whole volume and is favorable to combustion and respiration, while the other, amounting to five-sixths of the whole volume, is favorable to neither. The first was oxygen; the last azote, or nitrogen.[1]

It is now more than a century since these facts were discovered, and became the corner stones of modern chemistry. Up to that time it was mere empirical alchemy, and a fabric of erroneous notions. A number of methods, much superior as far as precision is concerned, have been devised for the purpose of air analysis, and of gas analysis generally.

The eudiometric method, propounded by Gay-Lussac and Humboldt, is one of the best known. It is based upon the fact that if hydrogen is added to air, and the electric spark passed through the mixture, the oxygen of the air and the hydrogen added to the mixture combine in definite and constant ratio and form water. A very simple calculation gives the amount of oxygen contained in the mixture. The weighing method of J. B. Dumas and Boussingault, invented in 1841, is quite different. It is based upon the fact that when air, deprived of aqueous vapor and carbon dioxide, is made to pass through a tube containing metallic copper reduced by means of hydrogen, and heated to redness, it yields its oxygen to the copper, and if the copper is weighed before and after, the amount or weight of oxygen contained in the volume of air experimented upon is at once known. If the remainder of the gas, that portion which has not combined with the copper, be collected in an empty receiver weighed before and after the experiment, the increase in weight of the receiver shows the quantity of nitrogen contained in the original volume of air. Twenty other methods, more or less similar to the preceding one, have been devised by Brunner, Regnault and Reiset, Doyère, Bunsen, Williamson, Russell,

[1] These names were given by Lavoisier. Oxygen is derived from ὀξύς, acid, and γεννάω, to produce, because one of the properties of oxygen is to form acids when combined with many other substances. Azote is derived from privative α and ζωή, life, because azote is not suitable for living animals, and can not maintain life.

etc., but this is not the place to describe them, and all text-books of chemistry give a full account of them.

It is enough for our purpose to know that it is fully established that atmospheric air is a mixture; that this mixture is principally made up of oxygen and nitrogen, and that we are provided with methods and implements by means of which air may be analyzed, and the least traces of its constituent elements detected.[1]

These elements are numerous, but they differ greatly in importance.

Fundamentally, air comprises 20.81 volumes of oxygen, 79.19 volumes of nitrogen, and some ten-thousandths of carbon dioxide. In some localities or under certain circumstances a few other[2] gases may also be found in air, in very small quantities.

We must now consider in turn each of these elements.

Oxygen comes first. Not that it is present in the greatest abundance, but from many points of view it is a most important part of the atmosphere.

This gas is heavier than air as a whole (while nitrogen is lighter), and in 1,000 liters of air there are 208 liters of oxygen against 792 of nitrogen. This ratio seems to be constant, although Dalton and Babinet, arguing theoretically, supposed that oxygen is less abundant in the air at high altitudes, and that the proportion of this gas decreases as the distance from the sea level is increased—oxygen being rather more abundant in low regions, and near the surface. Of course, if such were the case, the reverse would obtain for nitrogen. This gas should be more abundant at high levels, and less near the sea level. According to the views of Dalton and Babinet, at 10,000 meters above the sea level, 1,000 liters of air should contain only 184 liters of oxygen against 816 of nitrogen. These speculations may be interesting, but as they

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[1] In view of recent facts this is too positive a sentence. Great was the surprise of the chemists when they heard that Lord Rayleigh and Professor Ramsay had discovered a new element in atmospheric air. This should inspire them with some caution, and induce them not to put so much faith in the infallibility of their methods. More of this hereafter. [Note added to proofs in 1896].

[2] To the normal constituents of atmosphere one remains to be added, and that is argon, discovered in the year 1894 by Lord Rayleigh and Professor Ramsay, to whom, on this account, the $10,000 Thomas Hodgkins prize has been most deservedly awarded.

Argon, thus called because it seemed to be an inert and inactive gas, slow to combine with other substances, was certainly contained in Cavendish's test tubes, but Cavendish considered it as nitrogen, and thus failed to add this substance to the list of chemical elements. Argon is present in the atmosphere in the proportion of somewhat less than 1 per cent; M. Th. Schloesing obtains 0.935 argon for 100 air, in volumes. MM. MacDonald and Kellar have in vain endeavored to detect argon in the chemical constitution of animals and plants (mice and pease), but Mr. Ramsay has found it in meteoric iron. Argon liquefies at —128° under 38 atmospheres pressure, and freezes at —189°. It is not as inactive as at first supposed, as Berthelot has been able to combine it with benzine under the influence of the electric discharge. This gas does not seem to play any active part in respiration; it is inert and useless, like nitrogen. [Note added to proofs, 1896.]

are in direct contradiction with positive facts and observations we may dismiss them as "children of fancy." The chemist Thénard analyzed air collected at 7,000 meters height by Gay-Lussac, and found no trace of such difference. Similar observations, due to Dumas and Boussingault, prove that these theories are not sustained by stern reality, and, in brief, chemists are agreed that, as far as oxygen and nitrogen are concerned, the composition of atmospheric air is uniform and constant, with very slight exceptions. This is the result of numerous observations made in different and distant places, at different heights, at distant epochs, and Dumas and Boussingault, who have devoted much work and time to the matter, have always obtained similar ratios, or at least ratios so nearly identical that the differences are not more considerable than may occur in the best conducted experiments—they keep within the limits of unavoidable errors. So we may consider air as being as perfectly uniform in composition, as it might be expected to be in view of the circumstances.

Now, where did this oxygen originate? Whence does it come? From what source is it supplied? A complete answer to this question can only be given by those who know how things stood in the beginning, and who understand the origin of matter, force, life, and some other of those troublesome and perplexing problems. Oxygen must be a very anciently established inhabitant of our planet, and its origin, like that of the "old" families, is lost in obscure mystery. At all events there it is, and wherever it comes from, howsoever it has been evolved, one thing seems positive, and that is the fact that there are at present, as far as we know, no important sources whence a considerable amount of this gas may be derived and added to the current stock. In view of this, the stability of its normal ratio in the air, notwithstanding the enormous quantity of it consumed by living beings and in combustion, becomes a riddle well worthy of some attention.

We know that the entire atmosphere contains over one million billions of kilograms of oxygen; that nearly one-half of the weight of the minerals of our globe is oxygen; that eight-ninths of the weight of water consists of this same gas, which is, moreover, abundantly present in the tissues of all living organisms. On the other hand, we know at present of but one source of oxygen, discovered by Priestley, and further investigated by Perceval and Senebier. I refer to plants. It is a fact familiar to all that plants are endowed with the faculty—ascribed to the chlorophyll contained in their tissues[1]—of breaking up carbon dioxide into its elements; that is to say, into carbon which goes to the repair or increase of the tissues, and oxygen, which, on being freed, diffuses itself throughout the surrounding atmosphere. There certainly is one source of oxygen. Are there any others? Their existence is doubtful. Of course we know that a number of chemical

[1] The fact is probable but not certain, for chlorophyll has not yet been satisfactorily separated from the tissues in order to investigate its chemical powers.

reactions effect the liberation of oxygen, water electrolysis, the decomposition of chlorate of potassium, or of sulphuric acid under the influence of heat, for instance; but do any of these chemical processes, or any others similar in result if not in method, occur in nature on any important scale? We do not know, but it seems doubtful. At all events, since the composition of the atmosphere remains fairly constant, there must be some agency by means of which the enormous mass of oxygen which is daily, hourly, at every moment, absorbed in consequence of the organic and inorganic combustions occurring over the whole globe, is, sooner or later, returned to the atmosphere. Plants are the only agency at present known by which this process is effected. At all events they effect part of it. But are they equal to the task of effecting the whole? The question has not been yet answered in quite satisfactory terms. Mr. T. L. Phipson has recently endeavored to fill this gap, and to show that plants are even a more important source of oxygen than is commonly admitted. He cultivated a convolvulus plant in an artificial atmosphere, entirely devoid of oxygen, but containing some proportion of carbon dioxide, with the result that a part of the latter gas disappeared, its place being taken by oxygen, which can only have been evolved by the plant. Mr. G. Meyer had previously expressed the opinion that oxygen is thus generated, but Mr. Phipson's experiment is of great interest. The whole matter is very important, for, if the oxygen contained in the atmosphere has been evolved by plants, one may ask whether there has not been some time when the atmosphere was very poor in oxygen and very rich in carbon dioxide, and whether some time may not arrive when, conversely, the atmosphere will be well provided with oxygen and very deficient in carbon dioxide. If such were to be the case, the equilibrium and homogeneity of air, as far as its composition is concerned, would be very unstable and temporary matters. But no answer of a satisfactory character can yet be given to such questions.

It may be added that, according to less recent data, 1 hectare (a little over 2 acres) of forest exhausts each year the atmosphere of some 11,000 kilograms, or 5,596 cubic meters, of carbon dioxide, while in return it yields nearly as much (5,594 cubic meters) oxygen. A field of oats, similarly, returns about as much oxygen as it absorbs carbon dioxide. Perhaps other agencies are at work and make up for the enormous consumption of oxygen effected by human, animal, and plant respiration, and by inorganic combustions generally, and it does not seem to us that adequate proof has yet been furnished that plants alone are able to return to the atmosphere the oxygen which they, with all other living beings, take from it. Leaving out of the question the subject of the origin of oxygen, it is very difficult to ascertain the methods by which, notwithstanding an enormous consumption, the ratio of this gas remains fairly constant at the present time.

While the proportion of oxygen in air is constant, or tolerably uniform, it must not be forgotten that certain local conditions may tend to increase or decrease its normal ratio. Nor could it be otherwise. However rapid the diffusion of gases, it is reasonable to suppose that when one of the constituents of the atmosphere is being rapidly subtracted or added in great quantities, the normal ratio in that vicinity must be more or less altered. In a crowded room where ventilation is inadequate the ratio of oxygen decreases, and the same happens in places where intense combustion is going on—in mine shafts, where slow oxidization of materials is a nearly constant phenomenon. In brief, where the destruction of oxygen is not compensated by rapid ventilation, the proportion of this gas to the remainder of the air must decrease. Under the same conditions, of course, the ratio of carbon dioxide must and does increase, as repeated observations have shown. But such local accidents, such limited alterations of the composition of the air, have no influence on the general atmosphere; they are temporary, very slight, and therefore rapidly obliterated. Even the respiration of some two, three, or four million inhabitants, as in a large city, does not affect the composition of the air of the streets; and London, Chicago, or Paris exert no more influence on the surrounding atmosphere, into which they pour torrents of carbon dioxide, than any forest, for instance, where the case is reversed, and where oxygen is produced in abundance. Diffusion takes place immediately, and no appreciable alteration can be detected, save in very limited spaces and for a short period. And while the one gas is being removed in one place it is being added in another, and thus a compensation is rapidly effected.

Little need be said concerning nitrogen. This gas, as already stated, was discovered by Priestley, and Lavoisier showed that it is one of the elements of air. Its weight is lighter than that of air as a whole, and in 100 liters of air there are 79 of nitrogen. It neither burns nor maintains combustion; it plays no part in respiration; it can not help to maintain life. Not that it has any toxic properties, assuredly; but it is inert, indifferent, inactive. Little is known concerning its origin. We know that some mineral springs, sulphurous springs particularly, yield a certain amount of nitrogen, and the air ejected from the lungs of animals contains about as much as the same air when inspired. As is the case with oxygen, nitrogen seems to occur in the atmosphere in the same ratio everywhere.

The two gases, oxygen and nitrogen, are the main constituents of air, and compose the greater part thereof. They are the essentials, the other components, which must now be noticed, occurring only in very limited quantities, some in variable and small proportions. We might almost say that they are accessory components, judging from their quantity, had not experience shown that one of them at least plays a very important part in biology, one no less essential, in fact, than that of oxygen, for instance. This latter component is carbonic acid or carbon dioxide. It occurs only in very small quantity, 4 or 5 liters in 10,000 liters of air. This gas is comparatively heavy, and Priestley was cognizant of the fact that it is unable to support combustion or respiration. The proportions in air are not uniform and constant; they vary according to circumstances and places much more than is the case with the other gases. As early as 1827 De Saussure discovered very marked differences, obtaining as extreme figures 3.15 and 5.74 per 10,000. More recently, Boussingault and Lévy, comparing the proportion of carbonic acid in the air of Paris with that in the air of Andilly (a small village some 12 miles from Paris, near Montmorency), found also a notable difference between the two, there being 3.19 (per 10,000) in Paris and 2.99 in Andilly. Again, a somewhat smaller difference has been noticed by Roscoe and McDougall between the air in Manchester and that of the surrounding country; but at Clermont-Ferrand, in central France, Truchot found 3.15 per 10,000 and but 2.03 at the top of the Puy-de-Dôme, a neighboring mountain, and 1.72 at Pic de Sancy, another peak of the same group.

These instances are enough, we presume, to show that the ratio of carbonic acid to the total volume of the air varies considerably, much more than that of the two previously mentioned gases, and that this component is more abundant in cities than in the country.[1] This should not occasion wonder, as the amount of carbonic acid varies according to various circumstances of time and place. For instance, De Saussure noted that it increased during the night and during cloudy weather; its ratio changes with the season, from one year, and even from one month, to another, irregularly, and, in fact, from day to day. Above the ocean the variations are less, and in mid ocean the air is purer than over the continents. The same obtains on high mountains.

If, instead of considering the composition of air collected in the streets, in the country, or on mountains, we compare rather that which we breathe in dwellings and in all confined spaces where ventilation is more or less deficient, and where organic and inorganic combustions take place, with that which obtains in the open, the differences are still greater. Of course, it should be so. We must not forget that the air which each one of us expels through mouth or nose, at this very moment, contains nearly a hundred times more carbonic acid than was contained in the same air when we inhaled it a few seconds ago. This being the case, it is sufficient to imagine a confined room where one or many persons are sitting; there most certainly, provided the experiment lasts long enough, we shall find many different and increasing proportions of carbonic acid. That is, we might were the experiment not self-limited. For though, as Pettenkofer has observed, the 0.40 or 0.50

[1] In Austria, the amount of carbonic acid is about 34.3 liters per 100 cubic meters of air; in Germany it varies between 32 and 34; in the desert of Lybia, Von Pettenkofer found from 44 to 49. These are rather high figures. During the expedition for the observation of the transit of Venus, analyses made in different countries gave the following results: Florida, 29.2; Mexico, 27.3; Martinique, 28; Haiti, 27.8; Santa Cruz, 26.6. At Cape Horn, Hyades observed 23.1 and 28.5 as extreme figures.

per 1,000, which is the normal proportion of carbonic acid, may rise in a tolerably well-ventilated room to 0.54 and 0.70, or to 2.4 in an ill-ventilated sick room, and reach to 3.2 in a lecture room, 7.2 in a school-room, and even 21 in a stable in the Alps where men and beasts are huddled together in winter, the chinks being stopped against the cold, there occurs a limit which can not be passed; if the ratio increases, men and animals must soon die, and the experiment is over, the production of carbonic acid having come to an end. When the composition of the surrounding atmosphere is the same as that of the air which each of us expires (over 4 per cent carbonic acid, and less than 16 per cent oxygen), death must soon result, because there is too much carbonic acid in the air to allow that in the system to escape, and not enough oxygen for the needs of the body. More will be said on this point later on. It is enough here to show how considerable the ratio of carbonic acid may become in confined space, and how much greater are the variations in carbonic acid than in oxygen or nitrogen.

The cause of these variations is obvious. They are in close relation to the variations in the production of the gas under consideration, and upon this matter information is abundant.

Carbonic acid is produced in many ways; it has many sources. One of them has been referred to—animals and mankind. Bipeds and quadrupeds, in fact all animals, indeed, all living organisms, are sources of carbonic acid. All beings, from mere yeast cells to the lords of creation, breathe; all or nearly all take oxygen from the air and return carbonic acid to it. It is a familiar fact that fermentation in most cases—in the case of sweet substances particularly—is accompanied by a considerable production of carbonic acid. In wine-producing countries cases of asphyxia often occur in the cellars where fermentation is going on, owing to the amount of carbonic acid produced. All higher organisms, plants, and animals have the respiratory function, and one of the acts of respiration is the elimination of carbonic acid through the lungs. This unceasing production of carbonic acid by living organisms, whether plants or animals, is very variable in its activity, even within the limits of the same species and of the same individual. It is well known that the male produces more than the female, the adult more than the very young or the very old individual, the strong more than the weak, etc. It is well known, also, that this production of carbonic acid is increased by exercise, movement, light, and food, while it is decreased by rest, darkness, inanition. On the average each man exhales 20 liters of this gas per hour, and nearly 1 kilogram per diem (of twenty-four hours). The production is more considerable in sheep, and a bull exhales between 7 and 8 kilograms during the same lapse of time. However, in order to well appreciate the ratio of carbon dioxide exhalation, instead of considering the whole amount produced by any individual, it is better to refer this amount to the weight of the individual animal or person, to ascertain the quantity evolved per kilogram of weight. Viewing the matter in this light, we perceive that birds are the animals that give out the greatest quantity of carbonic acid. While 1 kilogram of ox excretes from 3 to 7 grams of carbon per twenty-four hours, 1 kilogram of fowl or turkey excretes 20 grams on an average, 1 kilogram of young chickens 56 grams, and 1 kilogram of sparrow nearly 60 grams. These facts quite agree with the exceedingly active respiratory function of birds, especially small birds.

Boussingault many years ago established the fact that the town of Paris alone, taking into consideration men and horses only, exhales nearly half a million cubic meters of carbonic acid per twenty-four hours (at present three-quarters of a million would be nearer the mark, but still even below it), and estimating the whole population of the globe as being one billion and a half, we find that mankind alone pours into the atmosphere one billion and a half kilograms of carbonic acid per diem (1,500,000,000 kilograms); that is to say, 720,000,000 cubic meters. Per annum the grand total is, in round numbers, 547,500,000,000 kilograms, or 262,800,000,000 cubic meters. So much for mankind only. If we wish to take into account the production of carbonic acid by animals, the difficulties are certainly great, and we can only proceed inferentially, and with less certainty. Girardin puts the production of carbonic acid by animals at something like double that of mankind, if not treble—let us say double, which means 1,095,000,000,000 kilograms per annum. But there remain other sources of carbonic acid: all plants which, although decomposing carbon dioxide as part of their method of nutrition, breathe in the same manner as animals, and exhale carbonic acid; all the combustions going on in our houses—fires, lights—in our factories and works, etc. (in Europe alone 550,000,000 tons of coal are burned each year, which means 80,000,000,000 cubic meters of carbon dioxide); the slow but uninterrupted production of the gas which is going on over the whole globe through the gradual combustion of decaying vegetable matter; the mineral springs—those of Auvergne only in France, giving off, according to Lecoq, some 7,000,000,000 cubic meters of gas; volcanoes and their surroundings—Cotopaxi alone being considered by Boussingault as giving off more carbonic acid than a whole city like Paris; the natural sources of gas, such as the Grotta del Cane[1] near Naples, etc. Under such circumstances, it is very difficult to form any idea of the total amount of carbonic acid discharged into the atmosphere. Armand Gautier, however, comes to the very probable conclusion that this amount can not be very far from 2,500,000,000,000

[1] The air in this grotto contains more than half its volume in carbonic acid. It derives its name from the fact that, in order to illustrate the noxious effects of the inferior stratum of air (where carbon dioxide, heavier, accumulates), it is the custom to introduce a dog into it, which soon falls, affected by asphyxia, while the visitors, owing to their higher stature, breathe the normal air, and feel nothing unusual. The dog, it must be added, is at once taken out into pure air, and soon revives, going through the experiment several times a day. Its health is very good, but its temper becomes unpleasant when a visitor appears. The animal knows what is coming.

cubic meters per annum, which means over 5,000,000,000,000 kilograms, the weight of the total atmosphere being 5,000,000,000,000,000,000—that is, one hundred thousand times greater. At all events, this is certainly below the mark.

Such being the enormous rate of production of carbonic acid, one may well wonder that the ratio of this gas in the total atmosphere remains as small as it is, it being easy enough to reckon what the ratio would become in the course of ten, twenty, or a hundred years, if there were not some agency at work by means of which it is destroyed or combined, and without which life would soon become extinct. That such agencies do exist and are in operation is a positive fact, and though we may not be acquainted with all of them, there are three at least which deserve notice. These agencies are plants, animals, and oceans.

Plants occupy the first place; for, while producing carbonic acid which they breathe, they absorb it in the course of the process of nutrition, taking its carbon into their tissues and yielding its oxygen to the atmosphere.[1]

Animals should be considered next; not all, to be sure, but all those which have a calcareous skeleton, internal or external. Such are corals, such are shellfish generally, and all aquatic and terrestrial animals, which, having a calcareous skeleton, must necessarily contain some amount of carbonic acid combined with lime. This compound seems to hold good for a long time, and if there are cases where the skeleton after death slowly decomposes, so that the carbonic acid has some chances of getting free again, there are a great many more in which it is preserved, and we know of considerable geological strata which are nothing else than enormous accumulations of the remains of animals that died centuries and hundreds of centuries ago. This process, by means of which a considerable amount of carbonic acid becomes fixed and imprisoned, so to say, was exceedingly active in earlier times; it is also very active at the present period, and the great space taken up by coral reefs in the mid Pacific and other oceans is but a gigantic laboratory of nature where carbonic acid is being, if not destroyed, at least hoarded and put by under a compact form, and, for a time at least, withdrawn from the general circulation of matter. To appreciate the importance of the storing process, it is only necessary to measure the thickness

[1] A writer in the Belgique Horticole, Vol. XXXV, 1885, p. 227, gives the following evaluation: One hectare of forest (1 hectare equals 2.471 acres) produces yearly 3,000 kilograms of carbon—1,600 kilograms under the form of wood and 1,400 under the form of leaves (weighed dry and exclusive of other substances). During one hundred and fifty days (on the average) of active vegetation, the trees must draw from the atmosphere 5,596 cubic meters (11,000 kilograms) of carbon dioxide. In exchange they give nearly as much oxygen (5,594 cubic meters). With a field of oats the same proportion obtains—as much oxygen is given off as carbonic acid is taken in. Thirty-two persons give off as much carbonic acid as is taken in by 1 hectare of oats or of forest, and they burn as much oxygen as the said surface of field or forest produces.

and extent of such masses of organic remains. All know that in every geological formation calcareous strata of great thickness are found, which are merely agglomerations of skeletons, and Van Dechen has endeavored to form some idea of the quantity of carbonic acid which may be contained in such strata. The result is very striking. He comes to the conclusion that in the lime strata of the Carboniferous epoch alone there is an amount of carbonic acid imprisoned which is six times more considerable than that at present contained in the whole atmosphere. The problem has been carried further by Sterry Hunt. Taking this result into consideration, and forming an estimate of the whole quantity of carbonic acid combined with lime in the whole geological series, he finds that the amount of carbonic acid thus imprisoned in the calcareous rocks would, if entirely liberated, form an atmosphere two hundred times more considerable than that which at present surrounds the planet. In such a case the pressure would be so much increased that the gas would necessarily become liquid. The inference which he draws (Brit. Association for the Adv. of Science, 1878) is that the enormous amount of carbonic acid at present stored in the depths of geological strata has never been simultaneously, even for a short time, present in the atmosphere, but that it must have reached the latter in small quantities and gradually. Mr. Sterry Hunt is of opinion that all this carbonic acid has come to our planet from celestial regions in the course of hundreds of centuries. Whatever may be thought of this interpretation as to the origin of the gas, one fact remains unassailable, and that is the enormous quantity of the latter stored up in the earth's crust; and if in the course of time organisms have been able to accumulate such a provision and are still operating as they undoubtedly are under our very eyes, we certainly can not help coming to the conclusion that we have here one of the most important agencies by means of which the atmosphere is being unceasingly kept sufficiently pure for maintaining life.

Lastly, come the oceans. Few are aware that the salt waters play a most interesting and important part in the general regulation of the atmosphere, and are one of the agencies which by absorbing carbonic acid prevent it from overaccumulating in the air. Mr. Schloesing's remarkable investigations have shown that the seas contain a large amount of dissolved carbonic acid, a much larger amount, in fact, than is to be found in the whole atmosphere. The equilibrium is preserved as follows: When carbon dioxide becomes more abundant than usual in air, in consequence of an increased production of this gas, and no compensatory destruction or withdrawal is effected by plants or animals,* part of it dissolves in the salt waters, and combines with the insoluble and neutral carbonate of lime, always present there, producing a soluble bicarbonate of lime which dissolves immediately, and, inversely, if the amount of carbonic acid in the atmosphere decreases, the soluble bicarbonate is decomposed into carbonic acid, which is set free and diffuses throughout the atmosphere, and neutral carbonate, which remains in the water. Briefly, so long as the tension of carbonic acid in the waters and that of carbonic acid in the atmosphere is the same, nothing is produced, but as soon as this equilibrium of tension is destroyed the sea restores it by the very simple process just described. This chemical adjustment works automatically at the moment it is needed, and to the extent and in the direction required. It must be added that this equilibrating function is possible mainly through the circumstance that the ocean contains a much larger amount of carbon dioxide than the atmosphere; according to Mr. Schloesing, about ten times as much. However great, then, the production of carbonic acid may be on the surface of the globe by all the agents we have enumerated, it would seem that the proportions of this gas in the atmosphere as a whole can vary but slightly, owing to the power of the sea to absorb it and maintain the equilibrium.

We have now exhausted the list of the agencies through which the amount of carbon dioxide in the air may be and is reduced when necessary, and they are important and powerful enough, as we have seen, to be equal to probable emergencies. Without them the globe would soon become uninhabitable. Poggendorf, in fact, has found that if all carbon dioxide produced could accumulate in the air the proportion would be doubled in eighty-six years. A few centuries would see the last of life as far as superior organisms are concerned.

Oxygen, nitrogen, carbonic acid, such are the main constituents of air. Those which follow are of less importance, but deserve a passing notice.

We may begin with ozone. This gas, discovered in 1840 by Schoenbein, has been made the subject-matter of many investigations by De Marignac, De la Rive, Becquerel, Frémy, Andrews, Tait, etc. Ozone is oxygen under a peculiar form—condensed oxygen, so to say, oxygen of high potency. It possesses strong oxidizing properties, and the amount which is found in the atmosphere varies considerably according to circumstances and places. This amount is on the average of 1 milligram per 100 cubic meters of air; 3½ milligrams are a maximum. This gas is generally wholly absent from the atmosphere of cities, and in the air which has passed through large centers of population. Paris offers good opportunities for illustrating this fact. When the wind is northerly, no ozone is found in the air at the Montsouris Observatory, situated in the south of Paris, while, when the wind is southerly and comes over the country without having yet crossed the town, ozone is found in the air. Generally speaking, then, the healthiest part of all towns is that which lies in the direction from which the prevailing wind comes; the air is purer and fresher and contains more ozone. In western Europe, where the prevailing winds are westerly and northerly, the northwestern and western parts are the most eligible.

The cause of the difference in the amount of atmospheric ozone is to be sought in the fact that cities contain a much larger quantity of oxidizable organic material than is the case with the country and small villages, and the result is that more ozone is absorbed from the atmosphere over and around cities than from the atmosphere over the country, over the fields, and especially over the oceans. Generally speaking, ozone is more abundant near forests and the sea; the atmosphere in mid ocean is particularly rich in it. May we not attribute the cause of the beneficial effects of life in the open air, of a residence in the country, near the sea or in the mountains, and of long sea voyages to the larger proportions of this gas found in those regions? Schoenbein thought so, and after him many have adopted the same view—among them an English physician, Cook, according to whom a definite relationship prevails in India between cholera and other zymotic diseases and the proportion of ozone in the air, the diseases increasing when ozone decreases, and decreasing when the latter becomes more abundant. In consequence of the greater abundance of ozone in the atmosphere over the country and in proximity to living plants, it might seem advisable to advocate the presence of plants in apartments, instead of excluding them as some feel inclined to do, arguing that plants are living beings, that they breathe, and that, accordingly, they increase the ratio of carbonic acid. The view in favor of plants has been strongly advocated by T. M. Anders (House Plants as Sanitary Agents, 1887, Lippincott); but the most important point which should be established in relation to this matter, the fact that plants do really produce ozone, does not seem placed on a satisfactory basis. Proof is still wanting. And this brings us to face the fact that very little is known concerning the origin of ozone. We do not know whether any agencies are at work now in nature evolving ozone to any important extent. In the laboratory ozone may be produced by the electric spark, and when so evolved causes the particular smell perceived in the vicinity of electrical machinery; ozone is also evolved during the electrolysis of water. Are we then to assume that in nature ozone is produced by thunderstorms, those gigantic counterparts of our electrical discharge, and under the influence of the electric currents so frequently in operation in the atmosphere? Many chemists think so, and if this is the case it should be easily shown that the ratio of ozone to air is in fairly exact relationship to the proportion of thunderstorms, or to their recent occurrence. Ozone should be most abundant under the Tropics, should decrease in high latitudes, where thunderstorms are least frequent, and should be more abundant just after a thunderstorm than before. But none of these points have been satisfactorily established.

Without attempting to solve the riddle and to ascertain the origin of ozone, a French chemist, M. Hautefeuille, who ascribes the blue color of the heavens, or of the atmosphere, to ozone, asserts that this gas is more abundant in the higher than in the lower strata of our atmosphere. It may be so; at all events we are not much the wiser for the assertion. While we know that ozone is nothing more than oxygen in an altered and allotropic condition, we are quite in the dark as to the methods by which this alteration is effected. We know that the ratio of ozone is very variable; that it is more abundant in May than in any other month; more abundant in the morning, from October to June, and in the evening, in July, August, and September, so that, upon the whole, it seems to follow fair weather and heat; but this hardly helps to solve the question, and much remains to be discovered.

Concerning ammonia, our information extends somewhat further than in the case of ozone. Ammonia is constantly present in the atmosphere. In 1857 Boussingault and, later, Schloesing, did good work in reference to this subject. They have shown that ammonia generally exists in combination with carbonic or nitric acid; only a small proportion is free. Its origin is easily ascertained, for ammonia is one of the by-products of organic putrefaction. Considering the amount of putrefaction which must take place on our planet, it is clear that this source is a fruitful one; and it must be added also that ammonia could not exist in an atmosphere where life was absent, nor in one where putrefaction was impossible, nor in an entirely aseptic atmosphere, the organisms themselves being aseptic. Although ammonia is a constant component, it is a very small one; air does not contain more than a few millionths of it; but water of atmospheric origin, rain, vapor, fog, etc., holds a larger proportion. M. Schloesing has devised ingenious apparatus and methods for ascertaining the proportions of ammonia in air and in rain water, as the matter is one of importance, particularly to agriculture, in view of the interchange of ammonia that occurs between air, rain, and ground water. One of the results has been to show that each hectare in France (something over 2 acres) receives yearly through rainfall, or from the atmosphere, 9.801 kilograms of nitrogen under the form of ammonia. This will be again referred to further on, when we come to consider the uses of this compound and its rôle in nature.

Other nitrogen compounds are also present in air—nitrous and nitric acids, for instance, both in very small quantities. It may be that they are formed under the influence of atmospheric electricity, as some experiments by Cavendish seem to show, and as indicated by some observations of Liebig, who detected nitrate of ammonia in the rain that falls during thunderstorms. It may be also, as Schoenbein suggests, that nitrous acid is formed by the action of nitrogen on water during the different oxidizations or combustions which go on rapidly in our works, factories, and so forth, and slowly in the field of nature. Nitric nitrogen is more abundant in and during winter, and it is more especially in rain water that its proportions have been ascertained. Generally some 0.73 milligram are present in each liter of rain water, and in France each hectare receives about 3.986 kilograms of this nitrogen through the rainfall. Added to the nitrogen received under form of ammonia, this gives us a total of 13.787 kilograms of nitrogen received by the soil.

Much of it is borrowed by plants. It has been observed in England and in France that rain water collected in cities or in their immediate vicinity contains more nitrogen (especially under the form of ammonia) than that collected in the country some distance away. Towns where industrial pursuits are thriving and active, where factories and furnaces keep their chimneys constantly at work, produce a large quantity of ammonia. London, Glasgow, and Manchester are specially noted for this. Some amount of carbureted hydrogen exists in the atmosphere (one ten-thousandth), and its name, marsh gas, gives a clue to its origin. Sulphureted hydrogen, also present in very small quantities, has its origin in some volcanoes and in the disintegrative processes going on in dead bodies or other lifeless organic materials. It is therefore often found in the vicinity of graveyards and of fecal matter. It is enough to merely mention the presence of a very slight proportion of boric acid, which is ejected into the atmosphere by volcanoes—by some at least.

Iodine has been detected in small quantities by Chatin, who is of the opinion that its presence or absence in the air and waters bears some relation to the occurrence of goiter in the human species. Very little can be said in support of this view. The atmosphere undoubtedly contains saline particles, and all observers who use the spectroscope have been more or less annoyed by the fact. But these particles are present under the solid form. They are positively in suspension in the air, and not under the form of vapor nor of gas. No very considerable mental effort is required to ascertain the origin of such particles. Dust pervades the whole atmosphere—that is, the lower strata at least—dust which has been torn from the soil in all countries of the world, in the deserts of Sahara, Kalahari, Gobi, or Atacama, in the lowlands, from the flanks of the mountain ranges, dust that has been poured out from the bowels of the earth by Cotopaxi and Kilauea, Vesuvius and Colima, Erebus, and Terror, and all this dust contains a large number of saline particles. The seas also contribute their share. The wind sweeps off the crest of the waves, blows the foam and brine inshore, often to considerable distances, with the result that the atmosphere contains a proportion of the salts of the sea, which often cover with a perceptible coating plants fairly distant from the shore. Farther inland the proportion of sea salts is decreased, but while not themselves apparent they exert apparent effects upon plants.[1] Another curious influence is exerted by these particles in quite a different direction. It is well known that aqueous solutions of salts may, under peculiar circumstances, be supersaturated; that is, may contain a larger proportion of dissolved salt than is consistent with theory. If air is allowed to come in contact with the surface, such a solution often suddenly crystallizes. M. Gernez, who has thoroughly investigated these phenomena, comes to the conclusion that the sudden crystallization is due to the presence

[1] Cf. P. Lesage: Influence du bord de la mer sur la structure des plantes.

in the atmosphere of a few particles of the corresponding salt, for it is a familiar fact that if the very smallest amount of a salt is dropped into a supersaturated solution of the same salt, the latter instantly crystallizes, just as a loaded gun goes off when the trigger is pulled. If this interpretation be correct, certainly air contains a large amount of sulphate of sodium, for supersaturated solutions of the latter crystallize very easily when not protected from contact with the general atmosphere. A fact that favors this explanation is that when the air in contact with a supersaturated solution is carefully filtered through a plug of asbestos or cotton it has no longer the power of inducing crystallization. It has been deprived by the plug of those particles which, by their conformity to the composition of the solution are able to induce the phenomenon referred to. If this explanation of M. Gernez is correct, the constant refusal of a supersaturated solution to crystallize when in contact with the general atmosphere would prove that the salt which it contains is not to be found free in the air. At all events, the interpretation is quite plausible and the fact is of interest.

Before dismissing this brief review of the main chemical constituents of the atmosphere, a word must be said concerning the volatile organic matters which Brown-Séquard and d'Arsonval thought they had found in expired air a few years ago. These two physiologists, collecting air expired by men or animals, and condensing, by means of cold, the aqueous vapor always present in such air, obtained a liquid to which they ascribed toxic properties. If such liquid is injected under the skin of an animal, it kills more or less rapidly, the results varying according to dose, the species experimented upon, and other circumstances. The inference was that expired air contains certain volatile substances excreted or exhaled by the lung surface and dissolved in the water derived from the condensation of pulmonary aqueous vapor, and from which they may be isolated by analysis. A very tempting inference, to be sure, for it seems clear that confined air vitiated by respiration, even after it is deprived of carbon dioxide, remains heavy, unpleasant, unhealthy, and even injurious, and if it has an unpleasant smell, the reason is probably because it contains peculiar organic matters. Do these matters—whose existence is suspected, not proven—accumulate in the liquid condensed by Brown-Séquard and d'Arsonval, and impart to it its toxic properties? The one great difficulty in answering this question is the fact that the different physiologists who have endeavored to repeat and confirm the above experiments in France, Germany, and Italy, have been unable to obtain the same results. They have not succeeded in obtaining from the breath any condensed liquid which had a toxic influence, and the most probable explanation is that some mistake was made by the original observers. When care is taken to exclude all elements except those derived from the breath no ill effects are observed on animals. It may very well have happened that Brown-Séquard and d'Arsonval did not take pains enough to prevent the contamination of the liquid, either by solid, and probably living, particles of nasal or buccal origin, or by impurities belonging to the apparatus and receiver in which condensation was effected. We can not, therefore, accept their original statement although there is a probability in favor of its truth. Further experiments are required to settle the matter.

III.—Biological Rôle of the Chemical Constituents of the Atmosphere.

Having now considered the constituents of the atmosphere, their relative proportions in the aerial mixture, their mode of production and distribution—that is, their mode of equilibration—and taking it as an established fact that the composition of air varies but slightly, remaining constant within the limits previously mentioned; having also briefly reviewed the part played by animate life in maintaining the composition of the atmosphere, we may now proceed to consider the chemical and physical influence of the atmosphere on the life of organisms.

For the sake of convenience and clearness, we shall begin with the chemical influence, and review in turn the influence of each separate constituent.

The life-maintaining gas of atmosphere, *par excellence*, is, to all appearances, oxygen—and we shall deal first with this element.

That its presence in air is indispensable for the proper execution of the respiratory functions is a fact familiar to all. Physiology has most clearly demonstrated, for a century past, the great importance and usefulness of this gas. It is essential to respiration. Man consumes large quantities of it.[1]

Inspired air, containing on the average 20 or 21 per cent of oxygen by volume—expired air containing only 16 per cent—4 per cent have, in consequence, been absorbed by the organism, and in twenty-four hours

[1] It should be noticed that neither men nor animals ever breathe pure air, nor can they do so under normal and natural circumstances. The reason is obvious. The lungs are never totally emptied. Even after the deepest expiration, there remains in the lungs and air passages a residue of air that can not be expelled (owing to the anatomical impossibility of total pulmonary contraction), and such air is vitiated and unfit for respiratory purposes. The next inspiration brings a certain amount of pure air, but, as a matter of course, it mixes with the impure residual air, and therefore becomes vitiated to some extent. The only parts which receive strictly pure air are the superior air passages. At the end of expiration they are full of impure air; but the very first result of inspiration is to return all this impure air to the lungs, and to fill the air passages with pure air. A part of this goes to the lungs, and all that remains in the nose, trachea, etc., is pure. All mucous membranes have some respiratory functions, so that a proportion of this pure air is used; but the most important of the respiratory organs is bathed in a vitiated atmosphere, and one may truly say that neither men nor animals ever breathe really pure atmospheric air. A very simple and ingenious experiment has

an average adult retains over 740 grams, or 516,500 cubic centimeters, a total amount of 500,000,000 cubic meters per day for the whole of mankind. The amount of oxygen required varies somewhat according to sex and age within the limits of the same species. During childhood and old age less is needed than during the prime of life. An adult may require 910 grams in twenty-four hours; an 8-year old child is content with 375. Various circumstances, such as vigor, health, temperature, rest, exercise, and so on, increase or diminish oxygen consumption. This oxygen is absorbed in our tissues, which it reaches chiefly through the agency of the lungs and blood; a small proportion, however (one-eightieth of the amount absorbed by the lungs), is absorbed by our skin, which has, therefore, some respiratory importance.[1] All our tissues need oxygen; all breathe. For it must not be forgotten that the lung is nothing more than an instrument in the respiratory process; the chemical operation which is the essential part of this function takes place elsewhere, in the tissues themselves. The lung is only the door by which oxygen enters the system. Physiologists held quite different views a century ago, and Lavoisier himself supposed that the main act of respiration takes place in the lung. What really happens is that oxygen, introduced into the lung, filters through the very thin walls of the pulmonary capillaries, where it finds in the red blood corpuscles a substance called hemoglobin, with which it unites to form a compound which bears the name of oxyhemoglobin. A very unstable compound it is, for throughout the tissues, in the capillary vessels of the whole body, oxygen is allowed to escape and effect its work among the cells. Numerous and complex reactions take place, and one set of them results in the formation of carbonic acid. The blood, therefore, is nothing more than a vehicle; it carries oxygen to the tissues and brings back to the lungs carbonic acid, which, if not allowed to escape, would soon cause death. The "organic combustions" do not occur in the lungs, as was thought a century ago; their seat is in the tissues, throughout the whole body.

While respiration is common to all animals, it is not equally active

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been devised by Prof. Charles Richet in order to give an experimental proof of the soundness of this inference. All that is required is an india-rubber tube, some 2 or 3 yards in length, of rather wide bore. This tube is so adapted to the respiratory apparatus of a dog or rabbit, that by some means or other he is made to breathe through it. Under such conditions death from asphyxia soon results. This experiment merely exaggerates the normal conditions; adding the tube amounts to nothing more than lengthening the air passages, and putting a greater distance between the lung and the atmosphere. The result is not a matter of surprise—external air can not reach the lungs. Inspiration is not sufficient to draw to the lung the whole of the air contained in the tube, plus a sufficient amount of pure air. Each inspiration introduces some fresh air in the end of the tube, each expiration expels it, and none reaches the animal, which is unceasingly breathing the same air over again and perishes from asphyxia, although in appearance breathing as freely as possible.

[1] Cutaneous respiration is quite sufficient, in winter, to maintain life in some animals; the frog, for instance.

in all; it is more intense in birds than in mammals; more intense in mammals than in reptiles and mollusks. An active animal will consume more oxygen than one that is slothful, sleeping, lethargic, or hibernating. Yet all animals breathe; none can dispense with oxygen, and if that gas fails them they die.

It is the same with plants. While for their nutrition they exhale oxygen (chlorophyllian function) during the day, under the influence of light, they breathe at all times, absorbing oxygen and exhaling carbonic acid, as Priestley has shown. Here, also, the intensity of the function may vary. Plants need a great amount of oxygen during germination, and this explains why many seeds can not germinate under water, where the access of oxygen is retarded and inadequate, or in compact soil, where air—oxygen—is also deficient. One sort of seed requires the hundredth of its weight in oxygen, another is quite satisfied with ten or twenty times less; but all need oxygen, as De Saussure proved nearly a century ago.

Plants also need oxygen for their growth, and at the flowering period they use a large amount of it, chemical operations being then so very rapid and intense that a quite perceptible heat is given out. During all moments of their life, from birth to death, plants breathe. Separate parts, such as leaves, twigs, flowers, fruits, need and use oxygen also—they are not dead; and a nosegay in a room plays its part in the withdrawal of oxygen as well as the person sitting at the table, the cat sleeping near the hearth, the lamps, the fire. A fruit or a leaf, in any closed receiver full of air, alters the composition of the latter, withdrawing oxygen and giving carbonic acid in its place.

In brief, without oxygen there would be no life, no animals, no plants; the whole planet would be one desolate landscape of rocks and sand, from which the solar heat would in vain strive to elicit the merest blade of grass, the smallest insect.

Such being the case, some might incline toward the opinion that life is abundant and intense in proportion to the amount of oxygen, while, where air is deficient, life also is wanting. Logical extremes are, however, almost invariably absurd, and the researches conducted during the last twenty years, by Paul Bert and Pasteur especially, go to show conclusively that both opinions are equally erroneous.

Living beings, as they are at present, are adapted to life in an atmosphere containing one-fourth oxygen and three-fourths nitrogen. Experience shows us that if the ratio of oxygen is decreased even by one-fourth, life can no longer be maintained. The adaptation of organisms to the atmosphere is thus very close, and this suggests the idea that perhaps a change in reverse direction might also be injurious; that an increase in the ratio of oxygen might prove harmful. Paul Bert has thrown much light on this question, and his experiments have amply proven a fact which at first sight seems most improbable, but is less surprising to those who always keep in mind the fact that living beings are adapted to their environment, and that the adaptation is often very strict. He has shown that oxygen—the vivifying gas *par excellence*, that which is essential to life—is also a violent poison; a poison for plants as well as for animals, for the cells and the whole organism. All that is required is for oxygen to acquire a certain tension in the atmosphere or—what amounts to the same—be present in a certain ratio above the normal, and it becomes an agent of death. This can be demonstrated in two ways. Animals or plants may be made to live in a normal atmosphere, but under higher pressure than the average; or, again, they may be placed in artificial air where the ratio of oxygen has been increased. In both cases the phenomena are similar; in both, death is the result. While a satisfactory explanation has not yet been proposed in the case of plants, Paul Bert has been able to show that animals die in a superoxygenated atmosphere as soon as their blood contains one-third more than the normal ratio of oxygen, because, in such an atmosphere, the hemoglobin of the red blood corpuscles is saturated with oxygen—a fact which never occurs under normal conditions—and a proportion of this gas then dissolves in the serum of the blood itself. The oxygen dissolved in the serum does all the harm. The tissues can not withstand the presence of free uncombined oxygen; they are killed. This is the *quo modo* of the phenomenon. The *quare* is yet wanting: Why do the tissues require combined oxygen, and why does free oxygen kill them? Here is a riddle for physiologists; it is one worth their pains and trouble.

Now, it must be said that while a certain increase in the ratio of oxygen results in death, lesser increases of a temporary character may be beneficial. Every poison kills, doubtless, but there are doses which not only do not kill, but even confer benefit and improve health. This toxicity of superabundant oxygen is undoubtedly one of the most curious facts that recent years have brought to light, and it is a very positive and demonstrable one.

On the other hand, to say that without free oxygen there can be no life would be incorrect. Pasteur's investigations have shown that if some micro-organisms can live only where air and oxygen are present, others, which have been termed anaerobic, much prefer an environment where air is wanting. Such is the case with those which cause fermentation. They induce fermentation only when in a medium devoid of oxygen, and, as Pasteur put it, fermentation is a consequence of life without air. What then occurs in a fermenting medium? A particular kind of microbe—each fermentation is due to a particular sort or species of microbe—is conveyed, by air, by water, or is purposely introduced, into that medium. During a time it lives there upon the oxygen which it finds. At last oxygen fails; all the provision has been expended, and diffusion has not taken place rapidly enough to meet the needs of the micro-organism. The latter has then to shift for itself in some manner. Free oxygen is wanting, to be sure, but nevertheless there is oxygen to be had—oxygen in combination with one or the other of the substances dissolved in the liquid under consideration. This the micro-organism uses for its wants. It withdraws this oxygen and releases it from its fetters—not for the benefit of oxygen certainly, but for its own advantage. As this release can not be effected without releasing also at least one and often many other constituents which were combined with the oxygen, they also are freed, and their escape is one of the characteristic phenomena of fermentation. Let us take an instance, that of alcoholic fermentation. This requires water in which cane or grape sugar is dissolved (cane juice or grape juice). The microbe removes from the sugar a portion of its component oxygen, thus decomposing it into free carbonic acid and alcohol. This is one instance among a hundred. In all the process is fundamentally the same. In all processes of fermentation a microbe is present which, unable to otherwise obtain its requisite supply of oxygen, takes it by decomposing the surrounding substances, changing them into new compounds, containing in part the same elements as the original but differently united. So we see that, upon the whole, anaerobic micro-organisms, which seem more or less to shun free oxygen and air, do really breathe oxygen, as other organisms are wont to do. Thus, so far as some organisms are concerned, life is not impossible where free oxygen is wanting; and, on the other hand, wherever life is present, some method exists by which oxygen may be secured. While anaerobic micro-organisms seem to be exceptions, they fall under the general law that living organisms must have oxygen.

Between such anaerobic organisms and those which need free oxygen many transition forms exist. It will be sufficient to recall the fact that vegetable cells are aerobic and anaerobic simultaneously, since they can produce alcoholic fermentation. "Let us place a beet root in carbonic acid," says Duclaux, "we shall see it produce alcohol. Cherries, plums, apples, all fruits containing sugar, entire sacchariferous plants, under the same circumstances do the same. Their sugar is in part broken up into alcohol and carbon dioxide. The only difference between these cells and those of yeast is that the former are less suited for anaerobic life, and the fermentation which they effect is less complete than that effected by yeast, and they stop or die before all the sugar has been transformed. But such differences are only differences in degree." If we now turn to animal cells, we find that they are also, in fact, anaerobic. Have we not seen that free oxygen dissolved in the serum of the blood is toxic, and that it kills? That the tissues do not breathe pure or free oxygen, but require to have it offered to them combined with hemoglobin? And what is this, if not true anaerobiosis?[1] Hence we must draw the inference that while all

[1] The notion that animal cells are anaerobic was propounded by Pasteur. A. Gautier, in 1893, took it up with some valuable arguments and experiments. These experiments have shown that quite a number of well-known disassimilation products

living organisms require oxygen, and must have it, a large number at all events require to have it offered to them in a combined form. All animals seem to prefer combined oxygen. As to plants, we are in the dark. Certainly free oxygen enters the stomata; but is the oxygen used as such by cells, or does it previously form some compound with some liquid in the plant? We do not know. What we do know, however, is that on our planet and under the present laws of organization and life where oxygen is wanting life is also wanting, and that where oxygen is in excess of the normal ratio life is impaired and after a time destroyed. Such is the main conclusion to be kept in mind.

We will now consider nitrogen, or azote. The name is significant. It means that this gas is not adequate to maintain life, for we all know that if an animal or plant be placed in an atmosphere containing nitrogen only, death ensues in a very short time. It should not be inferred that nitrogen is toxic. We inhale a large proportion of it without the slightest inconvenience; but it is inert, and neither burns nor maintains combustion. Its only function in respiration seems to be that of a diluent or moderator. Pure oxygen would be certain death, while, diluted with some amount of nitrogen, it is absorbed only in the requisite proportion. Nitrogen here plays the part of water added to wine—a useful part, most certainly, since we could not do without this diluent—but a negative one. But what more could be expected of an inert gas?

There is, however, a much more important part played by nitrogen in the economy of nature. It is abundant in organisms. It forms a large proportion of our frame and tissues and is most abundant in the atmosphere. Lastly, as shown by Magendie, when animals are deprived of food containing nitrogen, they die. Let us start from this well-established fact, that nitrogenous food is necessary to maintain life in animals—in higher animals at least. This nitrogenous food is, in the long run, provided by plants. While a few plants—lentils, for instance—yield fruits containing a large proportion of nitrogen, the greater number furnish nitrogenous food only by undergoing the transformations which animal digestion effects upon vegetable food—grass, hay, leaves, etc. Some animals require nitrogen in the form of meat, while a greater number are content with that contained in plants; but, upon the whole, nitrogen is always primarily provided by plants. Now, as nitrogen is essential to all animals, how do the plants which provide it manage to incorporate it? Where do they get it?

The soil contains some amount of nitrates, a proportion of which it is quite certain that plants absorb, for cultivation always impoverishes the soil, deprives it more or less of nitrogen, as chemistry shows, and in order to restore its fertility nitrogen must be added to it under

which are found in the blood, in the urine, etc., are produced by the cells of the tissues after circulation has entirely ceased, when air and oxygen are no more brought to them. The inference is that animal cells are, according to circumstances, aerobic or anaerobic.

the form of nitrogenous manures. But notice must be taken of the following facts. In the first place, forests—whose age is often very great—go on growing, although for centuries no manure has been added to the soil on which they grow, and the same is true of pasture land. Again, it is a well-known fact that if soil is manured with any nitrogenous manure, it yields more nitrogen in the crop than was given to it in the fertilizer. These facts, ascertained by Boussingault many years ago, suggested the idea that atmospheric nitrogen might play some part in the nutrition of plants, and that in some way or other they might borrow nitrogen from the atmosphere which contains such an amount of this substance.

To be sure, the atmosphere contains some ammonia (nitrogen and hydrogen combined), but the amount is very small. Mayer, of Heidelberg, while cultivating in the open air plants whose roots were immersed in nutrient solutions from which nitrogenous compounds were excluded, and protecting them against rain so as to exclude the influence of such nitrogenous compounds as exist in rain water, obtained a crop containing exactly the same amount of nitrogen as the seeds from which the plants grew—not a milligram more. This shows that the amount of ammonia, or other nitrogenous compounds, which may be borrowed from the atmosphere by plants in a direct manner is quite insignificant. But while plants may obtain very little or nothing from the atmosphere by direct process, the case is entirely altered when indirect processes are allowed to operate. Under such circumstances atmospheric ammonia when combined with the elements of the soil, plays an important part, as shown by Berthelot. Instead of remaining useless, as when contained in the atmosphere, it then becomes useful, and is utilized by plants. This process by which atmospheric ammonia combines with soil elements is not a spontaneous one such as that by which hydrogen burning in oxygen forms water—there is no unavoidable chemical reaction—it is effected by the agency of definite micro-organisms. While a specimen of soil left to itself under normal circumstances acquires more nitrogen, the same specimen remains unaltered (neither loses nor acquires nitrogen) when it has been previously sterilized by subjecting it to a heat above 105° or 110° C., by which all micro-organisms are killed. Again, M. Schloesing and Muntz have shown that it is by different micro-organisms that the nitrogen contained in nitrogenous organic matters of arable land is made to combine with other matters, and to form nitrates. One generates ammonia; another transforms ammonia into nitrous acid, which forms nitrates by combining with basic elements, and lastly a third micro-organism transforms the nitrites into nitrates; and this triple process is what is called nitrification—an operation fully investigated by Munro, Winogradsky, and Frankland.

Thus, by one means or another, atmospheric ammonia may be put within reach of plants and be used by them. But ammonia is however a very small proportion of the nitrogenous contents of the atmosphere.

Is there no other supply, and especially, is there no method by which pure atmospheric nitrogen may be also utilized by plants? In view of the considerable amount of nitrogen contained in atmosphere, the matter is one of great importance to plants.

The question has been answered by Hellriegel.[1] After twenty-five years' investigation, the learned director of the agricultural station of Bemberg has finally proved conclusively that certain plants at least have the power of assimilating atmospheric nitrogen. These plants belong to the leguminous family. While cereals, for instance, need to be provided with nitrogen under the form of nitrogenous compounds mingled with the soil, or under the form of nitrates or ammonia salts, lupines, pease, clover and such plants do very well without such compounds. And yet they contain nitrogen; moreover, agriculturists know that they not only do not require nitrogenous manure, but that after they have been grown on a soil they contain more nitrogen than the soil could possibly have furnished; hence the name of "bettering plants." If they are buried in the soil, they not only restore the amount of nitrogen which they may have derived from it, they add to it an excess which they have obtained elsewhere; that is to say, from the atmosphere. Plants grown in a soil totally deficient in nitrogen contain much more of it than the seeds from which they spring—provided, however, one condition is fulfilled. This condition is that the roots possess certain peculiar outgrowths or small tumors—nodules, as they are commonly called—in which a special sort of bacteria is found. If the bacteria are wanting, the plant does not grow well; it remains puny and deficient in nitrogen, but if watered with water to which has been added a culture of the requisite species of bacteria it becomes thrifty and yields an amount of nitrogen amounting to a hundredfold the weight contained in the seed.

It seems that in different species of leguminous plants the active and important species of bacteria are different. That which is adapted to acacia, for instance, although it does not suit pease, works well with beans, and vice versa. Are we to draw the inference that each species of this family has its own special bacterium? Nobbe is not of this opinion; he thinks there is only one species, which he calls *Bacterium radicola;* but that within this species a number of races or varieties has been evolved, each one specially adapted to a sort of communalism with a particular species of plant. For instance, if one individual of this bacterium lives in the nodosities of one particular plant, its progeny becomes specially adapted to life on the same species, and does not thrive on another species. Such is Nobbe's view briefly summarized, and it would explain many curious facts noticed by

[1] Hermann Hellriegel, born 1831, died September, 1895. This important work was accomplished with the cooperation of Mr. Wilfarth, and was made known in 1886 at the Naturforscher-Versammlung in Berlin. Varro and the old Roman farmers had noticed that beans, lupines, and vetches render the soil more fruitful, but Hellriegel and Wilfarth discovered the reason.

agriculturists and horticulturists concerning sympathies and antipathies between plants, and like matters.

The quantity of nitrogen which leguminous plants can obtain from the atmosphere by means of the bacteria which live on their roots may be very considerable; it may amount to 100 or 150 kilograms per hectare (2½ acres). Hence, it is an excellent plan with soils deficient in nitrogen to grow and turn under leguminous plants. It follows also that if a given soil seems unfit for the culture of a particular leguminous plant, this may be because it does not contain the necessary bacteria, and under such circumstances all that is required is to inoculate it. A culture is not required; it is enough to sprinkle some earth taken from a field in which leguminous plants of the same species have grown and thriven. The bacteria abound in that earth, and at once multiply in the field. This is no matter of mere laboratory experiment; the process has been tested on a large scale at Meppen in Germany, by M. Salfeld, with the best results, the crop having been then doubled and trebled.

This inoculation may be performed in another manner. M. Bréal, of the Paris Museum of Natural History, grows two lupines in separate pots, filled with sterilized earth. He inoculates the roots of the one with a needle dipped previously in a culture of the appropriate bacterium, while the other is not inoculated. The result is that the former thrives, while the latter remains puny and perishes.

Besides, Schloesing and Laurent have shown that if different leguminous plants are cultivated in a confined atmosphere the amount of nitrogen in the air decreases.

The general result of the very important labors of Hellriegel and Wilfarth, of Nobbe, of Sir John Lawes and Sir Henry Gilbert is, then, the discovery that different plants of the leguminous family—belonging in particular to the papilionaceous division—are endowed with a very special mode of nutrition, quite different from that of other phanerogams. By means of the cooperation of a few micro-organisms which dwell in and on their roots, they are enabled to draw free nitrogen from the air; not ammonia, nor any other form of combined nitrogen, but free nitrogen, which is used as a nutriment. And thus it happens that that enormous quantity of nitrogen which goes to make a large proportion of the atmosphere, instead of being useless as it seemed at first, is of very great importance to plant life. The probabilities are that it is even greater than it now appears. We feel it difficult to conceive that only a small proportion of plants are able to avail themselves of this source of nitrogen, and physiology teaches us that so far as the principal functions of life are concerned there reigns great similitude in the processes by which they are effected. That papilionaceous plants only, of the whole host of the vegetable world, should be able to acquire nitrogen in the manner described seems unlikely, and thence the opinion that a similar process and a similar function must obtain among other families of plants. This is but an hypothesis, however, and no definite statement can yet be made concerning this attempted generalization. Some facts, indeed, go against it, and show that certainly not all plants have the functions which we have noted in the papilionaceous family. Messrs. Schloesing and Laurent infer from experiment that some species at least are unable to make use of atmospheric nitrogen, and require to have it provided to them under the form of different compounds contained in the fragments and débris of other plants, which thus play the part of manure and food. While the lion and tiger eat the sheep and deer, some plants eat, so to say, their congeners, and exhibit a form of cannibalism. The latter obtain nitrogen from the atmosphere, and after death their remains serve as food for other plants. Such is the case with mosses and many cryptogams. So, observe the gradation: Inferior plants[1] draw nitrogen from the atmosphere; superior plants feed upon the remains of the lower;[2] and, lastly, animals feed on other animals or plants. Man eats both animals and plants, and crowns the edifice of life, as he supposes; but the solid substructure upon which all the building rests is merely an agglomeration of humble unnoticed forms, often invisible to the naked eye, whose functions are to provide the animal and vegetable kingdoms with an essential part of their food. Whether there is here a plan is not for me to decide, but most assuredly the connections and interactions are of interest.

This exposition may seem somewhat long, but it was necessary. It shows that certain plants, at least, can either directly or indirectly fix atmospheric nitrogen without having recourse to the nitrates of nitrogenous manures. Here again it is shown that air is indispensable to life. A gas that at first seems inert and useless is found, after careful investigation, to play a most important part in the nutrition of living organisms. Without nitrogen there would be no plants, no food, no animals, no mankind, in brief, no life at all. And if atmospheric nitrogen were to disappear, life would soon be extinguished. Who, then, will consider this element of the air as useless?

We now come to carbonic acid.

We all know that it is an essentially noxious compound, and doubtless there is little in its history to redeem its reputation. One-half of our respiratory function is concerned especially with the task of ridding

[1] And some superior plants also, such as those of the papilionaceous group; but even with them the process is indirect, as it is through very low organisms (bacteria) that nitrogen is brought to them.

[2] When Melchior Treub visited Krakatoa after the disaster of 1884, in order to investigate the floral repopulation of the island—seeds being brought by currents and winds from the surrounding parts in abundance—he noted that the first plants to appear were algæ and lichens. And it was only some time after the latter had taken a foothold, and, so to say, prepared a suitable soil, that higher plants were seen, and lastly phanerogams. This progression is quite in accordance with physiological facts.

our body of this substance, which is unceasingly generated in our tissues. It is not fit for breathing purposes, and all animals and plants perish in a confined atmosphere when the proportion of this gas rises above a very limited ratio. An atmosphere which contains one per cent carbon dioxide has evil effects upon most organisms, and when the ratio is ten per cent, life is endangered and death only a matter of time. Carbonic acid is of no use at all to the tissues, and when we breathe in an atmosphere where this gas is abundant, the blood corpuscles are not able, in the lungs, to get rid of the carbon dioxide they have collected in the body; so they keep it, and, keeping it, they can not take with them the amount of oxygen necessary for the cells and tissues. It may be asked why they keep the former. The reason is that gas exchanges between the blood and the atmosphere depend upon the amount or tension of the gas in both media. As soon as the tension of carbonic acid in the atmosphere is greater than that of the same gas in the blood, the blood corpuscles retain their carbonic acid. If the amount of carbonic acid in the atmosphere is increased, its tension becomes at some point superior to that of the same gas in the blood corpuscles. These, then, retain the noxious gas which takes the place which should be abandoned to oxygen. The result is death by asphyxia. Before death supervenes a condition of anæthesia is induced, which Bichat specially investigated by means of an ingenious experiment, through which the venous blood—well provided with carbonic acid, of course—of one animal was made to pass into the carotid and cerebral arteries of another, so that the latter had its brain irrigated with asphyxic blood, and was brought to a condition of anæsthesia. Even when applied locally to the surface of the skin, carbon dioxide induces a state of local and temporary insensibility, a fact which seems to have been long known and frequently utilized. Pliny relates in his Natural History that marble (carbonate of lime), when mixed with vinegar and placed upon the skin, puts the latter to sleep, i. e., renders it insensible, so that it may be cut and burned without inducing pain. In this case the anæsthetic agent is carbon dioxide, which is set free by the action of the acetic acid of the vinegar upon the carbonate of lime.

When carbon dioxide acts upon the entire organism, as when it is inhaled by the lungs, it induces general anæsthesia. This has been investigated by a number of physiologists, and one among them, M. Ozanam, has found it so satisfactory that he feels no hesitation in commending it as a substitute for ether or chloroform. His advice has never, to my knowledge, been followed by surgeons or physiologists, and some doubt may be expressed as to the expediency of using for surgical or other purposes so dangerous an agent. Some cases are known in which man has been deeply under the influence of carbon dioxide without fatal results. In such circumstances, anæsthesia has been complete. The patients relate, at least some of them, that before becoming unconscious there occurs a delightful condition during which they seem to be surrounded by a host of very brilliant lights, while exquisite music is played by some invisible orchestra. But this state is of short duration, and total unconsciousness soon occurs, which, if the toxic gas keeps on accumulating in the blood, is rapidly converted into eternal sleep. Cases of death by carbonic acid are not infrequent; they are met with particularly in the vicinity of fermenting liquids, such as brewers' vats or wine cellars; in places where carbon dioxide is naturally exhaled by "gas springs;" by thermal springs in some caves or grottoes, and in all ill-ventilated rooms where a proportionately large number of men or animals are gathered. In lecture and assembly rooms, which are often crowded, air vitiates rapidly; in theaters, in schools, in lecture halls, as much as 10 parts per thousand of carbonic acid has been observed, and in Alpine stables, as before referred to, where animals and men were crowded together, each seeking some warmth in the close vicinity of his neighbor, the ratio of 21 parts per thousand has been recorded.[1] Such atmosphere is toxic,[2] and proofs thereof are not wanting.

[1] M. G. H. Richards, of the Massachusetts Institute of Technology, has, during nine years past, made some 5,000 analyses of the air of lecture rooms. The normal average proportion of carbonic acid in external air is between 3.7 and 4.2 per 10,000. In buildings, the proportion increases according to circumstances. For instance, in empty rooms it is higher by 0.5 on the average in consequence of the decomposition of organic matter, which always remains after the passage of any number of human beings, in the cracks of the floor, on the walls, etc. In the parts of the building where people come and go, without stopping for any considerable time, the ratio is a little higher, and becomes 5 per 10,000. In lecture rooms things are at the worst, as might be expected, and the ratio is 6 or 8 and occasionally 10 or 12 volumes of carbonic acid per 10,000 of air. If such proportions are exceeded, work becomes difficult and unprofitable. Each adult exhales, on an average, according to Andral and Gavarret, some 22 liters of carbon dioxide per hour, so that a man breathing in a confined space 3 meters long, 2 meters high, and 2 meters wide would in twenty-four hours transform the whole of the air of this space into an air having exactly the composition of that exhaled from the lungs. It must not be forgotten that each gaslight, on an average, produces 128 liters of carbon dioxide per hour, and 10 grams of candle produce 14 liters. Under such circumstances no one can wonder that the atmosphere becomes so soon vitiated in rooms where any considerable number of persons are assembled.

[2] It is toxic in its natural condition, by which is meant, if oxygen is present in it only in the usual proportion. But, experimentally, such atmosphere may be prevented from becoming dangerous if its composition is altered by an addition of oxygen. Regnault and Reiset have seen dogs and rabbits live in an atmosphere containing 25 per cent carbon dioxide, 30 to 40 per cent oxygen, and about 40 per cent nitrogen. Even without increasing the ratio of oxygen, animals may live a short time in an atmosphere containing a large proportion of carbon dioxide—30 per cent, for instance, oxygen being 16 per cent (Le Blanc); and Snow has seen birds withstand some time the effects of an atmosphere containing 21 per cent oxygen, 59 nitrogen and 20 carbonic acid. But these experiments can not have any considerable duration, and the average limit of respirable atmosphere is set by the composition of expired air. An atmosphere containing 4 per cent carbon dioxide, 16 per cent oxygen, and 80 per cent nitrogen is inadequate to long maintain life. A lamp is soon extinguished in such an atmosphere, but man may live in it for a short time.

To avoid any danger of the vitiation of air, hygienists are agreed that more is

For instance, during the wars in India, 146 prisoners were one evening at 8 o'clock shut up in a small room. Out of the number only 50 were still living at 2 o'clock next morning, and at daybreak only 23, all dying. Again, after the battle of Austerlitz, out of 300 prisoners confined in an ill-ventilated cellar, 260 died in a few hours through asphyxia, induced by an excessive proportion of carbon dioxide. And at the celebrated Oxford assizes (the "fatal" or "black" assizes in 1557), the high sheriff and 300 other persons died suddenly in court from asphyxia induced by the same means. It may be that in these cases some other influence was also at work, and that some exhaled substance similar to that which Brown-Séquard and d'Arsonval thought they had detected, added its influence to that of carbonic acid; but the existence of this substance has not yet been proved, although it seems probable.

Other cases of poisoning by carbonic acid are met with in natural conditions. Men and animals are occasionally killed by such gas, exhaled by neighboring springs and accumulated in hollows or small valleys. Such "death valleys" have been described by many travelers. No plant is seen, not a blade of grass, not a shrub or tree. The soil is bare, stony, and as if struck with death. Here and there a skeleton is perceived bleaching in the sun—a skeleton of bird, mammal, or even man. Ignorant of the fatal properties of the valley, animals or men

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required than the 16 to 20 cubic meters of air per individual per hour, that was formerly considered as sufficient. In the best ventilated hospitals of Paris 100 cubic meters are provided, but under normal conditions 60 are quite enough for persons in good health. As a rule, the atmosphere of a room may be considered as vitiated as soon as it begins to smell close. When this happens, however, it must not be considered as due to the smell of carbonic acid itself, which is scentless. The smell of close air is due to organic substances—hitherto undefined, or only partly known—which are exhaled by men and animals, and probably more by the skin and its impurities than by the lungs themselves, and generally the amount of these substances is considered as roughly proportional to the amount of carbon dioxide met in the air. Smell is considered as indicating approximately the unhealthiness of the atmosphere as regards respiratory purposes, and is a safe enough criterion. When a room becomes close, it should be thoroughly ventilated, and in such case a draft should always be established, two doors or windows, on different sides of the room, being opened. One is not enough; both are required in order to completely expel the close air and replace it by pure. Generally servants—and masters as well—are content with imperfect ventilation. Such is especially the case in winter, when air is often vitiated by the presence of a gas, carbon monoxide, which is given off in very small quantities by different heating apparatus, stoves especially. Although this gas is never present in any great quantity, it is a source of considerable danger; and in countries where slow-combustion stoves are used, it is each year the cause of many deaths. Carbon monoxide has even greater affinities for hemoglobin than has oxygen, it therefore combines with it and thus there is no place left in the blood corpuscles for oxygen, and the blood then carries no more of the latter gas to the cells and tissues of the body. This gas is also found in the air of mines, but in the open air is not met with, or exists in such small quantities that it can not be detected by present methods.

have wandered there while in pursuit of food, and in the lower part, where the influence of wind is the least and where the heavy gas naturally accumulates, asphyxia rapidly ensues. None who enter come out alive, and the bird of prey soaring in the heights, whose keen eye perceives the victim in the death struggle, and who pounces down upon this welcome opportunity, is vanquished in turn and rises no more.

Fatal to animals as well as plants, expelled by both from the organism as soon as it is produced, carbonic acid appears to all under the feature of a death-dealing agent, as a gas whose toxicity is unquestionable. The only word that can be said in its behalf is that at the moment of death it may act a kindly part. Death in the majority of cases, as a consequence of disease, is induced by asphyxia. During the death struggle respiration fails gradually, becomes slower and more superficial, with the inevitable result that carbonic acid accumulates in the blood. It is probable that when man is about to fall into his last slumber, when the body is on the point of entering that final stage of dissolution and disintegration which we call death, carbonic acid intervenes and plays its part, slowly drawing the curtain, gently putting intelligence to sleep, rendering it unconscious, deaf to sound, insensible to pain, and by beneficial and kind anæsthesia easing the final act of physical life. This may well be so, and this gas which some physiologists consider one of the agents by which each of us is brought into the world by stimulating the contractions of the maternal womb, thus also assists us out of it.

This function, however, is not the only beneficial one which carbonic acid fulfills, and concerning that very unwholesome and toxic constituent of the atmosphere much remains to be said. The unfavorable features have been put in full light; it is but fair to do the same for the redeeming traits, and this shall proceed to do.

All animals directly or indirectly feed upon plants, and plants draw from the soil the greater part of their mineral constituents. Nitrogen and oxygen they borrow from the atmosphere. But what about carbon? The matter is important, as their frame and tissues contain a large quantity of this substance. Two sources are available. Carbonic acid—carbon combined with oxygen—is present in the soil, where it is to be found combined with different substances in the form of carbonates, and in humus, the superficial layer of the soil, made up of fragments of leaves, of branches, of roots dead and decomposed, of mosses, dead ferns, etc. But we can not take into account the carbon which exists in humus, as the first plants which appeared could not have made use of it. There remain the carbonates of the soil, and it would seem to follow that this must be where plants obtain the larger amount of the carbon they use, as Mathieu de Dombasle and many other agriculturists after him supposed. A number of experiments by Sprengel, De Saussure and others, have shown, however, that the part played by carbonates is less important than was thought, and more recently Liebig has established the fact that plants grow and thrive quite well in a soil whence all carbonates have been expelled. Where then do they get their carbon? We know now that they take it from the atmosphere. It is their privilege to decompose the carbonic acid contained in air and to liberate its elements; that is, oxygen which is exhaled and carbon which is retained in their tissues. And the cultivated area of France—some 41,000,000 hectares—absorbs by this means some 60,000,000 tons of carbon each year. This important operation can, however, be performed only under three conditions. As only green parts are capable of taking carbon from the air, the plant must be provided with chlorophyll—that green substance, which is the cause of the color of leaves, and must be exposed to the rays of the sun and to a favorable temperature. Chlorophyll can decompose carbonic acid only under the influence of light and moderate heat; in darkness and under too great or too low heat it no longer acts, and the result is that plants suffer and die, victims of inanition. For it must be clearly understood that the chlorophyllian function is one of nutrition, quite distinct from the respiratory function. In the latter function plants, like animals, absorb oxygen and exhale carbonic acid; in the former the reverse obtains. The one goes on during night and day, the other is in operation by daytime only, and the function of nutrition lasting less time must necessarily be more active than the respiratory process; otherwise the equilibrium would be destroyed and the plant would lose more than it acquires and consequently suffer.

It is by the leaves mainly, and by the roots in a lesser degree, that atmospheric carbon dioxide is absorbed; but in both cases the gas must be brought to the leaves, to the parts containing chlorophyll, because these parts only can use it—can take the carbon and expel the oxygen.

Hence it follows that this violent poison, this gas which is harmful for all organisms, and which kills them as soon as it accumulates in the atmosphere even in small proportions, is essential to all terrestrial life. If it were to be destroyed, if air were to contain no more of it, all plants on the surface of the earth would die within a short period—some weeks at most. After this, as a matter of course, herbivorous animals would die, and this would not require more than a month. Carnivorous animals would hold out a little longer, as the stronger would feed upon the weak, but after a few weeks they also would go in turn, and only a few miserable, half-starved specimens of mankind would be seen feebly struggling from one rotting carcass to another, amidst as barren scenery as can be observed by looking at the moon through a telescope, and they, too, would have to die soon after, notwithstanding cannibalism or such other extreme methods which dire necessity might suggest. In a few months all nature would be dead.

While carbonic acid is a poison, a substance which endangers life greatly, it is also a necessity for life, and in the proportions in which it exists in the atmosphere it is just as much a necessity as it would become a fatal danger if it were to be present in larger quantity.

Such are the relations between air considered from the chemical standpoint and life as it exists on earth; between air in its normal, unvitiated, average constitution and life as it manifests itself under the present circumstances.

IV.—Biological Influence of the Atmosphere Considered from the Physical Point of View.

We must now discuss another side of this complex question, we must deal with air considered as a physical substance, and especially as a substance having weight which presses upon all living organisms. This point of view is not less important than the preceding, and deserves some attention, by reason of the relations which exist between life and atmospheric pressure.

The atmosphere, as previously noticed, being a physical substance, possesses weight, and exerts a pressure upon the earth and all beings that inhabit it.[1]

As long as men or animals keep near sea level, or do not climb to exceedingly high altitudes, the normal average variations of pressure, as indicated by the barometer, are of small influence, and the much more considerable variations which are encountered when one ascends mountains or goes up in a balloon are not harmful as long as they do

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[1] The average pressure of the atmosphere varies, as before stated, according to the altitude of the locality, and also in the same locality at different times. At the sea level this average pressure amounts to a little over a kilogram per square centimeter, hence the total weight supported by an average man is about 18,000 kilograms. At Mexico the average weight per square centimeter goes down to 793 grams; at Quito, to 752; at Antisana, to 639; and it is no difficult matter to obtain the figure which represents the weight supported by man in such localities, when one knows that the skin surface of an average adult is somewhere between 1,400 and 1,500 square centimeters. The physicist Haüy, explaining and commenting upon the calculations by means of which the average pressure exerted upon the body is ascertained, remarks: "And that is the weight which those philosophers of old had to bear and resist who denied weight to the atmosphere."

This weight or pressure is considerable, but we do not feel it, as all the interior parts of our body exert the same pressure and therefore resist successfully that from the outside. It does not crush us any more than it crushes the soap bubbles, however thin they may be, because in both cases the resistance of internal air or tissues exactly counteracts that of external air. There are very few places in the body where the pressure from within outward does not exactly counteract the opposite pressure, in order to leave all movements perfectly free. Two exceptions, however, must be referred to—that of the pleuræ, between which no counter pressure exists, so that they are compelled by atmospheric pressure to keep strictly in contact, and that of certain articulations, where the head of a bone so exactly fits into a corresponding cavity that there is place for no air between, with the result that the atmospheric pressure forces the former into the latter and keeps it there with sufficient force to resist the counteracting weight of the limb.

not exceed certain limits. But beyond these limits danger exists for both animals and man, and while the effects are not exactly the same for all species, and do not occur at exactly the same altitude with all species, or even individuals of the same species, the general fact remains that at high altitudes, or under very low pressures, life is more or less endangered from different causes. In order to ascertain these causes it is not convenient to take men or animals into high altitudes, as the experimenter would be apt to be also influenced by the diminution of pressure, in consequence of which the value of his observations might be considerably reduced. A better method, easily available, is that used in laboratories, of providing large or small air-proof chambers in which the pressure may be increased or diminished at will, so that, without going out of the laboratory, the same patient or animal may be subjected by turn to the pressure which reigns at the bottom of the deepest mine, or even to far higher pressure, amounting to 800 or 1,000 atmospheres, and to that met on the top of the highest peak of the Himalayas, or at twice or three times that height in the lightest of balloons. With such instruments observation becomes easy, and is effected under the most favorable circumstances, as the operator is able to obtain at a few moments' notice exactly the amount of pressure he wishes to have.

The influence of those extreme pressures, high or low, where life becomes endangered, was very fully investigated by Jourdanet, and afterwards by Paul Bert, and those investigations have taught us by what means they become dangerous. The limits of pressure within which no harm occurs are variable according to species. All terrestrial and aquatic animals may and do resist certain variations in pressure, whether above or below the average. Man, for instance, can work at a kilometer below the sea level without any injury, and he can travel to the height of 5 or 6 kilometers in the atmosphere without being necessarily affected by the decrease of pressure. It is the same with birds and mammals, and surface or shore fishes may go pretty deep in the seas without experiencing any unpleasant effects, while deep-sea fish may travel upward for some time before reaching the danger line, so to speak. But for all organisms there are limits in the variation of pressure which can not be transgressed with impunity; there are limits beyond which life is destroyed.

How is death induced in such cases? We must consider the two different cases in turn, and shall begin with the effects of diminished pressure.

Four hundred years have now elapsed since a Jesuit missionary, Acosta, left us an excellent description of the accidents which attend ascensions in high mountains, or important diminution of pressure. "While ascending a mountain in Peru," writes Acosta, "I was suddenly affected by so strange and so mortal an evil that I nearly dropped from my horse to the ground. * * * I was alone with an Indian, and asked him to help me to keep on my animal, and I was taken with such pain, sobbing, and vomiting, that I thought I should die, and, moreover after having vomited food, phlegm (mucous matter), and bile, yellow first and afterwards green, I even threw up blood, such pains had I in my stomach; and I am sure that if it had lasted longer I would certainly have died. As it was it lasted only three or four hours, till we had reached a much lower region. And not only men, but animals also were affected." And further on, "I feel confident that the substance of the air in such places is so subtle and thin that it is unsuitable for human respiration, which requires it thicker and better adapted." This was written three hundred years before the time of Priestley and Lavoisier, and yet the expressions used by Acosta are really most happy. Atmospheric air in the altitudes is too thin, too rarefied, too subtle for the respiration of superior organisms. The evil described by Acosta is that which, in different countries and places, is named *puña*, *soroche*, *veta*, *mal des montagnes*, *mountain sickness*, *balloon sickness*. It has been more recently and fully described and investigated by Tschudi, Lortet, and many others; each has noticed the vertigo, vomiting, anxiety, and fainting which characterize it; and exact experiments—those of Lortet and Chauveau, among others—have shown that respiration is diminished and at the same time accelerated; intense muscular pains have been noticed, and also circulatory and nervous symptoms, which end in paralysis and death if the perturbations continue, as in case of the *Zenith* catastrophe.

While it would be quite superfluous for our present purpose to review the opinions which have at different times been entertained concerning the cause of these dangerous perturbations, we may briefly summarize the explanation thereof recently given by Paul Bert and others.

This is quite simple. The symptoms and death are due to a diminution in the tension of oxygen, which is itself due to the rarefaction of that gas. As everyone will understand, if the same volume contains in high altitudes less weight of air than in low altitudes or at the sea level, it follows that in the former condition there is less air available, less of each constituent, less oxygen. In the heights of the atmosphere air is made up of the same elements as below, but they are less in quantity although the proportions are the same; air is dilated, rarefied, thinner, less dense, and of the essential element—oxygen—a smaller quantity is inhaled at each respiratory movement, although the volume of inspired air is the same. Under such circumstances, as Paul Bert's investigations go to show, decrease of pressure kills, not mechanically, but by a chemical process. High altitudes kill because they induce a state of anoxyhæmia, a state in which the blood is deficient in oxygen. The animal—or man—in rarefied air, dies for the same reason that one dies in a confined atmosphere; in both cases there is an insufficiency of oxygen.

Another cause also operates, in the case of fishes or other aquatic animals that live at great depths, when they happen to rise too near the surface, thus coming from high to low pressure. The gases of the body, dissolved in the liquids (blood, etc.), have a higher tension than the outside pressure, and the result is that these gases expand and burst the tissues within which they are contained when the exterior pressure becomes less than that which reigns in the interior. The case is exactly that of a bladder inflated with air placed in the receiver of an air pump; if the air of the cylinder is gradually exhausted, the bladder swells until it explodes. This is an extreme case, which hardly occurs under natural conditions, but other accidents of a similar nature, which are explained by the same mechanism, often do occur in man or animals, as we shall show further on.

We can not leave this subject without adding a few words concerning mountain sickness. It is a well-known fact that at the same altitude different aeronauts or tourists are not equally affected. Of course this statement refers only to moderate altitudes, between 3,000 and 4,000 meters. At the very same place, on the same day, one person is a victim to mountain sickness and another is not. As only individuals of the same species are compared, the reason of the difference can only lie in personal or individual peculiarities; no specific physiological differences can exist such as those met with when one compares the influence of one and the same agency or poison, etc., upon individuals of different species; there is no evident and tangible cause such as that which one detects when comparing the resistance of the duck and of the common fowl to submersion, when the greater resistance of the former is due to its greater amount of blood, and consequently more considerable provision of oxygen. There are doubtless physiological differences of real importance between different individuals belonging to the same species, and between different varieties of the same species; considered *in toto* those differences are more important and more frequent than commonly supposed, and probably more important than those external morphological characters which are the bases of classification at present. But such important differences can not obtain between two individuals belonging to the same species, and the fact that they may occur one day and be wanting a week later, shows that they are merely accidental and temporary.

Mountain sickness is due to a condition of asphyxia, as already noticed, and this fact explains the differences referred to, as an ingenious experiment performed by M. Paul Regnard amply shows. This experiment was suggested by the proposal, made by a company, to build a lift by which to reach the top of the Jungfrau, the well-known Alpine peak. Before setting to work, it was desirable to ascertain whether the passage from low to high altitude would not produce unpleasant symptoms in the tourists using the lift,[1] and to show that

[1] The lift was to be established in vertical shafts from a horizontal tunnel at the base of the mountain to the top.

under the circumstances attending the excursion, mountain sickness was not to be feared. M. Regnard's experiment answers this question. As far as physiologists are concerned, the question was settled, but the general public required to be satisfied upon this point. The experiment is easily repeated in any laboratory, and it is quite unnecessary to ascend Mont Blanc or the Himalayas for the purpose. All that is required is a glass bell jar, an exhausting pump, and a pair of guinea pigs. The bell jar must be rather wide, and it is placed—inverted—upon a smooth and even surface, such as that which can be afforded by a thick pane of glass.

The edge of the jar is smeared with tallow, so that when placed upon the pane the access of air is entirely prevented. Under it are the two guinea pigs. One is free and does as he chooses; the other is placed in a small treadmill where he is compelled to exert himself somewhat in order to preserve his equilibrium, as the treadmill is made to turn round by means of electricity. The two animals represent, the first, an aeronaut, or a person quietly sitting in a lift where no exertion is required; the other, a mountain climber, who has to expend energy, and to work if he wants to get to the top; and now both must be placed in a condition similar to those which obtain in high altitudes. A few strokes of the air pump connected with the bell are enough to bring the pressure to correspond exactly with that which exists at 2,000, at 3,000, at 4,000 meters height, and a manometer shows the pressure produced. So this experiment begins, and the atmosphere within the bell is slowly rarefied, as would happen in the case of a slowly ascending lift or mountain climber, and because, also, rapid decrease of pressure would be most dangerous. Up to the decrease of pressure which corresponds to a 3,000 meters altitude both animals remain quite well, the one who works his way up, so to say, as well as the other who keeps quiet or only walks a few paces to the right or left. The process is continued and the rarefaction increased. Before the pressure corresponding to 4,000 meters altitude is attained, however, the "working" guinea pig manifests evidence of physiological discontent. Now and then he stumbles, and does not exactly keep pace with the treadmill; he even rolls over and is clearly out of breath. When the manometer shows the pressure to be that which corresponds to a 4,600 meters altitude (210 meters less than the altitude of Mont Blanc), this guinea pig is entirely disabled. He can walk no more; rolls on his back, and is rolled by the treadmill; he moves no longer. In fact, he seems quite dead. Life is not extinct, though, and the animal moves when air is again let into the jar. The other animal is in an excellent state of health. At no moment has he presented the slightest symptoms; he nibbles at cabbage, and seems quite unconcerned with the experiment. It does not affect him in the least.

It may then be considered as settled that the quantity and quality of the air contained in the jar are quite sufficient; that they are adequate to maintain life. And if one of the guinea pigs exhibits symptoms of asphyxia, these are not ascribable to the nature of the atmosphere. If the experiment is pursued and air further rarefied, it is not until the decrease of pressure corresponds to that which obtains at the top of some peaks of the Himalayas (8,000 meters, the altitude attained by Glaisher, but in a state of unconsciousness) that the hitherto unaffected guinea pig shows symptoms of asphyxia. Such symptoms were certain to occur, since the quantity of air was decreasing all the time and must at some moment become insufficient. And now the experiment has proceeded far enough, as there is no necessity at all for killing the animals, and death must surely be the result if the experiment is allowed to continue; air is now let in slowly. Both animals recover entirely, the latter in shorter time than the former.

Now, what does the experiment show? It shows that in itself altitude or the decrease of pressure corresponding to altitude within the limits of 3,000, 4,000, 5,000 meters or even more (under 8,000 meters) is not sufficient to induce asphyxia and the symptoms of mountain sickness. The proof thereof lies in the fact that the inactive guinea pig exhibited no asphyxic symptoms at such altitudes. At 8,000 meters these made their appearance. They were unavoidable. They might have begun a little earlier, they might begin a little later—that is, at rather lower or rather higher pressure—according to the species and individual; but it is certain that for all organisms there is a limit in the heights of the atmosphere above which air is too rare and tenuous to maintain life, and asphyxia must ensue. This first fact, however, was already known, and M. P. Regnard's experiment proves nothing new in that line. What it shows is that muscular effort hastens the production of asphyxia or mountain sickness, and of this the active guinea pig provides an excellent demonstration. Now, muscular effort hastens asphyxia or mountain sickness because it is itself a cause of relative asphyxia. The organism that works and expends energy uses more oxygen, and therefore needs more than that which keeps quiet. The panting which follows running, or is the consequence of rapid muscular work with the arms, legs, or whole body, of violent exercise, proves that the body requires more oxygen, and if the expired gases are analyzed it is shown that carbonic acid exhalation is increased, and it is clear, therefore, that more oxygen is required, since the oxygen contained in carbonic acid is borrowed from the inhaled air.

M. P. Regnard's guinea pigs are exact representations, the one of the aeronaut or of the person in the lift, the other of the Alpine climber; and since muscular exertion alone induces a state of incipient asphyxia it is to be expected that in rarefied air, which itself tends to the same end, that condition should occur quicker in the organism which by its activity goes, as one may say, to meet it.

Practical conclusions are easily drawn from this demonstration. There is no reason for the persons who may be carried up the Jungfrau in the projected lift to fear the effects of altitude. The example of the inactive guinea pig assures them of immunity, and except in some almost impossible cases of anæmia or weakness they will experience no discomfort. On the other hand, incipient alpinists must perceive that the advice commonly given by guides has a solid foundation. The example of the active guinea pig shows them that ascensions must be performed slowly, without haste, without great exertion, without getting out of breath. To be out of breath means incipient asphyxia, and asphyxia means mountain sickness. So the excursionist must learn to climb slowly, with careful and measured step.

In brief, high altitudes must unavoidably bring on asphyxia and mountain sickness, but at moderate altitudes both are avoidable by reducing the exertion; they may be brought on by increasing one's efforts, and it is only by assuming the nearly perfect immobility of the aeronaut that one can hope to attain without discomfort the highest altitudes, since it is during such immobility that the organism needs least air.

Having considered the case where an animal or man passes gradually from a low to a high level, we must now turn to another, that in which the change is sudden or extremely rapid. This is not exceptional, but does not occur in the course of mountain climbing, for obvious reasons; and in the case of balloon ascents, where it would seem to be of common occurrence, we rarely hear of any serious inconvenience experienced, although the balloon often seems to rise very rapidly. The truth is that it rises rapidly to a moderate altitude only, and that it gets into really high altitudes only after a lapse of time quite sufficient for adaptation. To encounter cases of rapid decrease of pressure, we must turn in another direction, and we find examples where men work under high pressure, for instance, in diving bells, under the surface of the sea or of a river, to explore a wreck or build the foundations of a pier or bridge. Here, in order to counteract the great pressure overhead, that of the water added to the normal sea-level pressure—and every ten meters in depth of water adds the pressure of one atmosphere—air must be forced into the bell or diving apparatus, and the men are subjected to a total pressure amounting to three or four atmospheres. As it sometimes accidentally happens that the passage from this high pressure to the normal air is very rapid, the study of the results is instructive for the present purpose. These are often most unfavorable and death not uncommonly ensues. The same occurs when an animal in a bell jar is rapidly subjected to a decrease of pressure, or when, in a bell jar, where an animal has been placed and the pressure gradually increased by forcing air into it, the pressure is suddenly decreased merely by allowing the air to escape into the atmosphere. In both cases, and in fact in all cases where the passage from relatively high to comparatively low pressure is rapid or quite sudden, symptoms arise which are generally fatal. The animal falls on its side and dies, even if the final pressure is one which, if brought on slowly, would not be injurious to life. The danger lies only in the rapidity of the change.

Post-mortem examination of the victim affords a clue to the cause of death, and makes all symptoms clear and intelligible. We find gas or air in free condition under the skin, in the tissues, in the blood vessels; this we never observe under normal conditions. These gases are the cause of death. All tissues, and the blood, of course, contain at all times gaseous matters—oxygen, nitrogen, carbonic acid—either dissolved in the liquids or combined with hemoglobin in the blood, and the amount of these gases varies according to external pressure, according to the tension of atmosphere. Now, if the atmospheric pressure decreases gradually, the tension of the gases of the organism decreases accordingly; and they escape gradually into the atmosphere without making any trouble. But if the decrease is sudden, this gradual escape can not be effected; the liberated gases have no time to escape; the result is that they accumulate in all parts of the body, and in the circulatory system they obstruct small vessels and paralyze the heart.[1] Such accidents are not uncommon among the workmen referred to, and this is the reason why they are always advised to come up slowly to the surface, and the deeper they have been the slower the change should be. They have little to fear from working in compressed air at 2, 3, or 4 atmospheres; the danger lies in the decrease of pressure, which, if sudden, is generally fatal. As they say in their own language, "You have to pay only when you come out."

So much for decrease of pressure, rapid or slow. In the one case it injures by a deficiency of oxygen, by anoxyhæmia, and the only way to counteract its effects is to be provided with a supply of oxygen of which small amounts may be inhaled now and then. Aeronauts intending to attain very high altitudes can not do without such a provision, and it is their custom now to always take with them a supply of oxygen. In the other, the injury is the result of a quite different process, purely mechanical, the sudden liberation of gases in the tissues and especially in the blood, where they immediately interfere with the circulation, and stop the heart's action. When moderate pressure suddenly follows high pressure, anoxyhæmia plays no part, and only the mechanical effects occur; if low pressure follows moderate and sufficient pressure, anoxyhæmia alone occurs if the passage is slow; anoxyhæmia and the mechanical liberation of gases ensue if the passage is rapid and sudden. In both cases, decrease of pressure interferes with life.

Let us now consider the reverse case, that of an increase of pressure. Under normal circumstances such increase is always unimportant.

[1] Just as air, even in very small quantity, drawn in the circulatory system through some lesion of the venous system near the heart induces death in a few seconds, as all physiologists know.

Even at the bottom of the deepest mines, although pressure is appreciably increased, this increase can not be considered as exerting the slightest evil influence, and its physiological effects are practically nil. The increase of pressure is much more important in the case of diving bells, and it is among workmen who are engaged in the building of piers and wharves, or in the exploration of wrecks, that we must search for information concerning the effects of high atmospheric pressure, unless we turn to animals experimentally subjected to such condition in bell jars connected with forcing pumps. When the increase is slight, the effects are also slight. Some buzzing in the ears, some bleeding at the nose, and a slight numbness in the limbs are those which are most appreciable. But, at the same time, the respiration and circulation are slower. In some cases there occurs an abnormal excitation of the nervous system similar to that observed during acute alcoholism. Such accidents are quite naturally ascribed to an increase in the tension of carbonic acid, which accumulates in the system and determines incipient asphyxia. This interpretation is correct as long as the increase of pressure is moderate. But when the increase of pressure is considerable, when we have to deal with pressure of six or more atmospheres, the case is altered, and the cause of the symptoms is different. This is shown by Paul Bert's various experiments. In order to delay the effects of increase of pressure, he added pure oxygen to the atmosphere inspired by the animals experimented upon, expecting by this means to prevent the toxic influence of carbonic acid. He was, therefore, considerably surprised when he perceived that this had no other result than to hasten the fatal issue. He then proceeded to a careful analysis of the symptoms and phenomena, and perceived that when the pressure is over 6 atmospheres the oxygen contained in the atmosphere, acquiring a high tension, becomes a poison. And none can wonder at this. An increase of the proportion of oxygen under normal pressure is attended by toxic symptoms; an increase in the pressure of oxygen, which amounts to the same thing, must exert the same influence. And the proof that oxygen is the only culprit lies in the fact that an animal can perfectly well endure a pressure of 20 atmospheres if the air is poor in oxygen, if oxygen, being less in quantity, has, in the mixture, a tension which does not exceed that which the normal amount of oxygen, in normal air, possesses under normal pressure. Under increased tension, as well as in increased proportion—for both conditions are identical as far as physiology is concerned—oxygen is a poison, and a very dangerous one, and this is the reason why man and animals die in a normal atmosphere, when the pressure exceeds certain limits. Be it rapid or slow, considerable increase of pressure kills through the agency of oxygen and of its toxic properties, by reason of oxygen being dissolved in the blood serum. If we leave out of consideration those cases where the variations of pressure are rapid, and where, as is the case with rapid decrease of pressure, a purely mechanical element comes into play, one sees that gradual variations operate, not physically nor mechanically, but in a purely chemical manner, by putting the organism under the influence of an atmosphere too rich or too poor in oxygen.

It must be added that in this case, as well as in many others, adaptive phenomena occur. The Indians and animals of the South American Cordilleras are unaffected by mountain sickness which attacks the unaccustomed traveler, and animals of the abysses of the sea live and thrive under pressures which no terrestrial or shore animal could endure.

This fact of adaptation to altitude, which is confirmed by the other fact that there are villages or cities permanently inhabited by man at 3,000 and 4,000 meters above sea level, has long been well known. It has especially attracted the attention of a French physiologist, Dr. Jourdanet, who discovered most of the facts which Paul Bert investigated later, but the mechanism of the phenomena has been only recently explained. Jourdanet supposed that the inhabitants of low levels, when transferred to high levels, meeting with low pressure and consequently a small proportion of oxygen, became affected by anoxyhæmia, a state characterized by the inability of the red blood corpuscles to absorb a sufficient proportion of oxygen—in brief, incipient asphyxia.

In that he was right; he also thought that adaptation is effected in the following manner: If the evil is not unbearable, the system begins to produce a larger supply of blood corpuscles; these can absorb only a small proportion of oxygen to be sure, but then they are more numerous and by this means the balance is restored, and the system may absorb a sufficient quantity of oxygen. Here, again, he was right, but he did not succeed in establishing his hypothesis on a firm basis. The latter task was achieved by Paul Bert, who examined specimens of the blood of Peruvian llamas and vicunas, and proved that the blood of such of these animals as live on the highlands contains a larger proportion of hemoglobin and of oxygen than that of those of the same species living on the plains at lower levels. For instance, 100 cubic centimeters of blood of llamas or vicunas living on the highlands contain between 19 and 21 cubic centimeters of oxygen, while the same amount of blood in animals of the same species living on the lowlands contains only 12 to 15 cubic centimeters.

These results have been very positively confirmed by the investigations of MM. Viault, Muntz, and Regnard. M. Muntz has shown that in common domestic rabbits allowed to go wild upon the heights of the Pic du Midi, in France, the blood, after ten months' sojourn in the mountain, contains much more hemoglobin than that of rabbits belonging to the same breeds released for the same length of time in the plains at Bagnères de Bigorre. But it may be objected that this experiment is not as conclusive as it seems to be, owing to the fact that the rabbits of the Pic du Midi may have been surrounded there by different environmental conditions other than those of altitude which may have produced the observed effects. In order to meet this argument M. Paul Regnard has devised an experiment which affords a very precise and unassailable demonstration. In this experiment the only difference is a difference in pressure. If the increase in the respiratory capacity of the blood that occurs in consequence of life at high altitudes is occasioned solely by diminution of pressure, it is clear that such diminution ought to produce the same effect at any altitude whatever. So M. Paul Regnard took two guinea pigs belonging to the same litter, placed one in a bell jar, where a special apparatus not only provided the necessary decrease of pressure (by exhausting the atmosphere to the requisite degree), but effected the necessary ventilation, while the other lived in the same laboratory under normal pressure. The decrease of pressure in the bell jar and the density of the atmosphere corresponded exactly to those which obtain at Santa Fe de Bogota, at 3,000 meters above sea level. Both animals were killed after a month, and the result was that the blood of the guinea pig under decreased pressure absorbed 21 cubic centimeters of oxygen (per 100 cubic centimeters blood), while that of the other animal living under normal pressure absorbed only 14 to 15 cubic centimeters of oxygen at the most. The fact is quite clear; the experiment most convincing. By some means not yet ascertained the blood of creatures living at high altitudes, and able to withstand the first unpleasant sensations, acquires the power of accumulating a large proportion of oxygen, and thus their systems are enabled to resist that incipient asphyxia which is the result of a smaller proportion of oxygen in the atmosphere.

This is an important point, from the practical side. It explains the beneficent influence of high-level stations (such as St. Moriz, in Switzerland) upon anæmic or tuberculous patients. It shows that in cases where the organism is weakened and physiologically impoverished, and particularly where the blood has lost some of its vitality, the patient will be benefited by living for some time in mountain resorts, even at comparatively high altitudes, his blood will acquire new life, and become more apt to fulfill its functions, owing to the increase of respiratory capacity that results from decrease of pressure.

It is evident, however, that the patient should begin with moderate altitudes, 1,500 meters, for instance; with altitudes which do not overtask the system, which do not palpably increase the physiological tendency toward asphyxia, and one should not forget that decrease of pressure which, if moderate, is beneficent, becomes invariably fatal if it exceeds certain limits. Man does not seem to be adapted to live permanently at altitudes over 4,000 or 5,000 meters, and if other animals are able to do so, it is quite certain that even for these also there is a limit upon which they can not trespass without dangerous results. The differences are only of degree, and upon the whole they are of small amount.

MOVEMENTS OF THE ATMOSPHERE.

We must now consider another side of the general topic of the physics of air. I refer to the movements which unceasingly occur in the vast ocean of gas which surrounds our planet. They are familiar to all. It is these that swell the sails of vessels and carry them across the oceans, that give the impulse to the old-fashioned windmill, that lift the waves and send them rolling from continent to continent; these, also, that, with cyclones and tornadoes, uproot trees, blow down houses, destroy crops, snap the giants of the forests like mere twigs, raise clouds of dust, and spread ruin and death on every side. Breeze or tempest, it always is air in motion, and in this case as well as in others air is both beneficent and maleficent. Concerning the cause of this motion, be it gentle or be it violent, it is enough to remind the reader that the main if not exclusive cause is in difference of calefaction, and that the wind blows from cool areas to warm ones.

What part can these movements of the atmosphere play in the life of our planet? What is their influence? A superficial glance is enough to show that this is manifold.

In the first place, they help to intermingle the constituents of the atmosphere. To be sure, the general constitution of air is the same everywhere, no considerable difference existing. But we have referred more than once to the numerous local causes of alteration. Consider, for instance, a large industrial town or a volcano. Both exhale an enormous amount of obnoxious gases which are poured into the atmosphere—carbon dioxide, carbon monoxide, and a hundred other substances, toxic or inert; at all events undesirable for breathing. A few figures have been given above concerning the amount of such gases produced by mankind, by combustion, etc., and we all know that in cities the composition of air is less pure than in the country; that Manchester, Birmingham, Chicago, Pittsburgh, etc., are less healthy than their surroundings. If there were no winds, most certainly things would be much worse than they are, and, the very fact that city air is inferior to country air, substantiates this assertion. Without winds all these gases would accumulate about the place where they originated. Of course some diffusion would take place, but the process would be a slow one, and a much too great proportion of unhealthy gases would at all times be found in the air of such places, which would thus be more insalubrious than they now are. Without winds locally vitiated air would remain such, just as is the case with the atmosphere in a closed room where men or animals are assembled; wind is the cleanser of the atmosphere, the great purifier, which mixes and purifies it, which chases it over lands and seas, over fields and forests, from pole to equator, and from equator to pole, thus dissipating in the whole mass those elements which, for one reason or another, are produced in greater abundance at some points; it maintains the purity of the atmosphere, or at least its homogeneity. If the atmosphere were motionless, the air in cities would be perpetually vitiated, and all the carbonic acid which originates there would be delayed in its travel toward the country, the fields, and the forests, in whose biology it plays so important a part; the vicinity of volcanoes, and even of cities, would be uninhabitable, and life in cities impossible.

Again, from a biological standpoint, the movements of the atmosphere are useful in another way. They prevent the air from remaining excessively dry in some regions and inordinately damp in others. The air which has accumulated a large amount of humidity while above an ocean, a lake, a river, a forest, does not remain there. It travels farther, and carries the aqueous vapor it contains inland, up mountains, and over plains. It transports the clouds, and carries the water drawn from the Pacific Ocean to fall in rain on the American continent; through the same agency the water drawn from the Atlantic falls on Europe, and the water of oceans is carried through the atmosphere to enormous distances to provide the continents with the rain essential to plants, animals, and man, both that immediately used and that which, sinking through the soil, comes to light again, sometimes at considerable distances, under the form of springs, which help to make the streams and rivers. If winds did not occur as they do, if the aerial ocean were motionless, the vapors which arise above the oceans and masses of water would not travel so fast, so far, nor in such quantity, and a great part of our globe would be condemned to drought and sterility. The other part would hardly be pleasanter; in an atmosphere saturated with vapor, as that would be, perspiration evaporates most slowly, and if the temperature were even moderately high, man would lead a sluggish life, shunning effort as inducing an uncomfortable condition, and living in a laziness and *far niente* which have never conduced to moral, mental, or physical advancement. Truly wind is no unimportant agency in civilization and in the general evolution of mankind.

Again, the movements of the atmosphere play an important part in the regulation of temperature, as they do in the regulation of humidity. If they did not occur, air would be perpetually warm in some places and perpetually cold in others, the radiation and diffusion of heat acting but slowly. The wind is beneficent in that it carries warm air to cold regions and cold air to warm ones, tempering the climate of each.

To end this chapter, a word must be said of the part which wind plays in the biology of many species of plants, by providing them with important means of dispersion. Many plants possess light seeds, which are, moreover, provided with appendages in the form of wings, or of feathery hairs, and such seeds are very easily carried to considerable distances over plains, over rivers, and even over narrow sea channels. Through the wind's agency, these species are transported to new habitats, where they may settle and thrive, spreading gradually over large tracts. Numbers of insects and birds are thus carried to great distances by storms, and are thus enabled to obtain a foothold upon islands or continents to which their own forces could not have brought them. And micro-organisms, last but by no means least, as far as importance, not size, is concerned, make great use of atmospheric movements. They possess no means of locomotion, and have no limbs to carry them to a distance; but the wind makes good this deficiency, and takes good care to scatter them far and wide. There are many epidemics propagated from city to city, from country to country; there are death-working as well as beneficent microbes scattered over the whole face of the earth, and thus air is again an agent of death and of life by its contents, no less than by its essential constituents. But air contains also a large proportion of non-living matter, of dead dust as contrasted with the living dust just referred to. Such dust also is scattered far and wide, and there is no doubt but that it may be carried from China to North America, and from the New World to Europe or Africa. This dispersal of dust may be of some importance in agriculture; at all events it plays no insignificant part in geology, and all have heard of the influence of winds in the formation and migration of dunes on the seacoasts. This influence is often important. In France, in the region at the south of Bordeaux and in certain parts of Brittany, the wind has brought so much sand from the dry shores at low tide that man has been compelled to retreat and to desert his villages. These, gradually covered by the particles carried by the winds, have finally been entirely engulfed and buried, as were Herculaneum and Pompeii of old under the cinders of Vesuvius, and the only remnant of a once inhabited and prosperous hamlet is a spire which sticks out of the plain of sand. Analogous phenomena are to be observed in all countries. In 1889, according to Mr. George P. Merrill, a storm occurred in Dakota during which the soil was torn up to the depth of 4 or 5 inches, and the particles accumulated easily in recognizable sand dunes. In the western plains of North America, also, the same event occurs, and these dunes, when once formed, travel and migrate from place to place. Some miles north of Lake Winnemucca (Nevada), Mr. Russell found a series of such dunes, 40 miles long, 8 miles wide, some of which were 75 feet high. Near Alkali Lake other dunes are 200 and 300 feet high, and on the eastern shore of Lake Michigan similar dunes have advanced upon forests, which they have invaded, smothered, and destroyed, and the tops only of the trees, dead as a matter of course, emerge above the hillocks of sand.

It should be observed that particles of sand driven by the wind exert an erosive influence. They act as files, and gradually wear away the rocks which they unceasingly batter, and thus the wind works in two ways toward the leveling of the globe; indirectly cooperating with water and with frost it helps to disintegrate the elements of rocks; and when they are broken down it carries the particles, which are the ultimate result of such disintegration, to the plains and to the sea.

If one observes that besides this work wind is capable of tremendous effort; that it wrenches from the soil the strongest trees; that it scatters to the ground in crumbling ruins the most solid monuments or buildings; if one considers that it could also effect a much greater amount of work than that which is at present effected, by driving sailing vessels or windmills, one can not forego the conclusion that in wind we have an enormous source of energy which is hardly utilized from the industrial point of view.

This is undoubtedly true. Wind is a most powerful force, whose limits can not possibly be estimated; that it could be utilized for man's benefit could hardly fail to suggest itself. Many centuries have passed since the first endeavor, and although some progress has been made, and has been satisfactory enough during a long period, no one will venture to assert that nothing more can be done.

Wind has been used on land and on sea; windmills have been invented in most lands, and few savage tribes have failed to become aware of the great help sails are to navigation. For centuries civilized nations were content with sailing vessels, and some of the latter were truly splendid achievements, able, it must be remembered, to cross the Atlantic—under favorable circumstances—in eleven days, which is still the duration of the trip for average steamships. But for three-quarters of a century steam has been used and defeated sails for long distances. The best steamers of the transatlantic lines are able to run from Queenstown to New York in five days and a half, and from New York to Havre in six days and a fraction. Wind has been defeated by steam on land also, and coal has taken the first place as a source of energy. But coal supplies are not inexhaustible, and thoughtful minds are concerned with the important problem of drawing upon those other resources which the movements of the atmosphere still provide, and which are by no means used as much as they might be. Coal is decreasing, and no fresh strata of the precious store are in process of formation as far as we are aware. It is burned at the rate of millions of tons each year, and mines are being steadily emptied of their contents. Forethought demands that future generations be not caught unawares, and that even now the problem of providing fresh sources of energy be considered. These are not wanting. The application of electricity to general uses has developed important possibilities, and provided us with a method by means of which energy may be obtained, transformed, and carried to a distance with the result that with proper apparatus the energy of rivers, of winds, of tides, of solar heat, may be utilized. Some important steps have been made in the required direction, and much has been done to utilize the energy contained in rivers under the form of falls, in Europe as well as in the United States, where the Niagara Falls are the best known instance. But concerning the power contained in wind, little has been done to take advantage of it. Sailing vessels are always numerous, to be sure, but windmills are, on the contrary, on the decrease, and no new method has been devised of late to increase the quantity of force derived from this source. M. Maximilian Plessner, however, has done good work in trying to call public attention to the matter.[1] Wind is doubtless very irregular, by turns strong or even violent, and a short time afterwards very gentle, and even ceasing. But a great deal depends upon localities. There are places and large regions where the wind is quite regular enough, as far as strength and constancy are concerned, and near the seashore it seldom fails. In the subtropical regions, also, trade winds are very constant, and in most parts of the globe the regularity of the wind increases with the altitude. The latter fact has been well shown by a continuous series of observations made at the Eiffel Tower, in Paris, since 1889. This amounts to asserting that, upon the whole, a considerable part of the globe is perfectly suited for investigations upon the best methods of deriving power from the winds. M. Plessner has calculated that a wall or curtain 1,000 meters high placed upon the fifty-fourth parallel between the twenty-fourth and thirty-eighth degrees of longitude, would receive, through the impact of the wind, a total sum of 100,000,000 horsepower, and 130 such walls would provide 13,000,000,000 horsepower, which means the power of 1,000 Niagaras. Of course no such apparatus could be erected and used, as the first storm would destroy the whole fabric; but this helps us to realize the tremendous amount of energy which speeds over our heads. The first requisite is some sort of motor driven by the wind, and an accumulator to store the energy and yield it at the required moment. M. Plessner has no admiration for the old windmill; he does not find therein the motor which engrosses his thoughts or dreams. The æolian wheel would be more suitable, but this also is below his requirements, and he is rather inclined to look upon sails as affording a possible solution of the problem. "The utilization of the power of winds," he writes, "and its transformation into mechanical work, are possible only by means of sailing vehicles, driven by wind upon a circular railway, the power generated by such rotation being transmitted to an axle, and thence to machinery." He therefore proposes a circular railway, at ground level, or, better still, elevated upon trestles. On this railway a circular or annular train, made of small cars coupled together, each carrying a mast and two sails at right angles with each other, is driven by the wind. These sails are automatically trimmed, and automatically, also, they expand or contract, or rather take in the wind or withdraw from it. As long as the wind blows, the train continues rotating, and if it is connected with a central axle, the latter may work dynamos and charge electric accumulators. A similar apparatus might be arranged in water, boats taking the place of the cars, and since the wind power

[1] See his book: Ein Blick auf die grossen Erfindungen des zwanzigsten Jahrhunderts—Die Dienstbarmachung der Windkraft für den elektrischen Motoren-Betrieb. Berlin, 1893.

is transformed into electricity the latter may be stored and kept in reserve, or transferred to a distance to perform 10, 20, 50 miles away any work that may be required.

Such is, in its main features, M. Plessner's project. Whether it be this or some other which is accepted, there is no doubt as to the necessity of trying to utilize a small fraction of the tremendous energy that produces the movements of the atmosphere, and is one of the results of the action of solar heat on our planet. There are certainly many ways in which the problem may be solved. For instance, a very simple method would be the using of wind power to force water into a reservoir at some height from which it might, at will, be let out to work turbines. In mountainous regions, and near the sea, in all places where water and wind are available, this system might be of service, however imperfect it may seem. At all events a great field is open to inventors, and a great harvest may be reaped by those who will work it with patience and skill. M. Plessner's investigations will prove very suggestive, and they may also find much that is useful in Mr. S. P. Langley's memoir on The Internal Work of the Wind. The facts referred to by Professor Langley are perhaps of more importance for the problem of aviation, or flight, and for the explanation of the soaring of the larger birds, which all have oftentimes seen sustaining themselves during whole hours, without apparent fatigue, or effort, but they are certainly very suggestive in the realm of aerodynamics. Mr. S. P. Langley has succeeded in proving that the force of the wind is not by any means as constant and uniform as is commonly supposed. It does not impart an approximately uniform movement, but a succession of short, rapid waves or pulsations of varying intensity, and fluctuating in direction on either side of the general course of the wind. He considers it as certain that an inclined or suitably curved surface, heavier than air, and free from all attachments whatsoever, may be uplifted and indefinitely supported in the air by means of "internal work," without any further expense of energy than that which is demanded for changing the inclinations of the plane according to the pulsations. It seems quite certain that under special conditions such a plane might advance against the wind, not only comparatively, but in the absolute sense. These data are very valuable, and may prove most useful for practical purposes.

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Having considered the general relationship between living organisms and the elements, pressure, and movements of the atmosphere, we must now proceed to illustrate the relationship between the physical contents of the air and living beings.

Air contains many elements that are accidental, temporary, and of minor importance. Some are gases; such as, for instance, carbon monoxide, carbureted hydrogen, and many others, for the most part obnoxious and toxic. Of these substances we shall say nothing here, because of their scarcity and irregular occurrence. They are not normal constituents of the atmosphere, and we may say that every substance known to chemistry may at some time or place be accidently present in the air. Only such bodies deserve notice as are normally present in the whole atmosphere, although they may be of minor importance. Under this head must be mentioned aqueous vapor and different solid materials, inanimate or animate, excluding those which are of volcanic origin, and dust, natural or artificial.

Aqueous vapor is always present in the atmosphere under the form of fog or clouds, and also in an invisible form. We will especially refer to the latter. It has a dual origin. The one part comes from evaporation, under the influence of heat, of the water of oceans, rivers, lakes, and moist soil. The amount of vapor produced depends upon the amount of heat, and also upon the amount of vapor already contained in the air. For each degree of temperature air can only contain a quite definite amount of vapor. The other part comes from living organisms, by transpiration through the skin and pulmonary surfaces of animals, by the evaporation which occurs from the leaves of plants. This production of aqueous vapor by living beings is very variable, and circumstances affect it greatly. An animal or man in dry air produces a large amount, since the expired air is quite saturated with it, but in moist air hardly any is produced, and that which is expired hardly does more than restore to the atmosphere the moisture taken from it. The whole of mankind pours into the atmosphere a total amount of some 15,000,000,000 kilograms of water per twenty-four hours, but a large proportion of this is merely returned; it has not been generated by man. Similarly, plants yield but a small amount of moisture if the air is already nearly saturated; they yield a very large amount if it is dry. It has been calculated, for example, that a wood of 500 adult and vigorous trees yields nearly 4,000 tons of aqueous vapor during the twelve hours of daylight. By night the amount is less considerable, and is only about one-fifth of the diurnal evaporation. This instance is enough to show that plants are most important producers of vapor. And if one only considers that in the United States, as an example, the total surface of plant leaves is at least four times that of the soil surface, one perceives how important must be the part of plants in the function we refer to. Physicists have estimated the total quantity of aqueous vapor in the atmosphere at 72,000,000,000,000 tons or cubic meters of water.

This vapor, which is very unequally diffused (since the maximum amount depends upon the temperature of air), and which varies in quantity according to the time, locality, and other circumstances, plays an important biological part. Air, when too dry irritates the respiratory organs; when too moist it impedes transpiration and its beneficent effects: *in medio virtus*, and the best condition is that in which air is neither very dry nor very moist.

Another more important part is played by this aqueous vapor in that it forms a sort of protecting screen, that, by day, tempers the solar heat by absorbing a portion of it and preventing it from scorching the vegetation and the soil, and at night, conversely, prevents excessive cooling of the earth's surface by radiation. It does not prevent the passage of luminous calorific rays, but absorbs a large amount of the dark thermic rays—whatever their source—and experiments by Tyndall, and especially Pouillet, and others, have shown that the atmosphere, by reason of the vapor it contains, absorbs about a quarter of the sun's heat, so that only three-quarters reach the earth proper. If this screen did not exist, our summer days would be much hotter and also much cooler. In the full glare of the sun the thermometer would stand higher than it does, and in the shade the temperature would be lower. We have an exact illustration of what would happen in what occurs on high mountains, or in balloons at great height. The higher we ascend the thinner becomes the layer of vapor interposed between the sun and ourselves. Under such circumstances the sun is scorching; its rays, nearly unopposed, exert a stronger influence upon persons and things and heat them highly, while the surrounding air is cold, as there is hardly any vapor to absorb solar heat. This fact has been well observed by Professor Langley during his ascent of Mount Whitney, and all alpinists have had experiences more or less similar. If, then, there were no vapor in the atmosphere, our summer days would, as is the case in high altitudes, be torrid and frigid at the same time—torrid in the sun, frigid in the shade, where the thermometer would certainly fall very low.

At night atmospheric vapor moderates radiation. During the night the earth gives off part of the heat it has received during the day, and this heat radiates into interplanetary space. When the sky is very clear and dry, radiation is considerable, and at all seasons a clear night is colder than a cloudy one, and night is colder in high altitudes where the overlying sheet of air and vapor is thin and rare, than in the lowlands, with a thicker atmospheric layer overhead. Radiation is unavoidable, because the temperature of celestial space is exceedingly low, probably inferior to 100° below zero (centigrade); but it is more rapid, and offers greater intensity when the air is dry and contains but a small quantity of vapor, because then the absorption by the atmosphere (by vapor, to be precise) of dark calorific rays radiated from the earth's surface is very slight. If there were no aqueous vapor in the air, a considerable cooling would begin as soon as the sun set, and such cooling does occur on high mountains and at high levels—in Thibet, for instance, which is both high and dry, and also in deserts, where the atmosphere is generally dry. In Sahara, after the hottest days under a scorching sun, the nights are generally very cool, and the thermometer runs down some 30° or 40° in a few hours. Such radiation and cooling must be very harmful, and most animals and plants could certainly not endure it. Vapor thus exerts a most beneficial influence, as it moderates the heat of day and the cold of night, and acts as a sort of regulator, by means of which some uniformity is established under antagonistic and conflicting conditions, and in spite of contrary influences. Quite certainly, if vapor did not exist, the physiology of the animals and plants of the lowlands would be different, or they would perish.

The parts played by the numerous solid particles found in the atmosphere are as varied as is their nature. Physically pure air is a myth and can only be obtained artificially, in laboratories, and when great care is exercised. Even at the greatest heights, where micro-organisms as well as vegetable or animal fragments are few and often totally wanting, mineral dust is always found. These particles are very small, to be sure, and their origin varies; some are of volcanic origin, and after important eruptions, such as that of Krakatoa, volcanic particles are very abundant in the atmosphere and may be years in settling or falling on land or sea; others are merely dust which the wind has swept off the surface of the planet, and a large proportion consists of minute fragments of aerolites which have fallen into the earth's sphere of attraction from interplanetary space.

Professor Newton has attempted to form some estimation of the number of such aerolites, and he comes to the conclusion that our atmosphere receives the enormous total of some 20,000,000 meteorites per twenty-four hours, each of which is large enough to produce the phenomenon known under the name of "shooting star." However small these fragments may be—and yet in order to become visible because of the heat evolved by friction against the atmosphere they can not be so very minute—they certainly bring to our planet a considerable amount of foreign matter, a large proportion of which remains some time suspended in the atmosphere before falling. In all places where the requisite observations have been made, and where instruments have been placed for collecting the mineral contents of the air, there has been obtained an abundant harvest of meteoric particles, easily recognizable by their form and structure, and the mud which slowly accumulates at the bottom of the sea contains a large number of these extra terrestrial bodies. As a matter of fact, mineral particles of foreign source are constantly pouring through our atmosphere in the form of a dry and invisible rain. A large amount of terrestrial dust is also found in this rain. Von Richthofen speaks of the particular aspect of the atmosphere in a part of China, where the sky is yellow and opaque. When the wind comes from the direction of Central Asia, all things are covered with a yellow dust which is brought by the wind from vast regions whose soil is covered with a layer of ochreous dust, which is driven to great distances over the Pacific. In Australia, rains of a sort of red mud have been observed—rain made into mud by the admixture of dust, the latter having been transported by the wind and storm from considerable distances. Such a rain has been noticed to fall over an area of 2,500 square miles. In the United States, a similar phenomenon has been observed. Prof. S. P. Langley, during the ascent of Mount Whitney, noticed that the middle strata of the atmosphere contained a large amount of red dust which was visible from above the level of these strata, while below, from the plains, no trace of it was detected by the eye. This dust had, perhaps, its source in China. The Krakatoa volcanic dust remained many years in the atmosphere and traveled many times entirely around our planet.

All this dust becomes easily perceptible to the naked eye, when we look at a ray of light in a dark room. But in order to well ascertain its origin, to know exactly what it is, microscope and aeroscope are wanted. By means of these instruments a very interesting microcosm is revealed. All sorts of particles are to be found in the air—small desiccated animals, such as worms, rotifers, vibrios, infusoria, fragments of insects, of wool, scales from the wings of butterflies, particles of hair, feathers, vegetable fibers, spores of fungi, pollen grains, flour, dust from the soil, and microbes. From our present standpoint many of these particles are of but slight interest to us, although it is a curious fact that volcanic dust may remain for years in the atmosphere at considerable altitudes, and travel around the earth with the winds, inducing those curious phenomena of light and color at sunrise and sunset which physicists and the public at large observed after the Krakatoa eruption. It is also a very curious fact, well illustrated by T. Aitken's investigations, that these particles are favorable to the production of rain. Under certain circumstances they play the part of a nucleus around which the vapor of the atmosphere condenses, and each particle becomes then the central part of a drop of rain.[1] What is of interest to us, from the biological point of view, is the presence of pollen grains, which explains how an isolated female plant may bear fruit even at a great distance from male plants of the same species; the presence of spores of fungi, which favors the dispersal of species; the presence of light seeds, which may be carried very far, and then fall to the ground, and develop an individual in a region where the species was never seen before. Again, the presence of microbes, to which we have previously referred; and which explains how many diseases are carried far and wide by the agency of the winds, such microbes being specially abundant in cities and in the vicinity of dwellings. At the Montsouris Observatory in Paris, M. Miquel finds between 30 and 770 microbes per cubic meter of air, according to winds, seasons, etc.; in the center of the town, Rue de Rivoli, the air contains 5,500 per cubic meter; in hospital wards, between

[1]Such being the case, in order to induce artificial rain, instead of trying to change the state of the atmosphere by means of explosions it would seem more rational to send dust into the heights. But at all events, the essential requisite is the presence of vapor, and this feature seems to have been sadly neglected in recent experiments. Nature provides rain by means of vapor and changes in temperature, not by explosions which can hardly have any influence.

40,000 and 80,000, while at 7,000 meters altitude, and above the sea at some distance from the shore, none at all are found. These figures are enough to show how the air under certain circumstances is a dangerous agent, and serves as a vehicle of death.

As we have seen, air is fraught with life as well as with death. Each of its constituents is essential to life, and each is also a cause of death. The one that appears to be the most vivifying of them all, becomes under certain conditions and doses, a fatal poison; the most useless, the most harmful is, when carefully investigated, an essential basis of the whole structure of life. And the general conclusion is that none could disappear, none could exist under a different form or in markedly different proportions, without soon altering the features of our planet and changing it into a naked and barren globe on whose surface no living being, of the present type, could be found.

If we study the subject more attentively we become aware of another fact. We perceive, to use again J. B. Dumas's very happy phrase, that all living beings are, at last analysis, nothing but condensed air, Plants exist mainly by reason of the existence of air, and animals and man can not exist without plants. The elements of plants are air, and animals live upon plants; the connection is direct and intimate, and man, therefore, is also only condensed air. And as this air, since the centuries during which mankind has existed, has been unceasingly migrating from generation to generation, from individual to individual, now part of some of our human ancestors, later returning to the atmosphere, and thus perpetually pursuing its cycle, our present organism is made of the same elements as that of our ancestors. Their substance is also ours. And this substance, which is also that of past animals and plants, goes on through space as an untiring wave. To-day or to-morrow a flower or a fruit, it will unite at one time to form a portion of a sluggish mollusk, at another to help build the brain of a Descartes, a Newton, a Pascal, a Shakespeare, a Helmholtz, a Joan of Arc. The cycle is never interrupted. No human eye witnessed its beginning; none will witness its end. It seems to be infinite and eternal—although, doubtless, it is neither—and alternating from life to death, as old as the world and yet as young as the newborn; if consciousness were among its attributes it would have gone through all that life may give—the highest joys, the deepest sorrows, and all emotions, the noblest as well as the basest.

The breeze which gently moves the leaves, the wind which moans through the high forests, is the sum total of all life that has been. It is the material of all that has had existence, of those that came before us, of those that are no more and for whom we weep. Now it becomes part of ourselves and to-morrow, perhaps, it will go on, pursuing its way, unceasingly metamorphosed from organism to organism without choice or favor, according to law, till the time comes when our globe, no longer heated by the cooling sun, shall slowly die. Then all the substance of past living organisms will rest and return to earth; mortal cold and darkness will reign; the curtain will drop upon the tragedy of life, and that which remains will be a frozen and gigantic tomb, rolling silent and desolate through the unfathomable depths of the darkened heavens.

> I will encounter darkness as a bride
> And hug it in my arms.
> (*Measure for Measure.*)