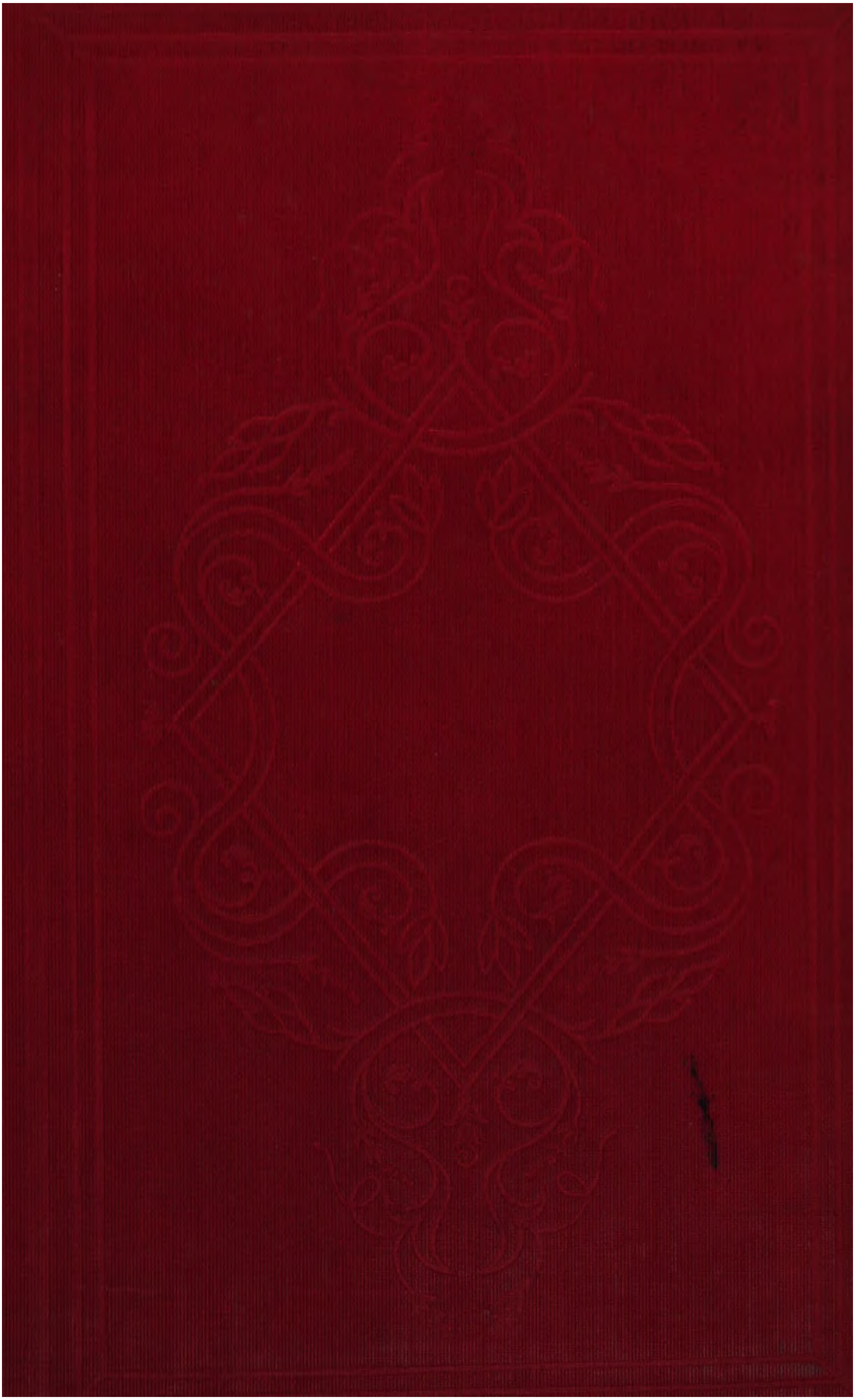

# FAMILIAR
# LETTERS ON CHEMISTRY.

## Second Series.

### THE PHILOSOPHICAL PRINCIPLES AND GENERAL LAWS OF THE SCIENCE.

BY JUSTUS LIEBIG, M.D., PH.D., F.R.S.,
PROFESSOR OF CHEMISTRY IN THE UNIVERSITY OF GIESSEN.

EDITED BY
JOHN GARDNER, M.D.,
MEMBER OF THE CHEMICAL SOCIETY.

LONDON:
PRINTED FOR TAYLOR AND WALTON,
UPPER GOWER STREET.

MDCCCXLIV.

LONDON:
BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.

# PREFACE.

THE rapid sale of *The Familiar Letters on Chemistry*—which in a very short time have passed through two editions in England, have been reprinted in America, and translated into Italian—satisfies me that my design in writing them has not been misunderstood; that they have supplied a want felt by a very numerous class of readers, in presenting at a glance a general view of the principal points of Chemistry, its objects and extent, and its application to other sciences, but more especially those of Agriculture and Physiology.

It is therefore with great pleasure that I now offer to my English friends a second series.

The most attentive observer could scarcely understand the various interests of our age, whether intellectual or material, without knowing the means and the methods by which we have obtained those acquisitions in the sciences, and those abundant resources in the arts, which enable us to supply the necessities of our social existence. So far as such a knowledge is a principal or an essential condition of improving the human mind, it becomes necessary to every educated man. To know the causes—to understand the forces to which we owe the great and manifold successes of modern times, is a great progress in mental acquirements. That which has been already accomplished being thus appreciated and appropriated, we are enabled to form a definite anticipation of what will be done in future.

The man who has made this acquisition, takes himself a part in the onward movement. All that at first sight may appear accidental or enigmatical in results vanishes, and every new phase of things presents to him its natural and necessary connexions. In thus taking possession of scientific discoveries as they are offered him, he may apply them to his own advantage according to his means and wishes; he may increase his own wealth, and disseminate its blessings among his fellow men.

Having prepared this second series of *Familiar Letters on Chemistry*, I consented to their publication, as a series of introductory dissertations to a course of Lectures in the *Lancet*. Their reception amongst the class to which that Journal extends has been very satisfactory to me; and I now trust that their separate publication, in the form originally intended, will be acceptable to the English public; that the favour bestowed upon my former labours will be extended to this little volume; and that it will be received as a token of my acknowledgment and gratitude.

JUSTUS LIEBIG.

GIESSEN, *Aug.* 1844.

# CONTENTS.

## LETTER I.

LETTER V.

LETTER VI.

LETTER VII.

LETTER VIII.

## LETTER IX.

## LETTER X.

## LETTER XI.

# ERRATA.

Page 71, line 6, *for* "$C_4 H O$," *read* "$C_4 H_5 O$."
Page 95, line 21, *for* "peroxide," *read* "sesquioxide."
Page 96, lines 1 and 12, *for* "green," *read* "red."
Page 181, last line, *for* "stearic," *read* "margaric."

# LETTERS ON CHEMISTRY.

## LETTER I.

My Dear Sir,

In entering upon another series of letters upon Chemistry, in which I purpose to render familiar the philosophical principles and general laws of the science, it will not be inappropriate to claim your attention, in a few preliminary remarks, to the bearings of chemistry, generally, upon the welfare of nations, and its relations to other sciences.

Whilst I am far from desiring that the sciences should be judged, their intrinsic value estimated, or their respective ranks determined, merely by the amount of economic advantages they afford to individual members of a state, yet it appears to me that some distinction should be made as to the degree of estimation in which particular sciences are held, and that encouragement to their progress should be awarded in proportion to the intellectual benefit, together with the material advantages, they are calculated to afford mankind.

It is, unquestionably, worthy of a nation,—a great nation,—to send out travellers for the purpose of increasing our knowledge of distant and unexplored regions, and to make us acquainted with the plants and animals inhabiting them, and even to make great sacrifices in fitting out expeditions for these important objects. I deem it equally desirable that collections of rare animals and minerals, vessels and utensils employed by men in past ages, remains of art, and other objects, should be made in museums. Every human being, endowed with the smallest share of sensibility, is capable of admiring and deriving improvement from these collections, and of discerning the great Creator in his varied works. The contemplation of them furnishes him with new ideas, elevates his understanding, quickens his perception, and corrects his judgment; but the impressions he derives from these sources are not susceptible of any practical applications; they do not render him more able to obtain the necessaries of life, or to bear his share of the burthens of the state, nor do they enable him to become more useful to his fellow-creatures. Precisely the same may be said of the great expenses incurred, and the sacrifices made, by institutions for the purpose of exhibiting to us in a living state those plants which grow naturally only in foreign climes, or which yield us useful remedies. Doubtless, it is highly proper that such collections and botanic gardens should enjoy the encouragement of learned societies, of universities, and the public.

We have, however, only to look around us to perceive at once that the science to which we are devoted,—Chemistry,—has by no means been favoured, in an equal degree, with other sciences, such as botany, mineralogy, geology, or geography; that hitherto no adequate encouragement has been extended to it, no sacrifices made to ensure its advancement, no efforts commensurate with its importance to extend its cultivation, and to make it an essential element in popular education. Herein lies a great disparity between chemistry and other sciences. It is not, however, difficult to discover the causes of this comparative neglect of chemistry. The literary man and the statesman have not been impressed, in the course of their early studies, with the principles indispensable to the successful study of nature. Chemistry was long known only as it was subservient to the physician for the preparation of his purgatives and his emetics. Whilst it was thus engrafted on the medical sciences it could obtain no independent position. The physician was but slenderly furnished with chemical truths, and yet the science had no existence except for him and the apothecary. When, however, those who framed the systems and guided the practice of education, saw the great advantages which agriculture, arts, and manufactures might derive from chemistry and natural philosophy, they admitted these sciences to a certain rank, and bestowed on them a certain measure of attention. From being merely an instrument of the physician, chemistry then became one of the main levers of commercial industry. The measures adopted to ensure this extended application of the science, however, were imperfect, and inadequate to the purpose. But chemistry is susceptible of being made subservient to far higher offices; it may be employed as a means of cultivating the mind, of training the human faculties for the universal investigation of nature. In this point of view it has not been contemplated. Many well-informed people still regard chemistry as the art of making experiments according to certain rules, very useful in the manufacture of soda and soap, in fixing good and permanent colours upon silk and cotton fabrics; but as an investigation of nature, or as an universal guide to its study, it is to most persons altogether unknown.

It is so congenial to the human mind to inquire into the causes of the natural phenomena existing around us, and presented to us in the daily changes taking place in all visible objects, that those sciences which give satisfactory explanations and correct answers to our inquiries, exercise more influence on the advancement of mental cultivation than any other. Thus the relations of light to the earth, the succession of day and night, the variations of the seasons, and the differences in the temperature of different climates, gave birth to *astronomy*. As the mind advances in knowledge, as it becomes enlightened by the influx of truths, no matter from what source, its capabilities are increased, its powers strengthened and elevated, and its progress in all other directions proportionately facilitated. When we obtain a correct knowledge of the link which connects certain associated phenomena, when we have made an acquisition of a new truth relative to causation, it becomes equivalent to a new and additional sense, enabling us to perceive innumerable phenomena which had previously escaped our notice, and which still remain mysterious or altogether invisible to others.

In the progressive growth of astronomy the other physical sciences were developed, and when these had been, to a certain degree, successfully cultivated, they gave birth to the science of chemistry. And now we may anticipate that ORGANIC CHEMISTRY will perfect our knowledge of the laws of life—the science of physiology.

But it must not be forgotten that our predecessors determined the duration of the year, explained the changes of the seasons, and calculated eclipses of the moon, without any acquaintance with the laws of gravitation; that people have built mills and constructed pumps without knowing anything of atmospheric pressure; that glass and porcelain were manufactured, stuffs dyed, and metals separated from their ores by mere empirical processes of art, and without the guidance of correct scientific principles. Even geometry had its foundation laid in experiments and observations; most of its theorems had been seen in practical examples, before the science was established by abstract reasoning. Thus, that the square of the hypothenuse of a right-angled triangle is equal to the sum of the squares of the other two sides, was an experimental discovery, or why did the discoverer sacrifice a hecatomb when he made out its *proof?*

How different now is the aspect of the discoveries of the naturalist, since the spiritual impetus of a true philosophy urges him to investigate phenomena in order to understand their *causes* and *laws*, whether in natural philosophy, chemistry, or in other sciences. From one sublime genius—from NEWTON—more light has proceeded than the labour of a thousand years preceding had been able to produce. The true theory of the movements of the heavenly bodies, the law which regulates the fall of bodies, *i. e.* gravitation, has become the parent of innumerable other discoveries. Navigation, and, in consequence, commerce and industry, immediately felt its influence, and every individual of our species has derived, and will continue to derive, as long as mankind exists, incalculable benefits therefrom, both intellectual and material.

Without an acquaintance with the history of physics it is impossible to form any correct opinion of the effect which the study of nature has exercised upon the cultivation of the mind. In our schools mere children are now taught truths, the attainment of which has cost immense labour and indescribable efforts. They smile when we tell them that an Italian philosopher wrote an elaborate treatise to prove that the snow found upon Mount Etna consists of the same substance as the snow upon the Alps of Switzerland, and that he related proof upon proof that both these snows, when melted, yielded water possessed of the same properties. And yet this conclusion was really not so very palpable, since the temperature of the two climates so widely differ, and no one in those days had any notion of the diffusion of heat over the surface of the earth. When a schoolboy takes a glassful of liquid, and placing a loose piece of paper over it, inverts the glass without spilling a drop of the contents, he only astonishes another child by his performance, and yet this is the identical experiment which renders the name of Torricelli immortal. It is a variation of that experiment with which the burgomaster of Magdeburgh (Otto von Guerike) threw the Emperor and the princes of the empire at Ratisbon into speechless astonishment. Our children have more correct notions of nature and natural phenomena than had Plato! they may treat with ridicule the errors which Pliny has committed in his Natural History!

By the study of history, of philosophy, and of the classics, we obtain a knowledge of the intellectual world, the laws of thought, of mental inquiry, and of the spiritual nature of man. Whilst we hold communion with the spirits of the great and good of all ages, we derive from the experience of past centuries the power of soothing and governing the passions, and of softening the heart; we are enabled to comprehend man as he exists at the present time, since his moral nature remains ever the same. We are taught to embellish, and present, in the most engaging form, the principles of truth, of right, and of religion, and thus to make the most enduring impression upon the minds of others. History and philosophy, however, could not prevent men from being burnt for witchcraft. For when the great Kepler went to Tubingen to save his mother from the stake, he succeeded only by proving that she possessed none of the characteristic signs essential to a witch!

Only sixty years ago was chemistry, like a grain of seed from a ripe fruit, separated from the other physical sciences. With Cavendish and Priestley its new era began. Medicine, pharmacy, and the artisan's workshop, had prepared the soil upon which this seed was to germinate and to flourish. The foundation of the science is, as is well known, an apparently very simple theory of the phenomena of combustion. We have now experienced the great benefits and blessings which have sprung and been diffused from this view. Since the discovery of *oxygen* the civilised world has undergone a revolution in manners and customs. The knowledge of the composition of the atmosphere, of the solid crust of the earth, and of water, and their influence upon the life of plants and animals, was linked with that discovery. The successful pursuit of innumerable trades and manufactures, the profitable separation of metals from their ores, also stand in the closest connection therewith. It may well be said that the material wealth of empires has increased many-fold since the time oxygen became known, and the fortunes of individuals have been augmented in proportion. Every discovery in chemistry has a tendency to bring forth similar fruits. Every application of its laws is capable of producing advantages to the state in some way or other, augmenting its powers, or promoting its welfare.

In many respects chemistry is analogous to mathematics. On the one hand, the application of this latter science enables us to measure land, to erect buildings, and to raise weights, and, as in arithmetic, becomes an instrument, the skilful employment of which secures most obvious and universal advantages; on the other hand, mathematics enable us to draw correct logical conclusions according to definite rules, teach us a peculiar language, which allows us to express a series of such conclusions in the most simple manner, by lines and symbols intelligible to every one who understands this language; give us the power to deduce truths by means of certain operations with these lines and symbols; and furnish us with an insight into relations of things formerly obscure or unknown to us. The mechanician, the natural philosopher, the astronomer, employ mathematics as an indispensable instrument for the attainment of their ends. They must, indeed, be so practised in its management that its application becomes a mechanical habit, requiring only the exercise of memory. But it is not the mere instrument which plans and executes the work, but the human intellect. You will admit that without the power of observation, without judgment, without sagacity, all mathematical knowledge is useless. You may imagine a man who; favoured by a good memory, has rendered himself intimately acquainted with every theorem of mathematics, who has obtained an eminent degree of skilfulness in handling this instrument, but who is altogether unable to invent a problem for solution. If you propose to him a problem, and give him the conditions for the solution of a question, he will succeed in obtaining an answer by performing the current operations with which he is familiar, and express it in a formula consisting of certain symbols, the meaning of which, however, is perfectly unintelligible to him, because he is deficient in other attainments essential for judging of its truth. Such a man is a mere calculating machine. But as soon as he possesses the capacity and the talent of proposing a question to himself, and testing the truth of his calculations by experiment, he becomes qualified to investigate nature. For from whence should he derive his problems if not from nature? He is denominated a mechanician, an astronomer, or a natural philosopher, if, starting from observation, he is able to ascertain the connection of certain phenomena and the causes producing them; and then is capable, not merely of expressing the results in a formula, in the language of the mathematician, but of making an application thereof, exhibiting his formula in the shape of a phenomenon or external fact, thereby testing its truth. The astronomer, the mechanician, the natural philosopher, therefore, in addition to mathematics, which they use only as an instrument, still require the art of observing and interpreting phenomena, the ability to present the results of abstract reasoning in a visible shape by means of a machine or some form of apparatus; in fact, to prove the correctness of their conclusions by experiment. The natural philosopher proposes to himself the solution of a problem,—he endeavours to ascertain the causes of a given phenomenon, the variations it undergoes, and the conditions under which these changes take place. If his questions have been correctly put, and all the circumstances (the factors) taken into account, he succeeds in obtaining, by the aid of mathematical processes, a simple expression for the unknown quantity or relation which has been the object of his search. This expression or formula, translated into ordinary language, explains the mutual connection of the observed phenomena, or of the experiments which he has instituted; and the formula is correct, when it enables him to produce a certain series of new phenomena which are its corollaries.

You may now perceive how the mathematics stand connected with the study of nature; and that, besides mathematics, a high degree of imagination, acuteness, and talent for observation, are required to make useful discoveries in astronomy and other physical sciences. It is an error to ascribe discoveries to mathematics. It happens with this, as with a thousand other things, that the effect is confounded with the cause. Thus, effects which have been ascribed to the steam-engine, belong properly to fire, to coals, or to the human mind. The true discoveries in mathematics are the successive steps towards the perfection of the instrument, by which it is rendered capable of innumerable useful applications, but mathematics alone make no discoveries in nature. They work upon data furnished to it, upon what has been observed by the senses, and ideas created by the mind. Experimental natural philosophy stands in this sense in contrast with mathematical natural philosophy. It is the former which discovers, examines, and prepares facts for the mathematician. The task of experimental physics is to express the laws, the general truths deduced, in the form of phenomena, to illustrate the mathematical formulæ by experiments, to make them manifest to the senses.

Chemistry, in answering her own questions, proceeds in the same manner as experimental physics. She teaches the methods of discovering and determining the qualities of the various substances of which the crust of the earth is composed, and which form the constituents of animal and vegetable organisms. We study the properties of bodies, and the alterations they undergo in contact with others. All our observations, taken collectively, form a language. Every property, every alteration which we perceive in bodies, is a word in that language. Certain definite relations are manifested in the deportment of bodies toward each other, a similarity in form, or analogy in properties, or diversities in both respects. Such diversities are as numerous and various as the words of the most copious language, and they are no less varied in their signification and in the relations which they bear to our senses.

The verbal meaning conveyed by the properties of bodies,—to pursue the illustration,—changes according to the mode in which these elements are arranged. As in all other languages, we have in that language whereby material bodies hold converse with us, articles, substantives, and verbs, with their variations of cases, declensions, and conjugations. We have also many synonymes; the same quantities of the same elements produce a poison, a remedy, or an aliment, a volatile or a fixed body, according to their manner of arrangement.

When we would understand the meaning of the properties of bodies, that is, of the words in which nature speaks to us, we use the alphabet to decipher and to read them; as, for instance, a fountain of mineral water in Savoy cures that remarkable enlargement of the thyroid gland denominated goître,—I put certain questions to that water, the combination of the several letters in its answer informs me that it contains *iodine*. A man, having partaken of some food, dies soon after, with all the symptoms of poisoning. The language of the phenomena, which is familiar to the chemist, tells him that arsenic, or corrosive sublimate, or some other body, was mixed with the food.

The chemist by his questions is thus enabled to make a mineral speak, to disclose its composition; it tells him that it contains sulphur, iron, chromium, silica, alumina, or any other element, arranged in a certain mode. This is CHEMICAL ANALYSIS.

Then, again, the language of phenomena teaches the chemist to make new combinations, from which he derives innumerable useful truths that are applicable to the improvement of manufactures and arts, to the preparation of remedies and metallurgy. THIS IS APPLIED CHEMISTRY.

Further, when the chemist has deciphered a compound into its constituent parts, as, for instance, ultramarine, it is required of him to combine the letters and to translate the word into a sensible and tangible shape, to exhibit the ultramarine again with all its properties. THIS IS SYNTHETIC CHEMISTRY.

Hitherto scarcely any demand has been made upon the science of chemistry, by arts, manufactures, or physiology, which has not been satisfied. Every question, clearly and definitely put, has been satisfactorily answered. It is only when an inquirer has no precise idea of what he seeks, that he has remained unsatisfied.

The last and most elevated object of chemistry is the investigation of the causes of natural phenomena, of their variations, and of those factors which are common to different series of phenomena. The chemist ascertains the laws which regulate natural phenomena, and by combining together all that is observable and has been observed by the senses, he at last attains to a general intellectual expression for them, in other words, to A THEORY.

But to enable us to read the book of nature, to understand its language, to perceive the truth of the theories of the philosopher, to subject to our will, and examine at our pleasure, the phenomena upon which a theory is based, and the powers producing them, we must necessarily learn the alphabet of the language, we must become acquainted with the signs or symbols employed, and by practice acquire skill in their management, and familiarity with their combinations. As in the higher branches of physics it is indispensable that the philosopher should have attained considerable practical skill in *mathematical analysis*, so the chemist must have a perfect knowledge, much practice, and a readiness in applying *chemical analysis*, to qualify him to investigate nature successfully; he must be able to test all his notions by experiment. Every experiment is a thought rendered perceptible to the senses. In order to prove, or disprove our conjectures, to establish, or to overthrow suggestions for the explanation of phenomena, we produce other phenomena at will, we seek their true interpretation by experiments.

There was a time when chemistry, in common with astronomy and all the physical sciences, was nothing more than an art, founded on empirical practice, subject only to rules discovered by experience; but since the causes of the changes in bodies which it effects, and their laws, *i. e.* the reasons of its rules, have become known, the empiric art has lost its value and importance. The acquisition of skill in manipulation by laborious and long-continued application, the tedious methods, and endless precautionary measures formerly necessary to success in chemical manufactures, have become wholly needless since a correct knowledge of causes has been obtained. The strange apparatus and utensils of the chemist of former ages, their stoves and stills, are now mere matters of curiosity. The success of an experiment, or a process, depends far less upon mechanical skill, than upon knowledge. Discoveries are made, not by manual dexterity, but by skill in the combining of means, and by the powers of thought and reflection.

In our lecture-room we teach the letters of the alphabet; in our laboratory their use. It is in the latter that the student acquires a readiness in reading the language of phenomena, that opportunities are furnished to him of learning the rules of combinations, of applying them, and of gaining a ready dexterity in their application. As soon as these signs, letters, and words, have become formed into an intellectual language there is no longer any danger of their being lost, or obliterated from his mind. With a knowledge of this language he may explore unknown regions, gather information, and make discoveries wherever its signs are current. This language enables him to understand the manners, customs, and wants prevailing in those regions. He may, indeed, without this knowledge, cross the frontiers of the known, and pass into the unknown territory; but he exposes himself to innumerable misunderstandings and errors. He asks for bread and he receives a stone.

*Medicine, Physiology, and Geology,* are unexplored regions, the forms of government, laws, and institutions of which the philosopher is desirous of learning. Without a knowledge of the language of phenomena, and the art of interpreting it, there is nothing for him to discover but mere forms and external qualities.

Look at the experiments of our best physiologists, listen to their language, and you must at once perceive in what their science is deficient, and be convinced that the mere knowledge of external forms and physical properties no longer satisfies them; they are deeply impressed with the importance, nay, the indispensable necessity, of a more profound, more intimate, more *chemical* insight into the composition and changes of organic bodies. But is such an insight possible without the knowledge of the chemical language?

If other and less judicious physiologists maintain that chemistry is incapable of any useful application to their science, this only proves that they understand neither the object nor the meaning of chemistry. They can no more read its language than they could a work written in Hebrew characters without having previously learned those characters.

It is not unworthy of remark, that as these physiologists profess to hold chemistry in contempt, so is physiology despised by many physicians; that medicine reproaches physiology, and with equal injustice, in the same manner as physiology reproaches chemistry. The physician who has learned medicine, not as a science, but as an empirical art, acknowledges no principles, he seeks only for *rules* derived from experience. The object of his inquiries is only whether a remedy, in any given case, had a good or a bad effect. This is all the empiric cares about. He never asks wherefore does this remedy so work? He never inquires into the reasons, the *causes*, of what he observes!

From what a different point of view should we contemplate the abnormal or diseased conditions of the human body, if we were previously acquainted with its normal state, if we had established the science of physiology upon a satisfactory basis!

How differently would the treatment of diseases be conducted if we had a perfect and accurate knowledge of the processes of digestion, assimilation, and excretion. Without this scientific foundation, without a clear insight into the very essence of natural phenomena, without a solid physiological and chemical education, we are constantly liable to fall into the most serious errors of practice. Can we wonder that men wholly ignorant of physiology and chemistry, although in other respects rational, should adopt the absurd notions of Hahnemann, that his doctrines should prevail in Germany and find disciples in all countries? Reason alone will not prevent whole nations from falling into the most abject superstitions, whilst even a child whose mind has been duly developed and instructed will repudiate the fear of ghosts and hobgoblins.

Can men who are totally incapable of apprehending the nature of philosophical investigation, who altogether miss its true spirit in their attempts to learn, who cannot, therefore, read the language of phenomena themselves,—can such men be expected to derive the least advantage from the discoveries of chemistry or physiology; and can they be deemed capable of making the most insignificant application to practical purposes of those discoveries? We often see such persons annoyed that truth should be so simple, and yet, in despite of all their labour and trouble, they cannot succeed in deriving from it any practical advantages. From such persons emanate the most absurd notions, attempts to furnish expositions of nature which are impossible. Hence has arisen the creation of a word, the *vis vitæ,* a miraculous thing by which they would explain all the phenomena they are unable to understand. With a totally incomprehensible, indefinable something, they would arrest inquiry and explain everything which is not comprehensible.

But this *vis vitæ* is itself but a subject of investigation, and in order to explore it, to comprehend its essence, to understand its operations and effects, the physician must pursue the same method which has been followed in natural philosophy and chemistry with such signal success.

There was certainly, at one time, no state of matter more obscure, more completely hidden from the corporeal and intellectual eye of man, than that which we denominate *electricity*. A thousand years elapsed from the birth of natural philosophy ere the human mind had obtained the slightest notion of the existence of this, the most stupendous power in nature, a power performing the most important part in all the alterations of inorganic matter, and all the processes of vegetable and animal life. By untiring researches the philosopher, undeterred by innumerable difficulties, has at length obtained a most intimate knowledge of electricity, and in many enterprises he avails himself of its service. He has traced its affinity to light, heat, and magnetism, and by its means he has subjected these kindred powers to his will. He can direct the course of the lightning and employ it as the means of extracting the noble metals from the poorest ores. By means of these forces he was first enabled to ascertain the true nature of the constituents of the solid matters of our earth: by them he sets ships in motion and multiplies costly objects of art!

When a power of nature, invisible and impalpable, is the subject of scientific inquiry, it is necessary, if we would comprehend its essence and properties, to study its manifestations and effects. For this purpose simple observation is insufficient, since error always lies on the surface and is gathered by the superficial inquirer, whilst truth must be sought in deeper regions.

If we interpret a phenomenon or observed fact erroneously, or if we entertain an incorrect conception of its connections and relations, we are said to commit an error. Our only protection against this is to test the truth or falsehood of our notions by producing the phenomenon ourselves, under various circumstances, and by examining the conditions of its first appearance, varying these conditions, and closely observing the influence of these alterations. In this manner our first observation is corrected and rendered clear to our minds. The fancy or imagination must never be entrusted with the interpretation of natural phenomena.

The true philosopher always seeks to explain and illustrate the facts of nature by creating phenomena; that is, by experiments, the devising and discovery of which is his task, and by which he causes the object of his investigation to speak, as it were, intelligibly to him. No single isolated phenomenon, taken by itself, can furnish us with its own explanation; it is by tracing its connections, by studying and arranging its antecedents and consequents, and well observing their several links, that we attain to a comprehension of it, and an understanding of its true cause. For we must never forget that every phenomenon has its reason, every effect its *cause*.

Such opinions as that the creative energy of nature produces the most various kinds of plants and animals out of putrid matter, without seeds or sperm; that nature abhors a vacuum; that iron and phosphorus are produced in the living body of animals, and the like, are emanations of ignorance and indolence, and display men's incapacity to discover the true origin and causes of things. But a thousand unconnected observations have no more value, as a demonstrative proof, than a single one. A hundred-weight of error will not form one grain of truth. If we do not succeed in discovering causes by our researches, we have no right to create them by the imagination; we must not allow mere fancy to proceed beyond the bounds of our knowledge. Thus, when we have learned that infusorial animalculæ are propagated by eggs, it only remains for us to inquire how the eggs are conveyed to where we find them. From the moment the imagination is allowed to solve questions left undecided by researches, investigation ceases, truth remains unascertained, and there is not only this negative evil, but in error we create a MONSTER, envious, malignant, and obstinate, which, when at length truth endeavours to make its way, crosses its path, combats, and strives to annihilate it! Thus it was in the time of Galileo; and thus it is still, everywhere, in every science, where mere hypotheses are admitted to usurp the place of truth.

If we acknowledge the incompleteness of our researches, and simply confess our inability to answer the questions which arise as we contemplate the phenomena of nature, those questions remain as problems for futurity to solve, and excite the attention and exertions of thousands;

zeal is kindled and kept alive, and in process of time their solution will certainly be accomplished. But if we create and give currency to imaginary explanations, inquiry is arrested, the mind becomes satisfied by mistaking the error for truth, and resting therein, and the progress of inquiry, as well as of truth, is impeded or altogether stayed. The imagination may thus create a hundred thousand errors in a hundred thousand cases; and yet nothing is more injurious to science, nothing more retards its advancement, than a single false doctrine promulgated and adopted, since it is infinitely difficult to root out old prejudices, and this precisely because that which is false or erroneous has been cherished as truth.

It is certainly not conformable to a true philosophy of nature to attempt an explanation of the processes of assimilation and secretion, before we have obtained a correct knowledge of *aliments*, and the sources whence they originate, and before *albumen*, *casein*, *blood*, *bile*, *cerebral substance*, *et cetera*, had been subjected to a searching investigation. Before these substances have been successfully analysed, they are mere words, the meaning of which is unknown. How could it be expected that any useful information should be derived from the mere terms, until the properties and relations of the substances themselves are known, and we have traced the metamorphoses they undergo when in contact with other bodies?

The cause of the phenomena of life is a force, which does not act at sensible distances; its activity becomes manifest only when the aliments or the blood come into immediate contact with the organ destined for their reception and alteration. Chemical power manifests itself precisely in the same manner; indeed there are no causes in nature producing motion or change in bodies—no powers more closely analogous to each other—than the chemical and vital powers. We know that wherever different substances are brought into contact with each other, chemical actions take place. To suppose that one of the most energetic powers of nature should take no part in the processes of animal organisms, although in those organisms all the conditions under which it commonly manifests its activity are united, would be against every established rule for the proper study of nature. But so far from there being any foundation for the opinion that the chemical actions are subject to the vital power, so as to become inoperative or imperceptible to us, the chemical effects of oxygen (for example) are manifest in full activity during every second of life. Moreover, urea, allantoin, the acid which is found in ants and water-beetles, namely formic acid, oxalic acid, the oils of valerian root, of the spireæ ulmaria, of the gualtheria procumbens, are products of the vital processes; but is their production attributable to the *vis vitæ?*

We are able to produce all these compounds by chemical processes. The chemist produces the crystalline substance found in the fluid of the allantoin of the cow, from the excrements of snakes and birds; he makes urea from charred blood; sugar, formic acid, and oxalic acid from saw-dust; the volatile oil of spireæ ulmaria, of gualtheria procumbens, from willow-bark; the volatile oil of valerian from potatoes. Thus we have successful examples enough to justify us in entertaining the hope that we shall, ere long, succeed in producing *quinine* and *morphine,* and those combinations of elements of which *albumen* and *fibrine,* or muscular fibre, consist, with all their characteristic properties.

Let us, however, carefully distinguish those effects which belong to the chemical, from those which depend peculiarly upon the vital power, and we shall be in the right channel for obtaining an insight into the latter. The chemist will never be able to produce an eye, a leaf, or a hair. But we know, with absolute certainty, that the formation of hydrocyanic acid in bitter almonds, of sinapine in mustard, and of sugar in germinating seeds, are results of chemical decomposition. We see that the stomach of a calf, when dead, with the addition of some hydrochloric acid, acts upon flesh, and upon coagulated albumen, precisely in the same manner as the living stomach acts; that is, these aliments become soluble, and are, in fact, digested. All this justifies us in inferring, that by this method of investigating nature, we shall arrive at a clear comprehension of the metamorphoses which aliments undergo in the living organism, and of the action of remedies.

Without a profound study of chemistry and natural philosophy, physiology and medicine will obtain no light to guide them in the performance of their most important offices, that is, in the investigation of the laws of life, the vital processes, and the removal of abnormal states of the organism. Without a knowledge of chemical actions the nature and effects of the vital force cannot be fathomed; the scientific physician can expect to derive assistance from chemistry only when he shall be able to put his questions to the chemist correctly.

Commerce and the arts have already derived immeasurable advantages from the progress of chemistry; mineralogy has become a new science since regard has been had to the composition of minerals and the chemical relations of their constituents. If the composition and chemical nature of rocks and strata are not in like manner investigated (and this has hitherto been much neglected), it will be impossible to effect any considerable progress in geology. Chemistry, moreover, is the foundation of agriculture, and it is impossible to accomplish a scientific consolidation of this important art without a knowledge of the constituents of the soil, and the aliments essential to the life of plants.

Without an acquaintance with chemistry, the statesman must remain a stranger to the vital interests of the state, to the means of its organic development and improvement; his attention cannot be sufficiently alive, nor his perception adequately acute, to what is really useful or injurious to his country,—to society. The highest economic or material interests of a country, the advantageous production and increase of food for man and animals, the preservation and restoration of health, are closely linked with the advancement and diffusion of the natural sciences, especially of chemistry.

Without the knowledge of natural phenomena, and the laws by which they are governed and controlled, the human mind is capable of forming no adequate conception of the goodness and unfathomable wisdom of the CREATOR; for whatever images the most cultivated mind and the most exalted imagination may be capable of inventing, these will appear, when compared with the realities of nature, but glittering and unsubstantial bubbles!

The great desideratum of the present age is practically manifested in the establishment of schools in which the natural sciences occupy the most prominent place in the course of instruction.

From these schools a generation will spring up, vigorous in understanding, qualified to accomplish all that is truly great, and to bring forth fruits of universal usefulness. Through them the resources, strength, and wealth of empires will be incalculably increased; and when, by the increase of knowledge, the weight which presses on human existence is lightened, the difficulties of obtaining subsistence lessened, and man is, in a great measure, disencumbered from the pressure of earthly cares and troubles, he will be able to devote his mind, with freer exertions and purer aim, to the highest purposes of his being.

## LETTER II.

My Dear Sir,

In my former Letter I endeavoured to exhibit the very powerful claims which the science of chemistry has upon the attention of the enlightened statesman, upon the guides of education, and upon the public at large. I advanced for it the claim, to stand, not merely as one in the list of many sciences, but, in the aggregate of its rules and principles, as an initial and normal method of pursuing every natural investigation; and I further maintained that it ought to rank with the classics and the mathematics in education, being, as it were, an *organon*—an instrumental means of attaining an intellectual habit and qualification for the observation and interpretation of nature. Moreover, I flatter myself that I proved that, since it is the basis of many of the economic arts, and of the other sciences, their future progress and ultimate perfection, and more especially of Physiology, Pathology, Practical Medicine, Geology, Mineralogy, and Agriculture, may be anticipated chiefly from the application of Chemistry; and, therefore, that every one engaged in the cultivation of those arts and sciences ought to be deeply interested in its advancement.

There are still many general aspects in which Chemistry may be contemplated both with pleasure and profit, and some of these I propose to present to you.

The history of man is the mirror of the development of his intellect. It shows us, in his acts, his faults and frailties, his virtues, his noble qualities, and his imperfections. The investigation of nature teaches us the history of the omnipotence, the perfection, and the inscrutable wisdom, of a higher Being, in his works and actions. Whilst we are ignorant of this history, the perfection of the human mind is altogether unimaginable. Without this knowledge the immortal spirit of man cannot attain to a consciousness of its own dignity, or form an adequate conception of its own rank in creation.

The religion of the Greeks and Romans—of the *heathen*—was, in its origin, founded upon an imperfect contemplation and false impression of natural phenomena. Those nations were intellectually blind to the immediate *causes* of the changes and fluctuations in things around them. They directed their prayers to the gross,—the more obvious,—powers of nature. Every superstition carries us back to heathenism. The exalted value, the sublimity of a right comprehension of nature, lies precisely in this, that it is the medium for a correct apprehension of Christian truth. And the divine origin of true Christian doctrine, indeed, is proved by the fact that we are indebted for it, and for a correct notion of a Being who is above all worlds, not to the imperfect way of empirical investigation, but to a higher enlightenment.

The space in which the systems composing the universe move, is illimitable. Were we to attempt to assign its limits, what could we imagine to be beyond? The number of worlds is infinitely great; it is inexpressible, indeed, by numbers. A ray of light traverses 180,000 miles in a second of time. A year comprises millions of seconds, yet there are fixed stars so immeasurably distant that their light would require billions of years to reach our eyes. We are acquainted with animals possessing teeth, and organs of motion and digestion, which are wholly invisible to the naked eye. Other animals exist, which, if measurable, would be found many thousands of times smaller, which, nevertheless, possess the same apparatus. These creatures, in the same manner as the larger animals, take nourishment, and are propagated by means of ova which must, consequently, be again, many hundreds of times smaller than their own bodies. It is only because our organs of vision are imperfect that we do not perceive creatures a million times smaller than these.

What variety and what infinite gradations do the constituents of our globe present to us in their properties and their conditions! There are bodies which are twenty times heavier than an equal volume of water, there are others which are ten thousand times lighter, the ultimate particles of which cannot be seen by the most powerful microscopes. Finally, we have in light,—that wonderful messenger which brings us daily intelligence of the continued existence of numberless worlds, —the expression of an immaterial essence which no longer obeys the laws of gravitation, and yet manifests itself to our senses by innumerable effects. Even the light of the sun—with the arrival of which, upon the earth, inanimate nature receives life and motion—we cleave asunder into rays, which, without any power of illumination, produce the most important alterations and decompositions in organic nature. We separate from light certain rays, which exhibit among themselves a diversity as great as exists amongst colours. But nowhere do we observe either a beginning or an end. The human mind perceives in nature no limit either above or below itself, and in this infinity,—scarcely conceivable, since it is in both directions unfathomable by human power,—not one drop of water falls to the ground, not one particle of dust changes its place, without compulsion. Nowhere beyond the sphere of his own being does man perceive a conscious will; he sees everything around him bound in the chains of invariable, immutable, fixed laws. Within himself alone he recognises a *something* which may govern these effects, a *will* which has the power to rule over all natural laws, a *spirit* which, in its manifestations, is independent of these natural powers, and which, when it is in its conceivable perfection, is subject only to its own laws.

The mere empirical knowledge of nature forces upon us, irresistibly, the conviction that this *something* within us is not the limit beyond which there exists nothing similar or more perfect. The inferior gradations only of this *something* are accessible to our powers of perception. And this conviction, like every other truth in inductive natural investigation, affirms the existence of a higher, indeed of an infinitely exalted Being, to contemplate and to comprehend whom our senses are too feeble, and of whom, in his greatness and sublimity, we can only form some conception by the highest cultivation of every faculty of our minds.

The knowledge of nature furnishes us with the most effectual means of advancing our intellectual powers to this degree of perfection.

The history of philosophy informs us that the wisest men, the most profound thinkers of antiquity, and, indeed, of all ages, considered the insight into the essence of natural phenomena, the acquaintance with natural laws, as an indispensable means for cultivating the mind. The study of external nature,—physics,—constituted a part of philosophy. Science renders the powers of nature the servants of man, whilst empiricism subjects man to their service. The empiric, placing himself on a level with an inferior or unconscious being, employs but a small portion of his power for the advantage of society. He permits effects to govern his will, whilst, by a true insight into their hidden connections, he might govern them.

The pertinence of these remarks will appear to you when I attempt to explain one of the most remarkable laws which lies at the foundation of modern Chemistry.

If, to the comparative anatomist, a small fragment of bone, a tooth, serves as a volume from which he can relate to us the history of a being belonging to a past world, describe its size and shape, point out to us the medium in which it breathed and lived, and demonstrate to us of what its nourishment consisted, whether animal or vegetable, and its organs of motion,—all this might be supposed to be the mere creation of a lawless imagination, if this small fragment of bone, this tooth, owed its form and constitution to mere chance. But the anatomist may safely assert all this as a reality, because every particle owes its form to definite laws, and because, when the form of a part is once known, it indicates the mode of construction of the whole.

It may not appear less wonderful to many that the chemist should be able, when he knows the proportion in which any single substance unites with another substance, to conclude and to assign the exact proportion in which the former will unite with all other bodies whatever.

The discovery of these laws, to which all the processes comprising number and measure are subordinate, in organic as well as in inorganic nature, and which regulate and govern all chemical actions, is acknowledged to be the most important acquisition of the present century, and the most productive in its results.

## LETTER III.

My Dear Sir,

The first point to which I would claim your attention in my intended exposition of the principles of Chemistry, is that tendency of bodies to combine with each other usually termed CHEMICAL AFFINITY.

In order to obtain a clear and vivid comprehension of the almost miraculous order and regularity in which bodies enter into combination with each other, we must bear in mind the meaning which the chemist attaches to the terms *combination* and *decomposition.* The rusting of iron, the bleaching of coloured stuffs when exposed to the air, the separation of metals from their ores, the preparation of innumerable objects of industry and commerce, and of medicines,—in short, all new forms and phenomena which present themselves to our senses when bringing into contact bodies of different properties,—all, with a very few exceptions, depend upon combination or decomposition. The ultimate causes of these new forms and phenomena are chemical forces, and these differ from all other forces, inasmuch as we perceive their existence only by their manifestations when bodies come into immediate contact with each other. As long as they remain at any measurable distances these forces have no action whatever. The domain of Chemistry is confined to this class of phenomena. Gravity, the electrical and magnetic forces, and heat, exercise an influence upon chemical processes; but as powers which act at a distance, which produce motion, or change of place, in bodies, in short, as natural phenomena, the determination of their nature and their laws, in a more confined sense, belongs to *physics.*

Iron rusts when exposed to the air. Sulphur and mercury combine, forming cinnabar. It is the CHEMICAL POWER which is active between a constituent of the atmosphere (oxygen) and the particles of the iron,—between the particles of the sulphur and the particles of the mercury,—and which is the cause of the change of their properties. This chemical power is the cause of the formation of a new body with altered properties, that is, of *a chemical combination.*

We obtain, again, the mercury from cinnabar by heating it with iron; and we obtain metallic iron from iron-rust by heating the latter to redness with charcoal. We *decompose* the cinnabar by iron, and the iron-rust by charcoal. The cause is, invariably, chemical power; the result invariably rests upon the formation of a compound. The iron which separates the mercury combines with the sulphur. We had sulphuret of mercury, we now obtain sulphuret of iron. The charcoal which reproduces metallic iron from iron-rust enters into combination with that constituent of the atmosphere (oxygen) which the iron had imbibed, and which has caused the rust.

The infinitely numerous chemical decompositions of compound bodies, the separation of one of their constituents, invariably depends upon this, that a newly added substance enters into combination with the remaining constituents. It is quite evident that these substances, under the given conditions, would not experience any change of properties, unless the cause which we designate "chemical power" were active between their particles. This chemical power has been styled *affinity*, in total defiance of the vernacular acceptation of the word. It is said that two substances have an affinity when, in contact with each other, they exhibit the faculty of combining together. This term (affinity) is decidedly wrong if it be intended to convey the meaning that such substances are related to each other.

Were we to place the fifty-six known elements promiscuously upon a table, a child would be able to divide them, by their external appearances, into two great classes:—one class, the individuals of which possess a metallic aspect; another class, deficient in this appearance. The first class comprehends the *metals*, the latter class of bodies the *metalloids.*

These principal classes, according to the similarity of several individuals in other properties, may again be divided into smaller groups, in which those most closely resembling each other may stand together. In the very same manner compound bodies manifest similarities or disparities in their properties; and if we arrange them into families, and thus bring those together which originate from the same elements, it will be found that the members of one and the same family have but very little, and frequently not even the slightest, tendency to combine with each other. They are related in their properties, but they have no attraction, no affinity, for each other; whilst the members of two different families, which have most dissimilar properties, have always the most powerful attraction for each other.

Thus, the combinations of two members of the same family possess all the more apparent qualities and defects of that family in an undiminished, and frequently in a higher, degree. But if two substances of quite opposite races enter into alliance, a new body is invariably formed, in which we cannot detect the originals.

Thus, iron and mercury (two metals) stand infinitely more closely related to each other, than iron and sulphur, or mercury and sulphur (a metal and a metalloid); in a compound of the two former we immediately recognise its origin; but who, looking at cinnabar, would guess that this substance contains the silvery fluid metal, and the yellow inflammable sulphur? Hence result, in the combinations themselves, various degrees of *affinity*, by which term we always designate the unequal tendency or faculty of their atoms to combine with each other; and it is upon these various degrees of attraction that all decompositions depend.

I have already stated that it is indispensably necessary to the manifestation of chemical affinity that the atoms of substances should be in immediate contact with each other, or at immeasurably small distances. Now every one knows the effect which heat exercises upon bodies. However firmly you may drive an iron nail into the wall, it will gradually become loose, and at last fall out. In summer the iron is more heated than during winter, it therefore expands in summer, and with great power forces wood and stone asunder, whilst in winter the iron contracts in a far greater degree than stone or wood. Expansion by heat supposes that the atoms of which a substance is composed separate to a certain distance from each other; contraction by cold implies that they approach each other. Now since a certain contiguity of atoms is a necessary condition for the action of chemical affinity, it is obvious, that by the mere effect of heat a number of chemical combinations must be resolved into their constituents; and this, indeed, always, in cases where the influence of heat causes the distance between the ultimate particles to extend beyond the sphere of their chemical attraction. This necessarily causes a separation. When the heat decreases, the atoms again approach each other, and at a certain point of proximity combination again ensues. We may imagine that at temperatures immeasurably high to us, substances exist in one and the same space, without combining, although they may possess the very strongest affinity for each other, and that, precisely because this high temperature neutralises their affinity,—opposes an insurmountable resistance to its operation. So, undoubtedly, the constituents of the earth, when they possessed an exceedingly high temperature, were arranged in quite a different manner from that in which we find them at present. Nay, it is not impossible that they should have floated through each other, as in a chaos, and that this chaos formed itself into our present minerals and rocks only when this temperature was greatly lowered.

Let us suppose that all the elements composing the earth, by the influence of a great heat, are transmuted into the same state in which oxygen and hydrogen gas exist at the common temperature of the atmosphere, the earth would be an enormous ball of gases, which everywhere would uniformly mix without entering into combination, just as is the case with oxygen and hydrogen, despite their exceedingly great affinity. At 350° C., mercury combines with the oxygen of the atmosphere, forming a red crystalline powder, and at 400° this powder is again decomposed into oxygen gas and mercurial vapour.

If we fuse a mixture of iron and lead, together with sulphur, in a crucible, the iron separates from the lead, and combines with the sulphur; as long as there remains any trace of iron in the lead, not a particle of sulphur combines with the lead, but only with the iron. When all the iron has combined with sulphur, that sulphur which still remains free, combines with the lead. Both metals have an affinity for sulphur, but the affinity of the iron is far greater than that of the lead. Hence it happens that, as is done largely in metallurgy, when iron is fused with sulphuret of lead ore (*galena*), the lead separates in a pure metallic state, whilst the iron combines with the sulphur, for which it possesses a far greater affinity. In a similar manner, at a red-heat, iron decomposes cinnabar, and expels the mercury by combining with the sulphur; but in this case the affinity of iron for sulphur is not the only cause of decomposition. No one has ever seen mercury red-hot, like iron for instance in the smith's forge; for, whilst iron remains compact and solid at this heat, mercury is converted into an invisible vapour; its particles obtain by heat the faculty of assuming the gaseous form. Now, this faculty depends upon the tendency of the atoms of a substance to repel each other,—to withdraw from each other,—and substances retain this tendency in their chemical combinations. Mercury evaporates, even at the common temperature; a drop gradually passes into the atmosphere when exposed: it requires certainly a longer time than a drop of water; nevertheless it will gradually disappear. Heat promotes this evaporation exceedingly. Cinnabar does not evaporate at the common temperature. This manifestly depends upon the circumstance that the tendency of the mercury to assume an aerial state, and to separate from the sulphur, meets with resistance. This resistance is the affinity of the sulphur, which is not to be overcome at the common temperature. Now, if the cinnabar be heated to that point at which the mercury assumes the gaseous state, not only does the affinity between the mercury and the sulphur become weakened, but, moreover, the tendency of the mercury to separate from the sulphur becomes strengthened. If any affinity, although only a weak one, comes at this juncture to the assistance of the heat, that, for instance, of iron for the sulphur, the sulphur separates from the mercury, which would not have happened without the concurrence of these several causes. Thus, the tendency of a substance to assume an aerial form at a certain temperature, acts an important part in all chemical processes of combination and decomposition. It modifies, increases, or diminishes the manifestations of affinity. In precisely a similar manner cohesive attraction—the faculty which the particles of a substance possess of maintaining their cohesion against all influences which tend to destroy it—has a share in the play of the affinities. We may, by the application of heat, melt sugar and common salt,—render their particles moveable in all directions,—destroy and annihilate their solid state. We may do the same by means of water; but in the water in which sugar and common salt dissolve, it is not the heat but the chemical affinity of the water which overcomes their cohesion. A fragment of bone calcined white is insoluble in water and alkaline fluids; the tendency of its particles to maintain their state, or, as it is termed in this case, their power of cohesion, is greater than the affinity of the fluid. In many acid fluids, as, for example, in vinegar, the contrary is the case, the fragment of bone dissolves therein; it is, consequently, obvious that if we bring the constituents of this fragment of bone (phosphoric acid and lime) into an acid fluid, we do not observe any kind of alteration to take place, because both the constituents of the bone are soluble in the acid fluid, no matter in what form they may exist. But if these constituents are brought together in water or an alkaline fluid, which opposes no obstacle to their combination into a solid substance, we shall have the bone-earth fall to the bottom as a white powder, a *precipitate*, as it is termed, being formed.

In this manner the chemist uses the different degrees of solubility of substances in various fluids and their deportment at a high temperature, as a powerful means of separation,—of analysis. All minerals, without exception, have their solvents. By altering the nature of the fluid, by the addition of other matters, the chemist modifies the solubility of the constituents of the mineral in this fluid, and in that manner he succeeds in separating all its constituents one by one. This is one method of analysis; the other consists in adding to the solution of a compound, consisting of five, six, or more constituents, successively, other substances, which enter into combination with one or other of those constituents, forming insoluble compounds. This is done in a certain definite order, just as if each constituent was contained in a different drawer, the opening of which required a particular key appropriated to itself.

## LETTER IV.

My Dear Sir,

My last Letter opened to you the simplest exposition I could furnish of the nature of what is called chemical affinity, which I explained to be a phraseology not in accordance with the common signification of the word *affinity*. I may further remark, that in all branches of science, and particularly in natural history, when *affinities* are spoken of, this term implies a relation or similarity of properties between several individuals; whereas, in Chemistry, it means only the aptness or tendency to unite and form a new and compound body.

I pointed out that in all cases where this affinity is called into play by the admixture of various compound bodies, certain decompositions and new combinations between the elements composing them, necessarily ensue. In studying these combinations and decompositions the question immediately arises, what is the quantity of any one given substance that is required to expel another substance from its combinations? Or, to take the example already employed, *how much* of the iron is necessary to separate the mercury from the sulphur in the cinnabar, and to take its place, so as to form a new sulphuret, the sulphuret of iron?

These questions have been studied, and satisfactory answers have been returned to them, in all their various bearings. If, in the example before us, *too small* a quantity of the iron is employed, a portion of the cinnabar remains undecomposed; if, on the contrary, *too much* iron is taken, the excess does *not* enter into combination with the sulphur. In all chemical decompositions, definite quantities of substances accomplish the changes, and these quantities remain, for all cases, invariable.

This manifestly depends upon the general law that bodies combine with each other only in immutable relative proportions by weight, and decomposition is, in fact, always the result of the formation of a new combination.

Thus, to decompose 117 parts of cinnabar I require exactly 27 parts of iron, and I obtain, as the result of the changes which take place upon their admixture, 101 parts of mercury and 43 parts of sulphuret of iron. Therefore, we have in cinnabar a compound of 16 parts of sulphur with 101 parts of mercury, which latter are expelled, and their place occupied by 27 parts of iron. Hence it follows, as a matter of course, that these 27 parts of iron must have combined with 16 parts of sulphur.

Now, it has been proved that the relative weights or proportions of iron and mercury which replace each other in these combinations with sulphur, remain the same in all cases where these substances replace each other. Thus, whenever mercury is expelled from any of its combinations, as, for example, those which it forms with oxygen, chlorine, bromine, iodine, &c., and replaced by iron, 27 parts of the iron are always necessary for replacing 101 parts of mercury. And experience has further demonstrated that wherever 101 parts of mercury are in combination with *any other substance whatever*, the weight of which we may designate by A (any quantity), this weight A of the substance in question will combine with 27 parts of iron.

All these facts are the unquestionable results of philosophical inquiry and induction; they have been ascertained and established by the chemist, with "THE BALANCE" in his hands. And, moreover, these fixed and unalterable relations do not merely apply to these few substances which we have spoken of as examples and illustrations only of the general law, but the same definite proportions of combining elements are observed *everywhere*, and in all *substances* whatever.

Thus, for instance, 16 parts of sulphur combine with 8 of oxygen, or with 1 of hydrogen; and whenever, in any form of compound, hydrogen is replaced by oxygen, or oxygen by hydrogen, we observe that for every 1 part of hydrogen 8 parts of oxygen, and for every 8 parts of oxygen 1 part of hydrogen, enter into combination.

But it is not merely that the relative proportions of oxygen and hydrogen, in all other compounds are the same, but also that the relative proportion of sulphur with those bodies is unalterably fixed in such a manner that, whenever the sulphur in a compound becomes replaced by hydrogen or oxygen, this replacement is accomplished by half its weight of oxygen, or by a sixteenth part of its weight of hydrogen.

One hydrogen combines with 16 sulphur; these 16 sulphur are replaced by 8 oxygen: the result of this substitution is the combination of 8 oxygen with 1 hydrogen forming water = 9.

Or 8 oxygen combine with 16 sulphur; these 16 sulphur are replaceable by 1 hydrogen. The result, again, is the combination of 1 hydrogen with 8 oxygen.

It will now be obvious to you that if the weight of any substance is known which combines with one, two, three, four, or more, of any other substance, these weights, whatever they may be, are also always expressive of the proportions in which these various substances will combine with each other. Thus 16 parts, by weight, of sulphur combine with 8 parts, by weight, of oxygen, with 1 part, by weight, of hydrogen, with 101 parts of mercury, or 27 parts of iron.

And, therefore, 8 parts of oxygen combine with 101 of mercury, forming an oxide of mercury; and 8 parts of oxygen combine with 27 parts of iron, forming oxide of iron, &c.

Finally,—and we have now arrived at the most general expression of the law,—when we know the proportion in which any substance, no matter what, will combine with all other substances, we know also, as an inevitable consequence, the exact proportions in which all substances whatever will combine with each other, provided they are possessed of the tendency to combine, the so-called chemical affinity.

The following Table scarcely requires, after these remarks, any explanation:—

| | | | | | |
|---|---|---|---|---|---|
| Oxygen | O | 8 | Potass (kalium) | K | 39·2 |
| Hydrogen | H | 1 | Lime (calcium) | Ca | 20·5 |
| Carbon | C | 6 | Silicon | Si | 14·8 |
| Sulphur | S | 16 | Lead (plumbum) | Pb | 103·8 |
| Nitrogen | N | 14 | Copper (cuprum) | Cu | 31·8 |
| Phosphorus | P | 31·4 | Quicksilver (hydrargyrum) | Hg | 101·4 |

These figures express the proportions, by weight, in which a few simple substances combine with each other; or, if the expression please you better, the equivalent amounts in which they replace each other in their combinations. Chemists are acquainted with the combining proportions, the equivalent numbers, of all the known simple bodies.

Further, it must be especially remarked that these relative numbers do not change when substances enter into combination with each other, and form more than one, or many compounds; for in these cases it is the simple multiple of the original number which now expresses the combining proportion.

Thus, for instance, 14 parts of nitrogen combine with 8 parts of oxygen, and form the substance known as the laughing gas, *nitrous oxide.*

There exists another compound of these substances, also a colourless gas (*nitric oxide*), which forms red fumes when it comes into contact with atmospheric air, and which to 14 parts of nitrogen contains twice 8 = 16 parts of oxygen.

A third compound contains 3 times 8 = 24 parts of oxygen, with 14 of nitrogen (*nitrous acid*).

A fourth contains 4 times 8 = 32 parts of oxygen to the 14 of nitrogen (*hyponitric acid*).

A fifth (*nitric acid*) contains 5 times 8 = 40 of oxygen, invariably, to 14 parts of nitrogen.

I may adduce another example in the compounds of carbon and oxygen.

Carbon combines with oxygen in two proportions: the first compound, an inflammable gas (*carbonic oxide*), contains 8 parts of oxygen to 6 parts of carbon; the other (*carbonic acid*), contains twice 8 = 16 oxygen to 6 of carbon. These are the fixed and immutable combining proportions, whenever these substances enter into any combination with any other substances whatever.

Again, from the analysis of acetic acid, it appears that this acid contains in 100 parts by weight, 47·06 carbon, 5·88 hydrogen, and 47·06 oxygen. These numbers in per cents. inform us how much oxygen and hydrogen are combined with 47·06 of carbon; and nothing is easier than the calculation for finding how much oxygen and hydrogen is in this substance combined with 6 carbon. This is a simple rule-of-three question. To 6 carbon we have in acetic acid $\frac{3}{4}$ hydrogen, and 6 of oxygen; or, to express the same in whole numbers, 24 carbon, *i. e.*, 4 times 6; 3 hydrogen, *i. e.*, 4 times $\frac{3}{4}$; and 24 oxygen = 3 times 8. Or, to look at it in another point of view, we know how much carbon and hydrogen are in acetic acid combined with 47·06 of oxygen, and we may calculate how much of these two elements are united with 8 of oxygen (that is, to another of these invariable numbers representing the simple elements); and we obtain, as the result, to 8 oxygen, 1 hydrogen and 8 carbon; and this, multiplied by 3, gives us precisely the same proportions.

The composition of all chemical compounds whatever may be expressed in the same manner, by invariable *numbers*, which on this account have been designated by the term *combining proportions,* and, with respect to their mutual power of substitution, *equivalents;* because, indeed, they express the quantities in which substances enter into admixture, or rather into chemical combination, or in which they produce analogous effects. Or, to state this in other words, if, in order to exercise any chemical action, we require for any given purpose 8 parts of oxygen, and if, instead of the oxygen, we are able and desire to employ for the same purpose sulphur, we invariably require 16 parts of the latter body, and the same of all other substances,—we require the amount expressed by their equivalent numbers. Thus these combining proportions are the representation of equal powers of action—of an exact analogy of effects.

## CHEMICAL SYMBOLS.

The establishment of the truth of the great natural law, that all bodies capable of entering into combination always do so in definite and fixed proportions, led chemists immediately to the invention of a symbolic language, a great and important means of advancing the science. The employment of symbols enables the chemist to express, in an exceedingly simple manner, the constitution of every compound body; to represent, in a most concise and easily comprehensible form, the changes which occur in its constitution by the substitution of one element for another, with the mode in which the constituents may be supposed to be arranged in every compound.

This symbolic language is exceedingly simple, and you will readily obtain a complete and satisfactory knowledge of it by attending to the following illustrations :—

In the first place, chemists have agreed to designate the *elements,* and at the same time their *equivalents,* by the initial letter of the names of the elements in the Latin language. Thus, the letter O, for example, in the symbolic language of Chemistry, signifies not merely the element oxygen, but neither more nor less than 8 parts by weight of oxygen.

H represents 1 part by weight of hydrogen ; S 16 parts by weight of sulphur.

By placing these letters, representing the simple bodies or elements, in juxta-position, we construct formulæ which express the constitution of compound bodies.

The vast advantages of this system are abundantly obvious. The most retentive memory would not be able to retain with accuracy and permanently the per-centage amount of the constituents of hundreds of compound bodies, whilst by the use of symbols and formulæ nothing is easier of apprehension and recollection; thus, the composition of water, which, stated according to the per-centage of its elements, is composed of 88.889 of oxygen, and 11.111 of hydrogen, is expressed by the chemist by the letters $H\ O$; the double amount, by $2\ H\ O$; the threefold amount, by $3\ H\ O$, and so on.

Carbonic oxide, which, as we have stated above, is composed of 6 carbon and 8 oxygen, is expressed by $C\ O$.

Carbonic acid, is 6 carbon, 16 oxygen, and is, therefore, written $C\ O_2$.

Acetic acid, $C_4\ H_3\ O_3$, and the combination of acetic acid and water by the formula, $C_4\ H_3\ O_3 + H\ O$.

Ether is represented by $C_4\ H_5\ O$.

Alcohol, which is considered to be a combination of ether and water, by $C_4\ H_5\ O + H\ O$.

The full meaning of which is, four equivalents of carbon = 4 times 6 parts = 24; five equivalents of hydrogen = 5 times 1 = 5; one equivalent of oxygen, and superadded to these an equivalent of water = 9, composed of one equivalent of hydrogen = 1, and one equivalent of oxygen = 8.

But the application of the term "equivalents" is extended also to compound bodies.

Amongst these there are many which arrange themselves into groups from their manifesting similar properties, or analogous chemical relations and characters, and which may be made to take each other's place, or function, in combinations. Every one is acquainted with the general properties of that group of substances which bears the name of ACIDS. The term *base* is, perhaps, not so universally understood. We designate compounds possessing the power of combining with acids and neutralising their acid properties by the word BASES. A combination of an *acid* with a base is denominated a SALT (this name has no reference to the taste). Now, in these compounds—in salts—one base may be made to replace another base, one acid another acid. Many metallic oxides, or combinations of oxygen with metals, are such bases; and it has been observed, from a minute examination of the proportions in which these metallic oxides replace each other, that very unequal weights of different bases are required in this substitution. In order to expel 10 parts of one base, 15 parts of another base, or 25 parts of a third base, and so on, are necessary. If the 10 parts of the first base contain 5 parts of oxygen, we find that the 15 parts of the second, or 25 of the third base, &c., will also contain neither more nor less than 5 parts of oxygen. The proportions of oxygen in the metallic bases replaced by each other, remain invariably the same; the metals alone combined with this oxygen vary in their proportions: they replace each other according to their equivalents, that is, for 39.2 of potassium, 101.4 of mercury are substituted.

Chemists have agreed to designate every quantity of a metallic oxide containing eight parts by weight, that is, one equivalent of oxygen, as *one equivalent of metallic oxide*, without regard to the amount of metal it may contain.

If, therefore, we once know the amount of an acid which is required to form a neutral salt with one equivalent of a base, this amount of acid remains invariably the same for an equivalent of any other base, since the other bases contain exactly the same amount of oxygen as the first, and since their mutual substitution depends exclusively upon the relative proportion of the oxygen.

Chemists have also agreed to call that amount of acid required for the saturation of one equivalent of a base, *one equivalent of acid.*

When you are familiar with these facts you will readily understand why chemists express the composition of acetic acid by the formula $C_4 H_3 O_3$, and not by $C_2 H 1\frac{1}{2} O 1\frac{1}{2}$, or any other. If we sum up the numbers indicated by these symbols ($C_4 = 4 \times 6 = 24$ carbon; $H_3 = 3$ hydrogen; $O_3 = 3 \times 8 = 24$ oxygen), we obtain as the result a total of 51. These 51 parts of acetic acid form the proportional amount (or one equivalent) of that acid which combines with one equivalent of any metallic oxide to form a salt.

This formula of an acid generally refers to one equivalent of a base, that of a base to one equivalent of an acid; the formula of any other compound invariably refers to the relative proportions in which its elements have been found to combine with the ascertained equivalent of some other substance. In many cases, however, formulæ are used expressive only of the mutual relations between two or several substances.

This symbolical language is of inestimable value for the comparison of the composition of various chemical compounds, and for facilitating the comprehension and expression of the alterations, transmutations, and decompositions which such bodies undergo.

The knowledge of the general law of equivalents (upon which the language of symbols is founded), and of the combining proportions of the elementary bodies, is of the utmost importance to the chemist.

For instance, suppose I have made an analysis of acetic acid, and I am desirous to ascertain whether the amounts of the several constituents which have resulted from my experiments are correct or not; that is, whether the proportions of the carbon, hydrogen, and oxygen, obtained in my analysis are really those existing in the acetic acid. For this purpose I have but to compare my percentage numbers with the equivalents of these elements (which have been determined with the utmost minuteness and accuracy), and the more or less my figures approach to the exact equivalents of the elements the more or less correct will have been my analysis. If my per-centage numbers differ to any considerable degree from the equivalent numbers, I am assured there has been an error somewhere in my processes, and I have to begin my labour over again. Thus, possessing the chemical equivalent numbers of all elementary bodies, we are able to exercise a strict control over chemical analysis, since whenever an experimenter has arrived by analysis at results indicating any sensible difference to these numbers, it follows that he must have fallen into some error, or that the substance under investigation does not possess the necessary degree of purity.

You will now, I trust, be able to understand the following formulæ, and to perceive, in the subsequent simple illustrations, somewhat of their high importance and value:—

$C_{14} H_6 O_2$ oil of bitter almonds.
$C_{14} H_6 O_4$ benzoic acid.

Now, the oil of bitter almonds, the composition of which is represented by the first of these formulæ, when exposed for some time to the atmosphere, absorbs oxygen, and becomes converted into benzoic acid. You perceive that these formulæ exhibit the relation between these two substances, and further that the conversion of one into the other has resulted from the absorption of *two equivalents* of oxygen, and this, translated into the numerical value of the formulæ, indicates exactly the quantity of oxygen concerned in this conversion. The formulæ thus express the quantitative difference in the two bodies.

Again, $C_4 H_5 O$ is ether.

$C_4 H_3 O_3$ acetic acid.

I have already mentioned above that alcohol is a combination of ether and water $C_4 H_5 O + HO$. Now, every one knows that acetic acid, or vinegar, is made, by exposing spirituous liquids to the atmosphere, and these formulæ show us at once what takes place in that species of fermentation. The ether in the alcohol is converted into acetic acid by the absorption of oxygen, and you may perceive that the transmutation of the one substance into the other is owing to the displacement of two equivalents of hydrogen, and the substitution of two equivalents of oxygen for this displaced hydrogen.

All this is exceedingly simple, and you cannot, I trust, fail to understand the use and value of symbols and formulæ, after these examples. And now, moreover, it will be evident to you why it is that whenever a new metal is discovered, it is sufficient to determine how much of the *metal* will combine with eight parts by weight of oxygen, to learn at once in what proportion it will combine with all other bodies; that is, what is its equivalent number. In like manner, when a new metalloid is discovered, it is sufficient to ascertain how much of it combines with 39.2 parts by weight of potassium, and in the same proportion it will combine with all other metals. It is precisely thus that the equivalents of lantanium and didymium (two new metals discovered recently in the ores of cerium), and of bromine, a new metalloid, found a few years since in sea-water, have been determined.

All these facts, which I have endeavoured to explain to you, are the results of true philosophical investigation; every equivalent number by which I have represented the combining proportion of the various bodies spoken of, has been adopted only after numberless analyses made with the greatest care, and by the most skilful chemists; the imagination has no share in the creation or disposition of the facts. But you must observe, that the mere facts, or the analyses upon which they are based, have not of themselves formed, or evolved, the great natural law which they represent and establish. The discovery of that law must be attributed to the sagacity and acuteness of a German chemist, and the name of RICHTER will remain as imperishable as the science itself.

## LETTER V.

My Dear Sir,

The human mind is never disposed to remain satisfied with the knowledge of mere facts, whether particular or general. It ever seeks to ascertain wherefore things are so? Why such and such phenomena occur? What is the cause of the general laws which we have reached in our investigations? It will, therefore, be readily imagined that an inquiry into the *cause* of that fixed and unalterable proportion in which bodies combine with each other must have occupied the mind of philosophical chemists. There must certainly be *some cause* which renders impossible the combination of elements in any other than certain definite proportions, *something* which opposes an invincible obstacle to any diminution or augmentation of these relative proportions.

The fixed and invariable amounts of the combining proportions or equivalents of bodies are the manifestations of this hidden cause, but these manifestations form the limit of the domain of true philosophical investigation; the cause itself is beyond our powers of perception,—our sphere of research,—and can only be a subject for the exercise of the imagination — for speculative ingenuity.

In endeavouring to develop the theory which at present prevails respecting the cause of the unchangeableness of chemical proportions, let me entreat you to bear in mind that its truth or falsehood has nothing whatever to do with the natural law itself. The latter is the expression of universal experience; it remains true, invariably and immutably, whatever may be our notions respecting its cause, and however these may, from time to time, vary and change.

A very ancient opinion respecting the nature of matter, well known as the theory of atoms, is exceedingly well adapted to render the law of definite proportions intelligible to our understanding. The application of this theory in modern times to the phenomena of Chemistry, and many investigations arising therefrom, extending and completing our knowledge of the law of definite proportionals, have highly distinguished the name of DALTON.

The atomic theory supposes that the space occupied by a solid, fluid, or aeriform body, is not in every part filled with matter, but that every such substance has pores, or interstices, between its particles of solid matter, which pores are not like those of a piece of wood, visible, but that they are of an infinitely smaller size. According to this view all bodies consist of exceedingly minute particles placed at a certain distance from each other, so that there exists between every two particles, or, rather, around every individual particle, a space not filled with the matter composing the substance itself.

It must be admitted that this view of the nature of matter is highly probable. We can compress a volume of air into a space a thousand times smaller than it originally occupied, and even fluid and solid substances are capable of being compressed into less space than they fill under ordinary circumstances, by mechanical pressure. A billiard-ball thrown with considerable force upon a hard substance becomes flattened, and, after rebounding, resumes its spherical form. All bodies expand and fill a larger space when heated, and contract into a smaller space when exposed to a low temperature.

All these well-known facts manifestly prove that the space which a body occupies at any given time depends upon accidental circumstances; that this space varies by the operation of many causes which expand or contract it. Now, if we must assume that the place within any body, occupied by one of its smallest particles, cannot at the same time be occupied by a second and a third particle, we cannot help drawing the conclusion that the augmentation or diminution of its volume which we have described, is a consequence of a greater or less distance between its particles,—that every particle of which the body is made up is surrounded by unfilled space. Thus, in a pound of fluid water, the particles of the water must evidently be nearer to each other than they are in a pound of steam, which occupies a space 1700 times greater than a pound of fluid water.

This theory affords us an intelligible insight into a number of phenomena, which, although simple in themselves, have hitherto been altogether inexplicable upon any other supposition.

Again, the atomic theory presupposes that the small particles composing the mass of any substance are incapable of further division,—that they are indivisible particles or *atoms*, a term applied to the ultimate particles of bodies, derived from the Greek *a*, *not*, and *τεμνω*, *to cut.*

It is impossible for the human mind to imagine particles of matter to be absolutely indivisible, since they cannot be infinitely small in a mathematical sense, that is to say, altogether without extension; and if extended, they cannot be indivisible. Moreover, these ultimate particles have a certain weight; and how minute soever we may assume this weight to be, yet we cannot consider the division of a particle possessing weight to be impossible, into two, three, nay, into a hundred parts. We must, therefore, assume that the ultimate atoms of bodies are only physically indivisible; they are only incapable of further subdivision so far as our powers of perception enable us to judge.

A physical *atom* in this sense, then, is a conglomeration of innumerable smaller imaginary particles, held together by a force or forces more powerful than all the means at our command for their further subdivision or dissolution.

With respect to these atoms, and the meaning the chemist attaches to the term, it is precisely analogous to the opinion held respecting certain substances as to their being elements, or simple, uncompounded bodies.

The fifty-six substances at present known and supposed to be simple bodies or elements are so considered, not absolutely, but only relatively to our powers, because we are not able by any means we possess at present to decompose them, —that is, to separate them into still more simple elements; and, adhering to the true principles of natural philosophy, we call them simple bodies or elements, until experience shall demonstrate them to be compound.

The history of science presents us with abundant illustrations of the supreme importance of a strict adherence to this rule of philosophical inquiry,—errors, false facts, and fallacious theories innumerable and incalculably mischievous, having invariably followed the transgression of the limits of experience.

Without disputing the infinite divisibility of matter, as the mathematician asserts, the chemist merely evinces the immovable standing of his science upon the solid foundation of experience, when he assumes the existence of physical ATOMS as an incontrovertible truth.

A professor of Tübingen has endeavoured, by an ingenious illustration, to render the atomic theory of chemists more intelligible. He compares atoms to the heavenly bodies, which, in comparison with the extent of the space in which they are suspended, are infinitely small, that is, are *atoms.* Innumerable suns, with their planets and attendant satellites, move in infinite space, at definite and measured distances from each other; they are individually indivisible, inasmuch as there exists no force capable of separating them into parts, tearing off from them anything material, or altering their size or form in such a degree as to be perceptible, or to impair or disturb their relations to the other heavenly bodies, but they are not indivisible *per se.*

In this sense the whole universe coalesces into one immense body, the atoms of which—that is, suns, planets, and satellites—are indivisible and immutable!

According to the atomic theory, then, a piece of glass, of cinnabar, of iron, &c., is a heap or conglomeration of atoms of glass, cinnabar, iron, &c., the connection of which, in masses, depends upon the power or attraction of cohesion. The smallest particle we can imagine of the iron is still *iron.* But we know, with incontrovertible certainty, with respect to the cinnabar, that its smallest particle, although physically indivisible, is made up of still smaller particles; that is, that it must contain particles of sulphur and particles of mercury; and we further know the relative proportions, by weight, of these two substances contained in the physically ultimate particle of cinnabar.

The iron consists of homogeneous atoms of iron; the cinnabar also consists of homogeneous atoms, each of which is cinnabar; but these latter atoms are not simple, like those of the iron, but they are capable of being separated into constituent parts: they are homogeneous as far as our powers of perception reach, but we nevertheless know their nature to be compound. We may, by the mere mechanical processes of filing, trituration, &c., reduce a piece of cinnabar into an innumerable quantity of small particles, but no merely mechanical force will enable us to overcome that power by which the heterogeneous particles forming the constituents of a complex atom like that of cinnabar are kept united.

It is precisely in this that chemical affinity differs from the power of cohesion, or cohesive attraction, as it is called,—that it becomes active and manifest only when *dissimilar* atoms are brought into contact with each other; and since it is impossible that atoms should penetrate and become mutually diffused throughout each other, it follows that such compound atoms must be formed by the aggregation, or grouping side by side, of the simple atoms, in consequence of the power of affinity acting so as to associate them into compound atoms,—one atom of one simple body being aggregated with one, two, three, or more atoms of another body, and so on,—every such group being a part exactly analogous to the mass of a substance perceptible to our senses. Thus, we may properly suppose the very smallest particle of cinnabar we can imagine, consists of a group of two atoms, namely, one atom of mercury, and one atom of sulphur.

When we consider that a thousand pounds weight of cinnabar contains exactly the same relative proportions of mercury and of sulphur as a single pound, or a single grain,—and although a piece of cinnabar large enough to be manifest to our senses, must contain, perhaps, millions of *atoms* of cinnabar,—yet it must be evident that in every single atom, equally as in the mass made up of millions of atoms, 101 parts of mercury are invariably united to 16 of sulphur. If we decompose cinnabar by means of iron, the atom of mercury is displaced, and an atom of iron is substituted for it. Or if we replace the sulphur of the cinnabar by oxygen, one atom of oxygen takes the place of the atom of sulphur.

You will now perceive that, according to this theory of the constitution of bodies, and their mutual substitution in combinations, the numbers denominated equivalents are neither more nor less than the weight of the atoms. The *absolute* weight of the atom of any substance it is not within the reach of our faculties to determine; but how much more or less weight one body brings into a combination than another, that is to say, the *relative* weight of atoms, can readily be ascertained.

If to replace 8 parts by weight of oxygen 16 parts by weight of sulphur are required, that is, double the weight of the oxygen, the atom of sulphur is twice as heavy as that of oxygen.

If substituting hydrogen for oxygen in any compound, only one-eighth part of the weight of the latter substance is required to one part of the former, it is evident that the weight of the atom of hydrogen is eight times lighter than the atom of oxygen. Carbonic oxide is a group of *two* atoms, containing one atom of carbon and one atom of oxygen. Carbonic acid is a group of *three* atoms, containing two atoms of oxygen to one of carbon.

The immutability of the combining properties of bodies is fully explained theoretically by thus assuming the existence of indivisible ultimate particles, which are of unequal weights, incapable of penetrating or being diffused through each other when they are united in chemical combination, but being arranged together side by side.

It is, however, in the highest degree expedient that you should discriminate between what is established on the sure ground of experience, and what in this subject is merely hypothetical.

The real experimental import of the equivalent numbers is the expression of the proportional and relative weight of bodies in which they produce analogous effects in chemical combinations; and these effects we represent to our minds, and render intelligible, by ascribing them to indivisible particles, or *atoms*, which occupy a certain space, and possess a certain form, or shape. We possess no means of ascertaining the *number* of atoms, even in the most simple compound, since for this purpose it would be necessary that we should be able to see and to count them, and therefore, notwithstanding our firm conviction of the existence of physical atoms, the supposition that the equivalent numbers are actually expressive of the absolute weights of the individual atoms, is really nothing better than an hypothesis, for which we have no further proofs.

One atom of cinnabar contains 16 of sulphur to 101 of mercury; now chemists, in assuming that these proportions express the relative weight of *one atom* of mercury and *one atom* of sulphur, pass from experimental certainty into hypothesis; for this mode of representation is merely hypothetical. 101 of mercury may, for aught we know to the contrary, represent the weight of two, three, four, or more *atoms*. Should it represent two atoms, one atom of mercury would be expressed by 50.5; should it represent three atoms, one atom would be expressed by 33.6. In the first case cinnabar would consist of two atoms, twice 50.5, in the latter case of three atoms, thrice 33.6 of mercury, to one atom of sulphur.

Whatever supposition we may entertain in this respect, whether we assume the composition of cinnabar to require two, three, or more atoms of mercury or sulphur, its constitution remains invariably the same. It is only the method by which we represent the composition of a chemical compound to our minds, which would vary with the hypothetical view respecting the number of atoms contained in the compound. It will always be most advisable to banish all that is hypothetical from the symbolic language of chemistry, more especially as the only purpose of this language is to demonstrate to our sense of sight, to render easy of apprehension, and to facilitate the recollection of, the compositions, substitutions, transmutations, and decompositions of chemical combinations. The method of representing the constitution of compound substances ought never to be used for expressing unsettled and mutable notions or speculative theories. The number of the equivalents of the constituents of a chemical compound is invariable, and strictly definable, but the number of atoms necessary to make up an equivalent will never be ascertained. There is not, however, the slightest disadvantage in assuming that the equivalents are the weights of the atoms themselves in cases where theoretical considerations, the mere explanation of ideas, is concerned. In this sense those numbers express merely the difference between the weights of various atoms; that is, by how much the weight of the atom of one body is heavier than that of another.

Every one in the least acquainted with arithmetic will now perceive that the selection of the numbers to represent the equivalents of the simple bodies is a matter of indifference, provided they all bear to each other the true relations,—the *relative* proportions, and not the absolute amount, being the true experimental conclusions. Hence there are several methods employed by various chemists in constructing tables of equivalent numbers. One of the most common, indeed, the one most generally employed, assumes as its starting point the composition of water. The proportional weight of hydrogen and oxygen, as they are combined in the composition of water, is taken as the initial numbers of the series. Water contains eight parts by weight of oxygen to one part by weight of hydrogen; hence 8 is employed to express the equivalent or atomic weight of oxygen, and hydrogen is assumed to be represented by 1. Upon the supposition, then, that water consists of a single atom of oxygen, combined with a single atom of hydrogen,—and, further, that in every conceivable combination into which these elements may enter, the replacement of one atom of hydrogen, or one atom of oxygen, invariably requires one atom of any other body, and neither more nor less,—then these equivalent weights of all other bodies express their atomic weights, and the numbers by which they are represented all refer to the assumed unit, or one part by weight of hydrogen in nine parts of water.

But if any person chooses to devise any other series of numbers, always maintaining strictly the same exact relative proportions, it may, of course, be done.

One other method which has also been used extensively, and has been supposed to present certain advantages, assumes the equivalent of oxygen to be 100. The numbers of this series are obtained by simply multiplying the former by 12½, which gives us 12.5 for hydrogen and 100 for oxygen, and the other numbers, representing the equivalents of other bodies, express the amount of each which is required to replace 100 of oxygen or 12.5 of hydrogen. The multiplication of the equivalents by one and the same number does not, of course, alter their relative proportions, and it is, therefore, quite immaterial whether we use numbers referring to hydrogen as a unit, or to oxygen as 100.

# LETTER VI.

My Dear Sir,

According to the theory which I have attempted to develope and make intelligible to you in my former letters, the ultimate particles of bodies, or *atoms*, must occupy a certain space, and possess a certain definite form. By their combination with each other, compound atoms are formed, which may occupy a larger or a smaller space than the simple atoms of which they are made up, taken together, in their uncombined state. The *form* of such compound atoms, it is evident, must vary with their composition, or according to the manner of arrangement of their elements. It is only in crystallisable bodies, however, the smallest molecules of which only have a definite form coming within the reach of our cognisance, that we can perceive the relation between the form of the particles of bodies and their chemical constitution. These relations have been observed, and very interesting investigations have been instituted upon this subject.

When two salts of different crystalline forms separate from the same fluid upon its evaporation, the crystals of one salt are formed precisely as they would be were the other salt not present in the fluid.

If we throw a handful of saltpetre and common culinary salt together into a sufficient quantity of water, both salts dissolve in the water. Upon placing the solution in a warm place the water gradually evaporates, and the two salts remain at the bottom of the vessel in the form of crystals, and we can distinguish with the naked eye the *cubes* of the common salt from the *long six-sided prisms* of the nitre. If we remove a crystal of the common salt from the solution, and wash off the adhering fluid from its surface, we find that it contains not the slightest trace of the saltpetre, and on the other hand the crystals of saltpetre retain not the slightest trace of common salt.

Both crystals are formed simultaneously in one and the same fluid, and, therefore, the inference is obvious that the atoms of common salt, in aggregating into crystals, attracted only atoms of common salt, whilst the atoms of the saltpetre attracted only their own kind. When all the water of the solution has been removed by evaporation, there will remain a mingled mass of common salt and saltpetre; but the individual crystals, however intimately intermixed, will remain, perfectly and distinctly, either common salt or saltpetre.

Again, if sulphate of magnesia and nitrate of potass (saltpetre) be added to a small proportion of hot water, and the saturated solution decanted, crystals of nitrate of potass will form, during the refrigeration of the solution, side by side; but, as in the former case, the individual crystals of sulphate of magnesia contain no nitrate of potass, and the individual crystals of nitrate of potass contain no sulphate of magnesia. The atoms of these substances had no kind of attraction, respectively, for the atoms of the other; on the contrary, we conclude that there must exist some species of repulsion between them both; for, if it were not so, surely the atoms of the saltpetre and common salt, or sulphate of magnesia, would not merely form side by side, but would completely intermix and crystallise in alternate layers.

It is altogether different with sulphate of magnesia and sulphate of nickel, or sulphate of zinc. When sulphate of magnesia and sulphate of zinc, or sulphate of nickel, crystallise together from the same solution, the separation of the two substances, as in former instances, does not take place. The individual crystals formed will contain both sulphate of zinc and sulphate of magnesia, or sulphate of nickel and sulphate of magnesia, and this in every possible proportion, according to the relative amount of the two salts present in the solution. This manifests the existence of a mutual attraction between the atoms of these substances, which attraction is, in each salt respectively, perfectly analogous to the attraction of the other; for an atom of sulphate of zinc attracts indiscriminately another atom of the same, or an atom of sulphate of magnesia; and, in like manner, with respect to the attraction of the sulphate of magnesia, there is no selection made between the different atoms, as happens when common salt and saltpetre are in the same substance.

If we compare a crystal of sulphate of magnesia with a crystal of sulphate of nickel, we find that they have identically the same crystalline form. The crystal of sulphate of magnesia looks like a white sulphate of nickel; the sulphate of nickel like a *green* sulphate of magnesia. There is no difference in their forms, no perceptible distinction in their sides or angles, between the two crystals.

Now, since a large crystal differs from a small one only by its consisting of an aggregation of smaller crystals, it is evident that the most minute,—the *ultimate* atom of sulphate of nickel, must necessarily have the same form as the most minute atom of sulphate of magnesia. Or, in other words, the *group* of elementary atoms which are united to form an atom of sulphate of zinc or sulphate of nickel, has the same form as the group constituting one atom of sulphate of magnesia; the crystal in which both are united side by side, and in alternate layers, possesses the form characteristic of both or either of its components.

But more extended observations have proved that the analogy between the crystalline forms of two substances is not the only cause of their crystallising together, or of the form of those crystals, wherein two are comprised, being the same as the form of their constituents.

Thus, a crystal of sal ammoniac possesses the same geometrical form as a crystal of alum, but these salts separate unmixed from solutions; the crystals of alum which are formed contain no sal ammoniac, and the crystals of sal ammoniac no alum. This happens, evidently, because the force with which alum atoms attract alum atoms, and sal ammoniac atoms sal ammoniac atoms, is far greater than the power of attraction which operates between atoms of sal ammoniac and atoms of alum, notwithstanding the identity of their crystalline forms. Indeed, as far as our observation extends, no such attraction in this case exists.

But what, then, is the cause of the attraction and intermingling of heterogeneous atoms in the same crystal?

If we compare the chemical constitution of those compounds which, notwithstanding the identity of their crystalline forms, yet do not crystallise in alternate layers or in mixed crystals, with the constitution of those substances which, under similar circumstances, enter into the same crystal, we find that the composition of the former is altogether diverse, whilst the composition of the latter is analogous in every respect. Thus, sulphate of magnesia, sulphate of zinc, and sulphate of nickel, contain exactly the same number of compound atoms; indeed, a crystal of sulphate of magnesia differs from a crystal of sulphate of zinc or sulphate of nickel, only inasmuch as the two latter, instead of one equivalent or atom of magnesium, contain one atom of nickel or of zinc; so that we may convert one into the other by separating the metallic equivalent of one salt by, and replacing it with, another. The atom of sal ammoniac contains only two compound atoms, whilst the atom of alum, although of the same crystalline form, is made up of thirty compound atoms. It is impossible to imagine a more dissimilar constitution, and these substances do not form mixed crystals when crystallised at the same time from the same solution.

Very numerous experiments and investigations have proved that analogy of chemical constitution in two bodies is generally attended with an analogous crystalline form, and, moreover, that two compounds possessing the same form of crystallisation, and separating together from solutions in mixed crystals having the same geometrical form as either substance by itself, have for the most part a strictly analogous constitution; that is, they contain the same number of atoms, or equivalents, arranged in the same manner.

In cases where two salts, of dissimilar crystalline forms, crystallise together, we invariably find the form of the mixed crystal is similar to the form of one of the two salts, and its composition is analogous to that of the salt, the form of which it has taken. Thus, from a mixed solution of sulphate of copper and sulphate of zinc, two salts of different forms and dissimilar composition, we obtain, by evaporation, mixed crystals, possessing either the form of sulphate of copper or that of sulphate of zinc, as the one or the other predominates in the solution; and we find that the constitution of the former is similar to sulphate of copper, and of the latter to sulphate of zinc.

The most striking illustrations of the fact that the similarity of the crystalline forms of many compounds is entirely independent of the diversity of their elements, are afforded by a group of salts called *alums*, by which term we designate compounds possessing a constitution similar to that of common alum. The constituents of this latter substance are sulphuric acid, alumina, potass, and water; it crystallises in large and regular octahedrons. Now, we may separate the alumina from this alum, and replace it by an equivalent of peroxide of iron, oxide of chromium, or peroxide sesquioxide of manganese, without causing any other alteration in its composition or form. The iron alum, which contains peroxide of iron instead of alumina, is colourless, and by its external appearance is not to be distinguished from the original alumina alum red except in colour, the former being of a dark ~~green~~, the latter of a violet hue.

If a crystal of chrome alum is thrown into a cold saturated solution of common or alumina alum, the atoms of the latter, separating during the gradual evaporation of the water, will dispose themselves upon the surfaces of the crystal of chrome alum. If the crystal be turned every day so as to insure an uniform increase upon its several faces, a regular octahedron of white and transparent alumina alum will be obtained, having in its red centre, as a nucleus, a dark ~~green~~ regular octahedron of chrome alum.

In the same manner we may separate the sulphuric acid from the alum, and replace it by chromic acid, or selenic acid, both acids possessing a constitution perfectly analogous to sulphuric acid.

We may also substitute ammonia for potass in the alum, without altering its form of crystallisation; and experience has proved, that not only in this instance of the alum, but in all cases where alumina, peroxide of iron, oxide of chromium, peroxide of manganese or sulphuric acid, chromic acid, and selenic acid, or potass and ammonia, replace each other in compounds, the form of the new compound is the same as that of the original compound. It is only in cases where a new constituent, in consequence of these substitutions, is added, or one of the original constituents is separated, that we find the form of the resulting crystal different from the first, because the *composition* in that case becomes altered.

Chemists have at length become acquainted with all those substances which replace each other in analogous combinations without varying the form of crystallisation, and have arranged them into groups. These bodies have received the appropriate designation of *isomorphous* (similiform). Thus, we denominate chlorine, bromine, iodine, cyanogen, fluorine,—or, again, lime, magnesia, protoxide of iron, protoxide of manganese,—*isomorphous:* by which we mean that those of their compounds which are analogous in constitution have the same crystalline form, and that these substances are capable of replacing each other in combinations without altering the form of their crystals. You will find no difficulty in understanding that a crystal of alum may contain peroxide of iron and alumina, or potass and ammonia, in perfectly indefinite and variable proportions, without ceasing on that account to be a crystal of alum, or to be considered one. It is involved in the characteristic property of isomorphous substances not to replace each other in certain definite and immutable proportions, but in all possible proportions. This appeared at first sight to stand opposed to the universality of the acknowledged laws of fixed and constant combining proportions. But the knowledge of the ultimate cause, that is, of the analogous form and like attraction of the particles of isomorphous bodies, explains it in the most simple and satisfactory manner.

This beautiful discovery has the most important and significant bearings upon mineralogy. When attempting to arrange minerals according to their constituents and composition, innumerable difficulties and perplexities arose. The most conscientious chemists contradicted each other as to the components of minerals presenting the most characteristic properties. Thus, while one found in the garnet of Arendal above 30 per cent. of magnesia, this was wholly wanting in the garnets of Fahlun, of Vesuvius, &c. In the noble garnet, analysts detected 27 per cent. of alumina, whilst not a trace of this substance was found in the yellow garnet of Altenau. What, then, are the constituents of garnet? Of what substance is it composed? This is now explained in a very simple manner. Where there was no alumina the isomorphous peroxide of iron was found; where the magnesia was absent, the isomorphous lime was found. It became evident that garnet contains varying amounts of isomorphous oxides, such as peroxide of iron and alumina or lime, protoxide of iron or protoxide of manganese, which are capable of replacing each other without altering the form of the resulting compound.

More minute and accurate admeasurements of the crystals have, however, subsequently shown that the similar combinations of isomorphous substances have not invariably the same form *exactly*, —that the angles which the sides of the crystals form with each other are not identically the same. One of the most cogent arguments for the soundness of our views respecting the existence of atoms is, that these deviations are explicable upon certain considerations attaching to the atomic theory.

Let us imagine a crystal formed by the arrangement, side by side, of atoms, each of which possesses a certain shape, and the form of the crystal to be dependent upon the form of its constituent atoms. For instance, alum. The alumina atom will occupy a certain definite space within the atom of alum. If we remove the atom of alumina from this crystal and substitute in its stead an atom of peroxide of iron, the crystal of alum will retain its original geometrical form, if the atom of peroxide of iron has the same *form* as the atom of alumina. But the form of the crystal of alum will remain absolutely the same only if the peroxide of iron atom is of exactly the same *size*,—if its volume be identical with the volume of the atom of alumina. But wherever the atom of the isomorphous body does not exactly fill the space occupied by the atoms to be displaced—*i. e.*, if its volume be smaller or larger—this will manifest itself in the inclination of the edges of the crystal towards its axis.

A very ingenious method has been devised for enabling us to compare the space which the atoms of two isomorphous substances, replacing each other in a combination, occupy. Every one knows that equal volumes of solid, fluid, and gaseous substances differ very much in weight. We commonly compare the relative space which a piece of wood and a piece of lead occupy, by saying that the wood is lighter than the lead,—a cubic inch of the former weighs more than eleven times heavier than a cubic inch of the latter. This difference of weight between equal volumes of different substances has been examined with great accuracy, and expressed in numbers. The designation *specific gravities* is given to these numbers. Now, in order to compare the *absolute weight* of two substances, we ascertain how many times a definite and known unit of weight, as a *pound,* for example, is contained in the mass of each, without any regard to their volume; and it has been agreed in like manner to determine the specific weights or gravities of substances by means of a unit of weight of a definite and known volume. How much a given volume of any substance is heavier than an equal volume of another substance, is expressed by numbers referring to the weight of an equal volume of water. The weight, then, of a given volume of water is adopted as the standard,—the *unit* of the specific gravities of all other substances. The number, therefore, designating the specific gravity or weight of a substance, expresses how many times heavier or lighter than an equal volume of water is a given volume of the substance; that is, how many times the weight of the unit is contained therein.

In order to ascertain the absolute weight of any substance, we place it upon one scale of the balance, and upon the other scale we place as many units of weight (pounds or ounces, for example), as will restore the perfect equilibrium of the balance. It is quite immaterial whether these units of weight consist of lead, iron, platinum, wood, or any other substance. Let us suppose that instead of iron, or other metallic weight, we had a pound or an ounce weight of water. If we place the substance, the weight of which we wish to ascertain, upon one scale, and as much water as will restore the equilibrium of the balance perfectly in the other, we obtain the weight of the substance represented in pounds or ounces of water. If we now compare the volume of the substance under examination with the space occupied by an equal weight of water, we know at once and with accuracy, how much more or less space an equal weight of water occupies than the equal weight of the weighed substance, in other words, we ascertain its *specific gravity*.

Thus, if we place upon one scale of the balance a cubic inch of iron, we require on the other scale 7¾ cubic inches of water to restore perfectly the equilibrium. One cubic inch of water, therefore, is 7¾ times lighter than a cubic inch of iron, one cubic inch of iron is 7¾ times heavier than a cubic inch of water.*

If we place upon one side of the balance 100 given volumes of oil of turpentine, and upon the other as much water as is required to restore the equilibrium of the balance perfectly, and then measure this water, it will be found that 86 volumes of the water are as heavy as the 100 volumes of oil of turpentine, or 86 volumes of oil of turpentine occupy the same space as 100 volumes of water; or again, as we may also express it, a given measure of oil of turpentine weighs only $\frac{86}{100}$ of an equal volume of water.

The numbers 7.75 for the specific gravity of iron, 11.3 for lead, 1.989 for sulphur, 4.498 for iodine, 1.38 for fluid chlorine, scarcely require any further explanation; they express how many times

---

* It may be well to mention, *en passant*, in what manner we ascertain the volume of such substances as cannot be measured by our ordinary instruments, as, for example, *sand*. The volume of sand, or of similar substances, may be determined with the greatest accuracy by the following method:—Take a glass tube, carefully graduated, to denote its capacity in cubic inches, every cubic inch being again divided into 100 parts. Fill this tube to half its capacity with water, and project into it a weighed amount of sand, or of the substance under examination. The water will rise in the tube. The difference in the level of the water thus produced indicates exactly the volume of the sand in cubic inches, and $\frac{1}{100}$ths of a cubic inch.

iron, lead, sulphur, iodine, fluid chlorine, weigh more than an equal volume of water. The difference in weight between two equal volumes of sulphur and iron, for example, presents relations precisely analogous to the difference between the numbers 1.989 and 7.75; that between equal volumes of iodine and chlorine is like that of the numbers 4.948 and 1.380, and so with the others.

The difference of weight between two substances of equal volumes remains, of course, invariably the same, however minute or extensive one may assume these volumes to be. Whenever the amount of the volume of one body is increased or decreased, as, for instance, doubled, the relative proportion must still be preserved in the numbers expressive of the specific gravities. The difference of weight between two cubic inches of iodine and one cubic inch of fluid chlorine, is expressed by $2 \times 4.948 = 9.896$ and 1.380, &c.

Now, it will be obvious to you that there is some *cause* upon which this difference of weight between equal volumes of different substances depends, and this cause is very satisfactorily explained upon the theory of the constitution of bodies which we have adopted. According to this view every substance consists of an aggregation of ponderable particles, or atoms, each of which occupies a certain space, and possesses a certain definite form.

Our knowledge of isomorphous bodies establishes indisputably the fact that their mutual substitution in combinations, without changing the crystalline form of the compound, depends upon the circumstance that their respective atoms possess one and the same form and size. Whenever the crystalline form of a compound is altered by substituting one element for another, we may be assured that the alteration in the form of the crystal is in consequence of the atoms of the substituted body having another form than the atom of the substance replaced, or its not occupying the same space in the combination. These facts, taken in connection, lead us to the conclusion that the ultimate particles of bodies which we denominate *atoms*, are of unequal magnitude or unequal weight. If we once admit this conclusion, it explains the specific gravity of bodies in a very simple and satisfactory manner. The reason, according to these preliminary data, that a given volume of lead is heavier than an equal volume of iron, iron heavier than sulphur, iodine heavier than an equal volume of chlorine, must be either that the *atom* of iodine is heavier than the atom of chlorine, &c., or that a portion of lead, for instance, contains in the same bulk a greater number of atoms than iron.

Let us suppose an equal number of atoms, say 1000, of iodine or chlorine, to be comprised within the space of one cubic inch, it is obvious that the specific gravities of these two substances express the difference of weight between their respective atoms. If the cubic inch of iodine weighs 4.948 grains, and the cubic inch of chlorine 1.380, then $\frac{1}{1000}$th of the cubic inch of iodine, containing one atom of iodine, would weigh 4.948, and $\frac{1}{1000}$th of a cubic inch of chlorine, containing one atom of chlorine, would weigh 1.380 grains.

Chlorine and iodine are isomorphous substances; we imagine their atoms to be of the same size and the same form, and if in equal volumes of iodine and chlorine an equal number of atoms of these substances are contained, their specific gravities must stand in the same relative proportion to each other as their equivalent numbers, which, therefore, would really express their atomic weights.

Exactly 1.380 grains of chlorine are required to displace and replace 4.948 grains of iodine. A simple rule-of-three calculation proves at once that there is this relation between the specific gravities of these bodies and their equivalents or atomic weights.

For, as 4.948 is to 1.380, so is 126 to 35.2.

The first two terms are the specific gravities, the latter two the equivalents of iodine and chlorine.

This remarkable relation has been found to extend to all isomorphous substances, and thus a physical property of bodies, namely, specific gravity, has unexpectedly been drawn into the sphere of chemical philosophy. The numbers expressing the specific gravities of bodies are equally expressive of the relative proportions in which they replace each other in combinations; that is to say, identically the same proportions which are found to exist between their equivalent numbers. Whenever there is found to be any diversity in isomorphous substances, that is, whenever the specific gravities do not exactly correspond in this respect with their equivalent numbers, the difference manifests itself in the inclination of the faces of their crystals, in the angles, for instance, which the edges form with the axis of the crystal. The form of the crystals is identically the same only when the atoms of isomorphous substances replacing each other have the same *volume,* together with the same *form.* Whenever the volume of the replacing atom is less in magnitude than that of the displaced atom, this will be perceptible in the form of the resulting crystal.

In order to compare, by means of numbers, the volumes which the atoms of different substances occupy, the following method has been devised.

Let us suppose the equivalent numbers to be real weights: let us assume, for instance, the number 35.2, for chlorine, to signify 35.2 ounces of chlorine; the number 126, for iodine, 126 ounces of iodine; 27.2, for iron, 27.2 ounces; 29.6, for nickel, 29.6 ounces of nickel; and let us divide each of these numbers by the weight of one cubic inch of chlorine, iodine, iron, nickel, or, what is the same thing, by the numbers representing their specific weights.

Assuming one cubic inch of water to weigh one ounce, one cubic inch of chlorine will weigh 1.380 ounces; one cubic inch of iodine, 4.948 ounces; one cubic inch of iron, 7.790 ounces; one cubic inch of nickel, 8.477 ounces. Taking these numbers (the specific gravities) as the divisors, the quotients will represent the number of cubic inches of chlorine, iodine, nickel, or iron, which are contained in one equivalent of each of these substances. In other words, we are informed by the resulting numbers how much space relatively to each other an equivalent of chlorine, iodine, nickel, and iron, respectively occupies; or, expressing it generally, the relative proportion which the volume of bodies bears to their equivalents or atomic weights.

Now, the atoms of isomorphous substances are, according to our supposition, of the same form and of equal size,—their number is equal in equal volumes. If, therefore, there are exactly the same number of atoms in one equivalent of chlorine as in one equivalent of iodine, we must, by dividing their atomic weights by their specific gravities, necessarily obtain as the quotient the same number.

The atomic weight of chlorine, 35.2, divided by its specific gravity, 1.380, gives 25; and the atomic weight of iodine, 126, divided by its specific gravity, 4.948, gives us precisely the same number, 25.

You will perceive that, admitting our data, it is impossible to be otherwise. The atomic weights or equivalent numbers of isomorphous bodies, *must,* when divided by the number representing their specific gravities, give identically the same quotient, precisely because they contain in equal volumes an equal number of atoms; and if, therefore, these atoms are not the same in size and form, the differences will be manifested in the quotients obtained.

A knowledge of the numbers representing the volumes of different bodies is of great importance in enabling us to perceive their mutual relations. They have been designated by the terms *atomic volumes* or *specific volumes.* Thus we say the atomic volume of chlorine is 25, that of iodine is also 25; both the numbers being the same, the substances themselves are isomorphous. The atomic volume of sulphur is 8,—very different from that of chlorine, with which substance sulphur is not isomorphous; but it is the same as that of selenium, with which, therefore, sulphur is isomorphous.

The accurate determination of the numbers representing the atomic volumes of substances is of the highest importance, since they enable us to perceive, at the first glance, what substances possess an equal or unequal number of atoms in equal volumes; and thus their mutual relations may be compared and understood.

# LETTER VII.

My Dear Sir,

Neither heat, electricity, nor the vital principle, are capable of connecting the particles of two dissimilar elements into a group,—of uniting them into a compound;—this, the chemical force alone is able to accomplish.

Everywhere in organic nature, in all combinations which are produced in the living animal or vegetable organisms, we meet with the same laws, we find the same fixed and immutable combining proportions, as in inorganic nature.

The substance of brain, of muscle, the constituents of blood, of milk, of bile, &c., are compound atoms, the formation and existence of which depends upon the affinity which acts between their ultimate particles, — their component elements. It is affinity, and no other power, which causes their aggregation. Separated from the living body, withdrawn from the influence of the vital principle, it is the chemical forces alone which determine the conditions of their ulterior existence. Upon these depend, according to their energy and direction, the strength or weakness of the resistance which they oppose to external causes of perturbation,—to forces tending to annihilate the chemical attraction existing between their component elements. But LIGHT, HEAT, the VITAL PRINCIPLE, and the FORCE OF GRAVITY, exercise a most decided influence upon the number of the simple atoms which unite to form a compound atom, and upon the manner of their arrangement. They determine the form, the properties, the characteristic qualities of the combinations, precisely because they are able to communicate motion to atoms at rest, and to annihilate motion by resistance.

Light, heat, the vital principle, the electric and magnetic forces, the power of gravity, manifest themselves as forces of motion and of resistance, and as such, change the direction, and vary the strength, of the chemical force; they are capable of elevating this force, of diminishing or even of annihilating it.

Mere mechanical motion suffices to impart a definite direction to the cohesive attraction of crystallising substances, and to alter the force of affinity in chemical combinations. We may lower the temperature of water, when completely at rest, far below the freezing-point, without causing it to crystallise. When in this state, the mere touch with a needle's point suffices to convert the whole mass into ice, in a moment. In order to form crystals, the smallest particles of bodies must be in a state of motion; they must alter, or change their place, or position, to be able to arrange themselves in the direction of their most powerful attraction. Many hot, saturated saline solutions deposit no crystals on cooling, when completely at rest; the smallest particle of dust, or a grain of sand, thrown into the solution suffices to induce crystallisation. The motion once imparted, propagates itself. The atom to which motion has just been communicated imparts the same impulse to the next, and so forth, the motion spreading throughout all the atoms of the mass.

When we bring metallic mercury into a solution of sulphuret of potassium, its surface becomes immediately covered with black amorphous sulphuret of mercury, and as often as this film is removed from the surface, it is renewed. If we place this mixture in a well-closed glass bottle, and attach this bottle to the frame of a saw in a saw-mill, which moves up and down several thousand times in an hour, the black powder becomes converted into the finest red cinnabar, the constitution of which differs from the black sulphuret, only by its crystalline character.

The common cast iron of commerce owes its hardness, brittleness, and crystalline texture to its containing carbon; pure iron, free from carbon, is but very rarely crystalline. The iron of meteoric stones differs from cast iron inasmuch as it possesses, with a most decided crystalline texture, the greatest malleability, like a very pure wrought iron. But a bar of wrought iron is tough in breaking, and filiform, or fasciculated, showing no crystalline texture in its fracture. Its smallest particles are intermixed without any order or arrangement; when it is polished, and its surface moistened with an acid, it does not exhibit the characteristic lines and markings of crystalline iron. But if this bar be exposed for a long time to feeble, but constantly repeated, strokes of a hammer, its atoms will be found to alter their position, and, through the influence of the mechanical motion imparted to them, they will arrange themselves in the direction of their most powerful attraction; the bar will become crystalline and brittle, like cast iron, the fracture being no longer tough and filiform, but even, and shining. This phenomenon is manifested more or less speedily in the iron axles of locomotive engines and travelling carriages, and becomes the cause of accidents which cannot be foreseen.

But it is not only upon the external form and character, and upon the arrangement of homogeneous particles, that mechanical forces have a determining influence, but also upon the manner of arrangement of heterogeneous atoms, that is, upon the existence of chemical combinations. The faintest friction, the slightest blow, causes fulminating mercury and fulminating silver to explode; the mere touch with a feather suffices to decompose the ammoniacal oxide of silver, or the ioduret of nitrogen. The mere putting the atoms into motion in these instances alters the direction of the chemical attraction. Owing to the motion imparted, the atoms arrange themselves into new groups. Their elements aggregate anew, forming new products.

Far more frequent and evident still is the influence which heat exercises upon the manifestation of affinity. Inasmuch as it overcomes resistances which oppose themselves to the action of affinity, it promotes and effects the formation of chemical combinations. When heat opposes, as a resisting power, the force of affinity, it alters the direction of attraction,—the arrangement of atoms,—it prevents or annihilates the exercise of the affinity. The attraction which dissimilar atoms have for each other, at lower degrees of heat, or lower temperatures, is different to that which they have at a higher temperature. In the highest conceivable degrees of heat, chemical combinations no longer take place.

When a solution of common culinary salt in water is exposed to a very low temperature, the salt crystallises in fine, large, transparent, and pellucid tables, which contain 38 per cent. and upwards of water in chemical combination, whilst the crystals of the same salt formed at common temperatures are always anhydrous. Upon the slightest touch, the hydrated crystals lose their transparency, and assume a milky appearance; if placed in the palm of the hand they deliquesce, and are converted into a mass of small cubes of common salt. The inconsiderable difference of ten degrees in the temperature causes the particles of this crystallising salt to manifest an affinity for water which they do not possess at a somewhat higher temperature, not even at the freezing point of water.

When carbonate of lime crystallises from its solution in cold water, its particles arrange themselves into the form of the Iceland or doubly refracting spar; when from hot water, we obtain it in the form of arragonite. Both these minerals, although so diverse in their crystalline forms, so different in hardness, specific gravity, and power of refracting light, contain, nevertheless, absolutely the same proportional amounts of carbonic acid and of lime.

We see in this instance, that particles of carbonate of lime in becoming solid, under the influence of different temperatures, form themselves into substances physically quite different. And it is even still more remarkable, that if we expose a crystal of arragonite to a feeble red-heat, that is, to a heat of a higher degree than that at which it was formed, a commotion or movement takes place throughout the whole mass of the crystal, and without the slightest alteration occurring in its weight, the entire crystal swells up, presenting the appearance of a cauliflower, and becomes converted into a heap of powder composed of minute crystals, each of which exhibits the rhomboidal form of common calcareous spar.

One of the most remarkable instances of the influence which heat exercises upon chemical combinations has been recently discovered, with respect to styrol, by Dr. Blyth. Styrol is a colourless, very limpid fluid, obtained from liquid storax; it possesses an agreeable odour, and a very great power of refracting light.

At 143° it boils and volatilises readily. If this volatile fluid be exposed in a closed vessel to a temperature somewhat higher than its boiling point, it becomes converted into a perfectly solid hard body, as transparent as the purest glass or crystal, and possessing the same refracting power as the original fluid. A glass globe, filled with styrol and hermetically sealed, being suspended in the sun for some time, the same transformation takes place, the fluid becomes solid and hard, without losing its transparency. If solid styrol be heated to a feeble red-heat, it fuses and distils over as fluid styrol.

The interior of a hen's egg undergoes, by the influence of a temperature of 165°, a complete alteration in all its properties. The fluid albumen, which, in its natural state, is nearly colourless, presenting only a very feeble yellow tint, assumes a white appearance like porcelain, and its particles lose entirely their mobility. We see that this most remarkable change takes place without the addition of anything material, and without the withdrawal of any substance whatever. Previous to the application of heat, the particles of the albumen admitted of their being intermixed with water in every proportion—they were soluble, but, in consequence of the motion imparted to them by heat, they have lost this property; their constituent atoms have grouped themselves into a new form; and it is the manner of their atomic arrangement which causes this alteration in the properties of the albumen. The chemical forces which were active between the particles of albumen, constitute the ultimate cause of this new mode of arrangement,—of these new physical properties. In this newly-acquired form they manifest a resistance to disturbing forces, of which they were originally deficient; they oppose the influence of heat, as they were not before capable of doing.

All organic substances exhibit similar phenomena; they all, without exception, are mutable and destructible by the influence of a more or less elevated temperature; the resistance which their atoms,—that is, the forces active in them,—oppose to the disturbing causes, being invariably manifested in a new manner of arrangement. Of a compound atom, one, two, or three new groups of atoms are formed in such order that a state of equilibrium is invariably restored. The power of resistance to disturbing forces,—that is, chemical force,—is stronger in the newly formed products than in the original substance, but the sum total of the power of affinity does not increase, it only becomes stronger or more intense in a certain direction.

What we mean by the *direction* of the force will be rendered more intelligible by contemplating the state of a particle of water in the centre of a mass of water, as, for instance, in a filled glass. The particle of water in the centre of the glass is attracted by all the surrounding particles in its immediate vicinity, and it exercises the same degree of attraction towards them, and equally on all sides. The mobility of the particle of water, and the facility of its displacement, depend upon the circumstance that all the attracting forces acting upon it are in a state of equilibrium. The application of the slightest external mechanical force suffices to remove it from its place; the least difference in the temperature, increasing or diminishing its density, causes a change in the position of the particle. If it were attracted more powerfully from one side than another, it would tend towards the direction of the most powerful attraction, a certain amount of force would be required to divert it from that direction.

The particles of the water upon the surface are precisely in this state; they are less mobile than the particles of the inferior layers, or those below the surface; they are more closely connected with each other, denser, in a more contracted state, as if influenced by external pressure.

With a certain degree of caution, a fine steel needle may be maintained swimming upon the surface of water, whilst, if submerged in the water, it instantly sinks to the bottom. This more powerful cohesion of the particles of water at the surface, arises from the particles attracting and being attracted *only in one direction*. The attracting force from below is not opposed by any attraction from above. To enable a steel needle to fall to the bottom of a vessel of water, the particles on the surface must first give way, must be displaced, but they do not yield thus although the needle presses upon them with a weight from seven to eight times greater than that of an equal volume of water.

The attracting force which maintains the connection of constituents in chemical combination, acts in precisely the same manner. The directions of the attractive force become multiplied with the number of elements,—with the number of atoms united into a group. The force of the attraction diminishes in the same proportion as the number of directions increases.

Two atoms united into a compound can only attract each other in one direction; the entire amount,—the sum total of their attracting force, manifests itself in this single direction. If a second and a third atom be added to the group, part of the force will be required to attract and retain these atoms also. The natural consequence of this is that the attraction of all the atoms for each other becomes weaker, and they, therefore, oppose a less powerful resistance than the first two atoms previously opposed to external causes tending to displace them.

The great and most marked distinction between organic and inorganic bodies lies in the former being combinations of a higher order. Although organic substances are composed of but three, four, or, at most, five elements, their atoms are, nevertheless, far more complex than those of mineral substances.

For example, a particle of common salt, or of cinnabar, presents a group of not more than two atoms, whilst an atom of sugar contains thirty-six elementary atoms, and the smallest particle of olive-oil consists of several hundred simple atoms.

In the common salt, the affinity or attraction is exerted only in one direction; in the atom of sugar, on the contrary, it is acting in thirty-six different directions. Without adding or withdrawing any element, we may conceive the thirty-six simple atoms, of which the atom of sugar consists, to be arranged in a thousand different ways; with every alteration in the position of any single atom of the thirty-six, the compound atom ceases to be an atom of sugar, since the properties belonging to it change with every alteration in the manner of the arrangement of its constituent atoms.

It is evident that impulses of motion, certain causes tending to disturb the force of affinity, which exercise no decomposing influence upon more simply constituted atoms,—as, for instance, those of inorganic substances,—may, nevertheless, be capable of producing alterations in organic atoms, that is, in all atoms of a higher order.

It is upon the greater complexity of composition of organic bodies, together with the lesser force with which, consequently, their constituent atoms attract each other, that their easier decomposibility depends; heat, for example, disturbs their composition with much greater facility than it does that of inorganic bodies. The atoms of the former, once put into motion, or by the action of heat being separated to a greater distance from each other, arrange themselves into less complex atoms, in which the force of attraction acts in fewer directions, and in which it is consequently able to oppose a proportionably stronger resistance to the further action of causes of disturbance,—of decomposition.

Minerals, all inorganic compounds, are formed by the free and unfettered action of chemical affinity; but the mode and manner of their aggregation, the arrangement of their particles, depend upon the co-operation of external and extraneous causes; these latter causes determine the form and the physical properties of the compound. If, for example, the temperature be higher or lower, whilst the atoms of a compound substance are combining, they will arrange themselves into quite different groups.

Precisely in the same manner as heat influences inorganic combinations, heat, light, and, above all, the vital principle, are the determining causes of the form and properties of compounds produced in living organisms; these causes determine the number of atoms and the mode and manner of their arrangement.

We are able to construct a crystal of alum from its elements, namely, sulphur, oxygen, potassium, and aluminum, inasmuch as heat as well as chemical affinity are, within a certain limit, at our free disposal, and thus we can determine the manner of arrangement of the simple and compound elements. But we cannot make an atom of sugar from the elements of sugar, because in their aggregation into the characteristic form of a sugar atom the vital principle co-operates, which is not within the reach of our control, as heat, light, the force of gravity, &c., are to a certain extent. But when the elements have once aggregated into organic atoms in the living organisms, they come under the same category with all other chemical compounds: we are able to guide, in various and manifold directions, the force which is active between these atoms, maintaining them in connection; we are able to alter this force, to increase or to annihilate it. We may produce atoms of a higher order by combining together two, three, four, or more compound organic atoms; we can decompose the more complex into less complex compound atoms; we can produce sugar from wood and from starch, and from sugar we can produce oxalic acid, lactic acid, acetic acid, aldehyde, alcohol, formic acid, &c., although we are altogether incapable of producing any of these compounds by direct combination of their elements.

The vital principle has not the slightest influence upon the combination of the simple elements into chemical compounds. No *element*, by itself, is capable of serving for the nutrition and development of any part of an animal or vegetable organism. All those substances which take a part in the processes of life are inferior groups of simple atoms, which, under the influence of the vital principle, combine into atoms of a higher order. The chemical force under the dominion of heat, determines the form and properties of all the more simple groups of atoms, whilst the vital principle determines the form and the properties of the higher order of atoms, that is, of organic atoms.

## LETTER VIII.

My Dear Sir,

In the preceding Letters I have endeavoured to explain to you the connection of the forces of gravity, heat and electricity, with the chemical force; and I have also pointed out the limits and peculiarities of the effects produced upon chemical affinities by the vital principle.

After the extinction of the vital principle in organic atoms, they maintain their form and properties,—the state into which they have been brought in living organisms,—only by reason of their inherent inertia. It is a great and comprehensive law of matter that its particles possess no self-activity, no inherent power of originating motion, when at rest; motion must be imparted by some external cause; and, in like manner, motion once imparted to a body can only be arrested by external resistance.

The constituents of vegetable and animal substances having been formed under the guidance and power of the vital principle, it is this principle which determines the direction of their molecular attraction. The vital principle, therefore, must be a motive power, capable of imparting motion to atoms at rest, and of opposing resistance to other forces producing motion, such as the chemical force, heat, and electricity. We are able to reliquefy and redissolve albumen after it has been coagulated by heat, but the vital principle alone is capable of restoring the original order and manner of the molecular arrangement in the smallest particles of albumen. Coagulated albumen is again converted into its original form, it is transformed into flesh and blood in the animal organism.

In the formation of vegetable and animal substances the vital principle opposes, as a force of resistance, the action of the other forces,—cohesive attraction, heat, and electricity,—forces which render the aggregation of atoms into combinations of the highest order impossible, except in living organisms. The vital principle annihilates the power of these forces to disturb the manifestation of chemical affinity; it promotes the formation of organic substances in a precisely similar manner as heat renders possible and favours the formation of inorganic compounds; that is, by removing altogether or diminishing the energy of other resisting forces.

Hence it is that when those complex combinations which constitute organic substances are withdrawn from the influence of the vital force,— when this no longer is opposed to the action of the other disturbing forces, great alterations immediately ensue in their properties, and in the arrangement of their constituents. The slightest chemical action, the mere contact of atmospheric air, suffices to cause a transposition in their atoms, and to produce new arrangements; in one word, to excite *decomposition.* Those remarkable phenomena take place which are designated by the terms FERMENTATION, PUTREFACTION, and DECAY; these are processes of decomposition, and their ultimate results are to reconvert the elements of organic bodies into that state in which they exist before they participate in the processes of life. Complex organic atoms of the highest order are, by fermentation, putrefaction, and decay, reduced into combinations of a lower order, into that state of combination of elements from which they originally sprang.

It is only recently that we have arrived at a satisfactory insight into these processes, and at a minute knowledge of the causes producing and sustaining these peculiar processes of decomposition, differing as they do, both in their forms and manifestations, from ordinary chemical decomposition. It has been decidedly proved that no vegetable or animal substance passes by itself into a state of fermentation or putrefaction, but that, under all circumstances, heat, and a chemical action arising from the presence and contact of hydrogen or oxygen, is essential to the origin of these processes.

The juice of the grape, while it is protected by the external skin from contact with atmospheric air, scarcely undergoes any perceptible alteration. A grape, by gradual exsiccation, becomes converted into a raisin. The slightest perforation through its external covering, as with the point of a needle, for instance, is sufficient to alter all the properties of the juice. Protected from the access of the air, withdrawn from the influence of the atmospheric oxygen and the effect this exerts upon one of its constituents, the juice (termed *must*), may be preserved for an indefinite period; easily transmutable as its constituents are, no alteration takes place, because no disturbing cause can reach them. But when exposed to the air at a suitable temperature, the grape-juice becomes agitated, a lively evolution of gas takes place, all the sugar it contained disappears, and, when the fermentation is complete, a clear fluid is produced, which has deposited a yellowish mud-like substance as a sediment; this is yeast. The liquid now contains a certain amount of alcohol, which, together with the carbonic acid expelled as gas, corresponds exactly to the amount of sugar it originally contained. The sediment or yeast separated from the clear fluid and added to an aqueous solution of pure sugar, induces the same phenomena, terminating ultimately in the total disappearance of the sugar, its decomposition and resolution into alcohol and carbonic acid. The yeast which has caused the decomposition of the sugar disappears with it; whilst decomposing the sugar it undergoes itself decomposition, although more slowly; and it thus, by degrees, loses completely the power of causing fermentation in another solution of sugar.

Animal fluids comport themselves in a precisely similar manner. Milk, whilst in the udder of the cow, urine whilst in the bladder, undergo, in a healthy state, no alteration of their properties. But in contact with air, milk coagulates without any evolution of gas; cheese separates in the form of a curdy mass, the fluid part becomes acid, and the sugar of milk contained in it disappears with the increasing acidification.

The fermentation of vegetable juices and the acidification and coagulation of milk, both belong to one and the same class of phenomena; the only difference between them consists in the form or state of the new products into which the constituents of the fluids arrange themselves. One of the new combinations produced in the grape-juice by fermentation is gaseous, namely, carbonic acid (hence the effervescing and frothing of the fluid); whilst, on the other hand, the products of the changes undergone by milk remain in solution in the fluid. The form and nature of the substances which are the result of fermentation being only accidental, we designate by the same term all processes of decomposition occurring in a similar manner, as in the juice of the grape, or in milk, no matter whether evolution of gas accompanies them or not.

In popular language, processes of putrefaction are distinguished from processes of fermentation, but the distinction does not admit of being scientifically established, since the difference between the two processes consists only in the different manner in which they affect our sense of smell.

Putrefaction, according to this distinction, is the process of fermentation in organic substances containing nitrogen and sulphur, which give rise to the formation of products of a disagreeable odour.

The complexity of organic atoms has been recognised as the ultimate cause of these phenomena. The facility with which transformation takes place in these depends upon the feeble force of attraction existing between the simple atoms of which they are made up and maintaining the existence of the complex atom, and upon their consequent easy mobility. The vegetable juices and animal fluids contain matters which, when withdrawn from the protection of the living organism, begin to undergo alteration from the instant they come into contact with the atmospheric oxygen. If we cut an apple, a potato, or a beetroot, the cut surface in the course of a few minutes loses its white colour, and assumes a brown tint; upon the slightest incision being made upon the green bark of a vegetable or upon a leaf, similar alterations immediately take place in the juice, although not always so perceptibly. The oxygen of the atmosphere in these cases combines with one of the constituents of the juice, and, at the same moment, the order of its molecular arrangement ceases, and a new arrangement results.

When the equilibrium of the mutual attractions of the simpler atoms of a compound is disturbed, a commotion ensues in the complex atom, and the component atoms arrange themselves in a different manner.

This motion, thus imparted, causes the action, once excited, to continue.

If fermentation has once been induced in a vegetable juice, in milk, in urine, in flesh, &c., the oxygen which formed the immediate cause of the phenomena of this process of decomposition, may be altogether excluded, and yet the process will not be arrested. Fermentation, once begun, proceeds incessantly and irresistibly without the further co-operation of the atmospheric oxygen. The first particle, the atoms of which the chemical action of the oxygen set in motion, being in contact with other particles similar to it in composition, the motion imparted to its atoms acts as an impulse upon the atoms of the contiguous particle, and it now depends upon the amount of attractive force, acting between the atoms of the particles at rest, whether the motion imparted to those of the first particle will be propagated or not. If the motion is more powerful than the resistance, it will be communicated to a second particle, the atoms of this second particle will be set in motion, and this in the same manner and the same direction as in the first particle; the motion or transposition of the second particle is communicated to a third, fourth, and, in short, to all the compound atoms in the fluid; and, therefore, the same products are formed as a natural consequence of the same manner of arrangement.

If the resistance, or force which maintains the elements of the other compound atoms in connection, is more powerful than the cause tending to produce an alteration in their position or their order of arrangement, that is, a division into new products, the action imparted to the first particle must gradually cease.

In ALDEHYDE we have one of the most interesting illustrations of the transformation of a non-nitrogenous substance, induced by disturbance in its component particles. Aldehyde is a colourless liquid, miscible with water, and so extremely volatile as to boil when poured into the warm hand, that is, at 70° Fahr.; it has a suffocating odour, and possesses the property of absorbing oxygen from the atmosphere with great avidity, by means of which it becomes. converted into acetic acid. In contact with solution of caustic potass it thickens, and is converted into a brown resinous mass. These are very remarkable properties, but they are of equally remarkable mutability. In its preparation aldehyde cannot be completely protected from contact with atmospheric oxygen. For although we pour newly-prepared aldehyde into a glass vessel, and immediately close the vessel and seal it hermetically, by fusing its aperture in the flame of a blow-pipe, some of the particles of the aldehyde will invariably have absorbed oxygen, and are, therefore, in a state of action, the cause of which must of necessity, upon the total exclusion of oxygen, cease to act. The process of oxidation of the aldehyde, indeed, ceases with the exclusion of oxygen, but the perturbation of the equilibrium in the attraction of its elements propagates itself. By the motion thus imparted to the oxidised particles of the aldehyde, the equilibrium of the adjoining particles is disturbed, causing the elementary atoms composing those particles to arrange themselves into a new group quite different to the original group. The motion in these particles is further imparted to those in contact with them, and so on, until it is propagated, at last, through the whole fluid; so that after the lapse of a few days or weeks we have no longer any aldehyde in the hermetically-closed vessel,—nay, not even a substance which has the slightest resemblance to aldehyde in its properties.

The fluid remaining is no longer miscible with water, but it swims like oil upon its surface; it possesses an agreeable ethereal odour; its boiling point is upwards of a hundred degrees higher than that of aldehyde; solution of caustic potass no longer converts it into a resinous mass; and it is no longer convertible into acetic acid; and yet, notwithstanding these differences in its properties, it is still identical in composition with aldehyde, containing the same elements, and those elements in precisely the same proportions; but its atoms are now closer together, they are arranged in a different manner and order. That the atoms composing the aldehyde in these two states are more closely compacted in the latter is ascertained by comparing the specific gravity of their respective vapours.

It is very obvious that fermentation is a process necessarily dependent upon time, that it cannot accomplish its results in an immeasurably short period, like other chemical processes, and this precisely because the decompositions it effects are brought about by the gradual and successive transmission of an action from particle to particle throughout a mass. It is also evident that all organic compounds are not susceptible of undergoing decomposition by fermentation; this property belongs exclusively to those complex atoms the elements of which are held together only by a feeble degree of affinity, whilst other substances wherein this attraction is stronger cannot, in this manner, be resolved into less complex constituents.

The most remarkable circumstance relating to these phenomena, and one which may be very easily manifested and decidedly proved, is that no chemical affinity from without, no external influence, has any share in the formation of the new products; the process consists simply in a falling asunder,—a separation of the elements,—as a consequence of the disturbed equilibrium of their attractions.

A sugar atom divides itself into two carbonic acid atoms and one alcohol atom; both together contain the elements of the sugar atom in quality and quantity. In fresh milk, we have milk-sugar; in sour milk, we have, in its stead, lactic acid: but milk-sugar and lactic acid are identical in their chemical composition; they both contain the same elements in the same proportion by weight; they differ only in the order of arrangement of these elements.

In many cases, however, the elements of water, or the elements of other compound atoms, take a certain share in the transformations, inasmuch as two or three or more compound atoms, dividing themselves side by side into simpler atoms, produce new substances having an affinity for each other. In such cases these products are not obtained separately, but in combination with each other.

Yeast, and other matters capable of exciting fermentation, are always substances the elements of which are themselves in a state of motion—in the act of transformation; their property of causing fermentation depends precisely upon this state, which, of course, is not susceptible of being fixed, and made permanent. As this transformation proceeds and becomes completed, the state of motion in the particles of ferment disappears, and with it the property of inducing in other organic atoms the same process of transformation which they themselves are undergoing. It is well known that fresh yeast only is capable of exciting fermentation, even a single day considerably diminishes its power of promoting this process.

A solution of tannic acid may be preserved for several years in a closed vessel, without any alteration in its properties; but in the state in which it is contained in extract of gall-nuts it gradually changes all its properties, and when kept in a warm place, in a moist state, it gradually disappears completely, and gallic acid is formed from it and deposited in a crystalline form. Besides tannic acid, gall-nuts contain another substance which, in contact with water, undergoes decomposition, and by the influence of its changes, the tannic acid is brought into a similar state of transformation.

In a similar manner lactic acid is formed in fermented carrots and cabbages in the well-known sour krout.

The non-nitrogenous constituents of plants and animals, such as sugar, gum, starch, fat, &c., do not pass by themselves into a state of fermentation upon coming into contact with oxygen: this property belongs usually only to more complex atoms, which, besides carbon, hydrogen, and oxygen, contain two more elements, namely, nitrogen and sulphur. These latter elements are the motive powers, the true exciters of fermentation—that is, of the transformation undergone by non-nitrogenous substances. So long as sugar and a nitrogenous substance, in a state of continuing decomposition, exist side by side, in a fluid, fermentation proceeds. While oxygen is excluded, both these processes of transformation, namely, that of the sugar and that of the nitrogenous substance, or ferment, complete themselves side by side, and limit each other mutually; so that, if the transformation of the sugar is completed before that of the ferment—as happens, for example, in wine poor in saccharine matter—a certain portion of the ferment remains without undergoing any further alteration. Such wines possess the property of again passing into a state of fermentation upon the addition of a fresh portion of sugar. If the transformation of the ferment is completed before that of the sugar, the still undecomposed sugar remains unaltered, as is the case, for instance, with the wines of southern countries. The presence of the substance which transmits the action of fermentation to the particles of sugar imparts to wine the property of being converted into vinegar by the contact of the atmospheric air; if that substance be completely removed from wine, it may be exposed to the air, at any temperature, and for any length of time, without becoming acid.

The ferments present in the juice of the grape, or in vegetable juices generally, are, without exception, substances having a similar composition to that of blood, or the casein of milk.

The amount of these constituents of blood produced in plants, as in the vine for instance, may be increased by supplying them with animal manures. Cow-dung is rich in alkalies, which exercise a certain influence upon the increase of the amount of saccharine matter produced by plants: it is poor in nitrogen and the phosphates; that is to say, in substances which minister to the formation of the constituents of blood. The excrements of man contain but a small amount of alkalies, but they act especially and favourably upon the production of the blood constituents; or, if you like the phraseology better, in producing ferments,—agents capable of exciting fermentation in the juices of plants.

It may now be easily understood that we can exercise a most decided influence upon the quality of the juice of the grape by our manner of cultivation, by a judicious choice of manures. We may rationally improve a *must*, rich in ferment, *i. e.* blood constituents, by the addition of sugar, and it is a matter of perfect indifference that this sugar has been produced in the organism of some other species of plant; or we may add to the expressed juice of our unripe grapes, the dried ripe grapes of southern climes. In a scientific point of view, these are real improvements which have nothing in them very recondite, very difficult of comprehension, or in any way objectionable.

I have already mentioned, that the nature, form, and properties of the new products formed in the processes of fermentation, depend upon the manner in which the atoms, in these transformations, arrange themselves anew; that is to say, upon the direction in which they attract each other. I may now invite your attention to the fact that HEAT exercises a very decided influence in these processes, and upon the manner of the molecular arrangement of atoms in their products, just as it does in ordinary chemical processes in inorganic matter.

The juices of carrots, beet-roots, onions, &c., are rich in saccharine matter; when fermented at common temperatures they yield the same products as the juice of the grape, namely, carbonic acid and an alcoholic fluid, and the nitrogenous constituent of the juice is deposited in the form of a sediment or dregs. At a higher temperature, from 100° to 120° Fahr., for instance, the manner of the whole transformation is changed. There is less evolution of gas, and no alcohol is formed. When the process of fermentation is completed, and we examine the fluid, we find none of the sugar which was originally present; its elements have become transformed into a large proportion of lactic acid; and, besides this, there is a substance perfectly analogous to gum, and another substance, which, moreover, is the most remarkable of these products, of a crystalline appearance, identical in properties and constitution with the sweet constituent of manna.

*Alcohol* and *carbonic acid* are the products of the transposition of sugar atoms at the common temperature. At a higher temperature the results of the transformations effected by fermentation are—carbonic acid, mannite, lactic acid, and gum.

We have every reason to believe that at high temperatures the manner of transformation in the elements of the substance exciting fermentation (the ferment) becomes altered, and that the change in the directions in which its atoms transpose and arrange themselves, determines the new arrangement of the sugar atoms and the new positions which they assume, because it is not only by different temperatures that different products may be formed out of one and the same substance, but the same result is obtained if an alteration is made in the *nature* of the ferment transmitting its own action to the substance upon which it operates.

Milk becomes sour from the sugar of milk which it contains being converted into lactic acid: this transformation is caused by the presence and contact of the caseous matter, which is itself undergoing a state of change—of transposition of its atoms—from the influence of the atmospheric oxygen. If, after the entire disappearance of the milk-sugar, we add a new portion, the process of fermentation will continue as long as any cheese remains in the fluid to act upon the sugar.

This manner of fermentation of milk-sugar without evolution of gas, is confined to the common temperature. At higher temperatures, as from 76° to 86°, the products are totally different; the cheese assumes the properties of ordinary yeast, and two consecutive processes of transformation take place in the milk-sugar. In the first place, the sugar enters into chemical combination with a certain amount of water, and becomes converted into grape-sugar—that is, a sugar possessing precisely the same character as that found in grapes; and subsequently to this, it is further transformed, while still in contact with the cheese, into alcohol and carbonic acid.

Thus, whilst milk at common temperatures yields lactic acid as the principal product of the decomposition of its sugar, at a higher temperature we obtain, as the product, an alcoholic fluid, which, upon distillation, furnishes a true brandy.

If, instead of yeast, a small quantity of white cheese-curd is added to a solution of common sugar, and kept at a temperature of 76° to 86°, and, moreover, some chalk added to maintain the fluid in a neutral state, a lively evolution of gas soon takes place,—the sugar totally disappears. Carbonic acid and hydrogen are given off in a gaseous state; and we find in the fluid a copious amount of *butyric acid*, one of the most interesting of the organic acids, which, until recently, was known only as a constituent of milk or of butter.

In ordinary fermentation, the atom of sugar divides itself into two products; but, in the fermentation I have just described, three new substances are produced. In the former, alcohol and carbonic acid; in the latter, instead of these, we obtain *butyric acid,* hydrogen gas, and carbonic acid. The relation of these substances to each other cannot be mistaken. Alcohol is *butyric acid* + *hydrogen.* The atom of butyric acid is an alcohol atom from which two atoms of hydrogen have separated.

Thus alterations in the nature of the products of fermentation ensue with every variation in the process induced by changes of temperature, or the presence of matters accidentally drawn in to participate in the transformations. The same grape-juice, when fermented at various temperatures, yields wine of dissimilar qualities and nature, depending upon the circumstance of the temperature of the air being higher or lower during autumn, according to the depth of the cellar in which the fermentation is conducted, which varies the quality, the odour, and the flavour of the wine. An uniform temperature of the place where the fermentation is conducted, ensuring its slow and gradual progress, is the principal condition depending upon our own control for the production of the best kinds of wine. The growers of wine will soon universally give the preference to deep rock cellars or vaults for conducting the process of fermentation: such vaults have been found particularly appropriate for the fabrication of the superior varieties of beer; and the advantages of these vaults mainly depend upon their constantly equal temperature.

The influence which extraneous substances exercise upon the products of vinous fermentation is strikingly exemplified in the fermentation of potato-mash. It is well known that in the manufacture of potato-spirit an oily liquid is obtained, besides the alcohol, possessing poisonous properties, a highly disagreeable smell, and nauseous taste; this is called *fusel oil.* It does not exist ready formed in the potato, but is a product of the transformation of sugar, for it is produced not only in the fermented potato-mash, but also in the fermentation of the last syrups obtained during the preparation of the beet-root sugar.

This fusel oil belongs, by its chemical properties, to the same class of bodies as alcohol; it is an alcohol from which the elements of water have been separated. Two atoms of fusel oil are formed by the aggregation of five atoms of alcohol, with separation of six atoms of water.

Fusel oil is produced in our spirit manufactories as an accidental and accessory product, in such large quantities that it is used for lighting the buildings. Its formation never takes place in fermenting fluids containing racemic acid, tartaric acid, or citric acid, or certain bitter substances, such as hops, or the extract, or volatile oil of hops.

Fusel oil is formed principally in alkaline or neutral fluids, and in such as contain lactic acid or acetic acid, and its production in the potato-mash may be prevented, in a great measure, by the addition of tartar to the fermenting fluid.

The odour and flavour of wines depend invariably upon certain combinations which are formed during fermentation. Old Rhine wines contain acetic ether, many of them a very minute proportion of butyric ether, which impart to them a peculiar and agreeable smell and taste, somewhat resembling old Jamaica rum. All wines contain œnanthic ether, upon the presence of which depends their vinous odour.

These various compounds are formed partly in the process of fermentation and partly while the wine is in the cask, by the action of acids, which are present, upon the alcohol of the wine. Œnanthic acid seems to be produced by fermentation, at least it has not been detected in the grape. The free acids which are present in the fermenting juice take a most decided part in the formation of those aromatic matters upon which odour and flavour depend. The wines of southern regions are produced from perfectly ripe grapes; they contain tartar, but no free organic acids; they scarcely possess the characteristic odour of wine, and with respect to bouquet or flavour they cannot bear a comparison with the noble French or with the Rhine wines.

# LETTER IX.

My Dear Sir,

The properties of common animal caseine (cheese), and the influence which its particles, when in a state of decomposition and transposition, exercise upon the particles of sugar in contact with them, are very remarkable and interesting; but far more extraordinary, and of surpassing interest, are the properties and action of vegetable caseine, as it is contained in the milk of almonds. It is universally known that when sweet almonds are reduced to a pulpy mass, mixed and rubbed down with from four to six times their weight of water, they yield a fluid, exhibiting, in its external appearance and properties, the greatest analogy to very rich cow's milk. The milky appearance of almond emulsion is caused by particles of oil, or fat in a state of minute mechanical division, being diffused through it, and these rise to the surface when this fluid is left at rest, and arrange themselves in the form of cream, just as is the case with the milk of the cow. Almond-milk, like animal milk, coagulates upon the addition of vinegar, and after a certain time, if left to itself, it turns sour. This milk contains a substance exactly analogous, in its properties, to animal caseine or cheese, and of the same ready mutability. The cheese of animal milk begins to undergo alteration from the instant it leaves the udder of the cow, and the change proceeds in it continuously, although it only becomes perceptible after the lapse of some time in the coagulation of the milk. In a manner precisely similar, transformation takes place in the elements of vegetable caseine, from the very moment that sweet almonds are converted into almond-milk. The vegetable caseine of the almond, like animal caseine, contains sulphur, but it contains a larger proportion of nitrogen than the latter substance. The circumstance that animal caseine does not produce the same effect as a ferment in all cases is, perhaps, to be ascribed to its inferior amount of nitrogen.

With respect to their influence upon the fermentation of sugar, the properties of animal and vegetable caseine are identical. If to a solution of grape-sugar (which is the same in composition as starch-sugar and the solid part of honey) milk of almonds, or pounded almonds freed by means of *cold pressure* from their mixed or fatty oil, be added, and the mixture be kept in a warm place, it will soon run into a lively vinous fermentation, and a brandy of a peculiar, but highly agreeable, flavour, may be obtained by distillation from the fermented fluid.

Animal caseine also produces the same effect; but the vegetable caseine of almond-milk causes decompositions and transformations in a number of organic compounds, such, for instance, as salicine and amygdaline, which animal caseine does not produce.

Salicine is that constituent of the bark of the willow which imparts to it its well-known intensely bitter taste, and the property of assuming a carmine-red tint when moistened with a few drops of concentrated sulphuric acid. Salicine may be very easily extracted from willow-bark by means of water. In its pure state it presents the form of white, shining, long, needle-like crystals, interwoven with each other like a silken web. Salicine, like sugar, is devoid of nitrogen, but the salicine atom is far more complex than the sugar atom.

If salicine is placed in almond-milk, its bitter taste soon disappears, and is replaced by a purely sweet flavour. At this juncture all the salicine has vanished, and we have grape-sugar in its place, together with a new substance totally different to salicine, namely, *saligenine.*

Sugar and saligenine, together, contain the elements of salicine. An atom of salicine, upon coming into contact with the caseine of almond-milk, is resolved into one sugar atom and one saligenine atom, without the addition or withdrawal of any element whatever.

The deportment of this vegetable caseine toward amygdaline is even still more remarkable. The peculiar products which are obtained from bitter almonds were, for a long time, considered to be a problem, nearly, if not altogether, inexplicable, until amygdaline was discovered to be a constituent of bitter almonds, and the changes it undergoes from the influence of vegetable caseine were brought to light.

If bitter almonds are finely powdered, mixed with water, and submitted to distillation, an aqueous fluid is obtained, with a strong odour, exhibiting a milky appearance from a number of small oil-globules being suspended in the fluid; these globules of oil coalesce, subside, and form a stratum of oil at the bottom of the vessel. This oil is, therefore, heavier than water; it is also volatile, and has a powerful smell and taste of bitter almonds: moreover, it is characterised by the property of solidifying, when exposed to the air with the absorption of oxygen, into inodorous crystals of benzoic acid. Besides this volatile oil, —which is an article of commerce to a considerable amount, being used in perfumery,—the water passing over contains also a considerable proportion of *hydrocyanic acid.* Neither of these two products of the distillation of bitter almonds with water, namely, hydrocyanic acid and oil of bitter almonds, can be detected by any means in the bitter almond itself. Were they contained in the bitter almond, as oil of turpentine exists in the resin of the pine, or oil of roses in the rose-petals, we might, of course, feel assured that they would admit of being extracted from the almonds by means of fatty or fixed oils, or other solvents. But the fat oil, which is easily obtained from bitter almonds by pressure, is as bland and insipid as that expressed from sweet almonds; not the slightest trace of hydrocyanic acid, nor of the volatile oil of bitter almonds, can be detected in it, although both substances are readily soluble in it. If bitter almonds are boiled with alcohol, not a trace, either of hydrocyanic acid, or of the volatile oil of bitter almonds, is found in the alcohol; but, upon evaporation, a white crystalline substance is obtained, of easy solubility in water, which imparts to its solution a slightly bitter taste. This substance differs materially from sugar and salicine by invariably containing a small amount of *nitrogen*. It is termed AMYGDALINE. The discoverer of this substance concluded that the hydrocyanic acid and volatile oil of bitter almonds are formed from it, or that the elements, the combination of which furnish those two bodies, must have aggregated, through the action of alcohol, to form amygdaline. Not finding any key to this enigma, he (as is but too frequently done) ascribed the formation of amygdaline, or the transformation of its elements into hydrocyanic acid and oil of bitter almonds, to the co-operation of an intangible and invisible something, which, from its nature, must be beyond the reach of our understanding.

All these phenomena admit of a very simple explanation. We now know that upon bringing a solution of amygdaline and water into fresh almond-milk, decomposition takes place in the course of a few seconds, and the amygdaline atom, in consequence of a new mode of molecular arrangement, resolves itself into hydrocyanic acid, volatile oil of bitter almonds, sugar, formic acid, and water, the atoms of which, ninety in number, were aggregated into one group in the amygdaline atom; that is, the amygdaline is constituted of the elements of all these substances combined into a single group or atom.

The quantity of amygdaline which, under these circumstances, is, through the agency of vegetable caseine, separated into those different compounds, depends, in a certain measure, upon the amount of water present in the mixture. Whether the water is sufficient to dissolve all the new-formed products, or insufficient for that purpose, determines whether all the amygdaline or only a part of it becomes decomposed. The volatile oil of bitter almonds requires thirty parts of water for its solution, the other products require less. If, therefore, only so much amygdaline is added to the almond-milk that to thirty parts of water no more than one part of oil of bitter almonds could be formed from it, the whole of the amygdaline disappears; if more amygdaline than this proportion is added to the mixture, the amygdaline added in excess undergoes no alteration. It is very evident that the chemical affinity of the water, that is, its solvent power, plays a part in this process of transformation; its affinity or attraction for one of the products co-operates as a cause of decomposition.

Now since the white constituent of bitter almonds is absolutely identical with the vegetable caseine of sweet almonds, it may easily be conceived that the amount of amygdaline existing, as such, in almonds, depends solely upon the greater or lesser amount of moisture contained in them—a part of the amygdaline, proportionate to the amount of water present, exists in the almond only in its products. The very small amount of water existing in the almond admits a correspondingly large quantity of amygdaline to remain; but when the almonds are finely powdered and mixed up with a large amount of water—when they are converted, for instance, into almond-milk,—the amount of amygdaline decreases with the increasing proportion of water added, until, at last, upon the further addition of water, it altogether disappears.

The deportment of amygdaline, with the white caseous constituent of almonds, assumes a still higher degree of interest when we consider that the presence of amygdaline in the almonds depends upon the accidental position of the tree upon which they grow. Botanists can find no perceptible difference between two trees, one of which bears sweet, the other bitter almonds. Instances are known of trees bearing bitter almonds which, by simple transplantation, were made to produce sweet almonds; and this is certainly one of the most interesting examples of the influence which certain constituents of the soil exercise upon the vital processes of plants.

The effect of the presence of water upon the existence of certain organic combinations is abundantly evident from the foregoing facts; there are, however, other instances which may be adduced in illustration, so highly interesting in themselves, that we cannot avoid introducing them in connection with this subject.

It is well known to every one that mustard-seed, powdered, and formed into a paste with water, yields in the course of a few minutes a mixture which, placed upon the skin, produces excessive irritation, so much so as even to raise blisters. This action is caused by a volatile oil containing sulphur, but free from oxygen. This oil may be obtained from mustard by distillation with water, in the same manner as the oil of bitter almonds is obtained from bitter almonds. It is to this volatile oil that the mustard eaten at table owes its smell and taste. In its purest state it is extremely acrid and pungent. Now, in the mustard-seed there exists no trace of this oil; the oil expressed from mustard-seeds is bland and destitute of any pungency. The volatile oil is formed from a substance rich in sulphur and nitrogen, and possessing itself no pungency. This substance, by the action of the vegetable caseine contained in the mustard-seeds, undergoes decomposition immediately upon the addition of a sufficient amount of water, and the volatile pungent oil is one of the new products originating from the transposition of its elements.

As vegetable caseine, in the seeds of mustard and in almonds, exercises a decomposing influence upon other constituents of the same seeds, in consequence of the state of transformation into which it passes immediately upon coming into contact with water, so also the similarly constituted sulphur and nitrogen compounds of nearly all seeds comport themselves, and especially that contained in the grain of the cereals, well known under the term *gluten.*

The flower of wheat, rye, or any of the cereals, when mixed with twenty times its amount of water at 75° C., = 167° F., yields a thick paste, which, after the lapse of a few hours, becomes thin and fluid, and assumes a very sweet taste. The starch of the flour absorbs a certain amount of water, and, in consequence of a new manner of arrangement of its atoms, changes first into a kind of gum and then into grape-sugar. This transformation is caused by the gluten of the flour passing itself into a state of decomposition. The liquefaction of the dough in the preparation of bread depends upon the same cause.

The same formation of sugar takes place in the germination of corn. All the starch contained in wheat, barley, rye, &c., becomes, during the development of the germ, converted into sugar by the action of the adjacent particles of gluten. The gluten itself assumes quite altered properties; it becomes soluble in water like starch.

If the aqueous extract of germinated corn (malt), prepared in the brewing of beer, which is called sweet-wort, is heated to the boiling point, a quantity of the gluten which had become soluble and dissolved in it, separates in a state in which it cannot be distinguished from coagulated animal albumen. The remaining portion of the gluten is contained in the wort in the same state as the matter in the juice of the grape, which contains sulphur and nitrogen, and which is, therefore, precisely the same in constitution, so that in the fermentation of the beer it separates in the form of yeast, which exactly resembles the yeast of wine.

In living organisms we observe phenomena of a similar kind, dependent upon identically the same, or, at least, closely analogous causes. Many plants with woody stems are found to contain in autumn a matter perfectly like the starch of potatoes, or the cereals, deposited in the substance of the wood, which in the spring, when the plants re-awaken to life, becomes converted into sugar. The ascending juice of the maple is so rich in sugar that in regions where this tree occurs in such numbers as to form forests, its juice is employed in the manufacture of sugar. We have every reason to believe that this sugar is formed by a transformation of starch, in a precisely similar manner as the sugar of germinating seeds.

The maturation, as it is called, or sweetening of winter fruits, when stored up for their preservation in straw, is the result of a true fermentation. Unripe apples and pears contain a considerable amount of starch, which becomes converted into sugar by the nitrogenous constituent of the juice passing into a state of decomposition, and transmitting its own mutations to the particles of starch in contact with it.

Redtenbacher has recently found formic acid to be a product of the fermentation of the leaves and twigs of pines. This discovery is the more interesting, as it will probably enable us to explain the presence of this acid in *ants*, especially in those species of these animals which, for their nourishment, partake only of substances in which no formic acid can be found.

The skin of animals, the mucous membrane of the stomach and intestines, and the urinary bladder, have many properties in common with *gluten* and *yeast*. In their fresh state these substances exercise not the slightest influence upon starch or milk-sugar, but when placed in water for a few hours, or even when simply exposed to the atmosphere, they quickly pass into a state of decomposition, which renders them capable of converting with great rapidity starch into sugar, and milk-sugar into lactic acid.

This property of the mucous membrane of the stomach of the calf has been made use of from time immemorial, in the preparation of cheese, in order to make milk coagulate, or, in other words, to effect a separation of the cheese from the other constituents of milk.

The solubility of cheese in milk is in consequence of the presence of alkaline phosphates and of free alkalies. In fresh milk these substances may be easily detected by the property it possesses of restoring the blue colour to reddened litmus-paper. The addition of any acid, by neutralising the alkali, causes the cheese to separate in its naturally insoluble state. The acid indispensable for the coagulation of milk is not added to the milk in the preparation of cheese, but it is formed in the milk at the expense of the milk-sugar present. A small quantity of water is left in contact with a small piece of a calf's stomach for a few hours or for a night;—the water absorbs a quantity of the decomposed mucous membrane so minute as to be scarcely ponderable; this is mixed with milk; its state of transformation is communicated (and this is a most important circumstance) not to the cheese, but to the milk-sugar, the elements of which transpose themselves into lactic acid, which neutralises the alkali, and thus causes the separation of the cheese. By means of litmus-paper the process may be followed and observed through all its stages; the alkaline reaction of the milk ceases as soon as the coagulation begins. If the cheese is not immediately separated from the whey, the formation of lactic acid continues, the fluid turns acid, and the cheese itself passes into a state of decomposition.

Fresh cheese-curd, carefully freed from water and milk-sugar, by expression, and the addition of salt, is a mixture of caseine and butter; it contains all the phosphate of lime, and part of the phosphate of soda, of the milk. When kept in a cool place, a series of transformations takes place, in consequence of which it assumes entirely new properties; it gradually becomes semi-transparent, and more or less soft throughout the whole mass; it exhibits a feebly acid re-action, and developes the characteristic caseous odour. Fresh cheese is very sparingly soluble in water, but after having been left to itself for two or three years it becomes —especially if all the fat be previously removed— almost completely soluble in cold water, forming with it a solution, which, like milk, is coagulated by the addition of acetic acid or the mineral acids. The cheese which, while fresh, is insoluble, returns during the maturation, or ripening, as it is called, to a state similar to that in which it originally existed in the milk. In those English, Dutch, and Swiss cheeses which are nearly inodorous, and in the superior kinds of French cheese, the caseine of the milk is present in its unaltered state. The odour and flavour of cheese is owing to the decomposition of the butter; the non-volatile acids, margaric acid and oleic acid, and the volatile butyric acid, capric and caproic acids, are liberated in consequence of the decomposition of glycerine (the sweet principle of oils, or, as it might be termed, the sugar of oil.) Butyric acid imparts to cheese its characteristic caseous odour, and the differences in its pungency or aromatic flavour depend upon the proportion of free butyric, capric, and caproic acids present.

The transition of caseine from its insoluble into its soluble state depends upon the decomposition of the phosphate of lime by the margaric acid of the butter: margarite of lime is formed whilst the phosphoric acid combines with the caseine, forming a compound soluble in water.

The bad smell of inferior kinds of cheese, especially those called meagre or poor cheeses, is caused by certain fetid products containing sulphur, and which are formed by the decomposition or putrefaction of the caseine. The alteration which the butter undergoes (that is, in becoming rancid), or which occurs in the milk-sugar still present, being transmitted to the caseine, changes the composition of the latter substance and deteriorates its nutritive properties.

The principal conditions for the preparation of the superior kinds of cheese (other obvious circumstances being, of course, duly regarded) are, a careful removal of the whey, which holds the milk-sugar in solution, and a low temperature during the maturation (or ripening) of the cheese.*

The differences in flavour and odour of various kinds of cheese depend upon the methods employed in their manufacture—upon the state of the rennet when added to the milk—upon the

---

* The quality of Roquefort cheese, which is prepared from sheep's milk, and is very excellent, depends exclusively upon the places where the cheeses are kept after pressing, and during maturation. These are cellars, communicating with mountain grottoes and caverns, which are kept constantly cool, at about 41° to 42° Fahr., by currents of air from the clefts in the mountains. The value of these cellars, or storehouses, varies with their property of maintaining an equable and low temperature. Giron (Ann. de Chimie. et de Physique, xlv. 371) mentions, that a certain cellar, the construction of which had cost 480*l.* (12,000 francs), was sold for 8600*l.* (215,000 francs), being found to maintain a suitable temperature. A convincing proof of the importance attached to temperature in the preparation of these superior cheeses.

addition of salt, and upon the state of the atmosphere during the period of making. It must be admitted that the plants, and especially the aromatic plants, upon which the animals feed, exercise some influence upon the quality of the cheese ; but this influence is very slight, and subordinate. The milk of the cow in spring, summer, and autumn, is very unequal in its composition, but this does not occasion any perceptible difference in the cheese prepared in one and the same dairy. If the plants upon which the cows feed exercised any considerable influence upon the quality of cheese, the same pastures could not, at different seasons, furnish cheese of similar quality, inasmuch as the development and flowering of different species of plants belong to various seasons.

I have, by personal inspection, satisfied myself that the method of preparing the cheese is quite different at Chedder from that practised in Gloucestershire, and this, again, differs from the plan pursued in the manufacture of Stilton cheese.

The stomach of the calf, and the mucous membrane of the stomach of animals generally, besides the power of converting milk-sugar into lactic acid, possess the property of rendering soluble, or liquefying, solid animal matters, when weak hydrochloric acid is present. The phenomena observed in this chemical operation have thrown a new and unexpected light upon the process of DIGESTION in the living animal organism. All ferments, as they are called, that is, substances which are capable of exciting fermentation, possess also, in a certain stage of their transformation, this power of liquefying and rendering soluble various aliments. We have already seen that extract of malt, and gluten, possess this power in reference to starch, but these are far surpassed in this property by the mucous membrane of the stomach. If a small portion of calf's stomach is placed for a few hours in warm water, mixed with so small an amount of hydrochloric acid as scarcely to impart an acid taste to the water, a solution is obtained which acts upon boiled meats, upon gluten, and upon hard-boiled albumen, in exactly the same manner as the gastric juice in the living stomach. This artificial digestive fluid is like gastric juice, inasmuch as both have an acid reaction, owing to the presence of hydrochloric acid. When pieces of muscular fibre, or hard-boiled albumen, are exposed in this artificial digestive fluid to a temperature of 37° C. (the temperature of the stomach = 98.6° Fahr.), they speedily become slimy, and transparent at the edges, and after the lapse of a few hours they become dissolved in a fluid rendered slightly turbid by particles of fat. The dissolving power of the hydrochloric acid, *per se*, becomes, by the addition of a scarcely ponderable amount of mucous membrane, in a state of decomposition, accelerated so greatly, that solution takes place in a fifth part of the time which is required under ordinary circumstances.

Physiologists have observed that in digestion the whole of the inner surface of the membrane of the stomach, *the epithelium*, separates completely from the other layers of the membrane.

It cannot be disputed that this *epithelium*, in coming into contact with the oxygen which the saliva carries into the stomach, inclosed in its air-bubbles or froth, undergoes an alteration, in consequence of which the contents of the stomach are dissolved in the shortest time.

It was for a long time believed that the accelerated dissolving power, which the mucous membrane of the stomach imparts to the hydrochloric fluid, depended upon the presence of a particular substance, a kind of digestive agent. The same opinion prevailed respecting a substance contained in the extract of malt, by which starch is converted into sugar; and these substances have received certain designations.

But what have been called *pepsine* and *diastase*, are nothing more than a portion of mucous membrane, or of gluten having passed into a state of decomposition. The action of these bodies depends entirely upon their condition, just as is the case with yeast.

With a piece of the mucous membrane of the stomach, in a certain stage of decomposition, we may render certain animal substances soluble; whilst, with the same membrane, in other stages of decomposition, we may convert starch into sugar, sugar into *lactic acid*, *mannite*, and *mucus;* or, further, into *alcohol* and *carbonic acid.*

In the same manner a watery infusion of fresh malt will convert starch-paste, in the space of a few minutes, into grape-sugar. The infusion or extract of malt loses this property after the lapse of a few days, and, in its stead, acquires the power of converting grape-sugar into lactic acid, mannite, and gum. And, again, after eight or ten days, the infusion becomes turbid, and causes the resolution of the sugar atom into alcohol and carbonic acid.

The phenomena we have described, if considered in their true signification, prove that the decompositions and transformations which occur in the processes of fermentation, are effected by matter, the smallest particles or atoms of which are in a state of motion and transposition,—a state susceptible of being communicated to other atoms in contact with the former, so as to cause the atoms and elements of these latter also, in consequence of the resulting disturbance of the equilibrium of their chemical attraction, to change their position, and to arrange themselves into one or several new groups.

We have observed that the products formed during fermentation alter with the temperature, and with the state of transformation in which the particles of the ferment exist. Hence it is obvious that the new manner of molecular arrangement, which determines the nature and properties of the new-formed products, stands in a definite and immediate relation to the mode and manner, direction and energy, of the motion and force acting upon them.

All organic substances become exciters of fermentation as soon as they pass into a state of decomposition; the changing condition once imparted, propagates itself in every organic atom, which is not itself, that is, by its own inherent energy, capable of annihilating the imparted motion, by presenting an adequate resistance.

Putrefying flesh, blood, bile, urine, the mucous membrane of the stomach, have this property in common with substances occurring in certain parts of plants, or in the vegetable juices. All substances capable of exciting fermentation, that is, as we understand it, all those complex atoms which, upon the mere contact of water or of oxygen, pass into a state of decomposition, possess certain properties in common; but every one of these, also, produces certain effects peculiar to itself, and it is in this respect they differ essentially from each other. These latter peculiar and individual actions and effects stand in the closest relation to their composition. Thus, the vegetable caseine of almonds acts upon starch and sugar precisely like gluten or yeast; but gluten and yeast are not capable of resolving *salicine* into saligenine and sugar, or amygdaline into hydrocyanic acid and oil of bitter almonds.

In like manner, animal membranes, in a certain condition, acquire all the properties of fermenting animal cheese or caseine, but the latter substance has no perceptible influence upon the solvent power of hydrochloric acid, upon the liquefaction of coagulated albumen and flesh.

The total of all the phenomena of fermentation establishes the correctness of the principle long since recognised by Laplace and Berthollet, namely, *that an atom or molecule put in motion by any power whatever will communicate its own motion to another atom in contact with it.*

This is a dynamical law of the most general application, manifested everywhere, when the resistance or force opposing the motion, such as the vital principle, the force of affinity, electricity, cohesion, &c., is not sufficiently powerful to arrest the motion imparted.

This law has only recently been recognised as a cause of the alterations in forms and properties which occur in chemical combinations; and it is the greatest and most enduring acquisition which chemical science has derived from the study of fermentation.

# LETTER X.

My Dear Sir,

The immediate and most energetic cause of all the alterations and transformations which organic atoms undergo, is, as I have already stated in the preceding Letters, the chemical action of oxygen. Fermentation and putrefaction manifest themselves only in consequence of the commencement of a process of decay; their completion is the restoration of a state of equilibrium. Whilst the oxygen is in the act of combining with any one of the elements of an organic substance, the original state of equilibrium of attraction in all its elements is destroyed, the substance decomposes, resolving itself,—all the molecular attractions being again equalised,—into a series of new products, which undergo no further change in their properties unless further causes of disturbance or alteration are brought to operate upon them.

Although the chemical action which the elements of organic atoms exercise upon each other in fermentation and putrefaction balances itself, inasmuch as a state of rest is induced between the attractions of the new formed products, yet this equilibrium does not exist with respect to their attraction for oxygen. The chemical action of oxygen upon organic substances ceases only when the capacity of the elements to combine with oxygen is exhausted. That action consists in nothing more than the affinity, or tendency of the oxygen to combine with those elements. A perfect equalisation of this tendency, therefore, can only ensue when the elements, by combining with oxygen, have formed such products as are totally incapable of absorbing any additional amount of oxygen. It is only then that the attractions of the elements of organic substances attain a perfect equilibrium with the attraction of oxygen.

Fermentation or putrefaction represents the first stage of the resolution of complex atoms into more simple combinations: the process of decay completes the circulation of the elements by transposing the products of fermentation and putrefaction into gaseous compounds. Thus the elements constituting all organised beings, which previously to participating in the vital process were oxygen compounds, such as with carbon and hydrogen, reassume the form of oxygen compounds. *The process of decay is a process of combustion taking place at the common temperature,*[*] in which the products of the fermentation and putrefaction of plants and animal bodies combine gradually with the oxygen of the atmosphere.

No organised substance, no part of any plant or animal, after the extinction of the vital principle, is capable of resisting the chemical action of air and moisture; for all that power of resistance which they temporarily possessed as the bearers of life, the media of the vital manifestations, completely ceases with the death of the organism; their elements fall again under the unlimited dominion of the chemical forces.

The clearing of the primeval forests of America, facilitating the access of air to that soil, so rich in vegetable remains, alters gradually, but altogether its constitution: after the lapse of a few

---

[*] In order to avoid the ambiguity attached to the word *decay*, from its being in vernacular language applied to several processes which it is desirable to distinguish, the author proposed to substitute the term EREMACAUSIS, and this has been very generally adopted in scientific treatises, being a convenient mode of expressing the relation of decay to ordinary combustion.

years no trace of organic remains can be found in it. The soil of Germany, in the time of Tacitus, was covered with a dense, almost impenetrable forest; it must, at that period have exactly resembled the soil of America, and have been rich in humus, and vegetable substances, but all the products of vegetable life in those primeval forests have completely vanished from our perceptions. The innumerable millions of molluscous and other animals, whose remains form extensive geological formations and mountains, have, after death, passed into a state of fermentation and putrefaction, and subsequently, by the continuous action of the atmosphere, all their soft parts have been transposed into gaseous compounds, and their shells and bones, their indestructible constituents, alone remain.

It is only in localities, under peculiar circumstances, where the access of oxygen was limited or altogether precluded, that we still find distinct remains of primeval vegetables in a state of retarded or impeded decay, as for example, in beds of turf and brown coal.

The presence of water, and a suitable temperature are indispensable conditions of the oxidising process of decay, just as they are necessary to putrefaction and fermentation. Perfect dryness, or a temperature below the freezing point, suspends all processes of decay and fermentation. The transmission of decomposition from one particle to another presupposes a change of place; it requires that the particles should possess mobility, or the power of free motion, and this is imparted to them by the presence of water. In decay it is more especially a certain elevated temperature which increases the aptitude of the elements of organic substances to combine with the oxygen of the atmosphere.

A great number of organic bodies, when in a moist state, are capable of absorbing oxygen, whilst many, and indeed most of them, are *per se* entirely deficient in this property.

If we place wet saw-dust, or moistened fragments of wood, in a vessel filled with atmospheric air, all the properties of the contained air become in a very short time completely altered. If a lighted splinter,—which of course would burn in atmospheric air,—is introduced after the lapse of two to three hours, its flame will be immediately extinguished. The air confined in the vessel, if examined, will be found to have lost all its oxygen, and to have acquired an equal volume of carbonic acid gas. If a fresh supply of atmospheric air is made to replace this, the same process again occurs, all the oxygen becomes converted into carbonic acid.

In the process of bleaching in the open air, or, as it is called, grass-bleaching, we have the process of decay applied to an important purpose in the arts upon a large scale. Linen or cotton textures consist of ordinary woody fibre, more or less coloured by extraneous organic substances, which were either contained in the plant whence the fibre has been derived, or have become mixed with it during the processes of preparation.

When linen or cotton fabrics are moistened with water and exposed to the light of the sun, a slow process of combustion, or decay, immediately begins upon the whole surface; the oxygen of the atmosphere in immediate contact with the linen or cotton is incessantly converted into carbonic acid. The weight of the fabric diminishes every second, precisely because it is in a state of combustion; all the colouring matters gradually disappear and with them a considerable amount of woody fibre, their elements being converted into oxygen compounds. If this action of air and light upon the linen or cotton continues for a considerable time, these substances lose their cohesion and become converted into a matter similar to that used in the manufacture of paper, and this matter still continues to decay as long as the essential condition of this change, that is, the absorption of oxygen, proceeds.

The nitrogenous constituents of plants and animals comport themselves towards oxygen in a manner precisely similar to the behaviour of the non-nitrogenous principle we have spoken of, namely, woody fibre. Fresh meat, as well as the first products of the decomposition of the nitrogenous constituents of plants in fermentation, that is, beer-yeast or wine-yeast, withdraw oxygen from atmospheric air, and, like woody fibre, yield in return an equal volume of carbonic acid.

When the Cemetery of the Innocents at Paris was removed from the interior of the town to the outside of the barriers, the buried corpses, which had accumulated to a depth of sixty feet, were found to a great extent apparently converted into fat. The substance of the skin, muscles, cellular tissue, and tendons, all the soft parts, and even the bones, had completely disappeared, leaving only the fat, which resisting longest the influence of decay, remained in the form of stearic acid. margaric

This human fat was employed to the extent of many tons by the soap-boilers and tallow-chandlers of Paris, for the manufacture of soap and candles.

If meat be suspended in running water, or buried in moist earth, nothing of it will remain after the lapse of some time, except the fat which it contains.

All substances susceptible of decay, when in a moist state, and exposed to the air and light at the common temperature, undergo precisely the same change as they would if exposed to a red-heat, in a dry state, that is, they absorb oxygen,—they undergo combustion.

Alcohol, one of the products of the fermentation of saccharine vegetable juices, is altogether incapable of undergoing the process of decay; when exposed to the air, whether in its pure state or mixed with water, it evaporates without combining with oxygen. Alcohol is readily inflammable at a higher temperature, and in burning is resolved into carbonic acid and water. It is obvious that its elements have a powerful affinity for oxygen; the high temperature is, however, a necessary condition of the manifestation of this affinity. Hydrogen gas and many other inflammable substances, are, in this respect, precisely similar to alcohol, their affinity for oxygen manifests itself only at certain high temperatures.

In the process of decay it has been likewise observed that a substance undergoing this state of elementary transposition exercises a remarkable influence upon the particles of an adjacent substance, which, *per se,* would not be capable of passing into the same state of change, decay, or transposition.

Many substances, when in contact with another in a state of decay, manifest, at common temperatures, an affinity for oxygen; that is, they enter into combination with this element, at this low temperature, whilst under other circumstances such a combination can only be effected by a far higher degree of heat.

The active absorption of oxygen, the combustion of the decaying substance, is transmitted to the particles of other substances in contact with it; they assume its characteristic state of activity; they, like it, combine with oxygen, as if undergoing a real combustion; but how this is effected does not appear to admit any further explanation. Contact with a substance, itself undergoing the process of decay is the chief condition of decay for all organic substances which do not possess the power of combining with oxygen at common temperatures. In consequence of the ensuing combination of its elements with oxygen, the temperature of the decaying substance rises above that of the surrounding medium; but great as the influence is which heat exercises in accelerating the process, it is not in this, as in other chemical processes, the cause of the manifestation of the affinity for oxygen.

If, in a vessel filled with common atmospheric air, to which a certain amount of hydrogen gas has been added, a linen bag be suspended, filled with wet sawdust, vegetable mould, &c., the process of decay will continue just as it would if they were exposed to the open air. They will convert the surrounding oxygen into carbonic acid. But what is very remarkable in this case, the hydrogen also participates in the process—it undergoes decay; that is, from being in contact with decaying substances, it acquires the power of combining with oxygen at the common temperature. If there be a sufficient amount of oxygen present, all the hydrogen gas is converted into water.

Other inflammable gases, both simple and compound, are affected under these circumstances in exactly the same manner as hydrogen. The vapour of alcohol, for example, when in a vessel containing wood or other substances in a state of decay, absorbs oxygen from the atmosphere, and becomes transformed into aldehyde, and subsequently into acetic acid, which, upon assuming a fluid state, is withdrawn from the further influence of the oxygen.

It is upon this power of substances undergoing decay, to increase the attraction of all organic substances for oxygen, and especially the affinity of alcohol for this element, that a speedy process for acidifying alcohol is based, which is termed the "quick vinegar process."

The transformation of fermented liquors into vinegar formerly required weeks, and even months, to accomplish, in consequence of the imperfect access of the air: we can now convert alcohol into vinegar in less than twenty-four hours; and this is effected mainly by making brandy diluted with water, or any other weak spirituous liquor, trickle slowly through casks filled with wood shavings, and at the same time causing a slight stream of air to circulate through these shavings. This method exposes to the air a surface of alcohol capable of absorbing oxygen by many thousand times more extensive than the old method; and consequently the time which alcohol, under ordinary circumstances, requires for its acidification, is abridged in the same proportion. At the commencement of this process it is usual to add to the dilute spirit a small quantity of some substance containing matter capable of undergoing the process of decay, such as beer-wort, honey, vinegar, &c.; but, after the lapse of a very short time, the surface of the wood-shavings passes into a state of oxidation, and from that moment effects the transformation of the spirit into vinegar without the further co-operation of extraneous decaying matter.

The application of our knowledge respecting the phenomena attendant upon decay, to the manufacture of beer and wine, is easy and obvious. The property of beer and wine to be converted into vinegar when in contact with the air, depends invariably upon the presence of foreign matters which transmit their own inherent aptitude to absorb oxygen to the particles of alcohol in contact with them. By removing completely all such substances from wine and beer, these lose altogether the property of acidifying, or of being converted into vinegar.

In the juice of grapes poor in sugar there remains, after the completion of the process of fermentation—that is, after the resolution of the sugar into carbonic acid and alcohol—a considerable amount of nitrogenous constituents retaining the same properties which they possessed in the juice previous to fermentation. This does not happen with the juice of the grapes of southern climates. These grapes are rich in sugar, and a considerable amount of this substance remains undecomposed after all nitrogenous matters have completely separated in an insoluble state, as yeast. Such wines alter very little when exposed to the air: the red wines of this kind, however, acidify, because their colouring matter is of ready mutability, and performs, when in contact with the air, the part of the nitrogenous constituents.

The nitrogenous constituents of the grape-juice which remain in wine, after fermentation, are those ferments, or exciters of fermentation in the sugar, of which I have already spoken in previous letters. After the complete transformation of the sugar, they exercise upon the alcohol exactly the same effect as the decaying wood—they are the exciting causes of the ensuing process of acidification.

The affinity of these substances for oxygen is very powerful; during the short space of time necessary to transfer wine from one cask into another, they absorb oxygen from the air, and induce a state of acidity in the wine, which goes on irresistibly if it be not checked by artificial means. It is well known that this check is practically effected by sulphuration. A piece of sulphur is burned in the cask destined to receive the wine, the contained air is thus deprived of its oxygen, and an amount of sulphurous acid is formed equal to the volume of the oxygen. This newly-formed sulphurous acid is rapidly absorbed by the moist internal surface of the cask. Sulphurous acid possesses a stronger affinity for oxygen than the exciters of acidification in the wine. The acid is gradually diffused from the internal surface of the cask through the wine, and withdraws from those substances, as well as from the wine itself, all the oxygen they have absorbed from the atmosphere, and thus reconverts the wine into the state in which it existed previously to being transferred into the new cask. The sulphurous acid in this process becomes converted into sulphuric acid, and exists as such in the wine.

When the wine is stored up in casks to ripen, a constant, although very slow, diffusion of air takes place through the pores of the wood, or, what comes to the same thing, the wine is incessantly in contact with a minute amount of oxygen; by means of which, after the lapse of a certain time, the entire quantity of the exciters of acidification, that is, the nitrogenous substances present in the wine, oxidise and separate in the form of a sediment or dregs, termed under-yeast.

The separation of yeast from wine or beer, during the fermentation of grape-juice or of wort, takes place in consequence of the absorption of oxygen, or, in other words, is a process of oxidation, occurring in the fermenting liquid. The nitrogenous constituent of barley is in its primary state insoluble in water, but in the process of malting, or whilst the grain is germinating, it becomes soluble in water, it assumes the same condition or nature which belongs to the nitrogenous constituent of grape-juice originally.

Both these substances lose their solubility in wine, or in beer, by absorbing oxygen. According to analyses in which we may confide, made with regard to this point, wine-yeast and beer-yeast are far richer in oxygen than the nitrogenous substances from which they are derived.

As long as any particles of sugar, in a state of fermentation, are present in the fluid together with these nitrogenous matters, the fluid itself supplies the oxygen required for their transformation into yeast by the decomposition of a small amount of the sugar or of water. This oxidising process within the fluid itself, which causes the nitrogenous constituents to become insoluble, ceases with the disappearance of the sugar; but it is renewed if the fluid is reconverted into a fermenting state, by the addition of new portions of sugar, and it ensues also when the surface of the fluid is exposed to the free access of the atmosphere. In the latter case the separation of the nitrogenous constituents is effected by the atmospheric oxygen, and is thus a consequence of their decay or slow combustion.

I have already stated that the presence of nitrogenous matters in alcohol causes the transformation of the alcohol into acetic acid when there is a sufficient supply of air; now it is owing to the inequalities in their relative affinities for oxygen, that during the maturation of wine in the storehouse, when the access of air is extremely limited, that the nitrogenous substances alone oxidise, and not the alcohol. In open vessels, under these circumstances, the wine would become converted into vinegar.

The preceding remarks render it obvious that if we possessed any means of preventing the transformation of alcohol into acetic acid we should be able to preserve wine and beer for an unlimited period, and to bring these liquors into a state of perfect maturity; for, under such circumstances, all those substances which cause wine and beer to acidify would become insoluble by combining with oxygen, and separate from the liquid, and with their perfect removal the alcohol present would altogether lose the property of absorbing oxygen.

Experimental art has discovered a means of accomplishing this purpose perfectly. It consists in maintaining the fluid at a low temperature when undergoing fermentation. The method, based upon this principle, and employed in Bavaria, is one which the most perfect theory could scarcely have surpassed in certainty and simplicity, and it seems impossible to devise one more in accordance with science.

The transformation of alcohol into acetic acid by contact with a substance in a state of decay occurs most rapidly at a temperature of 95° Fahrenheit. At lower temperatures the affinity of alcohol for oxygen decreases, and at from 46° to 50° Fahrenheit no combination with oxygen takes place under these circumstances, whilst the tendency of nitrogenous substances to absorb oxygen at this low temperature is scarcely diminished in any perceptible degree.

It is, therefore, obvious that if wort be fermented in wide, open, and shallow vessels, as is done in Bavaria, which afford free and unlimited access to the atmospheric oxygen, and this in a situation where the temperature does not exceed 46° to 50° Fahrenheit, a separation of the nitrogenous constituents, *i. e.*, the exciters of acidification, takes place simultaneously on the surface, and within the whole body of the liquid. The clearing of the beer is the sign by which it is known that these matters are separated. A more or less perfectly complete removal of these nitrogenous substances, however, according to this method of fermentation, depends upon the skill and experience of the brewer. It may be easily conceived that an absolutely perfect separation of them is attained only in rare and extremely happy instances. Nevertheless, the beer obtained in this manner is invariably far superior in quality and stability to that brewed according to the common method.

The exceedingly favourable influence which the adoption of this principle must exercise upon the manufacture of wine is indisputable. It is too evident to admit of a doubt that it will lead to the adoption of a more rational method than has hitherto been employed. The reason that it has not long since been in use, and that the growers of wine have not derived from it the great advantages it is calculated to afford, is obviously their imperfect knowledge respecting it; nay, I may say the total ignorance of the great majority of wine-growers and manufacturers upon this point.

Wine prepared by this method will, of course, bear the same relation to the wine prepared in the ordinary way, that Bavarian beer bears to common beer, in the fabrication of which the same amount of malt and hops has been employed. In the shortest possible time the same quality, the same maturity, may be attained by the wine which, under ordinary circumstances, would result, only after long and protracted storing. If it be borne in mind that the period for the manufacture of wine is the end of October, just at the cool season which is peculiarly favourable to the fermentation of beer, and that no other conditions are necessary to the vinous fermentation than a cool cellar, and open, wide, shallow fermenting vessels, and further, that under all circumstances the danger of acidification is much less with wine than with beer, it is evident that the best success may confidently be expected from the application of this method.*

The method employed at most places on the Rhine proceeds upon principles the very reverse of this. The wine is left to ferment, not in cool cellars, but in rooms, situate much too high and too warm; the access of air is completely precluded during the process of fermentation by tin-plate tubes, confined with water. These tubes certainly exercise an injurious effect upon the quality of the

---

* One of the most intelligent agriculturists and wine-growers of the Grand Duchy of Baden, Baron von Babo, remarks, in a letter to me, dated April, 1843, "With respect to the application of the Bavarian method of fermentation to the manufacture of my red wine last autumn, I am happy to inform you that it answered excellently. Our wine-makers cannot understand the matter, clear and obvious as it is, that the method which it is universally acknowledged yields most excellent results in the manufacture of beer, should be as advantageously applied to making wine."

An experiment made with red wine in the autumn of 1841, by the same nobleman, had afforded the same favourable results, especially as to the colour of the wine. Before these successful experiments it might have been thought that *red* wine was the rock upon which this method would founder, but we are now assured of its universal adaptation to the manufacture of wines.

wine; they are, in every respect, futile—the invention of some idle brain; they serve no object, and yet they are used by people who are too indolent to inquire into the matter, and who are wholly incapable of assigning any reason for their adoption.

## LETTER XI.

My Dear Sir,

The property of organic substances to pass into a state of fermentation and decay, in contact with atmospheric air, and, in consequence, to transmit these states of transmutation to other organic substances, is annihilated in all cases, without exception, by heating to the boiling point. This is certainly the most striking and evident proof that the ready mutability of these substances is connected with a certain mode of arrangement of their component atoms. We need only consider the coagulation of albumen by heat, to understand the manner in which heat acts in producing this effect. Most ferments have a constitution analogous to that of albumen, and, at a higher temperature, pass into a new state.

When sweet almonds are blanched, and allowed to remain even only a few seconds in boiling water, their power of acting upon amygdaline is completely annihilated. Amygdaline dissolves without alteration in almond-milk which has been heated to the boiling point. Malt altogether loses, by boiling, its property of converting starch into sugar.

Fresh animal milk, as is well known, coagulates, after being kept for two or three days, into a gelatinous mass. If fresh milk be heated daily to the boiling point it may be preserved for an indefinite period. The state of decomposition into which the dissolved caseine passes in contact with air becomes perfectly arrested; and it requires a more protracted action of the atmosphere to excite it again. Grape-juice, so readily mutable, and every fluid susceptible of fermentation, is affected in the same manner; when heated to the boiling point all fermentation in them ceases. Beer-wort, after boiling, requires the addition of yeast, that is, an extraneous substance already itself in a state of decomposition, in order to ferment in the shortest possible time.

It is obvious that if that particular state into which an organic substance is brought by contact with the atmosphere,—although this contact may have been but for an instant,—be destroyed by a high temperature, and oxygen (the only cause of its re-appearance) from the time of its boiling be excluded, these substances must, for an unlimited period, retain all the properties they possessed at the moment of boiling. Matter *per se* has no inherent power of mobility; without the influence of some external force upon the atoms none of them change their place, none alter their properties.

If a flask be filled with grape-juice and made air-tight, and then kept for a few hours in boiling water, or until the contained grape-juice has become throughout heated to the boiling point, the minute amount of oxygen contained in the air which entered the flask with the grape-juice becomes absorbed during the operation by the constituents of the juice, and thus the cause of further perturbation is removed. The wine does not now ferment, but remains perfectly sweet until the flask is again opened, and its contents brought into contact with the air. From this moment the same alteration begins to manifest itself which fresh juice undergoes; after the lapse of a few hours the contents of the flask are in full fermentation, and this state may be again interrupted and suspended, as at first, by repeating the boiling.

The knowledge of these properties, which are equally possessed by all other organic substances, without exception, has given rise to the most beautiful practical applications of them. Whilst, in former times, during long voyages, mariners were confined to salt and smoked meats, which, in the long run, always proved injurious to health, and thousands of human beings lost their lives for the want of fresh aliments, which were even more essential in sickness, these dangers and discomforts become more and more rare at the present day. This is certainly one of the most important contributions to the practical benefit of mankind ever made by science, and for this we are indebted to Gay-Lussac.

At Leith in the neighbourhood of Edinburgh, at Aberdeen, at Bordeaux, Marseilles, and in many parts of Germany, establishments of enormous magnitude exist, in which soup, vegetables, animal substances and viands of every description are prepared and sent to the greatest distances. The prepared aliments are enclosed in canisters of tinned iron plate, the covers are soldered air-tight, and the canisters exposed to the temperature of boiling water. When this degree of heat has penetrated to the centre of the contents, which it requires about three or four hours to accomplish, the aliments have acquired a stability which, one may almost say, is eternal. When the canister is opened after the lapse of several years, the contents appear just as if they were only recently enclosed. The colour, taste, and smell of the meat are completely unaltered. This valuable method of preparing food has been adopted by many persons in my neighbourhood and other parts of Germany, and has enabled our housewives to adorn their tables with green vegetables in the midst of winter, and with dishes at all times which otherwise could be obtained only at particular seasons. This method of preserving food will become of the greatest importance in provisioning fortresses, since the loss incurred in selling off old stores, and replacing them by new, especially with respect to meat, ham, &c., is far more considerable than the value of the tin canisters, which, moreover, may be repeatedly employed after being carefully cleansed.

I cannot conclude these remarks upon these remarkable phenomena in organic matters occurring after the death of plants and animals, without mentioning a notion which some persons, and especially physiologists, have formed respecting the causes producing them. They consider the resolution of higher organic vegetable atoms, into new products, that is fermentation, to be an effect of the manifestation of the life of *vegetable beings;* and putrefaction, that is, the same process in animal substances, to be the effect of the development or presence of *animal beings.* The resolution of the sugar-atom into carbonic acid and alcohol is, according to them, caused by the growth of plants of a low organisation, or fungi, which forms the yeast or ferment. The putrefaction of animal substances they ascribe to the development of microscopic animalculæ which, in most cases, are to be found in these substances. This is not an impossible supposition. These processes of transformation *may be* effected by these fungi and these animalculæ, inasmuch as the sugar may serve as nourishment to the fungi, and the animal matter to the animalculæ. In this case the newly formed productions of fermentation and putrefaction would be products of the vital processes of these plants and animals, similar to the fluid, solid, or gaseous excrements of the higher classes of plants and animals. Or, again, it might be *possible* that the force of cohesion of the higher organic atoms should become destroyed by contact with these living exciters of fermentation or putrefaction; and thus, in consequence of the vital force active in them being directed outwardly, the chemical affinity of the complex atoms becomes disturbed, and a new direction is given to the attractions of their component atoms. These two ways of explaining the phenomena of fermentation, and putrefaction, are, however, mere hypotheses which ought to have been subjected to a rigid examination before these processes were ascribed to the presence of fungi and animalculæ. The mere presence of these creatures cannot be considered an explanation of the phenomena, because the reason why, and the manner in which, they effect the changes must first be explained. This has not been by any means done, and, with the assumption of these views, fermentation and putrefaction remain as much a mystery as ever, or become even more mysterious. The notion is objectionable, also, on account of the very nature of the explanation. I need merely remind my reader that the power has been ascribed to the animal organism of creating the lime in bones, and in the egg-shells of birds, the phosphoric acid in the brain, the iron in the colouring matter of the blood, out of matters in which they could not be traced; but that, now we have found these substances to be always constituents of the aliments, their presence in the organism is no longer any enigma. To ascribe the presence of alkalies in the ashes of plants to the procreative power of nature, or to ascribe to this power the presence of fishes in places where previously none were found, or of plants in a soil in which it was presumed there were no seeds present, are views belonging to the infancy of natural science, to a crude unformed philosophy, but now they are no longer worthy of a student of nature. Our task is to create light, and a clear understanding of things, not to involve them in obscurity or darkness. If fungi possessed the property of inducing fermentation, of causing, for instance, the resolution of sugar into alcohol and carbonic acid, we might, indeed, admit the possibility of this view; but this property belongs to no real fungus in its living state. Yeast contains carbon and nitrogen in the same proportion as the constituents of the blood. No real fungus has this constitution. There is no yeast in the juice of the grape, or in beer-wort, for this is only produced during fermentation. . Now, if fermentation be owing to the growth, development, and increase of fungi, how does it happen that pure sugar, in contact with ready-formed yeast, consisting of fully grown fungi, runs into fermentation, and this, therefore, not in consequence of their further increase and development, but from the death and disappearance of the fungi.

The fermentation of wine and of beer-wort are not isolated phenomena, they are only particular instances of innumerable other cases belonging to the same class. It cannot, therefore, be admitted that inferences should be drawn as to the ultimate causes of the phenomena in all cases from imperfect observations and utterly arbitrary hypotheses, based exclusively upon these two instances. We know that animal caseine effects, like yeast, the resolution of sugar into alcohol and carbonic acid; almond-milk possesses the same property; and in neither of these instances do we find that these exciters of fermentation exhibit at any period the particular fungoid form of wine and beer-yeast—no spores are found in them. It is altogether overlooked that the products of fermentation and putrefaction vary with the temperature and other extraneous conditions; and that the resolution of the sugar-atom into alcohol and carbonic acid, or into lactic acid, mannite, butyric acid, or fusel oil, must depend upon one and the same cause, and that the exciters of these various methods of decomposition possess no similitude whatever in these cases to vegetable beings of a low organisation, *i. e.*, to fungi. If fermentation were an effect of a vital manifestation, the exciters of fermentation must necessarily possess, in all cases, an organic form.

With respect to the opinion that putrefaction is produced by microscopic animalculæ, this may be compared to the notion of a child who ascribes the rapid fall and course of the Rhine to the number of water-mills at Mayence, the wheels of which, he thinks, drive the water down to Bingen.

Can we imagine plants and animals to be the agents in destroying and annihilating the bodies of plants and animals, when they themselves and their own constituents suffer the same processes of destruction?

If the fungus be the cause of destruction of the oak, and the microscopic animal the cause of the dissolution of the dead elephant, to what cause are we to ascribe the putrefaction of the fungus and the microscopic animal after their death? They also ferment, putrefy, decay, and disappear gradually, first in the same manner as the oak and the elephant, and in the end are resolved into the same products.

It is impossible to admit the view we are combating when we consider that the presence of the animalculæ is quite accidental, and that, in most cases, we may prevent their appearance by the exclusion of light; that animal substances may be made to pass into putrefaction and decay without any co-operation of animalculæ; that in a thousand instances, in putrefying urine, bile, blood, no such animalculæ are formed; and that, in other instances, they appear only at a certain period, when the putrefaction has proceeded for some time. To ascribe putrefaction to the presence of animalculæ is the same as to ascribe to the presence of the beetles, which feed on animal excrements, or to the maggots we find in cheese, the state of decomposition of the excrements or of the cheese.

The presence of microscopic animalculæ, often perceived in such enormous numbers in putrefying matter, is not particularly to be wondered at, since they find there the conditions of their nutrition and development. Their appearance is not more extraordinary than the migration of salmon from the sea into rivers, or the growth of salt plants in the vicinity of salt-works; the only difference lies in our ability to trace the latter in their progress; whilst the germs of the fungi, and the eggs of infusorial animalculæ, in consequence of their extreme minuteness, and the ocean of atmosphere through which they are diffused, must make their appearance everywhere, when no obstacle opposes the development of their germs or eggs.

It is quite certain that in their presence putrefaction is exceedingly accelerated. Their nutrition presupposes the consumption of particles of the animal body for their own development. Its more rapid destruction must be the necessary consequence. We know that one single individual procreates many thousands in a very short time, but their growth and development are confined within definite limits; when they have once reached a certain size, they no longer increase in bulk, whilst they continue at the same time to partake of nutriment. Then what becomes, we must ask, of the food which no longer augments their size? Must it not undergo in their organism a similar alteration to that which a piece of meat or of bone undergoes in the body of a full-grown dog, the weight of which no longer increases? We know positively that the food of the dog serves for the support of the vital processes, and that its elements receive in its organism the form of carbonic acid and urea, which latter substance becomes resolved, after being eliminated from the organism, into carbonic acid and ammonia. This food, therefore, undergoes in the body the same alteration as if it had been burned in a stove, that is, it is subjected to eremacausis or decay.

The same occurs in decaying animal substances; they serve as nourishment for microscopic animalculæ, in the bodies of which their elements decay. These animalculæ die when their means of subsistence are exhausted, and their bodies putrefy and decay, and, perhaps, serve for the nourishment and development of other races of living beings. The elements of the original substance serve, in the bodies of animalculæ, to form combinations of constituent parts of their organisms, and thus pass through a series of intermediate compounds previous to their resolution into the ultimate products of the process of decay. But the constituents of animals which enter into combination with oxygen in the organism no longer belong to the living body. During the true putrefactive process, that is, the decomposition of animal substances with the exclusion of oxygen, gases are evolved (sulphuretted hydrogen, for instance,) which exercise a deleterious influence, and speedily put a limit to the life of even the microscopic animalculæ. The excrements of man, while putrefying, never exhibit the presence of microscopic animalculæ, whilst we find abundance of them in these excrements when in a state of decay. A wise arrangement of nature has assigned to the infusoria the dead bodies of higher orders of beings for their nourishment, and has in these animalculæ created a means of limiting, to the shortest possible period, the deleterious influence which the products of dissolution and decay exercise upon the life of the higher classes of animals. The recent discoveries which have been made respecting these creatures are so extraordinary and so admirable, that they deserve to be made universally known.

Count Rumford observed that cotton, silk, wool, and other organic substances, when exposed to the light of the sun under water, after the lapse of from three to four days gave rise to the evolution of pure oxygen gas. With the appearance of the first gas-bubbles the water assumes a greenish colour, and exhibits under the microscope the presence of an immense number of minute spherical animals, to which the green hue of the water is owing. No confervæ or other microscopic plants, to which the evolution of oxygen could be ascribed, were perceived.

These observations, made about seventy years ago, have been rescued from oblivion by recent observations.

In the salt-pans of the salt-works of Rodenberg, in the electorate of Hesse, a slimy and transparent mass is formed, which covers the bottom to the depth of from one to two inches, and is everywhere interspersed with large air-bubbles, which ascend in great numbers through the supernatant fluid, when the pellicles enclosing them are torn by agitating the mass with a stick. Pfankuch upon investigation found the air enclosed in these bubbles to be such pure oxygen that a wood splinter, the flame of which has been just extinguished, rekindles into a flame when immersed in it. This observation has been confirmed by Wöhler. The microscopic investigation of the mass at the bottom of the pans proved that it consisted of living infusoria, chiefly of the species navicula and gallionella, such as occur in the siliceous fossil strata of Franzensbad, and in the paper-like formations of Friberg. After being washed and dried, the mass, upon heating, evolved ammonia, and upon incineration left white ashes, consisting of the siliceous skeletons of these animalculæ, which preserved the original form of the animal so perfectly, that they looked like the original deposit only deprived of motion. About the same time, Messrs. Ch. and A. Worren, in the "Transactions of the Academy of Brussels" (1841), showed that water, with the co-operation of organic matters, evolves a gas containing as much as 61 per cent. of oxygen; and that this phenomenon is to be ascribed to the presence of *glamidamonas pulvisculus* (Ehrenberg), and some other green and red animalculæ belonging to a still lower grade in creation. I myself took an opportunity of verifying this remarkable fact, upon finding, in a trough of water in my garden, the fluid coloured green by the presence of various species of infusoria. I filtered it through a very fine sieve, in order to separate all confervæ or vegetable matters, and then exposed it to the light of the sun in an inverted beaker glass completely full, the aperture of which was confined by water. After the lapse of a fortnight, more than thirty cubic inches of gas had collected in the glass, which proved to be very rich in oxygen.

Without venturing to draw any inference from these data with respect to the mode of nutrition of these creatures, it is certain that the water in which infusoria exist, under the influence of the solar light, contains a source of pure vital air; it is certain that, from the moment these animals are perceived in the water, this water ceases to act injuriously upon the higher orders of plants and animals; for it is impossible to conceive that water should evolve pure oxygen, which contains putrefying or decaying substances—that is, matters which are capable of combining with oxygen.

Now, if we suppose some animal matter in a state of putrefaction or decay added to water of this kind, this matter must, of course, be resolved into its ultimate products, in the presence of such a source of oxygen, in an infinitely shorter space of time than would be the case were these infusoria not present.

In the most extensively diffused animalculæ, namely, the green and red infusoria, we recognise a most admirable cause which removes from water all substances injurious to the life of the higher classes of animals, and creates in their place nutritive matters for the sustenance of plants, and the oxygen indispensable to the respiration of animals.

The infusorial animalculæ cannot be the causes of putrefaction,—of the production of poisonous matter deleterious to plants and animals,—but an

INFINITELY WISE INTENTION designs them to accelerate the transition of the elements of putrefying substances into their ultimate products.

Among the fungi and agarics there are many species which develope themselves without light, and their growth and development are attended with all the circumstances characteristic of animal life. They contaminate the air and render it unfit for respiration, by absorbing oxygen and exhaling carbonic acid: in a chemical point of view, they are like animals without the power of motion.

In contradistinction to this class of beings, which can scarcely be called plants, there exist living beings endowed with motion and provided with the characteristic organs of animals, which act in the light like green plants; they, whilst multiplying in numbers and increasing in size, create sources of oxygen, and carry it with them wherever the access of oxygen in the form of air is impeded or altogether precluded.

It is evident that infusorial animalculæ can make their appearance, develope, and multiply, only in those places where they find an abundance of the necessary nourishment in a form adapted to assimilation. Several species, and these very widely diffused infusoria, are distinguished from other species by possessing certain inorganic constituents, namely, silica, which forms the shells, or cuirasses, as they may be termed, of *naviculæ, exilaria, bacillaria*, &c., and peroxide of iron, which is a constituent of many *gallionellæ*. The carbonate of lime of the chalk animalculæ is precisely similar to the shells of the common molluscous animals.

Many persons have pleased themselves with ascribing the enormous depositions of silica, of lime, and of peroxide of iron in the siliceous fossil strata, in emery, in tripoli, in chalk, and in bog ores, to the vital process of primeval infusoria, as if the formation of these enormous geological strata could be effected solely by the vital principle! But they have altogether overlooked the circumstance that chalk, silica, and peroxide of iron, must first be present as the necessary conditions of the life of these creatures before they could be developed; and that those constituents at the present moment are never absent from the sea, the lakes, the marshes, where the same forms of animalculæ occur in a living state.

The water in which these primeval infusoria lived contained the silica and the chalk in solution, and in a condition perfectly suitable for their deposition in the form of marble, quartz, and other similar mineral masses; and this deposition would have taken place inevitably in the ordinary manner, if the water had not contained the putrefying and decaying remains of preceding races of animals, and in them the other conditions of the life of siliceous and calcareous infusoria.

Without a combination of these circumstances, —the presence of these substances constituting the conditions of their existence,—none of these species of animalculæ would have propagated and increased to form these enormous masses. These infusorial animalculæ can only be considered accidental media of the form which the minute particles of these depositions exhibit—accidental, inasmuch as even without these creatures, deposition of the silica, the lime, the peroxide of iron, would have taken place. Sea-water contains the lime of the coral animals, of the innumerable mollusks existing in this medium, in the same form and condition as it is contained in lakes and in marshes, in which the chalk animalculæ develope themselves, or those mollusks the shells of which constitute the muschelkalk formations.

It is truly marvellous that the power active in animal organisms, the vital force, should be able to form, out of only four elements, a number of compounds, infinite even in the mathematical sense of the term; that by it carbon, oxygen, hydrogen, and nitrogen, should be formed into substances possessing all the properties of metallic oxides, or of inorganic acids and salts; that upon the verge of what is termed inorganic nature, a series of organic elements begins, and becomes so extensive as to surpass the limits of our conception. We see the whole of inorganic nature, all the numerous combinations of the metals, reproduced in organic nature: with carbon and nitrogen, with carbon, hydrogen, and oxygen, with nitrogen and hydrogen, are formed compound atoms, which, in their properties, are perfectly analogous to chlorine, to oxygen, or to sulphur, or to a metallic body,—not in a few isolated points of resemblance, but in all their properties. It is scarcely possible to imagine anything more wonderful than that carbon and nitrogen should form a gaseous compound (*cyanogen*), in which metals burn with the evolution of light and heat, as in oxygen gas; a compound substance which, in its properties and deportment, is a simple substance,—an *element*, the smallest particles of which possess the same form as those of chlorine, bromine, and iodine, since it replaces them in their combinations without any alteration in the crystalline form of the compound. It is in this, and in no other way, that the living organism creates elements, metals—metalloids,—groups of atoms so arranged that the forces, active within them, acquire the power to manifest themselves in far more manifold and diverse directions than is the case with inorganic atoms. But there is no power in nature to produce substances out of nothing, none capable of creating those causes which impart to matter its properties; iron never ceases to be iron, carbon never ceases to be carbon, nor hydrogen to be hydrogen. No iron, no sulphur, no phosphorus, can be created in the living organism. The opinions we have adverted to will be looked upon half a century hence with the same smile of compassion which we bestow upon the dreams and fancies of alchemy. It belongs to human nature to form such notions, to create such hypotheses, wherever the mind, as is the case in infancy, is too little developed to comprehend the truth.

The acquisition of the most common necessaries of life is ever the fruit alone of labour and of effort. It is the same with intellectual wealth,—the knowledge necessary to increase and perfect our mental and moral powers, to obtain an insight into and an apprehension of all truth. There is *want* only where no firm WILL exists, where no adequate efforts are exerted, the necessary means and instruments exist abundantly everywhere.

THE END.

LONDON:
BRADBURY AND EVANS, PRINTERS, WHITEFRIARS.

# WORKS BY PROFESSOR LIEBIG.

---

LIEBIG'S CHEMICAL LETTERS,
FIRST SERIES.

*Second Edition, fcap. 8vo, 4s. 6d., cloth,*

## FAMILIAR LETTERS ON CHEMISTRY;
AND
ITS RELATIONS TO COMMERCE, PHYSIOLOGY,
AND AGRICULTURE.

By Justus Liebig, M.D., Professor of Chemistry in the University of Giessen. Edited by John Gardner, M.D., Member of the Chemical Society.

**"That the public will discover its merits, and that it will find its way into the drawing-room as well as the library, and be equally prized by the advanced man of science and the student, we venture to say is certain; and it must increase the respect entertained for chemistry wherever it is read."—*Chemical Gazette.***

---

NEW EDITION OF LIEBIG'S AGRICULTURAL CHEMISTRY.

*Third Edition, with large additions and very numerous alterations,*
*One Volume 8vo, price 10s. 6d., cloth.*

## CHEMISTRY
IN ITS
APPLICATIONS TO AGRICULTURE AND PHYSIOLOGY.

By Justus Liebig, M.D., Ph. D., F.R.S., Professor of Chemistry in the University of Giessen. Edited, from the Manuscript of the Author, by Lyon Playfair, Ph. D.

**"It is not too much to say, that the publication of Professor Liebig's Organic Chemistry of Agriculture constitutes an era of great importance in the history of Agricultural Science. *Its acceptance as a standard is unavoidable; for, following closely in the straight path of inductive Philosophy, the conclusions which are drawn from its data are incontrovertible.*"—"We can truly say, that we have never risen from the perusal of a book with a more thorough conviction of the profound knowledge, extensive reading, and practical research of its author, and of the invincible power and importance of its reasonings and conclusions, than we have gained from the present volume."—*Silliman's Journal.***

---

TAYLOR AND WALTON, 28, UPPER GOWER STREET.

NEW EDITION OF LIEBIG'S ANIMAL CHEMISTRY.

*One Volume* 8vo, *price* 9s. 6d., *the Second Edition, with additions, of*

## ANIMAL CHEMISTRY;

OR,

## CHEMISTRY IN ITS APPLICATIONS TO PHYSIOLOGY AND PATHOLOGY.

By Justus Liebig, M.D., Ph. D., Professor of Chemistry in the University of Giessen. Edited, from the Author's Manuscript, by William Gregory, M.D., Professor of Chemistry, King's College, Aberdeen.

**"While we have given but a very imperfect sketch of this original and profound work, we have endeavoured to convey to the reader some notion of the rich store of interesting matter which it contains. The chemist, the physiologist, the medical man, and the agriculturist, will all find in this volume many new ideas and many useful practical remarks. It is the first specimen of what modern Organic Chemistry is capable of doing for Physiology; and we have no doubt that from its appearance physiology will date a new era in her advance." —*Quarterly Review*, No. 139.**

EDITED BY PROFESSORS LIEBIG AND GREGORY.

***Seventh Edition, complete in One Vol.* 8vo, 1300 *pages,* 1*l.* 8*s. cloth,***

## TURNER'S CHEMISTRY;

Edited by Justus Liebig, M.D., Professor of Chemistry in the University of Giessen, and William Gregory, M.D., Professor of Chemistry in King's College, Aberdeen.

**"There is no English work on Chemistry which has been in so many hands, and has met with such universal approbation, as Turner's Elements; and there is scarcely any work which has received so many additions and improvements in passing through its numerous editions. The present one appears to fulfil all that can be desired of a work of this kind. In the former editions, which were conducted by the late lamented Dr. Turner, the inorganic division of the subject was treated with that clearness, perspicuity, and beauty of arrangement, so peculiarly his own; but the organic part of the work, although giving a very good general outline of this part of chemistry, was not so full as could be wished, when the almost miraculous advances of this interesting branch of the science were taken into consideration. The edition now before us, by W. Gregory and J. Liebig, leaves nothing to be desired in this respect; they have rendered it exceedingly complete, carrying out at the same time the original idea of Turner. As a compendium of the present state of chemistry, and a text-book for all beginners, we consider it as unequalled by any in the English language, and we even doubt whether there are any of the Foreign manuals, of an equal size, which can venture to compete with it."—*Chemical Gazette*, Dec. 1, 1842.**

## PORTRAIT OF PROFESSOR LIEBIG OF GIESSEN.

***Drawn by Trautschold, Engraved by Rauch. Price 7s. 6d.***

TAYLOR AND WALTON, 28, UPPER GOWER STREET.

NEW WORK ON AGRICULTURAL CHEMISTRY.

*In One Volume, small 8vo,*

## LECTURES TO FARMERS ON AGRICULTURAL CHEMISTRY.

BY ALEXANDER PETZHOLDT.

PLATTNER ON THE BLOWPIPE.

*One Volume, 12mo,*

## THE USE OF THE BLOWPIPE

In the examination of Minerals, Ores, Furnace Products, and other metallic combinations, by Professor C. F. PLATTNER, Assay-Master at the Royal Freyberg Smelting Works. Translated from the German, with Notes, by DR. JAMES SHERIDAN MUSPRATT, of the University College and Giessen Laboratories. With a Preface by Professor LIEBIG. Illustrated by numerous Wood Engravings.

CHEMISTRY APPLIED TO THE ARTS, VOLUMES 1 AND 2, 8vo,

## APPLIED CHEMISTRY;

IN MANUFACTURES, ARTS, AND DOMESTIC ECONOMY.

Edited by E. A. PARNELL, Author of "Elements of Chemical Analysis;" late Assistant Chemical Lecturer in the Medical School of St. Thomas's Hospital. With numerous Wood Engravings, and other Illustrations.

Vol. I. 13*s*. cloth lettered, contains

PRELIMINARY OBSERVATIONS, GAS ILLUMINATION, PRESERVATION OF WOOD, DYEING, AND CALICO PRINTING.

◆

Vol. II. 13*s*. cloth lettered, contains

GLASS, STARCH, TANNIN, CAOUTCHOUC, BORAX, AND THE BORACIC LAGOONS, SOAP, SULPHUR, SULPHURIC ACID, AND SODA.

◆

Vol. III. will contain

DYEING MATERIALS.

⁂ *The Article on Dyeing and Calico Printing is illustrated by Specimens of Printed Cottons.*

TAYLOR AND WALTON, 28, UPPER GOWER STREET.

NEW WORK ON ALKALIMETRY, &c.

*In One Volume* 12*mo, price* 4*s. cloth,*

## NEW METHODS OF ALKALIMETRY,

AND

## OF DETERMINING THE COMMERCIAL VALUE OF ACIDS AND MANGANESE.

By Drs. Fresenius and Will, Chemical Assistants in the Laboratory of the University of Giessen. Edited by J. Lloyd Bullock, Member of the Chemical Society, and late of the Giessen and Paris Laboratories.

This little Work will prove of the highest importance to Calico Printers, Bleachers, Dyers, Manufacturers of Soap, Paper, and Prussiate of Potash; also to Chemists and to Dealers in Alkalies, Acids, &c.

CHEMICAL ANALYSIS.

*In One Volume* 8*vo, with Diagrams on Wood, price* 10*s.* 6*d. cloth,*

## ELEMENTS OF CHEMICAL ANALYSIS,

INORGANIC AND ORGANIC.

By Edward Andrew Parnell, late Assistant Lecturer on Chemistry in the Medical School of St. Thomas's Hospital.

" As an adjunct to the exertions of the teacher, but by no means superseding the necessity of oral and practical instruction, the work of Mr. Parnell appears likely to be in the highest degree useful; it will serve to convey to the attentive student a correct notion of the general routine of operations proper to each of the different classes of analytical research, and the principles upon which such modes of proceeding have been devised, besides affording him a fund of practical detail, an easy reference to which will certainly lighten his labours and accelerate his progress."—*Chemical Gazette,* Nov. 1842.

GIESSEN LABORATORY.

*Lately imported, Price* 12*s.*

EIGHT FOLIO PLATES, REPRESENTING THE

## CHEMICAL LABORATORY OF THE UNIVERSITY OF GIESSEN.

Accompanied by a Pamphlet (in German) descriptive of the same.

DR. BENCE JONES'S APPLICATION OF LIEBIG'S PHYSIOLOGY.

*In* 8*vo,* 6*s. cloth,*

## AN APPLICATION OF LIEBIG'S PHYSIOLOGY

TO THE PREVENTION AND CURE OF GRAVEL, CALCULUS, AND GOUT.

By H. Bence Jones, M.A., Cantab.; Licentiate of the College of Physicians.

"In thus expressing our opinion of the practical value of this publication, it is satisfactory to find ourselves supported by Professor Liebig himself, under whose immediate superintendence and sanction a translation into German is now preparing."—*Pharmaceutical Journal.*

TAYLOR AND WALTON, 28, UPPER GOWER STREET.

## LARDNER (DR.) THE STEAM ENGINE EXPLAINED AND ILLUSTRATED.

With an Account of its Invention and progressive Improvement, and its application to Navigation and Railways; including also a Memoir of WATT. Seventh Edition. Illustrated by numerous Engravings on Wood, and a Portrait of Watt. 8vo, cloth, 12*s.*

CONTENTS :—

CHAPTER I. Preliminary Matter.—CHAP. II. Engines of Savery and Newcomen. —CHAP. III. Early Career and Discoveries of James Watt.—CHAP. IV. Exposition of Physical Principles.—CHAP. V. Further Discoveries of Watt.—CHAP. VI. Watt's Engines. — CHAP. VII. Double-acting Engine. — CHAP. VIII. Double-acting Engine.—CHAP. IX. Boilers and Furnaces.—CHAP. X. Life of Watt.

### CHAPTER XI.

#### LOCOMOTIVE ENGINES ON RAILWAYS.

High-pressure Engines.—Effects of Railway Transport.—History of the Locomotive Engine.—Liverpool and Manchester Railway.—Experimental Trial.—Progressive Improvement of Locomotive Engines.—Detailed Description of the most improved Locomotive Engines.—Dr. Lardner's Experiments on the Great Western Railway.—Methods of surmounting steep inclinations.

### CHAPTER XII.

#### LOCOMOTIVE ENGINES ON TURNPIKE ROADS.

Railways and Stone Roads compared. — Gurney's Steam Carriage. — Two methods of applying Locomotive Engines upon common Roads. — Hancock's Steam Carriage.

### CHAPTER XIII.

#### STEAM NAVIGATION.

Form and Arrangement of Marine Engines.—Common Paddle-wheel.—Improved Efficiency of Marine Engines.—Iron Steam Vessels.—Steam Navigation to India.

### CHAPTER XIV.

#### AMERICAN STEAM NAVIGATION.

Steam Navigation first established in America.—The Hudson navigated by Steam.—Extension and Improvement of River Navigation.—American Steamers. —Difference between them and the European Steamers.—Steam Tugs.

---

NEW CHEMICAL TABLES—IN FOLIO, PART I., Price 4*s.*

## TABLES OF THE ELEMENTARY AND COMPOUND BODIES,

SYSTEMATICALLY ARRANGED AND ADAPTED AS TABLES OF EQUIVALENTS, OR AS CHEMICAL LABELS.

By CHARLES BUTTON and WARREN DE-LA-RUE.

---

TAYLOR AND WALTON, 28, UPPER GOWER STREET.

*Just Published, price* 10*s*. 6*d*., *One Volume* 8*vo*,

# THE GREAT PHYSICIAN;

## BY JOHN GARDNER, M.D.,

MEMBER OF THE CHEMICAL SOCIETY, EDITOR OF "LIEBIG'S LETTERS ON CHEMISTRY."

THE design of the Author in this work is to study the phenomena and laws of Diseases and Remedies for the Theological truths they involve concurrently with the Holy Scriptures, where there are many statements respecting the imposition of diseases, the purposes they subserve in the Divine government, and the design of remedies, and to trace the mutual bearings of both sources of information, in this department of knowledge.

**"Mr. Gardner is a Christian man, and he writes a book in which he endeavours to make salutary use of his medical and physiological studies for religious purposes. * * * * The work evinces piety and ability, and we should be glad to find that the author has met with encouragement to proceed with his labours."—*Christian Observer.—Article on Mesmerism*, Sept. 1843.**

**"Originality is the main feature of this work, at the same time its least recommendation. Elevated piety, sound philosophy, and great professional acumen, distinguish it. The style is unaffected, calm, elegant. * * We wish all success to this truly Christian volume."—*Christian Lady's Magazine.***

**"The work before us displays learning and ability."—*Morning Chronicle.***

**"The work, 'The Great Physician,' is evidently the production of a clear-thinking head and a sound heart; the subject, a new and most interesting one. * * I am no critic; I only know when I myself am pleased, and I can only say, that, without giving an unqualified assent to some of the positions, the work, as a whole, has interested me much."—*Author of the Christian Gentleman's Daily Walk.***

HATCHARD AND SON, PICCADILLY.