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FAMILIAR LETTERS ON CHEMISTRY,

AND ITS RELATION TO COMMERCE, PHYSIOLOGY, AND AGRICULTURE,

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PREFACE

The Letters contained in this little Volume embrace some of the most

important points of the science of Chemistry, in their application

to Natural Philosophy, Physiology, Agriculture, and Commerce. Some

of them treat of subjects which have already been, or will hereafter

be, more fully discussed in my larger works. They were intended to

be mere sketches, and were written for the especial purpose of

exciting the attention of governments, and an enlightened public, to

the necessity of establishing Schools of Chemistry, and of

promoting, by every means, the study of a science so intimately

connected with the arts, pursuits, and social well-being of modern

civilised nations.

For my own part I do not scruple to avow the conviction, that ere

long, a knowledge of the principal truths of Chemistry will be

expected in every educated man, and that it will be as necessary to

the Statesman, the Political Economist, and the Practical

Agriculturist, as it is already indispensable to the Physician, and

the Manufacturer.

In Germany, such of these Letters as have been already published,

have not failed to produce some of the results anticipated. New

professorships have been established in the Universities of

Goettingen and Wuertzburg, for the express purpose of facilitating

the application of chemical truths to the practical arts of life,

and of following up the new line of investigation and research--the

bearing of Chemistry upon Physiology, Medicine, and Agriculture,--which

may be said to be only just begun.

My friend, Dr. Ernest Dieffenbach, one of my first pupils, who is

well acquainted with all the branches of Chemistry, Physics, Natural

History, and Medicine, suggested to me that a collection of these

Letters would be acceptable to the English public, which has so

favourably received my former works.

I readily acquiesced in the publication of an English edition, and

undertook to write a few additional Letters, which should embrace

some conclusions I have arrived at, in my recent investigations, in

connection with the application of chemical science to the

physiology of plants and agriculture.

My esteemed friend, Dr. Gardner, has had the kindness to revise the

manuscript and the proof sheets for publication, for which I cannot

refrain expressing my best thanks.

It only remains for me to add a hope, that this little offering may

serve to make new friends to our beautiful and useful science, and

be a remembrancer to those old friends who have, for many years

past, taken a lively interest in all my labours.

JUSTUS LIEBIG

Giessen, Aug. 1843.

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LETTERS ON CHEMISTRY

LETTER I

My dear Sir,

The influence which the science of chemistry exercises upon human

industry, agriculture, and commerce; upon physiology, medicine, and

other sciences, is now so interesting a topic of conversation

everywhere, that it may be no unacceptable present to you if I trace

in a few familiar letters some of the relations it bears to these

various sciences, and exhibit for you its actual effect upon the

present social condition of mankind.

In speaking of the present state of chemistry, its rise and

progress, I shall need no apology if, as a preliminary step, I call

your attention to the implements which the chemist employs--the

means which are indispensable to his labours and to his success.

These consist, generally, of materials furnished to us by nature,

endowed with many most remarkable properties fitting them for our

purposes; if one of them is a production of art, yet its adaptation

to the use of mankind,--the qualities which render it available to

us,--must be referred to the same source as those derived

immediately from nature.

Cork, Platinum, Glass, and Caoutchouc, are the substances to which I

allude, and which minister so essentially to modern chemical

investigations. Without them, indeed, we might have made some

progress, but it would have been slow; we might have accomplished

much, but it would have been far less than has been done with their

aid. Some persons, by the employment of expensive substances, might

have successfully pursued the science; but incalculably fewer minds

would have been engaged in its advancement. These materials have

only been duly appreciated and fully adopted within a very recent

period. In the time of Lavoisier, the rich alone could make chemical

researches; the necessary apparatus could only be procured at a very

great expense.

And first, of Glass: every one is familiar with most of the

properties of this curious substance; its transparency, hardness,

destitution of colour, and stability under ordinary circumstances:

to these obvious qualities we may add those which especially adapt

it to the use of the chemist, namely, that it is unaffected by most

acids or other fluids contained within it. At certain temperatures

it becomes more ductile and plastic than wax, and may be made to

assume in our hands, before the flame of a common lamp, the form of

every vessel we need to contain our materials, and of every

apparatus required to pursue our experiments.

Then, how admirable and valuable are the properties of Cork! How

little do men reflect upon the inestimable worth of so common a

substance! How few rightly esteem the importance of it to the

progress of science, and the moral advancement of mankind!--There is

no production of nature or art equally adapted to the purposes to

which the chemist applies it. Cork consists of a soft, highly

elastic substance, as a basis, having diffused throughout a matter

with properties resembling wax, tallow, and resin, yet dissimilar to

all of these, and termed suberin. This renders it perfectly

impermeable to fluids, and, in a great measure, even to gases. It is

thus the fittest material we possess for closing our bottles, and

retaining their contents. By its means, and with the aid of

Caoutchouc, we connect our vessels and tubes of glass, and construct

the most complicated apparatus. We form joints and links of

connexion, adapt large apertures to small, and thus dispense

altogether with the aid of the brassfounder and the mechanist. Thus

the implements of the chemist are cheaply and easily procured,

immediately adapted to any purpose, and readily repaired or altered.

Again, in investigating the composition of solid bodies,--of

minerals,--we are under the necessity of bringing them into a liquid

state, either by solution or fusion. Now vessels of glass, of

porcelain, and of all non-metallic substances, are destroyed by the

means we employ for that purpose,--are acted upon by many acids, by

alkalies and the alkaline carbonates. Crucibles of gold and silver

would melt at high temperatures. But we have a combination of all

the qualities we can desire in Platinum. This metal was only first

adapted to these uses about fifty years since. It is cheaper than

gold, harder and more durable than silver, infusible at all

temperatures of our furnaces, and is left intact by acids and

alkaline carbonates. Platinum unites all the valuable properties of

gold and of porcelain, resisting the action of heat, and of almost

all chemical agents.

As no mineral analysis could be made perfectly without platinum

vessels, had we not possessed this metal, the composition of

minerals would have yet remained unknown; without cork and

caoutchouc we should have required the costly aid of the mechanician

at every step. Even without the latter of these adjuncts our

instruments would have been far more costly and fragile. Possessing

all these gifts of nature, we economise incalculably our time--to us

more precious than money!

Such are our instruments. An equal improvement has been accomplished

in our laboratory. This is no longer the damp, cold, fireproof vault

of the metallurgist, nor the manufactory of the druggist, fitted up

with stills and retorts. On the contrary, a light, warm, comfortable

room, where beautifully constructed lamps supply the place of

furnaces, and the pure and odourless flame of gas, or of spirits of

wine, supersedes coal and other fuel, and gives us all the fire we

need; where health is not invaded, nor the free exercise of thought

impeded: there we pursue our inquiries, and interrogate Nature to

reveal her secrets.

To these simple means must be added "The Balance," and then we

possess everything which is required for the most extensive

researches.

The great distinction between the manner of proceeding in chemistry

and natural philosophy is, that one weighs, the other measures. The

natural philosopher has applied his measures to nature for many

centuries, but only for fifty years have we attempted to advance our

philosophy by weighing.

For all great discoveries chemists are indebted to the

"balance"--that incomparable instrument which gives permanence to

every observation, dispels all ambiguity, establishes truth, detects

error, and guides us in the true path of inductive science.

The balance, once adopted as a means of investigating nature, put an

end to the school of Aristotle in physics. The explanation of

natural phenomena by mere fanciful speculations, gave place to a

true natural philosophy. Fire, air, earth, and water, could no

longer be regarded as elements. Three of them could henceforth be

considered only as significative of the forms in which all matter

exists. Everything with which we are conversant upon the surface of

the earth is solid, liquid, or aeriform; but the notion of the

elementary nature of air, earth, and water, so universally held, was

now discovered to belong to the errors of the past.

Fire was found to be but the visible and otherwise perceptible

indication of changes proceeding within the, so called, elements.

Lavoisier investigated the composition of the atmosphere and of

water, and studied the many wonderful offices performed by an

element common to both in the scheme of nature, namely, oxygen: and

he discovered many of the properties of this elementary gas.

After his time, the principal problem of chemical philosophers was

to determine the composition of the solid matters composing the

earth. To the eighteen metals previously known were soon added

twenty-four discovered to be constituents of minerals. The great

mass of the earth was shown to be composed of metals in combination

with oxygen, to which they are united in one, two, or more definite

and unalterable proportions, forming compounds which are termed

metallic oxides, and these, again, combined with oxides of other

bodies, essentially different to metals, namely, carbon and

silicium. If to these we add certain compounds of sulphur with

metals, in which the sulphur takes the place of oxygen, and forms

sulphurets, and one other body,--common salt,--(which is a compound

of sodium and chlorine), we have every substance which exists in a

solid form upon our globe in any very considerable mass. Other

compounds, innumerably various, are found only in small scattered

quantities.

The chemist, however, did not remain satisfied with the separation

of minerals into their component elements, i.e. their analysis; but

he sought by synthesis, i.e. by combining the separate elements and

forming substances similar to those constructed by nature, to prove

the accuracy of his processes and the correctness of his

conclusions. Thus he formed, for instance, pumice-stone, feldspar,

mica, iron pyrites, &c. artificially.

But of all the achievements of inorganic chemistry, the artificial

formation of lapis lazuli was the most brilliant and the most

conclusive. This mineral, as presented to us by nature, is

calculated powerfully to arrest our attention by its beautiful

azure-blue colour, its remaining unchanged by exposure to air or to

fire, and furnishing us with a most valuable pigment, Ultramarine,

more precious than gold!

The analysis of lapis lazuli represented it to be composed of

silica, alumina, and soda, three colourless bodies, with sulphur and

a trace of iron. Nothing could be discovered in it of the nature of

a pigment, nothing to which its blue colour could be referred, the

cause of which was searched for in vain. It might therefore have

been supposed that the analyst was here altogether at fault, and

that at any rate its artificial production must be impossible.

Nevertheless, this has been accomplished, and simply by combining in

the proper proportions, as determined by analysis, silica, alumina,

soda, iron, and sulphur. Thousands of pounds weight are now

manufactured from these ingredients, and this artificial ultramarine

is as beautiful as the natural, while for the price of a single

ounce of the latter we may obtain many pounds of the former.

With the production of artificial lapis lazuli, the formation of

mineral bodies by synthesis ceased to be a scientific problem to the

chemist; he has no longer sufficient interest in it to pursue the

subject. He may now be satisfied that analysis will reveal to him

the true constitution of minerals. But to the mineralogist and

geologist it is still in a great measure an unexplored field,

offering inquiries of the highest interest and importance to their

pursuits.

After becoming acquainted with the constituent elements of all the

substances within our reach and the mutual relations of these

elements, the remarkable transmutations to which the bodies are

subject under the influence of the vital powers of plants and

animals, became the principal object of chemical investigations, and

the highest point of interest. A new science, inexhaustible as life

itself, is here presented us, standing upon the sound and solid

foundation of a well established inorganic chemistry. Thus the

progress of science is, like the development of nature's works,

gradual and expansive. After the buds and branches spring forth the

leaves and blossoms, after the blossoms the fruit.

Chemistry, in its application to animals and vegetables, endeavours

jointly with physiology to enlighten us respecting the mysterious

processes and sources of organic life.

LETTER II

My dear Sir,

In my former letter I reminded you that three of the supposed

elements of the ancients represent the forms or state in which all

the ponderable matter of our globe exists; I would now observe, that

no substance possesses absolutely any one of those conditions; that

modern chemistry recognises nothing unchangeably solid, liquid, or

aeriform: means have been devised for effecting a change of state in

almost every known substance. Platinum, alumina, and rock crystal,

it is true, cannot be liquified by the most intense heat of our

furnaces, but they melt like wax before the flame of the

oxy-hydrogen blowpipe. On the other hand, of the twenty-eight

gaseous bodies with which we are acquainted, twenty-five may be

reduced to a liquid state, and one into a solid. Probably, ere long,

similar changes of condition will be extended to every form of

matter.

There are many things relating to this condensation of the gases

worthy of your attention. Most aeriform bodies, when subjected to

compression, are made to occupy a space which diminishes in the

exact ratio of the increase of the compressing force. Very

generally, under a force double or triple of the ordinary

atmospheric pressure, they become one half or one third their former

volume. This was a long time considered to be a law, and known as

the law of Marriotte; but a more accurate study of the subject has

demonstrated that this law is by no means of general application.

The volume of certain gases does not decrease in the ratio of the

increase of the force used to compress them, but in some, a

diminution of their bulk takes place in a far greater degree as the

pressure increases.

Again, if ammoniacal gas is reduced by a compressing force to

one-sixth of its volume, or carbonic acid is reduced to one

thirty-sixth, a portion of them loses entirely the form of a gas,

and becomes a liquid, which, when the pressure is withdrawn, assumes

again in an instant its gaseous state--another deviation from the

law of Marriotte.

Our process for reducing gases into fluids is of admirable

simplicity. A simple bent tube, or a reduction of temperature by

artificial means, have superseded the powerful compressing machines

of the early experimenters.

The cyanuret of mercury, when heated in an open glass tube, is

resolved into cyanogen gas and metallic mercury; if this substance

is heated in a tube hermetically sealed, the decomposition occurs as

before, but the gas, unable to escape, and shut up in a space

several hundred times smaller than it would occupy as gas under the

ordinary atmospheric pressure, becomes a fluid in that part of the

tube which is kept cool.

When sulphuric acid is poured upon limestone in an open vessel,

carbonic acid escapes with effervescence as a gas, but if the

decomposition is effected in a strong, close, and suitable vessel of

iron, we obtain the carbonic acid in the state of liquid. In this

manner it may be obtained in considerable quantities, even many

pounds weight. Carbonic acid is separated from other bodies with

which it is combined as a fluid under a pressure of thirty-six

atmospheres.

The curious properties of fluid carbonic acid are now generally

known. When a small quantity is permitted to escape into the

atmosphere, it assumes its gaseous state with extraordinary

rapidity, and deprives the remaining fluid of caloric so rapidly

that it congeals into a white crystalline mass like snow: at first,

indeed, it was thought to be really snow, but upon examination it

proved to be pure frozen carbonic acid. This solid, contrary to

expectation, exercises only a feeble pressure upon the surrounding

medium. The fluid acid inclosed in a glass tube rushes at once, when

opened, into a gaseous state, with an explosion which shatters the

tube into fragments; but solid carbonic acid can be handled without

producing any other effect than a feeling of intense cold. The

particles of the carbonic acid being so closely approximated in the

solid, the whole force of cohesive attraction (which in the fluid is

weak) becomes exerted, and opposes its tendency to assume its

gaseous state; but as it receives heat from surrounding bodies, it

passes into gas gradually and without violence. The transition of

solid carbonic acid into gas deprives all around it of caloric so

rapidly and to so great an extent, that a degree of cold is produced

immeasurably great, the greatest indeed known. Ten, twenty, or more

pounds weight of mercury, brought into contact with a mixture of

ether and solid carbonic acid, becomes in a few moments firm and

malleable. This, however, cannot be accomplished without

considerable danger. A melancholy accident occurred at Paris, which

will probably prevent for the future the formation of solid carbonic

acid in these large quantities, and deprive the next generation of

the gratification of witnessing these curious experiments. Just

before the commencement of the lecture in the Laboratory of the

Polytechnic School, an iron cylinder, two feet and a half long and

one foot in diameter, in which carbonic acid had been developed for

experiment before the class, burst, and its fragments were scattered

about with the most tremendous force; it cut off both the legs of

the assistant and killed him on the spot. This vessel, formed of the

strongest cast-iron, and shaped like a cannon, had often been

employed to exhibit experiments in the presence of the students. We

can scarcely think, without shuddering, of the dreadful calamity

such an explosion would have occasioned in a hall filled with

spectators.

When we had ascertained the fact of gases becoming fluid under the

influence of cold or pressure, a curious property possessed by

charcoal, that of absorbing gas to the extent of many times its

volume,--ten, twenty, or even as in the case of ammoniacal gas or

muriatic acid gas, eighty or ninety fold,--which had been long

known, no longer remained a mystery. Some gases are absorbed and

condensed within the pores of the charcoal, into a space several

hundred times smaller than they before occupied; and there is now no

doubt they there become fluid, or assume a solid state. As in a

thousand other instances, chemical action here supplants mechanical

forces. Adhesion or heterogeneous attraction, as it is termed,

acquired by this discovery a more extended meaning; it had never

before been thought of as a cause of change of state in matter; but

it is now evident that a gas adheres to the surface of a solid body

by the same force which condenses it into a liquid.

The smallest amount of a gas,--atmospheric air for instance,--can be

compressed into a space a thousand times smaller by mere mechanical

pressure, and then its bulk must be to the least measurable surface

of a solid body, as a grain of sand to a mountain. By the mere

effect of mass,--the force of gravity,--gaseous molecules are

attracted by solids and adhere to their surfaces; and when to this

physical force is added the feeblest chemical affinity, the

liquifiable gases cannot retain their gaseous state. The amount of

air condensed by these forces upon a square inch of surface is

certainly not measurable; but when a solid body, presenting several

hundred square feet of surface within the space of a cubic inch, is

brought into a limited volume of gas, we may understand why that

volume is diminished, why all gases without exception are absorbed.

A cubic inch of charcoal must have, at the lowest computation, a

surface of one hundred square feet. This property of absorbing gases

varies with different kinds of charcoal: it is possessed in a higher

degree by those containing the most pores, i.e. where the pores are

finer; and in a lower degree in the more spongy kinds, i.e. where

the pores are larger.

In this manner every porous body--rocks, stones, the clods of the

fields, &c.,--imbibe air, and therefore oxygen; the smallest solid

molecule is thus surrounded by its own atmosphere of condensed

oxygen; and if in their vicinity other bodies exist which have an

affinity for oxygen, a combination is effected. When, for instance,

carbon and hydrogen are thus present, they are converted into

nourishment for vegetables,--into carbonic acid and water. The

development of heat when air is imbibed, and the production of steam

when the earth is moistened by rain, are acknowledged to be

consequences of this condensation by the action of surfaces.

But the most remarkable and interesting case of this kind of action

is the imbibition of oxygen by metallic platinum. This metal, when

massive, is of a lustrous white colour, but it may be brought, by

separating it from its solutions, into so finely divided a state,

that its particles no longer reflect light, and it forms a powder as

black as soot. In this condition it absorbs eight hundred times its

volume of oxygen gas, and this oxygen must be contained within it in

a state of condensation very like that of fluid water.

When gases are thus condensed, i.e. their particles made to

approximate in this extraordinary manner, their properties can be

palpably shown. Their chemical actions become apparent as their

physical characteristic disappears. The latter consists in the

continual tendency of their particles to separate from each other;

and it is easy to imagine that this elasticity of gaseous bodies is

the principal impediment to the operation of their chemical force;

for this becomes more energetic as their particles approximate. In

that state in which they exist within the pores or upon the surface

of solid bodies, their repulsion ceases, and their whole chemical

action is exerted. Thus combinations which oxygen cannot enter into,

decompositions which it cannot effect while in the state of gas,

take place with the greatest facility in the pores of platinum

containing condensed oxygen. When a jet of hydrogen gas, for

instance, is thrown upon spongy platinum, it combines with the

oxygen condensed in the interior of the mass; at their point of

contact water is formed, and as the immediate consequence heat is

evolved; the platinum becomes red hot and the gas is inflamed. If we

interrupt the current of the gas, the pores of the platinum become

instantaneously filled again with oxygen; and the same phenomenon

can be repeated a second time, and so on interminably.

In finely pulverised platinum, and even in spongy platinum, we

therefore possess a perpetuum mobile--a mechanism like a watch which

runs out and winds itself up--a force which is never

exhausted--competent to produce effects of the most powerful kind,

and self-renewed ad infinitum.

Many phenomena, formerly inexplicable, are satisfactorily explained

by these recently discovered properties of porous bodies. The

metamorphosis of alcohol into acetic acid, by the process known as

the quick vinegar manufacture, depends upon principles, at a

knowledge of which we have arrived by a careful study of these

properties.

LETTER III

My dear Sir,

The manufacture of soda from common culinary salt, may be regarded

as the foundation of all our modern improvements in the domestic

arts; and we may take it as affording an excellent illustration of

the dependence of the various branches of human industry and

commerce upon each other, and their relation to chemistry.

Soda has been used from time immemorial in the manufacture of soap

and glass, two chemical productions which employ and keep in

circulation an immense amount of capital. The quantity of soap

consumed by a nation would be no inaccurate measure whereby to

estimate its wealth and civilisation. Of two countries, with an

equal amount of population, the wealthiest and most highly civilised

will consume the greatest weight of soap. This consumption does not

subserve sensual gratification, nor depend upon fashion, but upon

the feeling of the beauty, comfort, and welfare, attendant upon

cleanliness; and a regard to this feeling is coincident with wealth

and civilisation. The rich in the middle ages concealed a want of

cleanliness in their clothes and persons under a profusion of costly

scents and essences, whilst they were more luxurious in eating and

drinking, in apparel and horses. With us a want of cleanliness is

equivalent to insupportable misery and misfortune.

Soap belongs to those manufactured products, the money value of

which continually disappears from circulation, and requires to be

continually renewed. It is one of the few substances which are

entirely consumed by use, leaving no product of any worth. Broken

glass and bottles are by no means absolutely worthless; for rags we

may purchase new cloth, but soap-water has no value whatever. It

would be interesting to know accurately the amount of capital

involved in the manufacture of soap; it is certainly as large as

that employed in the coffee trade, with this important difference as

respects Germany, that it is entirely derived from our own soil.

France formerly imported soda from Spain,--Spanish sodas being of

the best quality--at an annual expenditure of twenty to thirty

millions of francs. During the war with England the price of soda,

and consequently of soap and glass, rose continually; and all

manufactures suffered in consequence.

The present method of making soda from common salt was discovered by

Le Blanc at the end of the last century. It was a rich boon for

France, and became of the highest importance during the wars of

Napoleon. In a very short time it was manufactured to an

extraordinary extent, especially at the seat of the soap

manufactories. Marseilles possessed for a time a monopoly of soda

and soap. The policy of Napoleon deprived that city of the

advantages derived from this great source of commerce, and thus

excited the hostility of the population to his dynasty, which became

favourable to the restoration of the Bourbons. A curious result of

an improvement in a chemical manufacture! It was not long, however,

in reaching England.

In order to prepare the soda of commerce (which is the carbonate)

from common salt, it is first converted into Glauber's salt

(sulphate of soda). For this purpose 80 pounds weight of

concentrated sulphuric acid (oil of vitriol) are required to 100

pounds of common salt. The duty upon salt checked, for a short time,

the full advantage of this discovery; but when the Government

repealed the duty, and its price was reduced to its minimum, the

cost of soda depended upon that of sulphuric acid.

The demand for sulphuric acid now increased to an immense extent;

and, to supply it, capital was embarked abundantly, as it afforded

an excellent remuneration. The origin and formation of sulphuric

acid was studied most carefully; and from year to year, better,

simpler, and cheaper methods of making it were discovered. With

every improvement in the mode of manufacture, its price fell; and

its sale increased in an equal ratio.

Sulphuric acid is now manufactured in leaden chambers, of such

magnitude that they would contain the whole of an ordinary-sized

house. As regards the process and the apparatus, this manufacture

has reached its acme--scarcely is either susceptible of improvement.

The leaden plates of which the chambers are constructed, requiring

to be joined together with lead (since tin or solder would be acted

on by the acid), this process was, until lately, as expensive as the

plates themselves; but now, by means of the oxy-hydrogen blowpipe,

the plates are cemented together at their edges by mere fusion,

without the intervention of any kind of solder.

And then, as to the process: according to theory, 100 pounds weight

of sulphur ought to produce 306 pounds of sulphuric acid; in

practice 300 pounds are actually obtained; the amount of loss is

therefore too insignificant for consideration.

Again; saltpetre being indispensable in making sulphuric acid, the

commercial value of that salt had formerly an important influence

upon its price. It is true that 100 pounds of saltpetre only are

required to 1000 pounds of sulphur; but its cost was four times

greater than an equal weight of the latter.

Travellers had observed near the small seaport of Yquiqui, in the

district of Atacama, in Peru, an efflorescence covering the ground

over extensive districts. This was found to consist principally of

nitrate of soda. Advantage was quickly taken of this discovery. The

quantity of this valuable salt proved to be inexhaustible, as it

exists in beds extending over more than 200 square miles. It was

brought to England at less than half the freight of the East India

saltpetre (nitrate of potassa); and as, in the chemical manufacture

neither the potash nor the soda were required, but only the nitric

acid, in combination with the alkali, the soda-saltpetre of South

America soon supplanted the potash-nitre of the East. The

manufacture of sulphuric acid received a new impulse; its price was

much diminished without injury to the manufacturer; and, with the

exception of fluctuations caused by the impediments thrown in the

way of the export of sulphur from Sicily, it soon became reduced to

a minimum, and remained stationary.

Potash-saltpetre is now only employed in the manufacture of

gunpowder; it is no longer in demand for other purposes; and thus,

if Government effect a saving of many hundred thousand pounds

annually in gunpowder, this economy must be attributed to the

increased manufacture of sulphuric acid.

We may form an idea of the amount of sulphuric acid consumed, when

we find that 50,000 pounds weight are made by a small manufactory,

and from 200,000 to 600,000 pounds by a large one annually. This

manufacture causes immense sums to flow annually into Sicily. It has

introduced industry and wealth into the arid and desolate districts

of Atacama. It has enabled us to obtain platina from its ores at a

moderate and yet remunerating price; since the vats employed for

concentrating this acid are constructed of this metal, and cost from

1000l. to 2000l. sterling. It leads to frequent improvements in the

manufacture of glass, which continually becomes cheaper and more

beautiful. It enables us to return to our fields all their potash--a

most valuable and important manure--in the form of ashes, by

substituting soda in the manufacture of glass and soap.

It is impossible to trace, within the compass of a letter, all the

ramifications of this tissue of changes and improvements resulting

from one chemical manufacture; but I must still claim your attention

to a few more of its most important and immediate results. I have

already told you, that in the manufacture of soda from culinary

salt, it is first converted into sulphate of soda. In this first

part of the process, the action of sulphuric acid produces muriatic

acid to the extent of one-and-a-half the amount of the sulphuric

acid employed. At first, the profit upon the soda was so great, that

no one took the trouble to collect the muriatic acid: indeed it had

no commercial value. A profitable application of it was, however,

soon discovered: it is a compound of chlorine, and this substance

may be obtained from it purer than from any other source. The

bleaching power of chlorine has long been known; but it was only

employed upon a large scale after it was obtained from this

residuary muriatic acid, and it was found that in combination with

lime it could be transported to distances without inconvenience.

Thenceforth it was used for bleaching cotton; and, but for this new

bleaching process, it would scarcely have been possible for the

cotton manufacture of Great Britain to have attained its present

enormous extent,--it could not have competed in price with France

and Germany. In the old process of bleaching, every piece must be

exposed to the air and light during several weeks in the summer, and

kept continually moist by manual labour. For this purpose, meadow

land, eligibly situated, was essential. Now a single establishment

near Glasgow bleaches 1400 pieces of cotton daily, throughout the

year. What an enormous capital would be required to purchase land

for this purpose! How greatly would it increase the cost of

bleaching to pay interest upon this capital, or to hire so much land

in England! This expense would scarcely have been felt in Germany.

Besides the diminished expense, the cotton stuffs bleached with

chlorine suffer less in the hands of skilful workmen than those

bleached in the sun; and already the peasantry in some parts of

Germany have adopted it, and find it advantageous.

Another use to which cheap muriatic acid is applied, is the

manufacture of glue from bones. Bone contains from 30 to 36 per

cent. of earthy matter--chiefly phosphate of lime, and the remainder

is gelatine. When bones are digested in muriatic acid they become

transparent and flexible like leather, the earthy matter is

dissolved, and after the acid is all carefully washed away, pieces

of glue of the same shape as the bones remain, which are soluble in

hot water and adapted to all the purposes of ordinary glue, without

further preparation.

Another important application of sulphuric acid may be adduced;

namely, to the refining of silver and the separation of gold, which

is always present in some proportion in native silver. Silver, as it

is usually obtained from mines in Europe, contains in 16 ounces, 6

to 8 ounces of copper. When used by the silversmith, or in coining,

16 ounces must contain in Germany 13 ounces of silver, in England

about 14 1/2. But this alloy is always made artificially by mixing

pure silver with the due proportion of the copper; and for this

purpose the silver must be obtained pure by the refiner. This he

formerly effected by amalgamation, or by roasting it with lead; and

the cost of this process was about 2l. for every hundred-weight of

silver. In the silver so prepared, about 1/1200 to 1/2000th part of

gold remained; to effect the separation of this by nitrio-hydrochloric

acid was more expensive than the value of the gold; it was therefore

left in utensils, or circulated in coin, valueless. The copper, too,

of the native silver was no use whatever. But the 1/1000th part of

gold, being about one and a half per cent. of the value of the silver,

now covers the cost of refining, and affords an adequate profit to

the refiner; so that he effects the separation of the copper, and

returns to his employer the whole amount of the pure silver, as well

as the copper, without demanding any payment: he is amply remunerated

by that minute portion of gold. The new process of refining is a most

beautiful chemical operation: the granulated metal is boiled in

concentrated sulphuric acid, which dissolves both the silver and the

copper, leaving the gold nearly pure, in the form of a black powder.

The solution is then placed in a leaden vessel containing metallic

copper; this is gradually dissolved, and the silver precipitated in

a pure metallic state. The sulphate of copper thus formed is also a

valuable product, being employed in the manufacture of green and

blue pigments.

Other immediate results of the economical production of sulphuric

acid, are the general employment of phosphorus matches, and of

stearine candles, that beautiful substitute for tallow and wax.

Twenty-five years ago, the present prices and extensive applications

of sulphuric and muriatic acids, of soda, phosphorus, &c., would

have been considered utterly impossible. Who is able to foresee what

new and unthought-of chemical productions, ministering to the

service and comforts of mankind, the next twenty-five years may

produce?

After these remarks you will perceive that it is no exaggeration to

say, we may fairly judge of the commercial prosperity of a country

from the amount of sulphuric acid it consumes. Reflecting upon the

important influence which the price of sulphur exercises upon the

cost of production of bleached and printed cotton stuffs, soap,

glass, &c., and remembering that Great Britain supplies America,

Spain, Portugal, and the East, with these, exchanging them for raw

cotton, silk, wine, raisins, indigo, &c., &c., we can understand why

the English Government should have resolved to resort to war with

Naples, in order to abolish the sulphur monopoly, which the latter

power attempted recently to establish. Nothing could be more opposed

to the true interests of Sicily than such a monopoly; indeed, had it

been maintained a few years, it is highly probable that sulphur, the

source of her wealth, would have been rendered perfectly valueless

to her. Science and industry form a power to which it is dangerous

to present impediments. It was not difficult to perceive that the

issue would be the entire cessation of the exportation of sulphur

from Sicily. In the short period the sulphur monopoly lasted,

fifteen patents were taken out for methods to obtain back the

sulphuric acid used in making soda. Admitting that these fifteen

experiments were not perfectly successful, there can be no doubt it

would ere long have been accomplished. But then, in gypsum,

(sulphate of lime), and in heavy-spar, (sulphate of barytes), we

possess mountains of sulphuric acid; in galena, (sulphate of lead),

and in iron pyrites, we have no less abundance of sulphur. The

problem is, how to separate the sulphuric acid, or the sulphur, from

these native stores. Hundreds of thousands of pounds weight of

sulphuric acid were prepared from iron pyrites, while the high price

of sulphur consequent upon the monopoly lasted. We should probably

ere long have triumphed over all difficulties, and have separated it

from gypsum. The impulse has been given, the possibility of the

process proved, and it may happen in a few years that the

inconsiderate financial speculation of Naples may deprive her of

that lucrative commerce. In like manner Russia, by her prohibitory

system, has lost much of her trade in tallow and potash. One country

purchases only from absolute necessity from another, which excludes

her own productions from her markets. Instead of the tallow and

linseed oil of Russia, Great Britain now uses palm oil and cocoa-nut

oil of other countries. Precisely analogous is the combination of

workmen against their employers, which has led to the construction

of many admirable machines for superseding manual labour. In

commerce and industry every imprudence carries with it its own

punishment; every oppression immediately and sensibly recoils upon

the head of those from whom it emanates.

LETTER IV

My dear Sir,

One of the most influential causes of improvement in the social

condition of mankind is that spirit of enterprise which induces men

of capital to adopt and carry out suggestions for the improvement of

machinery, the creation of new articles of commerce, or the cheaper

production of those already in demand; and we cannot but admire the

energy with which such men devote their talents, their time, and

their wealth, to realise the benefits of the discoveries and

inventions of science. For even when these are expended upon objects

wholly incapable of realisation,--nay, even when the idea which

first gave the impulse proves in the end to be altogether

impracticable or absurd, immediate good to the community generally

ensues; some useful and perhaps unlooked-for result flows directly,

or springs ultimately, from exertions frustrated in their main

design. Thus it is also in the pursuit of science. Theories lead to

experiments and investigations; and he who investigates will

scarcely ever fail of being rewarded by discoveries. It may be,

indeed, the theory sought to be established is entirely unfounded in

nature; but while searching in a right spirit for one thing, the

inquirer may be rewarded by finding others far more valuable than

those which he sought.

At the present moment, electro-magnetism, as a moving power, is

engaging great attention and study; wonders are expected from its

application to this purpose. According to the sanguine expectations

of many persons, it will shortly be employed to put into motion

every kind of machinery, and amongst other things it will be applied

to impel the carriages of railroads, and this at so small a cost,

that expense will no longer be matter of consideration. England is

to lose her superiority as a manufacturing country, inasmuch as her

vast store of coals will no longer avail her as an economical source

of motive power. "We," say the German cultivators of this science,

"have cheap zinc, and, how small a quantity of this metal is

required to turn a lathe, and consequently to give motion to any

kind of machinery!"

Such expectations may be very attractive, and yet they are

altogether illusory! they will not bear the test of a few simple

calculations; and these our friends have not troubled themselves to

institute.

With a simple flame of spirits of wine, under a proper vessel

containing boiling water, a small carriage of 200 to 300 pounds

weight can be put into motion, or a weight of 80 to 100 pounds may

be raised to a height of 20 feet. The same effects may be produced

by dissolving zinc in dilute sulphuric acid in a certain apparatus.

This is certainly an astonishing and highly interesting discovery;

but the question to be determined is, which of the two processes is

the least expensive?

In order to answer this question, and to judge correctly of the

hopes entertained from this discovery, let me remind you of what

chemists denominate "equivalents." These are certain unalterable

ratios of effects which are proportionate to each other, and may

therefore be expressed in numbers. Thus, if we require 8 pounds of

oxygen to produce a certain effect, and we wish to employ chlorine

for the same effect, we must employ neither more nor less than 35

1/2 pounds weight. In the same manner, 6 pounds weight of coal are

equivalent to 32 pounds weight of zinc. The numbers representing

chemical equivalents express very general ratios of effects,

comprehending for all bodies all the actions they are capable of

producing.

If zinc be combined in a certain manner with another metal, and

submitted to the action of dilute sulphuric acid, it is dissolved in

the form of an oxide; it is in fact burned at the expense of the

oxygen contained in the fluid. A consequence of this action is the

production of an electric current, which, if conducted through a

wire, renders it magnetic. In thus effecting the solution of a pound

weight, for example, of zinc, we obtain a definite amount of force

adequate to raise a given weight one inch, and to keep it suspended;

and the amount of weight it will be capable of suspending will be

the greater the more rapidly the zinc is dissolved.

By alternately interrupting and renewing the contact of the zinc

with the acid, and by very simple mechanical arrangements, we can

give to the iron an upward and downward or a horizontal motion, thus

producing the conditions essential to the motion of any machinery.

This moving force is produced by the oxidation of the zinc; and,

setting aside the name given to the force in this case, we know that

it can be produced in another manner. If we burn the zinc under the

boiler of a steam-engine, consequently in the oxygen of the air

instead of the galvanic pile, we should produce steam, and by it a

certain amount of force. If we should assume, (which, however, is

not proved,) that the quantity of force is unequal in these

cases,--that, for instance, we had obtained double or triple the

amount in the galvanic pile, or that in this mode of generating

force less loss is sustained,--we must still recollect the

equivalents of zinc and coal, and make these elements of our

calculation. According to the experiments of Despretz, 6 pounds

weight of zinc, in combining with oxygen, develops no more heat than

1 pound of coal; consequently, under equal conditions, we can

produce six times the amount of force with a pound of coal as with a

pound of zinc. It is therefore obvious that it would be more

advantageous to employ coal instead of zinc, even if the latter

produced four times as much force in a galvanic pile, as an equal

weight of coal by its combustion under a boiler. Indeed it is highly

probable, that if we burn under the boiler of a steam-engine the

quantity of coal required for smelting the zinc from its ores, we

shall produce far more force than the whole of the zinc so obtained

could originate in any form of apparatus whatever.

Heat, electricity, and magnetism, have a similar relation to each

other as the chemical equivalents of coal, zinc, and oxygen. By a

certain measure of electricity we produce a corresponding proportion

of heat or of magnetic power; we obtain that electricity by chemical

affinity, which in one shape produces heat, in another electricity

or magnetism. A certain amount of affinity produces an equivalent of

electricity in the same manner as, on the other hand, we decompose

equivalents of chemical compounds by a definite measure of

electricity. The magnetic force of the pile is therefore limited to

the extent of the chemical affinity, and in the case before us is

obtained by the combination of the zinc and sulphuric acid. In the

combustion of coal, the heat results from, and is measured by, the

affinity of the oxygen of the atmosphere for that substance.

It is true that with a very small expense of zinc, we can make an

iron wire a magnet capable of sustaining a thousand pounds weight of

iron; let us not allow ourselves to be misled by this. Such a magnet

could not raise a single pound weight of iron two inches, and

therefore could not impart motion. The magnet acts like a rock,

which while at rest presses with a weight of a thousand pounds upon

a basis; it is like an inclosed lake, without an outlet and without

a fall. But it may be said, we have, by mechanical arrangements,

given it an outlet and a fall. True; and this must be regarded as a

great triumph of mechanics; and I believe it is susceptible of

further improvements, by which greater force may be obtained. But

with every conceivable advantage of mechanism, no one will dispute

that one pound of coal, under the boiler of a steam-engine, will

give motion to a mass several hundred times greater than a pound of

zinc in the galvanic pile.

Our experience of the employment of electro-magnetism as a motory

power is, however, too recent to enable us to foresee the ultimate

results of contrivances to apply it; and, therefore, those who have

devoted themselves to solve the problem of its application should

not be discouraged, inasmuch as it would undoubtedly be a most

important achievement to supersede the steam-engine, and thus escape

the danger of railroads, even at double their expense.

Professor Weber of Gottingen has thrown out a suggestion, that if a

contrivance could be devised to enable us to convert at will the

wheels of the steam-carriage into magnets, we should be enabled to

ascend and descend acclivities with great facility. This notion may

ultimately be, to a certain extent, realised.

The employment of the galvanic pile as a motory power, however,

must, like every other contrivance, depend upon the question of its

relative economy: probably some time hence it may so far succeed as

to be adopted in certain favourable localities; it may stand in the

same relation to steam power as the manufacture of beet sugar bears

to that of cane, or as the production of gas from oils and resins to

that from mineral coal.

The history of beet-root sugar affords us an excellent illustration

of the effect of prices upon commercial productions. This branch of

industry seems at length, as to its processes, to be perfected. The

most beautiful white sugar is now manufactured from the beet-root,

in the place of the treacle-like sugar, having the taste of the

root, which was first obtained; and instead of 3 or 4 per cent., the

proportion obtained by Achard, double or even treble that amount is

now produced. And notwithstanding the perfection of the manufacture,

it is probable it will ere long be in most places entirely

discontinued. In the years 1824 to 1827, the prices of agricultural

produce were much lower than at present, while the price of sugar

was the same. At that time one malter [1] of wheat was 10s., and one

klafter [2] of wood 18s., and land was falling in price. Thus, food

and fuel were cheap, and the demand for sugar unlimited; it was,

therefore, advantageous to grow beet-root, and to dispose of the

produce of land as sugar. All these circumstances are now different.

A malter of wheat costs 18s.; a klafter of wood, 30s. to 36s. Wages

have risen, but not in proportion, whilst the price of colonial

sugar has fallen. Within the limits of the German commercial league,

as, for instance, at Frankfort-on-the-Maine, a pound of the whitest

and best loaf sugar is 7d.; the import duty is 31/d., or 30s. per

cwt., leaving 31/d. as the price of the sugar. In the year 1827,

then, one malter of wheat was equal to 40 lbs. weight of sugar,

whilst at present that quantity of wheat is worth 70 lbs. of sugar.

If indeed fuel were the same in price as formerly, and 70 lbs. of

sugar could be obtained from the same quantity of the root as then

yielded 40 lbs., it might still be advantageously produced; but the

amount, if now obtained by the most approved methods of extraction,

falls far short of this; and as fuel is double the price, and labour

dearer, it follows that, at present, it is far more advantageous to

cultivate wheat and to purchase sugar.

There are, however, other elements which must enter into our

calculations; but these serve to confirm our conclusion that the

manufacture of beet-root sugar as a commercial speculation must

cease. The leaves and residue of the root, after the juice was

expressed, were used as food for cattle, and their value naturally

increased with the price of grain. By the process formerly pursued,

75 lbs. weight of juice were obtained from 100 lbs. of beet-root,

and gave 5 lbs. of sugar. The method of Schutzenbach, which was

eagerly adopted by the manufacturers, produced from the same

quantity of root 8 lbs. of sugar; but it was attended with more

expense to produce, and the loss of the residue as food for cattle.

The increased expense in this process arises from the larger

quantity of fuel required to evaporate the water; for instead of

merely evaporating the juice, the dry residue is treated with water,

and we require fuel sufficient to evaporate 106 lbs. of fluid

instead of 75 lbs., and the residue is only fit for manure. The

additional 3 lbs. of sugar are purchased at the expense of much

fuel, and the loss of the residue as an article of food.

If the valley of the Rhine possessed mines of diamonds as rich as

those of Golconda, Visiapoor, or the Brazils, they would probably

not be worth the working: at those places the cost of extraction is

28s. to 30s. the carat. With us it amounts to three or four times as

much--to more, in fact, than diamonds are worth in the market. The

sand of the Rhine contains gold; and in the Grand Duchy of Baden

many persons are occupied in gold-washing when wages are low; but as

soon as they rise, this employment ceases. The manufacture of sugar

from beet-root, in the like manner, twelve to fourteen years ago

offered advantages which are now lost: instead, therefore, of

maintaining it at a great sacrifice, it would be more reasonable,

more in accordance with true natural economy, to cultivate other and

more valuable productions, and with them purchase sugar. Not only

would the state be the gainer, but every member of the community.

This argument does not apply, perhaps, to France and Bohemia, where

the prices of fuel and of colonial sugar are very different to those

in Germany.

The manufacture of gas for lighting, from coal, resin, and oils,

stands with us on the same barren ground.

The price of the materials from which gas is manufactured in England

bears a direct proportion to the price of corn: there the cost of

tallow and oil is twice as great as in Germany, but iron and coal

are two-thirds cheaper; and even in England the manufacture of gas

is only advantageous when the other products of the distillation of

coal, the coke, &c., can be sold.

It would certainly be esteemed one of the greatest discoveries of

the age if any one could succeed in condensing coal gas into a

white, dry, solid, odourless substance, portable, and capable of

being placed upon a candlestick, or burned in a lamp. Wax, tallow,

and oil, are combustible gases in a solid or fluid form, which offer

many advantages for lighting, not possessed by gas: they furnish, in

well-constructed lamps, as much light, without requiring the

expensive apparatus necessary for the combustion of gas, and they

are generally more economical. In large towns, or such establishments

as hotels, where coke is in demand, and where losses in stolen tallow

or oil must be considered, together with the labour of snuffing

candles and cleaning lamps, the higher price of gas is compensated.

In places where gas can be manufactured from resin, oil of turpentine,

and other cheap oils, as at Frankfort, this is advantageous so long

as it is pursued on small scale only. If large towns were lighted in

the same manner, the materials would rise in price: the whole amount

at present produced would scarcely suffice for two such towns as

Berlin and Munich. But no just calculation can be made from the

present prices of turpentine, resin, &c., which are not produced

upon any large scale.

[Footnote 1: Malter--a measure containing several bushels, but

varying in different countries.]

[Footnote 2: Klafter--a cord, a stack, measuring six feet every

way.]

LETTER V

My dear Sir,

Until very recently it was supposed that the physical qualities of

bodies, i.e. hardness, colour, density, transparency, &c., and still

more their chemical properties, must depend upon the nature of their

elements, or upon their composition. It was tacitly received as a

principle, that two bodies containing the same elements in the same

proportion, must of necessity possess the same properties. We could

not imagine an exact identity of composition giving rise to two

bodies entirely different in their sensible appearance and chemical

relations. The most ingenious philosophers entertained the opinion

that chemical combination is an inter-penetration of the particles

of different kinds of matter, and that all matter is susceptible of

infinite division. This has proved to be altogether a mistake. If

matter were infinitely divisible in this sense, its particles must

be imponderable, and a million of such molecules could not weigh

more than an infinitely small one. But the particles of that

imponderable matter, which, striking upon the retina, give us the

sensation of light, are not in a mathematical sense infinitely

small.

Inter-penetration of elements in the production of a chemical

compound, supposes two distinct bodies, A and B, to occupy one and

the same space at the same time. If this were so, different

properties could not consist with an equal and identical

composition.

That hypothesis, however, has shared the fate of innumerable

imaginative explanations of natural phenomena, in which our

predecessors indulged. They have now no advocate. The force of

truth, dependent upon observation, is irresistible. A great many

substances have been discovered amongst organic bodies, composed of

the same elements in the same relative proportions, and yet

exhibiting physical and chemical properties perfectly distinct one

from another. To such substances the term Isomeric (from 1/ao1/

equal and aei1/o1/ part) is applied. A great class of bodies, known

as the volatile oils, oil of turpentine, essence of lemons, oil of

balsam of copaiba, oil of rosemary, oil of juniper, and many others,

differing widely from each other in their odour, in their medicinal

effects, in their boiling point, in their specific gravity, &c., are

exactly identical in composition,--they contain the same elements,

carbon and hydrogen, in the same proportions.

How admirably simple does the chemistry of organic nature present

itself to us from this point of view! An extraordinary variety of

compound bodies produced with equal weights of two elements! and how

wide their dissimilarity! The crystallised part of the oil of roses,

the delicious fragrance of which is so well known, a solid at

ordinary temperatures, although readily volatile, is a compound body

containing exactly the same elements, and in the same proportions,

as the gas we employ for lighting our streets; and, in short, the

same elements, in the same relative quantities, are found in a dozen

other compounds, all differing essentially in their physical and

chemical properties.

These remarkable truths, so highly important in their applications,

were not received and admitted as sufficiently established, without

abundant proofs. Many examples have long been known where the

analysis of two different bodies gave the same composition; but such

cases were regarded as doubtful: at any rate, they were isolated

observations, homeless in the realms of science: until, at length,

examples were discovered of two or more bodies whose absolute

identity of composition, with totally distinct properties, could be

demonstrated in a more obvious and conclusive manner than by mere

analysis; that is, they can be converted and reconverted into each

other without addition and without subtraction.

In cyanuric acid, hydrated cyanic acid, and cyamelide, we have three

such isomeric compounds.

Cyanuric acid is crystalline, soluble in water, and capable of

forming salts with metallic oxides.

Hydrated cyanic acid is a volatile and highly blistering fluid,

which cannot be brought into contact with water without being

instantaneously decomposed.

Cyamelide is a white substance very like porcelain, absolutely

insoluble in water.

Now if we place the first,--cyanuric acid,--in a vessel hermetically

sealed, and apply a high degree of heat, it is converted by its

influence into hydrated cyanic acid; and, then, if this is kept for

some time at the common temperature, it passes into cyamelide, no

other element being present. And, again inversely, cyamelide can be

converted into cyanuric acid and hydrated cyanic acid.

We have three other bodies which pass through similar changes, in

aldehyde, metaldehyde, and etaldehyde; and, again two, in urea and

cyanuret of ammonia. Further, 100 parts of aldehyde hydrated butyric

acid and acetic ether contain the same elements in the same

proportion. Thus one substance may be converted into another without

addition or subtraction, and without the participation of any

foreign bodies in the change.

The doctrine that matter is not infinitely divisible, but on the

contrary, consists of atoms incapable of further division, alone

furnishes us with a satisfactory explanation of these phenomena. In

chemical combinations, the ultimate atoms of bodies do not penetrate

each other, they are only arranged side by side in a certain order,

and the properties of the compound depend entirely upon this order.

If they are made to change their place--their mode of arrangement--by

an impulse from without, they combine again in a different manner,

and another compound is formed with totally different properties. We

may suppose that one atom combines with one atom of another element

to form a compound atom, while in other bodies two and two, four and

four, eight and eight, are united; so that in all such compounds the

amount per cent. of the elements is absolutely equal; and yet their

physical and chemical properties must be totally different, the

constitution of each atom being peculiar, in one body consisting of

two, in another of four, in a third of eight, and in a fourth of

sixteen simple atoms.

The discovery of these facts immediately led to many most beautiful

and interesting results; they furnished us with a satisfactory

explanation of observations which were before veiled in mystery,--a

key to many of Nature's most curious recesses.

Again; solid bodies, whether simple or compound, are capable of

existing in two states, which are known by the terms amorphous and

crystalline.

When matter is passing from a gaseous or liquid state slowly into a

solid, an incessant motion is observed, as if the molecules were

minute magnets; they are seen to repel each other in one direction,

and to attract and cohere together in another, and in the end become

arranged into a regular form, which under equal circumstances is

always the same for any given kind of matter; that is, crystals are

formed.

Time and freedom of motion for the particles of bodies are necessary

to the formation of crystals. If we force a fluid or a gas to become

suddenly solid, leaving no time for its particles to arrange

themselves, and cohere in that direction in which the cohesive

attraction is strongest, no crystals will be formed, but the

resulting solid will have a different colour, a different degree of

hardness and cohesion, and will refract light differently; in one

word, will be amorphous. Thus we have cinnabar as a red and a

jet-black substance; sulphur a fixed and brittle body, and soft,

semitransparent, and ductile; glass as a milk-white opaque

substance, so hard that it strikes fire with steel, and in its

ordinary and well-known state. These dissimilar states and

properties of the same body are occasioned in one case by a regular,

in the other by an irregular, arrangement of its atoms; one is

crystalline, the other amorphous.

Applying these facts to natural productions, we have reason to

believe that clay-slate, and many kinds of greywacke, are amorphous

feldspar, as transition limestone is amorphous marble, basalt and

lava mixtures of amorphous zeolite and augite. Anything that

influences the cohesion, must also in a certain degree alter the

properties of bodies. Carbonate of lime, if crystallised at ordinary

temperatures, possesses the crystalline form, hardness, and

refracting power of common spar; if crystallised at a higher

temperature, it has the form and properties of arragonite.

Finally, Isomorphism, or the equality of form of many chemical

compounds having a different composition, tends to prove that matter

consists of atoms the mere arrangement of which produces all the

properties of bodies. But when we find that a different arrangement

of the same elements gives rise to various physical and chemical

properties, and a similar arrangement of different elements produces

properties very much the same, may we not inquire whether some of

those bodies which we regard as elements may not be merely

modifications of the same substance?--whether they are not the same

matter in a different state of arrangement? We know in fact the

existence of iron in two states, so dissimilar, that in the one, it

is to the electric chain like platinum, and in the other it is like

zinc; so that powerful galvanic machines have been constructed of

this one metal.

Among the elements are several instances of remarkable similarity of

properties. Thus there is a strong resemblance between platinum and

iridium; bromine and iodine; iron, manganese, and magnesium; cobalt

and nickel; phosphorus and arsenic; but this resemblance consists

mainly in their forming isomorphous compounds in which these

elements exist in the same relative proportion. These compounds are

similar, because the atoms of which they are composed are arranged

in the same manner. The converse of this is also true: nitrate of

strontia becomes quite dissimilar to its common state if a certain

proportion of water is taken into its composition.

If we suppose selenium to be merely modified sulphur, and phosphorus

modified arsenic, how does it happen, we must inquire, that

sulphuric acid and selenic acid, phosphoric and arsenic acid,

respectively form compounds which it is impossible to distinguish by

their form and solubility? Were these merely isomeric, they ought to

exhibit properties quite dissimilar!

We have not, I believe, at present the remotest ground to suppose

that any one of those substances which chemists regard as elements

can be converted into another. Such a conversion, indeed, would

presuppose that the element was composed of two or more ingredients,

and was in fact not an element; and until the decomposition of these

bodies is accomplished, and their constituents discovered, all

pretensions to such conversions deserve no notice.

Dr. Brown of Edinburgh thought he had converted iron into rhodium,

and carbon or paracyanogen into silicon. His paper upon this subject

was published in the Transactions of the Royal Society of Edinburgh,

and contained internal evidence, without a repetition of his

experiments, that he was totally unacquainted with the principles of

chemical analysis. But his experiments have been carefully repeated

by qualified persons, and they have completely proved his ignorance:

his rhodium is iron, and his silicon an impure incombustible coal.

LETTER VI

My dear Sir,

One of the most remarkable effects of the recent progress of science

is the alliance of chemistry with physiology, by which a new and

unexpected light has been thrown upon the vital processes of plants

and animals. We have now no longer any difficulty in understanding

the different actions of aliments, poisons, and remedial agents--we

have a clear conception of the causes of hunger, of the exact nature

of death; and we are not, as formerly, obliged to content ourselves

with a mere description of their symptoms. It is now ascertained

with positive certainty, that all the substances which constitute

the food of man must be divided into two great classes, one of which

serves for the nutrition and reproduction of the animal body, whilst

the other ministers to quite different purposes. Thus starch, gum,

sugar, beer, wine, spirits, &c., furnish no element capable of

entering into the composition of blood, muscular fibre, or any part

which is the seat of the vital principle. It must surely be

universally interesting to trace the great change our views have

undergone upon these subjects, as well as to become acquainted with

the researches from which our present knowledge is derived.

The primary conditions of the maintenance of animal life, are a

constant supply of certain matters, animal food, and of oxygen, in

the shape of atmospheric air. During every moment of life, oxygen is

absorbed from the atmosphere in the organs of respiration, and the

act of breathing cannot cease while life continues.

The observations of physiologists have demonstrated that the body of

an adult man supplied abundantly with food, neither increases nor

diminishes in weight during twenty-four hours, and yet the quantity

of oxygen absorbed into his system, in that period, is very

considerable. According to the experiments of Lavoisier, an adult

man takes into his system from the atmosphere, in one year, no less

than 746 pounds weight of oxygen; the calculations of Menzies make

the quantity amount even to 837 pounds; but we find his weight at

the end of the year either exactly the same or different one way or

the other by at most a few pounds. What, it may be asked, has become

of the enormous amount of oxygen thus introduced into the human

system in the course of one year? We can answer this question

satisfactorily. No part of the oxygen remains in the body, but is

given out again, combined with carbon and hydrogen. The carbon and

hydrogen of certain parts of the animal body combine with the oxygen

introduced through the lungs and skin, and pass off in the forms of

carbonic acid and vapour of water. At every expiration and every

moment of life, a certain amount of its elements are separated from

the animal organism, having entered into combination with the oxygen

of the atmosphere.

In order to obtain a basis for the approximate calculation, we may

assume, with Lavoisier and Seguin, that an adult man absorbs into

his system 32 1/2 ounces of oxygen daily,--that is, 46,037 cubic

inches = 15,661 grains, French weight; and further, that the weight

of the whole mass of his blood is 24 pounds, of which 80 per cent.

is water. Now, from the known composition of the blood, we know that

in order to convert its whole amount of carbon and hydrogen into

carbonic acid and water, 64.102 grains of oxygen are required. This

quantity will be taken into the system in four days and five hours.

Whether the oxygen enters into combination directly with the

elements of the blood, or with the carbon and hydrogen of other

parts of the body, it follows inevitably--the weight of the body

remaining unchanged and in a normal condition--that as much of these

elements as will suffice to supply 24 pounds of blood, must be taken

into the system in four days and five hours; and this necessary

amount is furnished by the food.

We have not, however, remained satisfied with mere approximation: we

have determined accurately, in certain cases, the quantity of carbon

taken daily in the food, and of that which passes out of the body in

the faeces and urine combined--that is, uncombined with oxygen; and

from these investigations it appears that an adult man taking

moderate exercise consumes 13.9 ounces of carbon, which pass off

through the skin and lungs as carbonic acid gas. [1]

It requires 37 ounces of oxygen to convert 13 9/10 of carbon into

carbonic acid. Again; according to the analysis of Boussingault,

(Annales de Chim. et de Phys., lxx. i. p.136), a horse consumes 79

1/10 ounces of carbon in twenty-four hours, a milch cow 70 3/4

ounces; so that the horse requires 13 pounds 3 1/2 ounces, and the

cow 11 pounds 10 3/4 ounces of oxygen. [2]

As no part of the oxygen taken into the system of an animal is given

off in any other form than combined with carbon or hydrogen, and as

in a normal condition, or state of health, the carbon and hydrogen

so given off are replaced by those elements in the food, it is

evident that the amount of nourishment required by an animal for its

support must be in a direct ratio with the quantity of oxygen taken

in to its system. Two animals which in equal times take up by means

of the lungs and skin unequal quantities of oxygen, consume an

amount of food unequal in the same ratio. The consumption of oxygen

in a given time may be expressed by the number of respirations; it

is, therefore, obvious that in the same animal the quantity of

nourishment required must vary with the force and number of

respirations. A child breathes quicker than an adult, and,

consequently, requires food more frequently and proportionably in

larger quantity, and bears hunger less easily. A bird deprived of

food dies on the third day, while a serpent, confined under a bell,

respires so slowly that the quantity of carbonic acid generated in

an hour can scarcely be observed, and it will live three months, or

longer, without food. The number of respirations is fewer in a state

of rest than during labour or exercise: the quantity of food

necessary in both cases must be in the same ratio. An excess of

food, a want of a due amount of respired oxygen, or of exercise, as

also great exercise (which obliges us to take an increased supply of

food), together with weak organs of digestion, are incompatible with

health.

But the quantity of oxygen received by an animal through the lungs

not only depends upon the number of respirations, but also upon the

temperature of the respired air. The size of the thorax of an animal

is unchangeable; we may therefore regard the volume of air which

enters at every inspiration as uniform. But its weight, and

consequently the amount of oxygen it contains, is not constant. Air

is expanded by heat, and contracted by cold--an equal volume of hot

and cold air contains, therefore, an unequal amount of oxygen. In

summer atmospheric air contains water in the form of vapour, it is

nearly deprived of it in winter; the volume of oxygen in the same

volume of air is smaller in summer than in winter. In summer and

winter, at the pole and at the equator, we inspire an equal volume

of air; the cold air is warmed during respiration and acquires the

temperature of the body. In order, therefore, to introduce into the

lungs a given amount of oxygen, less expenditure of force is

necessary in winter than in summer, and for the same expenditure of

force more oxygen is inspired in winter. It is also obvious that in

an equal number of respirations we consume more oxygen at the level

of the sea than on a mountain.

The oxygen taken into the system is given out again in the same

form, both in summer and winter: we expire more carbon at a low than

at a high temperature, and require more or less carbon in our food

in the same proportion; and, consequently, more is respired in

Sweden than in Sicily, and in our own country and eighth more in

winter than in summer. Even if an equal weight of food is consumed

in hot and cold climates, Infinite Wisdom has ordained that very

unequal proportions of carbon shall be taken in it. The food

prepared for the inhabitants of southern climes does not contain in

a fresh state more than 12 per cent. of carbon, while the blubber

and train oil which feed the inhabitants of Polar regions contain 66

to 80 per cent. of that element.

From the same cause it is comparatively easy to be temperate in warm

climates, or to bear hunger for a long time under the equator; but

cold and hunger united very soon produce exhaustion.

The oxygen of the atmosphere received into the blood in the lungs,

and circulated throughout every part of the animal body, acting upon

the elements of the food, is the source of animal heat.

[Footnote 1: This account is deduced from observations made upon the

average daily consumption of about 30 soldiers in barracks. The food

of these men, consisting of meat, bread, potatoes, lentils, peas,

beans, butter, salt, pepper, &c., was accurately weighed during a

month, and each article subjected to ultimate analysis. Of the

quantity of food, beer, and spirits, taken by the men when out of

barracks, we have a close approximation from the report of the

sergeant; and from the weight and analysis of the faeces and urine,

it appears that the carbon which passes off through these channels

may be considered equivalent to the amount taken in that portion of

the food, and of sour-crout, which was not included in the

estimate.]

[Footnote 2: 17.5 ounces = 0.5 kilogramme.]

LETTER VII

My dear Sir,

The source of animal heat, its laws, and the influence it exerts

upon the functions of the animal body, constitute a curious and

highly interesting subject, to which I would now direct your

attention.

All living creatures, whose existence depends upon the absorption of

oxygen, possess within themselves a source of heat, independent of

surrounding objects.

This general truth applies to all animals, and extends to the seed

of plants in the act of germination, to flower-buds when developing,

and fruits during their maturation.

In the animal body, heat is produced only in those parts to which

arterial blood, and with it the oxygen absorbed in respiration, is

conveyed. Hair, wool, and feathers, receive no arterial blood, and,

therefore, in them no heat is developed. The combination of a

combustible substance with oxygen is, under all circumstances, the

only source of animal heat. In whatever way carbon may combine with

oxygen, the act of combination is accompanied by the disengagement

of heat. It is indifferent whether this combination takes place

rapidly or slowly, at a high or at a low temperature: the amount of

heat liberated is a constant quantity.

The carbon of the food, being converted into carbonic acid within

the body, must give out exactly as much heat as if it had been

directly burnt in oxygen gas or in common air; the only difference

is, the production of the heat is diffused over unequal times. In

oxygen gas the combustion of carbon is rapid and the heat intense;

in atmospheric air it burns slower and for a longer time, the

temperature being lower; in the animal body the combination is still

more gradual, and the heat is lower in proportion.

It is obvious that the amount of heat liberated must increase or

diminish with the quantity of oxygen introduced in equal times by

respiration. Those animals, therefore, which respire frequently, and

consequently consume much oxygen, possess a higher temperature than

others, which, with a body of equal size to be heated, take into the

system less oxygen. The temperature of a child (102 deg) is higher

than that of an adult (99 1/2 deg). That of birds (104 deg to 105.4

deg) is higher than that of quadrupeds (98 1/2 deg to 100.4 deg) or

than that of fishes or amphibia, whose proper temperature is from

2.7 to 3.6 deg higher than that of the medium in which they live.

All animals, strictly speaking, are warm-blooded; but in those only

which possess lungs is the temperature of the body quite independent

of the surrounding medium.

The most trustworthy observations prove that in all climates, in the

temperate zones as well as at the equator or the poles, the

temperature of the body in man, and in what are commonly called

warm-blooded animals, is invariably the same; yet how different are

the circumstances under which they live!

The animal body is a heated mass, which bears the same relation to

surrounding objects as any other heated mass. It receives heat when

the surrounding objects are hotter, it loses heat when they are

colder, than itself.

We know that the rapidity of cooling increases with the difference

between the temperature of the heated body and that of the

surrounding medium; that is, the colder the surrounding medium the

shorter the time required for the cooling of the heated body.

How unequal, then, must be the loss of heat in a man at Palermo,

where the external temperature is nearly equal to that of the body,

and in the polar regions, where the external temperature is from 70

deg to 90 deg lower!

Yet, notwithstanding this extremely unequal loss of heat, experience

has shown that the blood of the inhabitant of the arctic circle has

a temperature as high as that of the native of the south, who lives

in so different a medium.

This fact, when its true significance is perceived, proves that the

heat given off to the surrounding medium is restored within the body

with great rapidity. This compensation must consequently take place

more rapidly in winter than in summer, at the pole than at the

equator.

Now, in different climates the quantity of oxygen introduced into

the system by respiration, as has been already shown, varies

according to the temperature of the external air; the quantity of

inspired oxygen increases with the loss of heat by external cooling,

and the quantity of carbon or hydrogen necessary to combine with

this oxygen must be increased in the same ratio.

It is evident that the supply of the heat lost by cooling is

effected by the mutual action of the elements of the food and the

inspired oxygen, which combine together. To make use of a familiar,

but not on that account a less just illustration, the animal body

acts, in this respect, as a furnace, which we supply with fuel. It

signifies nothing what intermediate forms food may assume, what

changes it may undergo in the body; the last change is uniformly the

conversion of its carbon into carbonic acid, and of its hydrogen

into water. The unassimilated nitrogen of the food, along with the

unburned or unoxidised carbon, is expelled in the urine or in the

solid excrements. In order to keep up in the furnace a constant

temperature, we must vary the supply of fuel according to the

external temperature, that is, according to the supply of oxygen.

In the animal body the food is the fuel; with a proper supply of

oxygen we obtain the heat given out during its oxidation or

combustion. In winter, when we take exercise in a cold atmosphere,

and when consequently the amount of inspired oxygen increases, the

necessity for food containing carbon and hydrogen increases in the

same ratio; and by gratifying the appetite thus excited, we obtain

the most efficient protection against the most piercing cold. A

starving man is soon frozen to death. The animals of prey in the

arctic regions, as every one knows, far exceed in voracity those of

the torrid zone.

In cold and temperate climates, the air, which incessantly strives

to consume the body, urges man to laborious efforts in order to

furnish the means of resistance to its action, while, in hot

climates, the necessity of labour to provide food is far less

urgent.

Our clothing is merely an equivalent for a certain amount of food.

The more warmly we are clothed the less urgent becomes the appetite

for food, because the loss of heat by cooling, and consequently the

amount of heat to be supplied by the food, is diminished.

If we were to go naked, like certain savage tribes, or if in hunting

or fishing we were exposed to the same degree of cold as the

Samoyedes, we should be able with ease to consume 10 lbs. of flesh,

and perhaps a dozen of tallow candles into the bargain, daily, as

warmly clad travellers have related with astonishment of these

people. We should then also be able to take the same quantity of

brandy or train oil without bad effects, because the carbon and

hydrogen of these substances would only suffice to keep up the

equilibrium between the external temperature and that of our bodies.

According to the preceding expositions, the quantity of food is

regulated by the number of respirations, by the temperature of the

air, and by the amount of heat given off to the surrounding medium.

No isolated fact, apparently opposed to this statement, can affect

the truth of this natural law. Without temporary or permanent injury

to health, the Neapolitan cannot take more carbon and hydrogen in

the shape of food than he expires as carbonic acid and water; and

the Esquimaux cannot expire more carbon and hydrogen than he takes

in the system as food, unless in a state of disease or of

starvation. Let us examine these states a little more closely.

The Englishman in Jamaica perceives with regret the disappearance of

his appetite, previously a source of frequently recurring enjoyment;

and he succeeds, by the use of cayenne pepper, and the most powerful

stimulants, in enabling himself to take as much food as he was

accustomed to eat at home. But the whole of the carbon thus

introduced into the system is not consumed; the temperature of the

air is too high, and the oppressive heat does not allow him to

increase the number of respirations by active exercise, and thus to

proportion the waste to the amount of food taken; disease of some

kind, therefore, ensues.

On the other hand, England sends her sick to southern regions, where

the amount of the oxygen inspired is diminished in a very large

proportion. Those whose diseased digestive organs have in a greater

or less degree lost the power of bringing the food into the state

best adapted for oxidation, and therefore are less able to resist

the oxidising influence of the atmosphere of their native climate,

obtain a great improvement in health. The diseased organs of

digestion have power to place the diminished amount of food in

equilibrium with the inspired oxygen, in the mild climate; whilst in

a colder region the organs of respiration themselves would have been

consumed in furnishing the necessary resistance to the action of the

atmospheric oxygen.

In our climate, hepatic diseases, or those arising from excess of

carbon, prevail in summer; in winter, pulmonary diseases, or those

arising from excess of oxygen, are more frequent.

The cooling of the body, by whatever cause it may be produced,

increases the amount of food necessary. The mere exposure to the

open air, in a carriage or on the deck of a ship, by increasing

radiation and vaporisation, increases the loss of heat, and compels

us to eat more than usual. The same is true of those who are

accustomed to drink large quantities of cold water, which is given

off at the temperature of the body, 98 1/2 deg. It increases the

appetite, and persons of weak constitution find it necessary, by

continued exercise, to supply to the system the oxygen required to

restore the heat abstracted by the cold water. Loud and long

continued speaking, the crying of infants, moist air, all exert a

decided and appreciable influence on the amount of food which is

taken.

We have assumed that carbon and hydrogen especially, by combining

with oxygen, serve to produce animal heat. In fact, observation

proves that the hydrogen of the food plays a no less important part

than the carbon.

The whole process of respiration appears most clearly developed,

when we consider the state of a man, or other animal, totally

deprived of food.

The first effect of starvation is the disappearance of fat, and this

fat cannot be traced either in the urine or in the scanty faeces.

Its carbon and hydrogen have been given off through the skin and

lungs in the form of oxidised products; it is obvious that they have

served to support respiration.

In the case of a starving man, 32 1/2 oz. of oxygen enter the system

daily, and are given out again in combination with a part of his

body. Currie mentions the case of an individual who was unable to

swallow, and whose body lost 100 lbs. in weight during a month; and,

according to Martell (Trans. Linn. Soc., vol. xi. p.411), a fat pig,

overwhelmed in a slip of earth, lived 160 days without food, and was

found to have diminished in weight, in that time, more than 120 lbs.

The whole history of hybernating animals, and the well-established

facts of the periodical accumulation, in various animals, of fat,

which, at other periods, entirely disappears, prove that the oxygen,

in the respiratory process, consumes, without exception, all such

substances as are capable of entering into combination with it. It

combines with whatever is presented to it; and the deficiency of

hydrogen is the only reason why carbonic acid is the chief product;

for, at the temperature of the body, the affinity of hydrogen for

oxygen far surpasses that of carbon for the same element.

We know, in fact, that the graminivora expire a volume of carbonic

acid equal to that of the oxygen inspired, while the carnivora, the

only class of animals whose food contains fat, inspire more oxygen

than is equal in volume to the carbonic acid expired. Exact

experiments have shown, that in many cases only half the volume of

oxygen is expired in the form of carbonic acid. These observations

cannot be gainsaid, and are far more convincing than those arbitrary

and artificially produced phenomena, sometimes called experiments;

experiments which, made as too often they are, without regard to the

necessary and natural conditions, possess no value, and may be

entirely dispensed with; especially when, as in the present case,

Nature affords the opportunity for observation, and when we make a

rational use of that opportunity.

In the progress of starvation, however, it is not only the fat which

disappears, but also, by degrees all such of the solids as are

capable of being dissolved. In the wasted bodies of those who have

suffered starvation, the muscles are shrunk and unnaturally soft,

and have lost their contractibility; all those parts of the body

which were capable of entering into the state of motion have served

to protect the remainder of the frame from the destructive influence

of the atmosphere. Towards the end, the particles of the brain begin

to undergo the process of oxidation, and delirium, mania, and death

close the scene; that is to say, all resistance to the oxidising

power of the atmospheric oxygen ceases, and the chemical process of

eremacausis, or decay, commences, in which every part of the body,

the bones excepted, enters into combination with oxygen.

The time which is required to cause death by starvation depends on

the amount of fat in the body, on the degree of exercise, as in

labour or exertion of any kind, on the temperature of the air, and

finally, on the presence or absence of water. Through the skin and

lungs there escapes a certain quantity of water, and as the presence

of water is essential to the continuance of the vital motions, its

dissipation hastens death. Cases have occurred, in which a full

supply of water being accessible to the sufferer, death has not

occurred till after the lapse of twenty days. In one case, life was

sustained in this way for the period of sixty days.

In all chronic diseases death is produced by the same cause, namely,

the chemical action of the atmosphere. When those substances are

wanting, whose function in the organism is to support the process of

respiration, when the diseased organs are incapable of performing

their proper function of producing these substances, when they have

lost the power of transforming the food into that shape in which it

may, by entering into combination with the oxygen of the air,

protect the system from its influence, then, the substance of the

organs themselves, the fat of the body, the substance of the

muscles, the nerves, and the brain, are unavoidably consumed.

The true cause of death in these cases is the respiratory process,

that is, the action of the atmosphere.

A deficiency of food, and a want of power to convert the food into a

part of the organism, are both, equally, a want of resistance; and

this is the negative cause of the cessation of the vital process.

The flame is extinguished, because the oil is consumed; and it is

the oxygen of the air which has consumed it.

In many diseases substances are produced which are incapable of

assimilation. By the mere deprivation of food, these substances are

removed from the body without leaving a trace behind; their elements

have entered into combination with the oxygen of the air.

From the first moment that the function of the lungs or of the skin

is interrupted or disturbed, compounds, rich in carbon, appear in

the urine, which acquires a brown colour. Over the whole surface of

the body oxygen is absorbed, and combines with all the substances

which offer no resistance to it. In those parts of the body where

the access of oxygen is impeded; for example, in the arm-pits, or in

the soles of the feet, peculiar compounds are given out,

recognisable by their appearance, or by their odour. These compounds

contain much carbon.

Respiration is the falling weight--the bent spring, which keeps the

clock in motion; the inspirations and expirations are the strokes of

the pendulum which regulate it. In our ordinary time-pieces, we know

with mathematical accuracy the effect produced on their rate of

going, by changes in the length of the pendulum, or in the external

temperature. Few, however, have a clear conception of the influence

of air and temperature on the health of the human body; and yet the

research into the conditions necessary to keep it in the normal

state is not more difficult than in the case of a clock.

LETTER VIII

My dear Sir,

Having attempted in my last letter to explain to you the simple and

admirable office subserved by the oxygen of the atmosphere in its

combination with carbon in the animal body, I will now proceed to

present you with some remarks upon those materials which sustain its

mechanisms in motion, and keep up their various functions,--namely,

the Aliments.

If the increase in mass in an animal body, the development and

reproduction of its organs depend upon the blood, then those

substances only which are capable of being converted into blood can

be properly regarded as nourishment. In order then to ascertain what

parts of our food are nutritious, we must compare the composition of

the blood with the composition of the various articles taken as

food.

Two substances require especial consideration as the chief

ingredients of the blood; one of these separates immediately from

the blood when it is withdrawn from the circulation.

It is well known that in this case blood coagulates, and separates

into a yellowish liquid, the serum of the blood, and a gelatinous

mass, which adheres to a rod or stick in soft, elastic fibres, when

coagulating blood is briskly stirred. This is the fibrine of the

blood, which is identical in all its properties with muscular fibre,

when the latter is purified from all foreign matters.

The second principal ingredient of the blood is contained in the

serum, and gives to this liquid all the properties of the white of

eggs, with which it is indeed identical. When heated, it coagulates

into a white elastic mass, and the coagulating substance is called

albumen.

Fibrine and albumen, the chief ingredients of blood, contain, in

all, seven chemical elements, among which nitrogen, phosphorus, and

sulphur are found. They contain also the earth of bones. The serum

retains in solution sea salt and other salts of potash and soda, in

which the acids are carbonic, phosphoric, and sulphuric acids. The

globules of the blood contain fibrine and albumen, along with a red

colouring matter, in which iron is a constant element. Besides

these, the blood contains certain fatty bodies in small quantity,

which differ from ordinary fats in several of their properties.

Chemical analysis has led to the remarkable result, that fibrine and

albumen contain the same organic elements united in the same

proportion,--i.e., that they are isomeric, their chemical

composition--the proportion of their ultimate elements--being

identical. But the difference of their external properties shows

that the particles of which they are composed are arranged in a

different order. (See Letter V).

This conclusion has lately been beautifully confirmed by a

distinguished physiologist (Denis), who has succeeded in converting

fibrine into albumen, that is, in giving it the solubility, and

coagulability by heat, which characterise the white of egg.

Fibrine and albumen, besides having the same composition, agree also

in this, that both dissolve in concentrated muriatic acid, yielding

a solution of an intense purple colour. This solution, whether made

with fibrine or albumen, has the very same re-actions with all

substances yet tried.

Both albumen and fibrine, in the process of nutrition, are capable

of being converted into muscular fibre, and muscular fibre is

capable of being reconverted into blood. These facts have long been

established by physiologists, and chemistry has merely proved that

these metamorphoses can be accomplished under the influence of a

certain force, without the aid of a third substance, or of its

elements, and without the addition of any foreign element, or the

separation of any element previously present in these substances.

If we now compare the composition of all organised parts with that

of fibrine and albumen, the following relations present themselves:--

All parts of the animal body which have a decided shape, which form

parts of organs, contain nitrogen. No part of an organ which

possesses motion and life is destitute of nitrogen; all of them

contain likewise carbon and the elements of water; the latter,

however, in no case in the proportion to form water.

The chief ingredients of the blood contain nearly 17 per cent. of

nitrogen, and from numerous analyses it appears that no part of an

organ contains less than 17 per cent. of nitrogen.

The most convincing experiments and observations have proved that

the animal body is absolutely incapable of producing an elementary

body, such as carbon or nitrogen, out of substances which do not

contain it; and it obviously follows, that all kinds of food fit for

the production either of blood, or of cellular tissue, membranes,

skin, hair, muscular fibre, &c., must contain a certain amount of

nitrogen, because that element is essential to the composition of

the above-named organs; because the organs cannot create it from the

other elements presented to them; and, finally, because no nitrogen

is absorbed from the atmosphere in the vital process.

The substance of the brain and nerves contains a large quantity of

albumen, and, in addition to this, two peculiar fatty acids,

distinguished from other fats by containing phosphorus (phosphoric

acid?). One of these contains nitrogen (Fremy).

Finally, water and common fat are those ingredients of the body

which are destitute of nitrogen. Both are amorphous or unorganised,

and only so far take part in the vital process as that their

presence is required for the due performance of the vital functions.

The inorganic constituents of the body are, iron, lime, magnesia,

common salt, and the alkalies.

The nutritive process is seen in its simplest form in carnivorous

animals. This class of animals lives on the blood and flesh of the

graminivora; but this blood and flesh are, in all their properties,

identical with their own. Neither chemical nor physiological

differences can be discovered.

The nutriment of carnivorous animals is derived originally from

blood; in their stomach it becomes dissolved, and capable of

reaching all other parts of the body; in its passage it is again

converted into blood, and from this blood are reproduced all those

parts of their organisation which have undergone change or

metamorphosis.

With the exception of hoofs, hair, feathers, and the earth of bones,

every part of the food of carnivorous animals is capable of

assimilation.

In a chemical sense, therefore, it may be said that a carnivorous

animal, in supporting the vital process, consumes itself. That which

serves for its nutrition is identical with those parts of its

organisation which are to be renewed.

The process of nutrition in graminivorous animals appears at first

sight altogether different. Their digestive organs are less simple,

and their food consists of vegetables, the great mass of which

contains but little nitrogen.

From what substances, it may be asked, is the blood formed, by means

of which of their organs are developed? This question may be

answered with certainty.

Chemical researches have shown, that all such parts of vegetables as

can afford nutriment to animals contain certain constituents which

are rich in nitrogen; and the most ordinary experience proves that

animals require for their support and nutrition less of these parts

of plants in proportion as they abound in the nitrogenised

constituents. Animals cannot be fed on matters destitute of these

nitrogenised constituents.

These important products of vegetation are especially abundant in

the seeds of the different kinds of grain, and of peas, beans, and

lentils; in the roots and the juices of what are commonly called

vegetables. They exist, however, in all plants, without exception,

and in every part of plants in larger or smaller quantity.

These nitrogenised forms of nutriment in the vegetable kingdom may

be reduced to three substances, which are easily distinguished by

their external characters. Two of them are soluble in water, the

third is insoluble.

When the newly-expressed juices of vegetables are allowed to stand,

a separation takes place in a few minutes. A gelatinous precipitate,

commonly of a green tinge, is deposited, and this, when acted on by

liquids which remove the colouring matter, leaves a grayish white

substance, well known to druggists as the deposite from vegetable

juices. This is one of the nitrogenised compounds which serves for

the nutrition of animals, and has been named vegetable fibrine. The

juice of grapes is especially rich in this constituent, but it is

most abundant in the seeds of wheat, and of the cerealia generally.

It may be obtained from wheat flour by a mechanical operation, and

in a state of tolerable purity; it is then called gluten, but the

glutinous property belongs, not to vegetable fibrine, but to a

foreign substance, present in small quantity, which is not found in

the other cerealia.

The method by which it is obtained sufficiently proves that it is

insoluble in water; although we cannot doubt that it was originally

dissolved in the vegetable juice, from which it afterwards

separated, exactly as fibrine does from blood.

The second nitrogenised compound remains dissolved in the juice

after the separation of the fibrine. It does not separate from the

juice at the ordinary temperature, but is instantly coagulated when

the liquid containing it is heated to the boiling point.

When the clarified juice of nutritious vegetables, such as

cauliflower, asparagus, mangelwurzel, or turnips, is made to boil, a

coagulum is formed, which it is absolutely impossible to distinguish

from the substance which separates as a coagulum, when the serum of

blood, or the white of an egg, diluted with water, are heated to the

boiling point. This is vegetable albumen. It is found in the

greatest abundance in certain seeds, in nuts, almonds, and others,

in which the starch of the gramineae is replaced by oil.

The third nitrogenised constituent of the vegetable food of animals

is vegetable caseine. It is chiefly found in the seeds of peas,

beans, lentils, and similar leguminous seeds. Like vegetable

albumen, it is soluble in water, but differs from it in this, that

its solution is not coagulated by heat. When the solution is heated

or evaporated, a skin forms on its surface, and the addition of an

acid causes a coagulum, just as in animal milk.

These three nitrogenised compounds, vegetable fibrine, albumen, and

caseine, are the true nitrogenised constituents of the food of

graminivorous animals; all other nitrogenised compounds occurring in

plants, are either rejected by animals, as in the case of the

characteristic principles of poisonous and medicinal plants, or else

they occur in the food in such very small proportion, that they

cannot possibly contribute to the increase of mass in the animal

body.

The chemical analysis of these three substances has led to the very

interesting result that they contain the same organic elements,

united in the same proportion by weight; and, what is still more

remarkable, that they are identical in composition with the chief

constituents of blood, animal fibrine, and albumen. They all three

dissolve in concentrated muriatic acid with the same deep purple

colour, and even in their physical characters, animal fibrine and

albumen are in no respect different from vegetable fibrine and

albumen. It is especially to be noticed, that by the phrase,

identity of composition, we do not here intend mere similarity, but

that even in regard to the presence and relative amount of sulphur,

phosphorus, and phosphate of lime, no difference can be observed.

How beautifully and admirably simple, with the aid of these

discoveries, appears the process of nutrition in animals, the

formation of their organs, in which vitality chiefly resides! Those

vegetable principles, which in animals are used to form blood,

contain the chief constituents of blood, fibrine and albumen, ready

formed, as far as regards their composition. All plants, besides,

contain a certain quantity of iron, which reappears in the colouring

matter of the blood. Vegetable fibrine and animal fibrine, vegetable

albumen and animal albumen, hardly differ, even in form; if these

principles be wanting in the food, the nutrition of the animal is

arrested; and when they are present, the graminivorous animal

obtains in its food the very same principles on the presence of

which the nutrition of the carnivora entirely depends.

Vegetables produce in their organism the blood of all animals, for

the carnivora, in consuming the blood and flesh of the graminivora,

consume, strictly speaking, only the vegetable principles which have

served for the nutrition of the latter. Vegetable fibrine and

albumen take the form in the stomach of the graminivorous animal as

animal fibrine and albumen do in that of the carnivorous animal.

From what has been said, it follows that the development of the

animal organism and its growth are dependent on the reception of

certain principles identical with the chief constituents of blood.

In this sense we may say that the animal organism gives to the blood

only its form; that it is incapable of creating blood out of other

substances which do not already contain the chief constituents of

that fluid. We cannot, indeed, maintain that the animal organism has

no power to form other compounds, for we know that it is capable of

producing an extensive series of compounds, differing in composition

from the chief constituents of blood; but these last, which form the

starting-point of the series, it cannot produce.

The animal organism is a higher kind of vegetable, the development

of which begins with those substances with the production of which

the life of an ordinary vegetable ends. As soon as the latter has

borne seed, it dies, or a period of its life comes to a termination.

In that endless series of compounds, which begins with carbonic

acid, ammonia, and water, the sources of the nutrition of

vegetables, and includes the most complex constituents of the animal

brain, there is no blank, no interruption. The first substance

capable of affording nutriment to animals is the last product of the

creative energy of vegetables.

The substance of cellular tissue and of membranes, of the brain and

nerves, these the vegetable cannot produce.

The seemingly miraculous in the productive agency of vegetables

disappears in a great degree, when we reflect that the production of

the constituents of blood cannot appear more surprising than the

occurrence of the fat of beef and mutton in cocoa beans, of human

fat in olive-oil, of the principal ingredient of butter in palm-oil,

and of horse fat and train-oil in certain oily seeds.

LETTER IX

My dear Sir,

The facts detailed in my last letter will satisfy you as to the

manner in which the increase of mass in an animal, that is, its

growth, is accomplished; we have still to consider a most important

question, namely, the function performed in the animal system by

substances destitute of nitrogen; such as sugar, starch, gum,

pectine, &c.

The most extensive class of animals, the graminivora, cannot live

without these substances; their food must contain a certain amount

of one or more of them, and if these compounds are not supplied,

death quickly ensues.

This important inquiry extends also to the constituents of the food

of carnivorous animals in the earliest periods of life; for this

food also contains substances, which are not necessary for their

support in the adult state. The nutrition of the young of carnivora

is obviously accomplished by means similar to those by which the

graminivora are nourished; their development is dependent on the

supply of a fluid, which the body of the mother secretes in the

shape of milk.

Milk contains only one nitrogenised constituent, known under the

name of caseine; besides this, its chief ingredients are butter

(fat), and sugar of milk. The blood of the young animal, its

muscular fibre, cellular tissue, nervous matter, and bones, must

have derived their origin from the nitrogenised constituent of

milk--the caseine; for butter and sugar of milk contain no nitrogen.

Now, the analysis of caseine has led to the result, which, after the

details I have given, can hardly excite your surprise, that this

substance also is identical in composition with the chief

constituents of blood, fibrine and albumen. Nay more--a comparison

of its properties with those of vegetable caseine has shown--that

these two substances are identical in all their properties;

insomuch, that certain plants, such as peas, beans, and lentils, are

capable of producing the same substance which is formed from the

blood of the mother, and employed in yielding the blood of the young

animal.

The young animal, therefore, receives in the form of caseine,--which

is distinguished from fibrine and albumen by its great solubility,

and by not coagulating when heated,--the chief constituent of the

mother's blood. To convert caseine into blood no foreign substance

is required, and in the conversion of the mother's blood into

caseine, no elements of the constituents of the blood have been

separated. When chemically examined, caseine is found to contain a

much larger proportion of the earth of bones than blood does, and

that in a very soluble form, capable of reaching every part of the

body. Thus, even in the earliest period of its life, the development

of the organs, in which vitality resides, is, in the carnivorous

animal, dependent on the supply of a substance, identical in organic

composition with the chief constituents of its blood.

What, then, is the use of the butter and the sugar of milk? How does

it happen that these substances are indispensable to life?

Butter and sugar of milk contain no fixed bases, no soda nor potash.

Sugar of milk has a composition closely allied to that of the other

kinds of sugar, of starch, and of gum; all of them contain carbon

and the elements of water, the latter precisely in the proportion to

form water.

There is added, therefore, by means of these compounds, to the

nitrogenised constituents of food, a certain amount of carbon; or,

as in the case of butter, of carbon and hydrogen; that is, an excess

of elements, which cannot possibly be employed in the production of

blood, because the nitrogenised substances contained in the food

already contain exactly the amount of carbon which is required for

the production of fibrine and albumen.

In an adult carnivorous animal, which neither gains nor loses

weight, perceptibly, from day to day, its nourishment, the waste of

organised tissue, and its consumption of oxygen, stand to each other

in a well-defined and fixed relation.

The carbon of the carbonic acid given off, with that of the urine;

the nitrogen of the urine, and the hydrogen given off as ammonia and

water; these elements, taken together, must be exactly equal in

weight to the carbon, nitrogen, and hydrogen of the metamorphosed

tissues, and since these last are exactly replaced by the food, to

the carbon, nitrogen, and hydrogen of the food. Were this not the

case, the weight of the animal could not possibly remain unchanged.

But, in the young of the carnivora, the weight does not remain

unchanged; on the contrary, it increases from day to day by an

appreciable quantity.

This fact presupposes, that the assimilative process in the young

animal is more energetic, more intense, than the process of

transformation in the existing tissues. If both processes were

equally active, the weight of the body could not increase; and were

the waste by transformation greater, the weight of the body would

decrease.

Now, the circulation in the young animal is not weaker, but, on the

contrary, more rapid; the respirations are more frequent; and, for

equal bulks, the consumption of oxygen must be greater rather than

smaller in the young than in the adult animal. But, since the

metamorphosis of organised parts goes on more slowly, there would

ensue a deficiency of those substances, the carbon and hydrogen of

which are adapted for combination with oxygen; because, in the

carnivora, nature has destined the new compounds, produced by the

metamorphosis of organised parts, to furnish the necessary

resistance to the action of the oxygen, and to produce animal heat.

What is wanting for these purposes an Infinite Wisdom has supplied

to the young in its natural food.

The carbon and hydrogen of butter, and the carbon of the sugar of

milk, no part of either of which can yield blood, fibrine, or

albumen, are destined for the support of the respiratory process, at

an age when a greater resistance is opposed to the metamorphosis of

existing organisms; or, in other words, to the production of

compounds, which, in the adult state, are produced in quantity amply

sufficient for the purpose of respiration.

The young animal receives the constituents of its blood in the

caseine of the milk. A metamorphosis of existing organs goes on, for

bile and urine are secreted; the materials of the metamorphosed

parts are given off in the form of urine, of carbonic acid, and of

water; but the butter and sugar of milk also disappear; they cannot

be detected in the faeces.

The butter and sugar of milk are given out in the form of carbonic

acid and water, and their conversion into oxidised products

furnishes the clearest proof that far more oxygen is absorbed than

is required to convert the carbon and hydrogen of the metamorphosed

tissues into carbonic acid and water.

The change and metamorphosis of organised tissues going on in the

vital process in the young animal, consequently yield, in a given

time, much less carbon and hydrogen in the form adapted for the

respiratory process than correspond to the oxygen taken up in the

lungs. The substance of its organised parts would undergo a more

rapid consumption, and would necessarily yield to the action of the

oxygen, were not the deficiency of carbon and hydrogen supplied from

another source.

The continued increase of mass, or growth, and the free and

unimpeded development of the organs in the young animal, are

dependent on the presence of foreign substances, which, in the

nutritive process, have no other function than to protect the

newly-formed organs from the action of the oxygen. The elements of

these substances unite with the oxygen; the organs themselves could

not do so without being consumed; that is, growth, or increase of

mass in the body,--the consumption of oxygen remaining the

same,--would be utterly impossible.

The preceding considerations leave no doubt as to the purpose for

which Nature has added to the food of the young of carnivorous

mammalia substances devoid of nitrogen, which their organism cannot

employ for nutrition, strictly so called, that is, for the

production of blood; substances which may be entirely dispensed with

in their nourishment in the adult state. In the young of carnivorous

birds, the want of all motion is an obvious cause of diminished

waste in the organised parts; hence, milk is not provided for them.

The nutritive process in the carnivora thus presents itself under

two distinct forms; one of which we again meet with in the

graminivora.

In graminivorous animals, we observe, that during their whole life,

their existence depends on a supply of substances having a

composition identical with that of sugar of milk, or closely

resembling it. Everything that they consume as food contains a

certain quantity of starch, gum, or sugar, mixed with other matters.

The function performed in the vital process of the graminivora by

these substances is indicated in a very clear and convincing manner,

when we take into consideration the very small relative amount of

the carbon which these animals consume in the nitrogenised

constituents of their food, which bears no proportion whatever to

the oxygen absorbed through the skin and lungs.

A horse, for example, can be kept in perfectly good condition, if he

obtain as food 15 lbs. of hay and 4 1/2 lbs. of oats daily. If we

now calculate the whole amount of nitrogen in these matters, as

ascertained by analysis (1 1/2 per cent. in the hay, 2.2 per cent.

in the oats), in the form of blood, that is, as fibrine and albumen,

with the due proportion of water in blood (80 per cent.), the horse

receives daily no more than 4 1/2 oz. of nitrogen, corresponding to

about 8 lbs. of blood. But along with this nitrogen, that is,

combined with it in the form of fibrine or albumen, the animal

receives only about 14 1/2 oz. of carbon.

Without going further into the calculation, it will readily be

admitted, that the volume of air inspired and expired by a horse,

the quantity of oxygen consumed, and, as a necessary consequence,

the amount of carbonic acid given out by the animal, are much

greater than in the respiratory process in man. But an adult man

consumes daily abut 14 oz. of carbon, and the determination of

Boussingault, according to which a horse expires 79 oz. daily,

cannot be very far from the truth.

In the nitrogenised constituents of his food, therefore, the horse

receives rather less than the fifth part of the carbon which his

organism requires for the support of the respiratory process; and we

see that the wisdom of the Creator has added to his food the

four-fifths which are wanting, in various forms, as starch, sugar,

&c. with which the animal must be supplied, or his organism will be

destroyed by the action of the oxygen.

It is obvious, that in the system of the graminivora, whose food

contains so small a portion, relatively, of the constituents of the

blood, the process of metamorphosis in existing tissues, and

consequently their restoration or reproduction, must go on far less

rapidly than in the carnivora. Were this not the case, a vegetation

a thousand times more luxuriant than the actual one would not

suffice for their nourishment. Sugar, gum, and starch, would no

longer be necessary to support life in these animals, because, in

that case, the products of the waste, or metamorphosis of the

organised tissues, would contain enough carbon to support the

respiratory process.

LETTER X

My dear Sir,

Let me now apply the principles announced in the preceding letters

to the circumstances of our own species. Man, when confined to

animal food, requires for his support and nourishment extensive

sources of food, even more widely extended than the lion and tiger,

because, when he has the opportunity, he kills without eating.

A nation of hunters, on a limited space, is utterly incapable of

increasing its numbers beyond a certain point, which is soon

attained. The carbon necessary for respiration must be obtained from

the animals, of which only a limited number can live on the space

supposed. These animals collect from plants the constituents of

their organs and of their blood, and yield them, in turn, to the

savages who live by the chase alone. They, again, receive this food

unaccompanied by those compounds, destitute of nitrogen, which,

during the life of the animals, served to support the respiratory

process. In such men, confined to an animal diet, it is the carbon

of the flesh and of the blood which must take the place of starch

and sugar.

But 15 lbs. of flesh contain no more carbon than 4 lbs. of starch,

and while the savage with one animal and an equal weight of starch

should maintain life and health for a certain number of days, he

would be compelled, if confined to flesh alone, in order to procure

the carbon necessary for respiration, during the same time, to

consume five such animals.

It is easy to see, from these considerations, how close the

connection is between agriculture and the multiplication of the

human species. The cultivation of our crops has ultimately no other

object than the production of a maximum of those substances which

are adapted for assimilation and respiration, in the smallest

possible space. Grain and other nutritious vegetables yield us, not

only in starch, sugar, and gum, the carbon which protects our organs

from the action of oxygen, and produces in the organism the heat

which is essential to life, but also in the form of vegetable

fibrine, albumen, and caseine, our blood, from which the other parts

of our body are developed.

Man, when confined to animal food, respires, like the carnivora, at

the expense of the matters produced by the metamorphosis of

organised tissues; and, just as the lion, tiger, hyaena, in the

cages of a menagerie, are compelled to accelerate the waste of the

organised tissues by incessant motion, in order to furnish the

matter necessary for respiration, so, the savage, for the very same

object, is forced to make the most laborious exertions, and go

through a vast amount of muscular exercise. He is compelled to

consume force merely in order to supply matter for respiration.

Cultivation is the economy of force. Science teaches us the simplest

means of obtaining the greatest effect with the smallest expenditure

of power, and with given means to produce a maximum of force. The

unprofitable exertion of power, the waste of force in agriculture,

in other branches of industry, in science, or in social economy, is

characteristic of the savage state, or of the want of knowledge.

In accordance with what I have already stated, you will perceive

that the substances of which the food of man is composed may be

divided into two classes; into nitrogenised and non-nitrogenised.

The former are capable of conversion into blood; the latter are

incapable of this transformation.

Out of those substances which are adapted to the formation of blood,

are formed all the organised tissues. The other class of substances,

in the normal state of health, serve to support the process of

respiration. The former may be called the plastic elements of

nutrition; the latter, elements of respiration.

Among the former we reckon--

Vegetable fibrine.

Vegetable albumen.

Vegetable caseine.

Animal flesh.

Animal blood.

Among the elements of respiration in our food, are--

Fat. Pectine.

Starch. Bassorine.

Gum. Wine.

Cane sugar. Beer.

Grape sugar. Spirits.

Sugar of milk.

The most recent and exact researches have established as a universal

fact, to which nothing yet known is opposed, that the nitrogenised

constituents of vegetable food have a composition identical with

that of the constituents of the blood.

No nitrogenised compound, the composition of which differs from that

of fibrine, albumen, and caseine, is capable of supporting the vital

process in animals.

The animal organism unquestionably possesses the power of forming,

from the constituents of its blood, the substance of its membranes

and cellular tissue, of the nerves and brain, and of the organic

part of cartilages and bones. But the blood must be supplied to it

perfect in everything but its form--that is, in its chemical

composition. If this be not done, a period is rapidly put to the

formation of blood, and consequently to life.

This consideration enables us easily to explain how it happens that

the tissues yielding gelatine or chondrine, as, for example, the

gelatine of skin or of bones, are not adapted for the support of the

vital process; for their composition is different from that of

fibrine or albumen. It is obvious that this means nothing more than

that those parts of the animal organism which form the blood do not

possess the power of effecting a transformation in the arrangement

of the elements of gelatine, or of those tissues which contain it.

The gelatinous tissues, the gelatine of the bones, the membranes,

the cells and the skin suffer, in the animal body, under the

influence of oxygen and moisture, a progressive alteration; a part

of these tissues is separated, and must be restored from the blood;

but this alteration and restoration are obviously confined within

very narrow limits.

While, in the body of a starving or sick individual, the fat

disappears and the muscular tissue takes once more the form of

blood, we find that the tendons and membranes retain their natural

condition, and the limbs of the dead body their connections, which

depend on the gelatinous tissues.

On the other hand, we see that the gelatine of bones devoured by a

dog entirely disappears, while only the bone earth is found in his

excrements. The same is true of man, when fed on food rich in

gelatine, as, for example, strong soup. The gelatine is not to be

found either in the urine or in the faeces, and consequently must

have undergone a change, and must have served some purpose in the

animal economy. It is clear that the gelatine must be expelled from

the body in a form different from that in which it was introduced as

food.

When we consider the transformation of the albumen of the blood into

a part of an organ composed of fibrine, the identity in composition

of the two substances renders the change easily conceivable. Indeed

we find the change of a dissolved substance into an insoluble organ

of vitality, chemically speaking, natural and easily explained, on

account of this very identity of composition. Hence the opinion is

not unworthy of a closer investigation, that gelatine, when taken in

the dissolved state, is again converted, in the body, into cellular

tissue, membrane and cartilage; that it may serve for the

reproduction of such parts of these tissues as have been wasted, and

for their growth.

And when the powers of nutrition in the whole body are affected by a

change of the health, then, even should the power of forming blood

remain the same, the organic force by which the constituents of the

blood are transformed into cellular tissue and membranes must

necessarily be enfeebled by sickness. In the sick man, the intensity

of the vital force, its power to produce metamorphoses, must be

diminished as well in the stomach as in all other parts of the body.

In this condition, the uniform experience of practical physicians

shows that gelatinous matters in a dissolved state exercise a most

decided influence on the state of the health. Given in a form

adapted for assimilation, they serve to husband the vital force,

just as may be done, in the case of the stomach, by due preparation

of the food in general.

Brittleness in the bones of graminivorous animals is clearly owing

to a weakness in those parts of the organism whose function it is to

convert the constituents of the blood into cellular tissue and

membrane; and if we can trust to the reports of physicians who have

resided in the East, the Turkish women, in their diet of rice, and

in the frequent use of enemata of strong soup, have united the

conditions necessary for the formation both of cellular tissue and

of fat.

LETTER XI

My dear Sir,

In the immense, yet limited expanse of the ocean, the animal and

vegetable kingdoms are mutually dependent upon, and successive to

each other. The animals obtain their constituent elements from the

plants, and restore them to the water in their original form, when

they again serve as nourishment to a new generation of plants.

The oxygen which marine animals withdraw in their respiration from

the air, dissolved in sea water, is returned to the water by the

vital processes of sea plants; that air is richer in oxygen than

atmospheric air, containing 32 to 33 per cent. Oxygen, also,

combines with the products of the putrefaction of dead animal

bodies, changes their carbon into carbonic acid, their hydrogen into

water, and their nitrogen assumes again the form of ammonia.

Thus we observe in the ocean a circulation takes place without the

addition or subtraction of any element, unlimited in duration,

although limited in extent, inasmuch as in a confined space the

nourishment of plants exists in a limited quantity.

We well know that marine plants cannot derive a supply of humus for

their nourishment through their roots. Look at the great sea-tang,

the Fucus giganteus: this plant, according to Cook, reaches a height

of 360 feet, and a single specimen, with its immense ramifications,

nourishes thousands of marine animals, yet its root is a small body,

no larger than the fist. What nourishment can this draw from a naked

rock, upon the surface of which there is no perceptible change? It

is quite obvious that these plants require only a hold,--a fastening

to prevent a change of place,--as a counterpoise to their specific

gravity, which is less than that of the medium in which they float.

That medium provides the necessary nourishment, and presents it to

the surface of every part of the plant. Sea-water contains not only

carbonic acid and ammonia, but the alkaline and earthy phosphates

and carbonates required by these plants for their growth, and which

we always find as constant constituents of their ashes.

All experience demonstrates that the conditions of the existence of

marine plants are the same which are essential to terrestrial

plants. But the latter do not live like sea-plants, in a medium

which contains all their elements and surrounds with appropriate

nourishment every part of their organs; on the contrary, they

require two media, of which one, namely the soil, contains those

essential elements which are absent from the medium surrounding

them, i.e. the atmosphere.

Is it possible that we could ever be in doubt respecting the office

which the soil and its component parts subserve in the existence and

growth of vegetables?--that there should have been a time when the

mineral elements of plants were not regarded as absolutely essential

to their vitality? Has not the same circulation been observed on the

surface of the earth which we have just contemplated in the

ocean,--the same incessant change, disturbance and restitution of

equilibrium?

Experience in agriculture shows that the production of vegetables on

a given surface increases with the supply of certain matters,

originally parts of the soil which had been taken up from it by

plants--the excrements of man and animals. These are nothing more

than matters derived from vegetable food, which in the vital

processes of animals, or after their death, assume again the form

under which they originally existed, as parts of the soil. Now, we

know that the atmosphere contains none of these substances, and

therefore can replace none; and we know that their removal from a

soil destroys its fertility, which may be restored and increased by

a new supply.

Is it possible, after so many decisive investigations into the

origin of the elements of animals and vegetables, the use of the

alkalies, of lime and the phosphates, any doubt can exist as to the

principles upon which a rational agriculture depends? Can the art of

agriculture be based upon anything but the restitution of a

disturbed equilibrium? Can it be imagined that any country, however

rich and fertile, with a flourishing commerce, which for centuries

exports its produce in the shape of grain and cattle, will maintain

its fertility, if the same commerce does not restore, in some form

of manure, those elements which have been removed from the soil, and

which cannot be replaced by the atmosphere? Must not the same fate

await every such country which has actually befallen the once

prolific soil of Virginia, now in many parts no longer able to grow

its former staple productions--wheat and tobacco?

In the large towns of England the produce both of English and

foreign agriculture is largely consumed; elements of the soil

indispensable to plants do not return to the fields,--contrivances

resulting from the manners and customs of English people, and

peculiar to them, render it difficult, perhaps impossible, to

collect the enormous quantity of the phosphates which are daily, as

solid and liquid excrements, carried into the rivers. These

phosphates, although present in the soil in the smallest quantity,

are its most important mineral constituents. It was observed that

many English fields exhausted in that manner immediately doubled

their produce, as if by a miracle, when dressed with bone earth

imported from the Continent. But if the export of bones from Germany

is continued to the extent it has hitherto reached, our soil must be

gradually exhausted, and the extent of our loss may be estimated, by

considering that one pound of bones contains as much phosphoric acid

as a hundred-weight of grain.

The imperfect knowledge of Nature and the properties and relations

of matter possessed by the alchemists gave rise, in their time, to

an opinion that metals as well as plants could be produced from a

seed. The regular forms and ramifications seen in crystals, they

imagined to be the leaves and branches of metal plants; and as they

saw the seed of plants grow, producing root, stem and leaves, and

again blossoms, fruit and seeds, apparently without receiving any

supply of appropriate material, they deemed it worthy of zealous

inquiry to discover the seed of gold, and the earth necessary for

its development. If the metal seeds were once obtained, might they

not entertain hopes of their growth?

Such ideas could only be entertained when nothing was known of the

atmosphere, and its participation with the earth, in administering

to the vital processes of plants and animals. Modern chemistry

indeed produces the elements of water, and, combining them, forms

water anew; but it does not create those elements--it derives them

from water; the new-formed artificial water has been water before.

Many of our farmers are like the alchemists of old,--they are

searching for the miraculous seed,--the means, which, without any

further supply of nourishment to a soil scarcely rich enough to be

sprinkled with indigenous plants, shall produce crops of grain a

hundred-fold.

The experience of centuries, nay, of thousands of years, is

insufficient to guard men against these fallacies; our only security

from these and similar absurdities must be derived from a correct

knowledge of scientific principles.

In the first period of natural philosophy, organic life was supposed

to be derived from water only; afterwards, it was admitted that

certain elements derived from the air must be superadded to the

water; but we now know that other elements must be supplied by the

earth, if plants are to thrive and multiply.

The amount of materials contained in the atmosphere, suited to the

nourishment of plants, is limited; but it must be abundantly

sufficient to cover the whole surface of the earth with a rich

vegetation. Under the tropics, and in those parts of our globe where

the most genial conditions of fertility exist,--a suitable soil, a

moist atmosphere, and a high temperature,--vegetation is scarcely

limited by space; and, where the soil is wanting, it is gradually

supplied by the decaying leaves, bark and branches of plants. It is

obvious there is no deficiency of atmospheric nourishment for plants

in those regions, nor are these wanting in our own cultivated

fields: all that plants require for their development is conveyed to

them by the incessant motions of the atmosphere. The air between the

tropics contains no more than that of the arctic zones; and yet how

different is the amount of produce of an equal surface of land in

the two situations!

This is easily explicable. All the plants of tropical climates, the

oil and wax palms, the sugar cane, &c., contain only a small

quantity of the elements of the blood necessary to the nutrition of

animals, as compared with our cultivated plants. The tubers of the

potato in Chili, its native country, where the plant resembles a

shrub, if collected from an acre of land, would scarcely suffice to

maintain an Irish family for a single day (Darwin). The result of

cultivation in those plants which serve as food, is to produce in

them those constituents of the blood. In the absence of the elements

essential to these in the soil, starch, sugar and woody fibre, are

perhaps formed; but no vegetable fibrine, albumen, or caseine. If we

intend to produce on a given surface of soil more of these latter

matters than the plants can obtain from the atmosphere or receive

from the soil of the same surface in its uncultivated and normal

state, we must create an artificial atmosphere, and add the needed

elements to the soil.

The nourishment which must be supplied in a given time to different

plants, in order to admit a free and unimpeded growth, is very

unequal.

On pure sand, on calcareous soil, on naked rocks, only a few genera

of plants prosper, and these are, for the most part, perennial

plants. They require, for their slow growth, only such minute

quantities of mineral substances as the soil can furnish, which may

be totally barren for other species. Annual, and especially summer

plants, grow and attain their perfection in a comparatively short

time; they therefore do not prosper on a soil which is poor in those

mineral substances necessary to their development. To attain a

maximum in height in the short period of their existence, the

nourishment contained in the atmosphere is not sufficient. If the

end of cultivation is to be obtained, we must create in the soil an

artificial atmosphere of carbonic acid and ammonia; and this surplus

of nourishment, which the leaves cannot appropriate from the air,

must be taken up by the corresponding organs, i.e. the roots, from

the soil. But the ammonia, together with the carbonic acid, are

alone insufficient to become part of a plant destined to the

nourishment of animals. In the absence of the alkalies, the

phosphates and other earthy salts, no vegetable fibrine, no

vegetable caseine, can be formed. The phosphoric acid of the

phosphate of lime, indispensable to the cerealia and other

vegetables in the formation of their seeds, is separated as an

excrement, in great quantities, by the rind and barks of ligneous

plants.

How different are the evergreen plants, the cacti, the mosses, the

ferns, and the pines, from our annual grasses, the cerealia and

leguminous vegetables! The former, at every time of the day during

winter and summer, obtain carbon through their leaves by absorbing

carbonic acid which is not furnished by the barren soil on which

they grow; water is also absorbed and retained by their coriaceous

or fleshy leaves with great force. They lose very little by

evaporation, compared with other plants. On the other hand, how very

small is the quantity of mineral substances which they withdraw from

the soil during their almost constant growth in one year, in

comparison with the quantity which one crop of wheat of an equal

weight receives in three months!

It is by means of moisture that plants receive the necessary

alkalies and salts from the soil. In dry summers a phenomenon is

observed, which, when the importance of mineral elements to the life

of a plant was unknown, could not be explained. The leaves of plants

first developed and perfected, and therefore nearer the surface of

the soil, shrivel up and become yellow, lose their vitality, and

fall off while the plant is in an active state of growth, without

any visible cause. This phenomenon is not seen in moist years, nor

in evergreen plants, and but rarely in plants which have long and

deep roots, nor is it seen in perennials in autumn and winter.

The cause of this premature decay is now obvious. The

perfectly-developed leaves absorb continually carbonic acid and

ammonia from the atmosphere, which are converted into elements of

new leaves, buds, and shoots; but this metamorphosis cannot be

effected without the aid of the alkalies, and other mineral

substances. If the soil is moist, the latter are continually

supplied to an adequate amount, and the plant retains its lively

green colour; but if this supply ceases from a want of moisture to

dissolve the mineral elements, a separation takes place in the plant

itself. The mineral constituents of the juice are withdrawn from the

leaves already formed, and are used for the formation of the young

shoots; and as soon as the seeds are developed, the vitality of the

leaves completely ceases. These withered leaves contain only minute

traces of soluble salts, while the buds and shoots are very rich in

them.

On the other hand, it has been observed, that where a soil is too

highly impregnated with soluble saline materials, these are

separated upon the surface of the leaves. This happens to culinary

vegetables especially, whose leaves become covered with a white

crust. In consequence of these exudations the plant sickens, its

organic activity decreases, its growth is disturbed; and if this

state continues long, the plant dies. This is most frequently seen

in foliaceous plants, the large surfaces of which evaporate

considerable quantities of water. Carrots, pumpkins, peas, &c., are

frequently thus diseased, when, after dry weather, the plant being

near its full growth, the soil is moistened by short showers,

followed again by dry weather. The rapid evaporation carries off the

water absorbed by the root, and this leaves the salts in the plant

in a far greater quantity than it can assimilate. These salts

effloresce upon the surface of the leaves, and if they are

herbaceous and juicy, produce an effect upon them as if they had

been watered with a solution containing a greater quantity of salts

than their organism can bear.

Of two plants of the same species, this disease befalls that which

is nearest its perfection; if one should have been planted later, or

be more backward in its development, the same external cause which

destroys the one will contribute to the growth of the other.

LETTER XII

My dear Sir,

Having now occupied several letters with the attempt to unravel, by

means of chemistry, some of the most curious functions of the animal

body, and, as I hope, made clear to you the distinctions between the

two kinds of constituent elements in food, and the purposes they

severally subserve in sustaining life, let me now direct your

attention to a scarcely less interesting and equally important

subject--the means of obtaining from a given surface of the earth

the largest amount of produce adapted to the food of man and

animals.

Agriculture is both a science and an art. The knowledge of all the

conditions of the life of vegetables, the origin of their elements,

and the sources of their nourishment, forms its scientific basis.

From this knowledge we derive certain rules for the exercise of the

ART, the principles upon which the mechanical operations of farming

depend, the usefulness or necessity of these for preparing the soil

to support the growth of plants, and for removing every obnoxious

influence. No experience, drawn from the exercise of the art, can be

opposed to true scientific principles, because the latter should

include all the results of practical operations, and are in some

instances solely derived therefrom. Theory must correspond with

experience, because it is nothing more than the reduction of a

series of phenomena to their last causes.

A field in which we cultivate the same plant for several successive

years becomes barren for that plant in a period varying with the

nature of the soil: in one field it will be in three, in another in

seven, in a third in twenty, in a fourth in a hundred years. One

field bears wheat, and no peas; another beans or turnips, but no

tobacco; a third gives a plentiful crop of turnips, but will not

bear clover. What is the reason that a field loses its fertility for

one plant, the same which at first flourished there? What is the

reason one kind of plant succeeds in a field where another fails?

These questions belong to Science.

What means are necessary to preserve to a field its fertility for

one and the same plant?--what to render one field fertile for two,

for three, for all plants?

These last questions are put by Art, but they cannot be answered by

Art.

If a farmer, without the guidance of just scientific principles, is

trying experiments to render a field fertile for a plant which it

otherwise will not bear, his prospect of success is very small.

Thousands of farmers try such experiments in various directions, the

result of which is a mass of practical experience forming a method

of cultivation which accomplishes the desired end for certain

places; but the same method frequently does not succeed, it indeed

ceases to be applicable to a second or third place in the immediate

neighbourhood. How large a capital, and how much power, are wasted

in these experiments! Very different, and far more secure, is the

path indicated by SCIENCE; it exposes us to no danger of failing,

but, on the contrary, it furnishes us with every guarantee of

success. If the cause of failure--of barrenness in the soil for one

or two plants--has been discovered, means to remedy it may readily

be found.

The most exact observations prove that the method of cultivation

must vary with the geognostical condition of the subsoil. In basalt,

graywacke, porphyry, sandstone, limestone, &c., are certain elements

indispensable to the growth of plants, and the presence of which

renders them fertile. This fully explains the difference in the

necessary methods of culture for different places; since it is

obvious that the essential elements of the soil must vary with the

varieties of composition of the rocks, from the disintegration of

which they originated.

Wheat, clover, turnips, for example, each require certain elements

from the soil; they will not flourish where the appropriate elements

are absent. Science teaches us what elements are essential to every

species of plants by an analysis of their ashes. If therefore a soil

is found wanting in any of those elements, we discover at once the

cause of its barrenness, and its removal may now be readily

accomplished.

The empiric attributes all his success to the mechanical operations

of agriculture; he experiences and recognises their value, without

inquiring what are the causes of their utility, their mode of

action: and yet this scientific knowledge is of the highest

importance for regulating the application of power and the

expenditure of capital,--for insuring its economical expenditure and

the prevention of waste. Can it be imagined that the mere passing of

the ploughshare or the harrow through the soil--the mere contact of

the iron--can impart fertility miraculously? Nobody, perhaps,

seriously entertains such an opinion. Nevertheless, the modus

operandi of these mechanical operations is by no means generally

understood. The fact is quite certain, that careful ploughing exerts

the most favourable influence: the surface is thus mechanically

divided, changed, increased, and renovated; but the ploughing is

only auxiliary to the end sought.

In the effects of time, in what in Agriculture are technically

called fallows--the repose of the fields--we recognise by science

certain chemical actions, which are continually exercised by the

elements of the atmosphere upon the whole surface of our globe. By

the action of its oxygen and its carbonic acid, aided by water,

rain, changes of temperature, &c., certain elementary constituents

of rocks, or of their ruins, which form the soil capable of

cultivation, are rendered soluble in water, and consequently become

separable from all their insoluble parts.

These chemical actions, poetically denominates the "tooth of time,"

destroy all the works of man, and gradually reduce the hardest rocks

to the condition of dust. By their influence the necessary elements

of the soil become fitted for assimilation by plants; and it is

precisely the end which is obtained by the mechanical operations of

farming. They accelerate the decomposition of the soil, in order to

provide a new generation of plants with the necessary elements in a

condition favourable to their assimilation. It is obvious that the

rapidity of the decomposition of a solid body must increase with the

extension of its surface; the more points of contact we offer in a

given time to the external chemical agent, the more rapid will be

its action.

The chemist, in order to prepare a mineral for analysis, to

decompose it, or to increase the solubility of its elements,

proceeds in the same way as the farmer deals with his fields--he

spares no labour in order to reduce it to the finest powder; he

separates the impalpable from the coarser parts by washing, and

repeats his mechanical bruising and trituration, being assured his

whole process will fail if he is inattentive to this essential and

preliminary part of it.

The influence which the increase of surface exercises upon the

disintegration of rocks, and upon the chemical action of air and

moisture, is strikingly illustrated upon a large scale in the

operations pursued in the gold-mines of Yaquil, in Chili. These are

described in a very interesting manner by Darwin. The rock

containing the gold ore is pounded by mills into the finest powder;

this is subjected to washing, which separates the lighter particles

from the metallic; the gold sinks to the bottom, while a stream of

water carries away the lighter earthy parts into ponds, where it

subsides to the bottom as mud. When this deposit has gradually

filled up the pond, this mud is taken out and piled in heaps, and

left exposed to the action of the atmosphere and moisture. The

washing completely removes all the soluble part of the disintegrated

rock; the insoluble part, moreover, cannot undergo any further

change while it is covered with water, and so excluded from the

influence of the atmosphere at the bottom of the pond. But being

exposed at once to the air and moisture, a powerful chemical action

takes place in the whole mass, which becomes indicated by an

efflorescence of salts covering the whole surface of the heaps in

considerable quantity. After being exposed for two or three years,

the mud is again subjected to the same process of washing, and a

considerable quantity of gold is obtained, this having been

separated by the chemical process of decomposition in the mass. The

exposure and washing of the same mud is repeated six or seven times,

and at every washing it furnishes a new quantity of gold, although

its amount diminishes every time.

Precisely similar is the chemical action which takes place in the

soil of our fields; and we accelerate and increase it by the

mechanical operations of our agriculture. By these we sever and

extend the surface, and endeavour to make every atom of the soil

accessible to the action of the carbonic acid and oxygen of the

atmosphere. We thus produce a stock of soluble mineral substances,

which serves as nourishment to a new generation of plants, materials

which are indispensable to their growth and prosperity.

LETTER XIII

My dear Sir,

Having in my last letter spoken of the general principles upon which

the science and art of agriculture must be based, let me now direct

your attention to some of those particulars between chemistry and

agriculture, and demonstrate the impossibility of perfecting the

important art of rearing food for man and animals, without a

profound knowledge of our science.

All plants cultivated as food require for their healthy sustenance

the alkalies and alkaline earths, each in a certain proportion; and

in addition to these, the cerealia do not succeed in a soil

destitute of silica in a soluble condition. The combinations of this

substance found as natural productions, namely, the silicates,

differ greatly in the degree of facility with which they undergo

decomposition, in consequence of the unequal resistance opposed by

their integral parts to the dissolving power of the atmospheric

agencies. Thus the granite of Corsica degenerates into a powder in a

time which scarcely suffices to deprive the polished granite of

Heidelberg of its lustre.

Some soils abound in silicates so readily decomposable, that in

every one or two years, as much silicate of potash becomes soluble

and fitted for assimilation as is required by the leaves and straw

of a crop of wheat. In Hungary, extensive districts are not uncommon

where wheat and tobacco have been grown alternately upon the same

soil for centuries, the land never receiving back any of those

mineral elements which were withdrawn in the grain and straw. On the

other hand, there are fields in which the necessary amount of

soluble silicate of potash for a single crop of wheat is not

separated from the insoluble masses in the soil in less than two,

three, or even more years.

The term fallow, in Agriculture, designates that period in which the

soil, left to the influence of the atmosphere, becomes enriched with

those soluble mineral constituents. Fallow, however, does not

generally imply an entire cessation of cultivation, but only an

interval in the growth of the cerealia. That store of silicates and

alkalies which is the principal condition of their success is

obtained, if potatoes or turnips are grown upon the same fields in

the intermediate periods, since these crops do not abstract a

particle of silica, and therefore leave the field equally fertile

for the following crop of wheat.

The preceding remarks will render it obvious to you, that the

mechanical working of the soil is the simplest and cheapest method

of rendering the elements of nutrition contained in it accessible to

plants.

But it may be asked, Are there not other means of decomposing the

soil besides its mechanical subdivision?--are there not substances,

which by their chemical operation will equally well or better render

its constituents suitable for entering into vegetable organisms?

Yes: we certainly possess such substances, and one of them, namely,

quick-lime, has been employed for the last century past in England

for this purpose; and it would be difficult to find a substance

better adapted to this service, as it is simple, and in almost all

localities cheap and easily accessible.

In order to obtain correct views respecting the effect of quick-lime

upon the soil, let me remind you of the first process employed by

the chemist when he is desirous of analysing a mineral, and for this

purpose wishes to bring its elements into a soluble state. Let the

mineral to be examined be, for instance, feldspar; this substance,

taken alone, even when reduced to the finest powder, requires for

its solution to be treated with an acid for weeks or months; but if

we first mix it with quick-lime, and expose the mixture to a

moderately strong heat, the lime enters into chemical combination

with certain elements of the feldspar, and its alkali (potass) is

set free. And now the acid, even without heat, dissolves not only

the lime, but also so much of the silica of the feldspar as to form

a transparent jelly. The same effect which the lime in this process,

with the aid of heat, exerts upon the feldspar, it produces when it

is mixed with the alkaline argillaceous silicates, and they are for

a long time kept together in a moist state.

Common potters' clay, or pipe-clay, diffused through water, and

added to milk of lime, thickens immediately upon mixing; and if the

mixture is kept for some months, and then treated with acid, the

clay becomes gelatinous, which would not occur without the admixture

with the lime. The lime, in combining with the elements of the clay,

liquifies it; and, what is more remarkable, liberates the greater

part of its alkalies. These interesting facts were first observed by

Fuchs, at Munich: they have not only led to a more intimate

knowledge of the nature and properties of the hydraulic cements,

but, what is far more important, they explain the effects of caustic

lime upon the soil, and guide the agriculturist in the application

of an invaluable means of opening it, and setting free its

alkalies--substances so important, nay, so indispensable to his

crops.

In the month of October the fields of Yorkshire and Oxfordshire look

as it they were covered with snow. Whole square miles are seen

whitened over with quicklime, which during the moist winter months,

exercises its beneficial influence upon the stiff, clayey soil, of

those counties.

According to the humus theory, quick-lime ought to exert the most

noxious influence upon the soil, because all organic matters

contained in it are destroyed by it, and rendered incapable of

yielding their humus to a new vegetation. The facts are indeed

directly contrary to this now abandoned theory: the fertility of the

soil is increased by the lime. The cerealia require the alkalies and

alkaline silicates, which the action of the lime renders fit for

assimilation by the plants. If, in addition to these, there is any

decaying organic matter present in the soil supplying carbonic acid,

it may facilitate their development; but it is not essential to

their growth. If we furnish the soil with ammonia, and the

phosphates, which are indispensable to the cerealia, with the

alkaline silicates, we have all the conditions necessary to ensure

an abundant harvest. The atmosphere is an inexhaustible store of

carbonic acid.

A no less favourable influence than that of lime is exercised upon

the soil of peaty land by the mere act of burning it: this greatly

enhances its fertility. We have not long been acquainted with the

remarkable change which the properties of clay undergo by burning.

The observation was first made in the process of analysing the clay

silicates. Many of these, in their natural state, are not acted on

by acids, but they become perfectly soluble if heated to redness

before the application of the acid. This property belongs to

potters' clay, pipe-clay, loam, and many different modifications of

clay in soils. In their natural state they may be boiled in

concentrated sulphuric acid, without sensible change; but if feebly

burned, as is done with the pipe-clay in many alum manufactories,

they dissolve in the acid with the greatest facility, the contained

silica being separated like jelly in a soluble state. Potters' clay

belongs to the most sterile kinds of soil, and yet it contains

within itself all the constituent elements essential to a most

luxurious growth of plants; but their mere presence is insufficient

to secure this end. The soil must be accessible to the atmosphere,

to its oxygen, to its carbonic acid; these must penetrate it, in

order to secure the conditions necessary to a happy and vigorous

development of the roots. The elements present must be brought into

that peculiar state of combination which will enable them to enter

into plants. Plastic clay is wanting in these properties; but they

are imparted to it by a feeble calcination.

At Hardwicke Court, near Gloucester, I have seen a garden (Mr.

Baker's) consisting of a stiff clay, which was perfectly sterile,

become by mere burning extremely fertile. The operation was extended

to a depth of three feet. This was an expensive process, certainly;

but it was effectual.

The great difference in the properties of burnt and unburnt clay is

illustrated by what is seen in brick houses, built in moist

situations. In the town of Flanders, for instance, where most

buildings are of brick, effloresences of salts cover the surfaces of

the walls, like a white nap, within a few days after they are

erected. If this saline incrustation is washed away by the rain, it

soon re-appears; and this is even observed on walls which, like the

gateway of Lisle, have been erected for centuries. These saline

incrustations consist of carbonates and sulphates, with alkaline

bases; and it is well known these act an important part in

vegetation. The influence of lime in their production is manifested

by their appearing first at the place where the mortar and brick

come into contact.

It will now be obvious to you, that in a mixture of clay with lime,

all the conditions exist for the solution of the silicated clay, and

the solubility of the alkaline silicates. The lime gradually

dissolving in water charged with carbonic acid, acts like milk of

lime upon the clay. This explains also the favourable influence

which marl (by which term all those varieties of clay rich in chalk

are designated) exerts upon most kinds of soil. There are marly

soils which surpass all others in fertility for all kinds of plants;

but I believe marl in a burnt state must be far more effective, as

well as other materials possessing a similar composition; as, for

instance, those species of limestone which are adapted to the

preparation of hydraulic cements,--for these carry to the soil not

only the alkaline bases useful to plants, but also silica in a state

capable of assimilation.

The ashes of coals and lignite are also excellent means of

ameliorating the soil, and they are used in many places for this

purpose. The most suitable may be readily known by their property of

forming a gelatinous mass when treated with acids, or by becoming,

when mixed with cream of lime, like hydraulic cement,--solid and

hard as stone.

I have now, I trust, explained to your satisfaction, that the

mechanical operations of agriculture--the application of lime and

chalk to lands, and the burning of clay--depend upon one and the

same scientific principle: they are means of accelerating the

decomposition of the alkaline clay silicates, in order to provide

plants, at the beginning of a new vegetation, with certain inorganic

matters indispensable for their nutrition.

LETTER XIV

My dear Sir,

I treated, in my last letter, of the means of improving the

condition of the soil for agricultural purposes by mechanical

operations and mineral agents. I have now to speak of the uses and

effects of animal exuviae, and vegetable matters or manures--properly

so called.

In order to understand the nature of these, and the peculiarity of

their influence upon our fields, it is highly important to keep in

mind the source whence they are derived.

It is generally known, that if we deprive an animal of food, the

weight of its body diminishes during every moment of its existence.

If this abstinence is continued for some time, the diminution

becomes apparent to the eye; all the fat of the body disappears, the

muscles decrease in firmness and bulk, and, if the animal is allowed

to die starved, scarcely anything but skin, tendon, and bones,

remain. This emaciation which occurs in a body otherwise healthy,

demonstrates to us, that during the life of an animal every part of

its living substance is undergoing a perpetual change; all its

component parts, assuming the form of lifeless compounds, are thrown

off by the skin, lungs, and urinary system, altered more or less by

the secretory organs. This change in the living body is intimately

connected with the process of respiration; it is, in truth,

occasioned by the oxygen of the atmosphere in breathing, which

combines with all the various matters within the body. At every

inspiration a quantity of oxygen passes into the blood in the lungs,

and unites with its elements; but although the weight of the oxygen

thus daily entering into the body amounts to 32 or more ounces, yet

the weight of the body is not thereby increased. Exactly as much

oxygen as is imbibed in inspiration passes off in expiration, in the

form of carbonic acid and water; so that with every breath the

amount of carbon and hydrogen in the body is diminished. But the

emaciation--the loss of weight by starvation--does not simply depend

upon the separation of the carbon and hydrogen; but all the other

substances which are in combination with these elements in the

living tissues pass off in the secretions. The nitrogen undergoes a

change, and is thrown out of the system by the kidneys. Their

secretion, the urine, contains not only a compound rich in nitrogen,

namely urea, but the sulphur of the tissues in the form of a

sulphate, all the soluble salts of the blood and animal fluids,

common salt, the phosphates, soda and potash. The carbon and

hydrogen of the blood, of the muscular fibre, and of all the animal

tissues which can undergo change, return into the atmosphere. The

nitrogen, and all the soluble inorganic elements are carried to the

earth in the urine.

These changes take place in the healthy animal body during every

moment of life; a waste and loss of substance proceeds continually;

and if this loss is to be restored, and the original weight and

substance repaired, an adequate supply of materials must be

furnished, from whence the blood and wasted tissues may be

regenerated. This supply is obtained from the food.

In an adult person in a normal or healthy condition, no sensible

increase or decrease of weight occurs from day to day. In youth the

weight of the body increases, whilst in old age it decreases. There

can be no doubt that in the adult, the food has exactly replaced the

loss of substance: it has supplied just so much carbon, hydrogen,

nitrogen, and other elements, as have passed through the skin,

lungs, and urinary organs. In youth the supply is greater than the

waste. Part of the elements of the food remain to augment the bulk

of the body. In old age the waste is greater than the supply, and

the body diminishes. It is unquestionable, that, with the exception

of a certain quantity of carbon and hydrogen, which are secreted

through the skin and lungs, we obtain, in the solid and fluid

excrements of man and animals, all the elements of their food.

We obtain daily, in the form of urea, all the nitrogen taken in the

food both of the young and the adult; and further, in the urine, the

whole amount of the alkalies, soluble phosphates and sulphates,

contained in all the various aliments. In the solid excrements are

found all those substances taken in the food which have undergone no

alteration in the digestive organs, all indigestible matters, such

as woody fibre, the green colouring matter of leaves ( chlorophyle),

wax, &c.

Physiology teaches us, that the process of nutrition in animals,

that is, their increase of bulk, or the restoration of wasted parts,

proceeds from the blood. The purpose of digestion and assimilation

is to convert the food into blood. In the stomach and intestines,

therefore, all those substances in the food capable of conversion

into blood are separated from its other constituents; in other

words, during the passage of the food through the intestinal canal

there is a constant absorption of its nitrogen, since only azotised

substances are capable of conversion into blood; and therefore the

solid excrements are destitute of that element, except only a small

portion, in the constitution of that secretion which is formed to

facilitate their passage. With the solid excrements, the phosphates

of lime and magnesia, which were contained in the food and not

assimilated, are carried off, these salts being insoluble in water,

and therefore not entering the urine.

We may obtain a clear insight into the chemical constitution of the

solid excrements without further investigation, by comparing the

faeces of a dog with his food. We give that animal flesh and

bones--substances rich in azotised matter--and we obtain, as the

last product of its digestion, a perfectly white excrement, solid

while moist, but becoming in dry air a powder. This is the phosphate

of lime of the bones, with scarcely one per cent. of foreign organic

matter.

Thus we see that in the solid and fluid excrements of man and

animals, all the nitrogen--in short, all the constituent ingredients

of the consumed food, soluble and insoluble, are returned; and as

food is primarily derived from the fields, we possess in those

excrements all the ingredients which we have taken from it in the

form of seeds, roots, or herbs.

One part of the crops employed for fattening sheep and cattle is

consumed by man as animal food; another part is taken directly--as

flour, potatoes, green vegetables, &c.; a third portion consists of

vegetable refuse, and straw employed as litter. None of the

materials of the soil need be lost. We can, it is obvious, get back

all its constituent parts which have been withdrawn therefrom, as

fruits, grain and animals, in the fluid and solid excrements of man,

and the bones, blood and skins of the slaughtered animals. It

depends upon ourselves to collect carefully all these scattered

elements, and to restore the disturbed equilibrium of composition in

the soil. We can calculate exactly how much and which of the

component parts of the soil we export in a sheep or an ox, in a

quarter of barley, wheat or potatoes, and we can discover, from the

known composition of the excrements of man and animals, how much we

have to supply to restore what is lost to our fields.

If, however, we could procure from other sources the substances

which give to the exuviae of man and animals their value in

agriculture, we should not need the latter. It is quite indifferent

for our purpose whether we supply the ammonia (the source of

nitrogen) in the form of urine, or in that of a salt derived from

coal-tar; whether we derive the phosphate of lime from bones,

apatite, or fossil excrements (the coprolithes).

The principal problem for agriculture is, how to replace those

substances which have been taken from the soil, and which cannot be

furnished by the atmosphere. If the manure supplies an imperfect

compensation for this loss, the fertility of a field or of a country

decreases; if, on the contrary, more are given to the fields, their

fertility increases.

An importation of urine, or of solid excrements, from a foreign

country, is equivalent to an importation of grain and cattle. In a

certain time, the elements of those substances assume the form of

grain, or of fodder, then become flesh and bones, enter into the

human body, and return again day by day to the form they originally

possessed.

The only real loss of elements we are unable to prevent is of the

phosphates, and these, in accordance with the customs of all modern

nations, are deposited in the grave. For the rest, every part of

that enormous quantity of food which a man consumes during his

lifetime ( say in sixty or seventy years), which was derived from

the fields, can be obtained and returned to them. We know with

absolute certainty, that in the blood of a young or growing animal

there remains a certain quantity of phosphate of lime and of the

alkaline phosphates, to be stored up and to minister to the growth

of the bones and general bulk of the body, and that, with the

exception of this very small quantity, we receive back, in the solid

and fluid excrements, all the salts and alkaline bases, all the

phosphate of lime and magnesia, and consequently all the inorganic

elements which the animal consumes in its food.

We can thus ascertain precisely the quantity, quality, and

composition of animal excrements, without the trouble of analysing

them. If we give a horse daily 4 1/2 pounds' weight of oats, and 15

pounds of hay, and knowing that oats give 4 per cent. and hay 9 per

cent. of ashes, we can calculate that the daily excrements of the

horse will contain 21 ounces of inorganic matter which was drawn

from the fields. By analysis we can determine the exact relative

amount of silica, of phosphates, and of alkalies, contained in the

ashes of the oats and of the hay.

You will now understand that the constituents of the solid parts of

animal excrements, and therefore their qualities as manure, must

vary with the nature of the creature's food. If we feed a cow upon

beetroot, or potatoes, without hay, straw or grain, there will be no

silica in her solid excrements, but there will be phosphate of lime

and magnesia. Her fluid excrements will contain carbonate of potash

and soda, together with compounds of the same bases with inorganic

acids. In one word, we have, in the fluid excrements, all the

soluble parts of the ashes of the consumed food; and in the solid

excrements, all those parts of the ashes which are insoluble in

water.

If the food, after burning, leaves behind ashes containing soluble

alkaline phosphates, as is the case with bread, seeds of all kinds,

and flesh, we obtain from the animal by which they are consumed a

urine holding in solution these phosphates. If, however, the ashes

of food contain no alkaline phosphates, but abound in insoluble

earthy phosphates, as hay, carrots, and potatoes, the urine will be

free from alkaline phosphates, but the earthy phosphates will be

found in the faeces. The urine of man, of carnivorous and

graminivorous animals, contains alkaline phosphates; that of

herbivorous animals is free from these salts.

The analysis of the excrements of man, of the piscivorous birds (as

the guano), of the horse, and of cattle, furnishes us with the

precise knowledge of the salts they contain, and demonstrates, that

in those excrements, we return to the fields the ashes of the plants

which have served as food,--the soluble and insoluble salts and

earths indispensable to the development of cultivated plants, and

which must be furnished to them by a fertile soil.

There can be no doubt that, in supplying these excrements to the

soil, we return to it those constituents which the crops have

removed from it, and we renew its capability of nourishing new

crops: in one word, we restore the disturbed equilibrium; and

consequently, knowing that the elements of the food derived from the

soil enter into the urine and solid excrements of the animals it

nourishes, we can with the greatest facility determine the exact

value of the different kinds of manure. Thus the excrements of pigs

which we have fed with peas and potatoes are principally suited for

manuring crops of potatoes and peas. In feeding a cow upon hay and

turnips, we obtain a manure containing the inorganic elements of

grasses and turnips, and which is therefore preferable for manuring

turnips. The excrement of pigeons contains the mineral elements of

grain; that of rabbits, the elements of herbs and kitchen

vegetables. The fluid and solid excrements of man, however, contain

the mineral elements of grain and seeds in the greatest quantity.

LETTER XV

My dear Sir,

You are now acquainted with my opinions respecting the effects of

the application of mineral agents to our cultivated fields, and also

the rationale of the influence of the various kinds of manures; you

will, therefore, now readily understand what I have to say of the

sources whence the carbon and nitrogen, indispensable to the growth

of plants, are derived.

The growth of forests, and the produce of meadows, demonstrate that

an inexhaustible quantity of carbon is furnished for vegetation by

the carbonic acid of the atmosphere.

We obtain from an equal surface of forest, or meadow-land, where the

necessary mineral elements of the soil are present in a suitable

state, and to which no carbonaceous matter whatever is furnished in

manures, an amount of carbon, in the shape of wood and hay, quite

equal, and oftimes more than is produced by our fields, in grain,

roots, and straw, upon which abundance of manure has been heaped.

It is perfectly obvious that the atmosphere must furnish to our

cultivated fields as much carbonic acid, as it does to an equal

surface of forest or meadow, and that the carbon of this carbonic

acid is assimilated, or may be assimilated by the plants growing

there, provided the conditions essential to its assimilation, and

becoming a constituent element of vegetables, exist in the soil of

these fields.

In many tropical countries the produce of the land in grain or

roots, during the whole year, depends upon one rain in the spring.

If this rain is deficient in quantity, or altogether wanting, the

expectation of an abundant harvest is diminished or destroyed.

Now it cannot be the water merely which produces this enlivening and

fertilising effect observed, and which lasts for weeks and months.

The plant receives, by means of this water, at the time of its first

development, the alkalies, alkaline earths, and phosphates,

necessary to its organization. If these elements, which are

necessary previous to its assimilation of atmospheric nourishment,

be absent, its growth is retarded. In fact, the development of a

plant is in a direct ratio to the amount of the matters it takes up

from the soil. If, therefore, a soil is deficient in these mineral

constituents required by plants, they will not flourish even with an

abundant supply of water.

The produce of carbon on a meadow, or an equal surface of forest

land, is independent of a supply of carbonaceous manure, but it

depends upon the presence of certain elements of the soil which in

themselves contain no carbon, together with the existence of

conditions under which their assimilation by plants can be effected.

We increase the produce of our cultivated fields, in carbon, by a

supply of lime, ashes, and marl, substances which cannot furnish

carbon to the plants, and yet it is indisputable,--being founded

upon abundant experience,--that in these substances we furnish to

the fields elements which greatly increase the bulk of their

produce, and consequently the amount of carbon.

If we admit these facts to be established, we can no longer doubt

that a deficient produce of carbon, or in other words, the

barrenness of a field does not depend upon carbonic acid, because we

are able to increase the produce, to a certain degree, by a supply

of substances which do not contain any carbon. The same source

whence the meadow and the forest are furnished with carbon, is also

open to our cultivated plants. The great object of agriculture,

therefore, is to discover the means best adapted to enable these

plants to assimilate the carbon of the atmosphere which exists in it

as carbonic acid. In furnishing plants, therefore, with mineral

elements, we give them the power to appropriate carbon from a source

which is inexhaustible; whilst in the absence of these elements the

most abundant supply of carbonic acid, or of decaying vegetable

matter, would not increase the produce of a field.

With an adequate and equal supply of these essential mineral

constituents in the soil, the amount of carbonic acid absorbed by a

plant from the atmosphere in a given time is limited by the quantity

which is brought into contact with its organs of absorption.

The withdrawal of carbonic acid from the atmosphere by the vegetable

organism takes place chiefly through its leaves; this absorption

requires the contact of the carbonic acid with their surface, or

with the part of the plant by which it is absorbed.

The quantity of carbonic acid absorbed in a given time is in direct

proportion to the surface of the leaves and the amount of carbonic

acid contained in the air; that is, two plants of the same kind and

the same extent of surface of absorption, in equal times and under

equal conditions, absorb one and the same amount of carbon.

In an atmosphere containing a double proportion of carbonic acid, a

plant absorbs, under the same condition, twice the quantity of

carbon. Boussingault observed, that the leaves of the vine, inclosed

in a vessel, withdrew all the carbonic acid from a current of air

which was passed through it, however great its velocity. (Dumas

Lecon, p.23.) If, therefore, we supply double the quantity of

carbonic acid to one plant, the extent of the surface of which is

only half that of another living in ordinary atmospheric air, the

former will obtain and appropriate as much carbon as the latter.

Hence results the effects of humus, and all decaying organic

substances, upon vegetation. If we suppose all the conditions for

the absorption of carbonic acid present, a young plant will increase

in mass, in a limited time, only in proportion to its absorbing

surface; but if we create in the soil a new source of carbonic acid,

by decaying vegetable substances, and the roots absorb in the same

time three times as much carbonic acid from the soil as the leaves

derive from the atmosphere, the plant will increase in weight

fourfold. This fourfold increase extends to the leaves, buds,

stalks, &c., and in the increased extent of the surface, the plant

acquires an increased power of absorbing nourishment from the air,

which continues in action far beyond the time when its derivation of

carbonic acid through the roots ceases. Humus, as a source of

carbonic acid in cultivated lands, is not only useful as a means of

increasing the quantity of carbon--an effect which in most cases may

be very indifferent for agricultural purposes--but the mass of the

plant having increased rapidly in a short time, space is obtained

for the assimilation of the elements of the soil necessary for the

formation of new leaves and branches.

Water evaporates incessantly from the surface of the young plant;

its quantity is in direct proportion to the temperature and the

extent of the surface. The numerous radical fibrillae replace, like

so many pumps, the evaporated water; and so long as the soil is

moist, or penetrated with water, the indispensable elements of the

soil, dissolved in the water, are supplied to the plant. The water

absorbed by the plant evaporating in an aeriform state leaves the

saline and other mineral constituents within it. The relative

proportion of these elements taken up by a plant, is greater, the

more extensive the surface and more abundant the supply of water;

where these are limited, the plant soon reaches its full growth,

while if their supply is continued, a greater amount of elements

necessary to enable it to appropriate atmospheric nourishment being

obtained, its development proceeds much further. The quantity, or

mass of seed produced, will correspond to the quantity of mineral

constituents present in the plant. That plant, therefore, containing

the most alkaline phosphates and earthy salts will produce more or a

greater weight of seeds than another which, in an equal time has

absorbed less of them. We consequently observe, in a hot summer,

when a further supply of mineral ingredients from the soil ceases

through want of water, that the height and strength of plants, as

well as the development of their seeds, are in direct proportion to

its absorption of the elementary parts of the soil in the preceding

epochs of its growth.

The fertility of the year depends in general upon the temperature,

and the moisture or dryness of the spring, if all the conditions

necessary to the assimilation of the atmospheric nourishment be

secured to our cultivated plants. The action of humus, then, as we

have explained it above, is chiefly of value in gaining time. In

agriculture, this must ever be taken into account and in this

respect humus is of importance in favouring the growth of

vegetables, cabbages, &c.

But the cerealia, and plants grown for their roots, meet on our

fields, in the remains of the preceding crop, with a quantity of

decaying vegetable substances corresponding to their contents of

mineral nutriment from the soil, and consequently with a quantity of

carbonic acid adequate to their accelerated development in the

spring. A further supply of carbonic acid, therefore, would be quite

useless, without a corresponding increase of mineral ingredients.

From a morgen of good meadow land, 2,500 pounds weight of hay,

according to the best agriculturists, are obtained on an average.

This amount is furnished without any supply of organic substances,

without manure containing carbon or nitrogen. By irrigation, and the

application of ashes or gypsum, double that amount may be grown. But

assuming 2,500 pounds weight of hay to be the maximum, we may

calculate the amount of carbon and nitrogen derived from the

atmosphere by the plants of meadows.

According to elementary analysis, hay, dried at a temperature of 100

deg Reaumur, contains 45.8 per cent. of carbon, and 1 1/2 per cent.

of nitrogen. 14 per cent. of water retained by the hay, dried at

common temperatures, is driven off at 100 deg. 2,500 pounds weight

of hay, therefore, corresponds to 2,150 pounds, dried at 100 deg.

This shows us, that 984 pounds of carbon, and 32.2 pounds weight of

nitrogen, have been obtained in the produce of one morgen of meadow

land. Supposing that this nitrogen has been absorbed by the plants

in the form of ammonia, the atmosphere contains 39.1 pounds weight

of ammonia to every 3640 pounds weight of carbonic acid (=984

carbon, or 27 per cent.), or in other words, to every 1,000 pounds

weight of carbonic acid, 10.7 pounds of ammonia, that is to about

1/100,000, the weight of the air, or 1/60,000 of its volume.

For every 100 parts of carbonic acid absorbed by the surface of the

leaves, the plant receives from the atmosphere somewhat more than

one part of ammonia.

With every 1,000 pounds of carbon, we obtain--

From a meadow . 32 7/10 pounds of nitrogen.

From cultivated fields,

In Wheat . 21 1/2 " "

Oats . 22.3 " "

Rye . 15.2 " "

Potatoes . 34.1 " "

Beetroot . 39.1 " "

Clover . 44 " "

Peas . 62 " "

Boussingault obtained from his farm at Bechelbronn, in Alsace, in

five years, in the shape of potatoes, wheat, clover, turnips, and

oats, 8,383 of carbon, and 250.7 nitrogen. In the following five

years, as beetroot, wheat, clover, turnips, oats, and rye, 8,192 of

carbon, and 284.2 of nitrogen. In a further course of six years,

potatoes, wheat, clover, turnips, peas, and rye, 10,949 of carbon,

356.6 of nitrogen. In 16 years, 27,424 carbon, 858 1/2 nitrogen,

which gives for every 1,000 carbon, 31.3 nitrogen.

From these interesting and unquestionable facts, we may deduce some

conclusions of the highest importance in their application to

agriculture.

1. We observe that the relative proportions of carbon and nitrogen,

stand in a fixed relation to the surface of the leaves. Those

plants, in which all the nitrogen may be said to be concentrated in

the seeds, as the cerealia, contain on the whole less nitrogen than

the leguminous plants, peas, and clover.

2. The produce of nitrogen on a meadow which receives no

nitrogenised manure, is greater than that of a field of wheat which

has been manured.

3. The produce of nitrogen in clover and peas, which agriculturists

will acknowledge require no nitrogenised manure, is far greater than

that of a potato or turnip field, which is abundantly supplied with

such manures.

Lastly. And this is the most curious deduction to be derived from

the above facts,--if we plant potatoes, wheat, turnips, peas, and

clover, (plants containing potash, lime, and silex,) upon the same

land, three times manured, we gain in 16 years, for a given quantity

of carbon, the same proportion of nitrogen which we receive from a

meadow which has received no nitrogenised manure.

On a morgen of meadow-land, we obtain in plants, containing silex,

lime, and potash, 984 carbon, 32.2 nitrogen. On a morgen of

cultivated land, in an average of 16 years, in plants containing the

same mineral elements, silex, lime, and potash, 857 carbon, 26.8

nitrogen.

If we add the carbon and nitrogen of the leaves of the beetroot, and

the stalk and leaves of the potatoes, which have not been taken into

account, it still remains evident that the cultivated fields,

notwithstanding the supply of carbonaceous and nitrogenised manures,

produced no more carbon and nitrogen than an equal surface of

meadow-land supplied only with mineral elements.

What then is the rationale of the effect of manure,--of the solid

and fluid excrements of animals?

This question can now be satisfactorily answered: that effect is the

restoration of the elementary constituents of the soil which have

been gradually drawn from it in the shape of grain and cattle. If

the land I am speaking of had not been manured during those 16

years, not more than one-half, or perhaps than one-third part of the

carbon and nitrogen would have been produced. We owe it to the

animal excrements, that it equalled in production the meadow-land,

and this, because they restored the mineral ingredients of the soil

removed by the crops. All that the supply of manure accomplished,

was to prevent the land from becoming poorer in these, than the

meadow which produces 2,500 pounds of hay. We withdraw from the

meadow in this hay as large an amount of mineral substances as we do

in one harvest of grain, and we know that the fertility of the

meadow is just as dependent upon the restoration of these

ingredients to its soil, as the cultivated land is upon manures. Two

meadows of equal surface, containing unequal quantities of inorganic

elements of nourishment,--other conditions being equal,--are very

unequally fertile; that which possesses most, furnishes most hay. If

we do not restore to a meadow the withdrawn elements, its fertility

decreases. But its fertility remains unimpaired, with a due supply

of animal excrements, fluid and solid, and it not only remains the

same, but may be increased by a supply of mineral substances alone,

such as remain after the combustion of ligneous plants and other

vegetables; namely, ashes. Ashes represent the whole nourishment

which vegetables receive from the soil. By furnishing them in

sufficient quantities to our meadows, we give to the plants growing

on them the power of condensing and absorbing carbon and nitrogen by

their surface. May not the effect of the solid and fluid excrements,

which are the ashes of plants and grains, which have undergone

combustion in the bodies of animals and of man, be dependent upon

the same cause? Should not the fertility, resulting from their

application, be altogether independent of the ammonia they contain?

Would not their effect be precisely the same in promoting the

fertility of cultivated plants, if we had evaporated the urine, and

dried and burned the solid excrements? Surely the cerealia and

leguminous plants which we cultivate must derive their carbon and

nitrogen from the same source whence the graminea and leguminous

plants of the meadows obtain them! No doubt can be entertained of

their capability to do so.

In Virginia, upon the lowest calculation, 22 pounds weight of

nitrogen were taken on the average, yearly, from every morgen of the

wheat-fields. This would amount, in 100 years, to 2,200 pounds

weight. If this were derived from the soil, every morgen of it must

have contained the equivalent of 110,000 pounds weight of animal

excrements (assuming the latter, when dried, at the temperature of

boiling water, to contain 2 per cent.).

In Hungary, as I remarked in a former Letter, tobacco and wheat have

been grown upon the same field for centuries, without any supply of

nitrogenised manure. Is it possible that the nitrogen essential to,

and entering into, the composition of these crops, could have been

drawn from the soil?

Every year renews the foliage and fruits of our forests of beech,

oak, and chesnuts; the leaves, the acorns, the chesnuts, are rich in

nitrogen; so are cocoa-nuts, bread-fruit, and other tropical

productions. This nitrogen is not supplied by man, can it indeed be

derived from any other source than the atmosphere?

In whatever form the nitrogen supplied to plants may be contained in

the atmosphere, in whatever state it may be when absorbed, from the

atmosphere it must have been derived. Did not the fields of Virginia

receive their nitrogen from the same source as wild plants?

Is the supply of nitrogen in the excrements of animals quite a

matter of indifference, or do we receive back from our fields a

quantity of the elements of blood corresponding to this supply?

The researches of Boussingault have solved this problem in the most

satisfactory manner. If, in his grand experiments, the manure which

he gave to his fields was in the same state, i.e. dried at 110 deg

in a vacuum, as it was when analysed, these fields received, in 16

years, 1,300 pounds of nitrogen. But we know that by drying all the

nitrogen escapes which is contained in solid animal excrements, as

volatile carbonate of ammonia. In this calculation the nitrogen of

the urine, which by decomposition is converted into carbonate of

ammonia, has not been included. If we suppose it amounted to half as

much as that in the dried excrements, this would make the quantity

of nitrogen supplied to the fields 1,950 pounds.

In 16 years, however, as we have seen, only 1,517 pounds of

nitrogen, was contained in their produce of grain, straw, roots, et

cetera--that is, far less than was supplied in the manure; and in

the same period the same extent of surface of good meadow-land (one

hectare = a Hessian morgen), which received no nitrogen in manure,

2,062 pounds of nitrogen.

It is well known that in Egypt, from the deficiency of wood, the

excrement of animals is dried, and forms the principal fuel, and

that the nitrogen from the soot of this excrement was, for many

centuries, imported into Europe in the form of sal ammoniac, until a

method of manufacturing this substance was discovered at the end of

the last century by Gravenhorst of Brunswick. The fields in the

delta of the Nile are supplied with no other animal manures than the

ashes of the burnt excrements, and yet they have been proverbially

fertile from a period earlier than the first dawn of history, and

that fertility continues to the present day as admirable as it was

in the earliest times. These fields receive, every year, from the

inundation of the Nile, a new soil, in its mud deposited over their

surface, rich in those mineral elements which have been withdrawn by

the crops of the previous harvest. The mud of the Nile contains as

little nitrogen as the mud derived from the Alps of Switzerland,

which fertilises our fields after the inundations of the Rhine. If

this fertilising mud owed this property to nitrogenised matters;

what enormous beds of animal and vegetable exuviae and remains ought

to exist in the mountains of Africa, in heights extending beyond the

limits of perpetual snow, where no bird, no animal finds food, from

the absence of all vegetation!

Abundant evidence in support of the important truth we are

discussing, may be derived from other well known facts. Thus, the

trade of Holland in cheese may be adduced in proof and illustration

thereof. We know that cheese is derived from the plants which serve

as food for cows. The meadow-lands of Holland derive the nitrogen of

cheese from the same source as with us; i.e. the atmosphere. The

milch cows of Holland remain day and night on the grazing-grounds,

and therefore, in their fluid and solid excrements return directly

to the soil all the salts and earthy elements of their food: a very

insignificant quantity only is exported in the cheese. The fertility

of these meadows can, therefore, be as little impaired as our own

fields, to which we restore all the elements of the soil, as manure,

which have been withdrawn in the crops. The only difference is, in

Holland they remain on the field, whilst we collect them at home and

carry them, from time to time, to the fields.

The nitrogen of the fluid and solid excrements of cows, is derived

from the meadow-plants, which receive it from the atmosphere; the

nitrogen of the cheese also must be drawn from the same source. The

meadows of Holland have, in the lapse of centuries, produced

millions of hundredweights of cheese. Thousands of hundredweights

are annually exported, and yet the productiveness of the meadows is

in no way diminished, although they never receive more nitrogen than

they originally contained.

Nothing then can be more certain than the fact, that an exportation

of nitrogenised products does not exhaust the fertility of a

country; inasmuch as it is not the soil, but the atmosphere, which

furnishes its vegetation with nitrogen. It follows, consequently,

that we cannot increase the fertility of our fields by a supply of

nitrogenised manure, or by salts of ammonia, but rather that their

produce increases or diminishes, in a direct ratio, with the supply

of mineral elements capable of assimilation. The formation of the

constituent elements of blood, that is, of the nitrogenised

principles in our cultivated plants, depends upon the presence of

inorganic matters in the soil, without which no nitrogen can be

assimilated even when there is a most abundant supply. The ammonia

contained in animal excrements exercises a favourable effect,

inasmuch as it is accompanied by the other substances necessary to

accomplish its transition into the elements of the blood. If we

supply ammonia associated with all the conditions necessary to its

assimilation, it ministers to the nourishment of the plants; but if

this artificial supply is not given they can derive all the needed

nitrogen from the atmosphere--a source, every loss from which is

restored by the decomposition of the bodies of dead animals and the

decay of plants. Ammonia certainly favours, and accelerates, the

growth of plants in all soils, wherein all the conditions of its

assimilation are united; but it is altogether without effect, as

respects the production of the elements of blood where any of these

conditions are wanting. We can suppose that asparagin, the active

constituent of asparagus, the mucilaginous root of the marsh-mallow,

the nitrogenised and sulphurous ingredients of mustard-seed, and of

all cruciferous plants, may originate without the aid of the mineral

elements of the soil. But if the principles of those vegetables,

which serve as food, could be generated without the co-operation of

the mineral elements of blood, without potash, soda, phosphate of

soda, phosphate of lime, they would be useless to us and to

herbivorous animals as food; they would not fulfil the purpose for

which the wisdom of the Creator has destined them. In the absence of

alkalies and the phosphates, no blood, no milk, no muscular fibre

can be formed. Without phosphate of lime our horses, sheep and

cattle, would be without bones.

In the urine and in the solid excrements of animals we carry

ammonia, and, consequently, nitrogen, to our cultivated plants, and

this nitrogen is accompanied by all the mineral elements of food

exactly in the same proportions, in which both are contained in the

plants which served as food to the animals, or what is the same, in

those proportions in which both can serve as nourishment to a new

generation of plants, to which both are essential.

The effect of an artificial supply of ammonia, as a source of

nitrogen, is, therefore, precisely analogous to that of humus as a

source of carbonic acid--it is limited to a gain of time; that is,

it accelerates the development of plants. This is of great

importance, and should always be taken into account in gardening,

especially in the treatment of the kitchen-garden; and as much as

possible, in agriculture on a large scale, where the time occupied

in the growth of the plants cultivated is of importance.

When we have exactly ascertained the quantity of ashes left after

the combustion of cultivated plants which have grown upon all

varieties of soil, and have obtained correct analyses of these

ashes, we shall learn with certainty which of the constituent

elements of the plants are constant and which are changeable, and we

shall arrive at an exact knowledge of the sum of all the ingredients

we withdraw from the soil in the different crops.

With this knowledge the farmer will be able to keep an exact record,

of the produce of his fields in harvest, like the account-book of a

well regulated manufactory; and then by a simple calculation he can

determine precisely the substances he must supply to each field, and

the quantity of these, in order to restore their fertility. He will

be able to express, in pounds weight, how much of this or that

element he must give in order to augment its fertility for any given

kind of plants.

These researches and experiments are the great desideratum of the

present time. TO THE UNITED EFFORTS OF THE CHEMISTS OF ALL COUNTRIES

WE MAY CONFIDENTLY LOOK FOR A SOLUTION OF THESE GREAT QUESTIONS, and

by the aid of ENLIGHTENED AGRICULTURISTS we shall arrive at a

RATIONAL system of GARDENING, HORTICULTURE, and AGRICULTURE,

applicable to every country and all kinds of soil, and which will be

based upon the immutable foundation of OBSERVED FACTS and

PHILOSOPHICAL INDUCTION.

LETTER XVI

My dear Sir,

My recent researches into the constituent ingredients of our

cultivated fields have led me to the conclusion that, of all the

elements furnished to plants by the soil and ministering to their

nourishment, the phosphate of lime--or, rather, the phosphates

generally--must be regarded as the most important.

In order to furnish you with a clear idea of the importance of the

phosphates, it may be sufficient to remind you of the fact, that the

blood of man and animals, besides common salt, always contains

alkaline and earthy phosphates. If we burn blood and examine the

ashes which remain, we find certain parts of them soluble in water,

and others insoluble. The soluble parts are, common salt and

alkaline phosphates; the insoluble consist of phosphate of lime,

phosphate of magnesia, and oxide of iron.

These mineral ingredients of the blood--without the presence of

which in the food the formation of blood is impossible--both man and

animals derive either immediately, or mediately through other

animals, from vegetable substances used as food; they had been

constituents of vegetables, they had been parts of the soil upon

which the vegetable substances were developed.

If we compare the amount of the phosphates in different vegetable

substances with each other, we discover a great variety, whilst

there is scarcely any ashes of plants altogether devoid of them, and

those parts of plants which experience has taught us are the most

nutritious, contain the largest proportion. To these belong all

seeds and grain, especially the varieties of bread-corn, peas,

beans, and lentils.

It is a most curious fact that if we incinerate grain or its flour,

peas, beans, and lentils, we obtain ashes, which are distinguished

from the ashes of all other parts of vegetables by the absence of

alkaline carbonates. The ashes of these seeds when recently

prepared, do not effervesce with acids; their soluble ingredients

consist solely of alkaline phosphates, the insoluble parts of

phosphate of lime, phosphate of magnesia, and oxide of iron:

consequently, of the very same salts which are contained in blood,

and which are absolutely indispensable to its formation. We are thus

brought to the further indisputable conclusion that no seed suitable

to become food for man and animals can be formed in any plant

without the presence and co-operation of the phosphates. A field in

which phosphate of lime, or the alkaline phosphates, form no part of

the soil, is totally incapable of producing grain, peas, or beans.

An enormous quantity of these substances indispensable to the

nourishment of plants, is annually withdrawn from the soil and

carried into great towns, in the shape of flour, cattle, et cetera.

It is certain that this incessant removal of the phosphates must

tend to exhaust the land and diminish its capability of producing

grain. The fields of Great Britain are in a state of progressive

exhaustion from this cause, as is proved by the rapid extension of

the cultivation of turnips and mangel wurzel--plants which contain

the least amount of the phosphates, and therefore require the

smallest quantity for their development. These roots contain 80 to

92 per cent. of water. Their great bulk makes the amount of produce

fallacious, as respects their adaptation to the food of animals,

inasmuch as their contents of the ingredients of the blood, i.e. of

substances which can be transformed into flesh, stands in a direct

ratio to their amount of phosphates, without which neither blood nor

flesh can be formed.

Our fields will become more and more deficient in these essential

ingredients of food, in all localities where custom and habits do

not admit the collection of the fluid and solid excrements of man,

and their application to the purposes of agriculture. In a former

letter I showed you how great a waste of phosphates is unavoidable

in England, and referred to the well-known fact that the importation

of bones restored in a most admirable manner the fertility of the

fields exhausted from this cause. In the year 1827 the importation

of bones for manure amounted to 40,000 tons, and Huskisson estimated

their value to be from L 100,000 to L 200,000 sterling. The

importation is still greater at present, but it is far from being

sufficient to supply the waste.

Another proof of the efficacy of the phosphates in restoring

fertility to exhausted land is afforded by the use of the guano--a

manure which, although of recent introduction into England, has

found such general and extensive application.

We believe that the importation of one hundred-weight of guano is

equivalent to the importation of eight hundred-weight of wheat--the

hundred-weight of guano assumes in a time which can be accurately

estimated the form of a quantity of food corresponding to eight

hundred-weight of wheat. The same estimate is applicable in the

valuation of bones.

If it were possible to restore to the soil of England and Scotland

the phosphates which during the last fifty years have been carried

to the sea by the Thames and the Clyde, it would be equivalent to

manuring with millions of hundred-weights of bones, and the produce

of the land would increase one-third, or perhaps double itself, in

five to ten years.

We cannot doubt that the same result would follow if the price of

the guano admitted the application of a quantity to the surface of

the fields, containing as much of the phosphates as have been

withdrawn from them in the same period.

If a rich and cheap source of phosphate of lime and the alkaline

phosphates were open to England, there can be no question that the

importation of foreign corn might be altogether dispensed with after

a short time. For these materials England is at present dependent

upon foreign countries, and the high price of guano and of bones

prevents their general application, and in sufficient quantity.

Every year the trade in these substances must decrease, or their

price will rise as the demand for them increases.

According to these premises, it cannot be disputed, that the annual

expense of Great Britain for the importation of bones and guano is

equivalent to a duty on corn: with this difference only, that the

amount is paid to foreigners in money.

To restore the disturbed equilibrium of constitution of the

soil,--to fertilise her fields,--England requires an enormous supply

of animal excrements, and it must, therefore, excite considerable

interest to learn, that she possesses beneath her soil beds of

fossil guano, strata of animal excrements, in a state which will

probably allow of their being employed as a manure at a very small

expense. The coprolithes discovered by Dr. Buckland, (a discovery of

the highest interest to Geology,) are these excrements; and it seems

extremely probable that in these strata England possesses the means

of supplying the place of recent bones, and therefore the principal

conditions of improving agriculture--of restoring and exalting the

fertility of her fields.

In the autumn of 1842, Dr. Buckland pointed out to me a bed of

coprolithes in the neighbourhood of Clifton, from half to one foot

thick, inclosed in a limestone formation, extending as a brown

stripe in the rocks, for miles along the banks of the Severn. The

limestone marl of Lyme Regis consists, for the most part, of

one-fourth part of fossil excrements and bones. The same are

abundant in the lias of Bath, Eastern and Broadway Hill, near

Evesham. Dr. Buckland mentions beds, several miles in extent, the

substance of which consists, in many places, of a fourth part of

coprolithes.

Pieces of the limestone rock in Clifton, near Bristol, which is rich

in coprolithes and organic remains, fragments of bones, teeth, &c.,

were subjected to analysis, and were found to contain above 18 per

cent. of phosphate of lime. If this limestone is burned and brought

in that state to the fields, it must be a perfect substitute for

bones, the efficacy of which as a manure does not depend, as has

been generally, but erroneously supposed, upon the nitrogenised

matter which they contain, but on their phosphate of lime.

The osseous breccia found in many parts of England deserves especial

attention, as it is highly probable that in a short time it will

become an important article of commerce.

What a curious and interesting subject for contemplation! In the

remains of an extinct animal world, England is to find the means of

increasing her wealth in agricultural produce, as she has already

found the great support of her manufacturing industry in fossil

fuel,--the preserved matter of primeval forests,--the remains of a

vegetable world. May this expectation be realised! and may her

excellent population be thus redeemed from poverty and misery!

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