RUDOLF STEINER EDUCATION

THE PHYSICAL SCIENCES II

FOR AGE GROUPS 13/14

Chemistry

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These notes are intended for the use of teachers, parents, and all those interested in the education of the child.

They are based on the author's forty years contact with Rudolf Steiner's work and thirty years practical experience in the classroom.

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INTRODUCTION

In the parallel booklet "The Physical Sciences 1" there are many indications with regard to the teaching of science in general, to which the reader is recommended to refer.

The study of chemistry adds another dimension to the understanding of the physical world but it is often taught so "objectively" that it seems to have little connection with the human being and the rest of the world, yet one thing can only be properly understood if it is seen in relationship to everything else. It must, therefore, be a task of education to deal not only with a subject comprehensively but also to show that subject in relation to man and the world, as well as to further the development of the human being. This is the task the teacher must set himself whether he is dealing with chemistry or with any other subject. There is another important point to be borne in mind. Chemistry teaches fundamental concepts concerning the processes in nature and the human being but it should not be a purely intellectual exercise. In the chemical world is beauty, wonder, fear and horror, which can engage the feeling and the will, and these faculties of the human being should not be excluded. Much depends on the teacher's attitude and enthusiasm. There is much beauty, for instance, in the process of crystallization; there is wonder that the human mind can investigate nature and produce new substances; there can be horror and fear that a knowledge of chemistry can unleash destructive and demonic forces.

In earlier classes children have learnt something about the four elements, the threefold human being, animals, plants, minerals. In the year before taking up chemistry they will have studied physics. Now other aspects appear and a new world opens.

Besides being a new world to children, it is a relatively new world to mankind. The modern scientific age dates back only a few hundred years and chemistry, as we know it, is not more than two hundred years old.

What is this new world? It is one which deals with the nature of substances and their transformations under certain conditions. In physics the children have learnt something about the various states of matter; now they learn of its nature. They have learnt about the effect of explosives; now they learn of the substances which bring about explosions.

Chemistry, by definition, is that branch of natural science which deals with the composition and properties of the different kinds of matter (solids, liquids, gases) and their reaction to each other in various conditions. It is then a physical science and metaphysics would appear to have no place in it. But, as in physics, we may learn the laws of planetary movement yet might have to ask who devised these, so in chemistry, we might ask whence the substance and whence the laws. Eventually we are led to a prime cause: "In the beginning God created the heaven and the earth." Then each substance must have some specific value. We are led to ask what is the nature, the sense, the being of each substance, and how does it relate to everything else.

It is not being suggested that the teacher should directly instruct the children thus. It is to be hoped that during the previous years of schooling the children have developed a feeling for the divinely inspired creation. In any case, it is a thought which the teacher can have in mind and therefore bring to, and convey, a certain reverence for the materials he uses. All material substance can evoke a sense of wonder in the mind. Air, water, a tree, soil, even a stone is a marvel. He might recall the witch's house in the story of Hansel and Gretel. When the material with which it was built disintegrated, it was found to consist of precious stones and jewels. Equally there are chemical processes and reactions which savour of magic and which can certainly arouse feelings of wonder.

Attention can be called to the fact that all nature is full of contrasts and that life exists between these. There are the rhythms of day and night, summer and winter. There is sleeping and waking, dying and being born. There is light and dark and there are the colours which arise between them. There is fire and water, earth and air, spirit and matter. A study of chemistry will show that similar contrasts can be found in material substances and processes.

It can be explained and demonstrated that earthly substances are affected by the stars and the planets. In this connection the work of L. Kolisko should be studied.

If a substance is considered in its various relationships, it may be possible to learn its function in the world order. The Chaldeans studied the movements of the stars in order to fathom the nature of God. Perhaps in a similar way we can seek to understand matter.

Furthermore, without having to say as much, but merely by demonstration and explanation, it is possible to show that we live in a wisdom-filled world, as shown by the cycle of respiration and photosynthesis; by the connection between plant, animal and soil fertility. These are chemical processes. The relationships in the natural world should awaken a feeling for something other than the mere physical at work — at least an echo of the spiritual. We can explain how living processes have a chemical background but we must make sure that it is understood that chemical processes of themselves do not engender life.

The impact of chemistry on our lives must also be described. Substances are now manufactured which do not exist in nature but which are useful to us. We must also point out the questionable side as, for instance, in food production. Artificial vitamins are produced, synthetic food is on the way, but are we not then asking the body to assimilate substances to which it is not adapted? And what could be the result?

There is so much in the world of chemistry that the teaching, as with many other subjects, has to be "symptomatic"; that is, one thing is demonstrated as an example of many others. It is difficult to set up a meaningful systematic sequence. The teacher is faced with the problem of which came first, the chicken or the egg. He needs to proceed from one step to the next, from the familiar to the unfamiliar, but it so often appears that he needs the second step before he can take the first. There is also the great danger of trying to do too much and of confusing the pupils.

Although this book may emphasise certain points or present special features, some acquaintance should also be made with the commonly accepted teaching matter, possibly formulae and equations, although these are really matters for later study. Certainly the elementary chemical processes and terms must be learnt. Many of these will, of course, be demonstrated or appear in the normal course of instruction, but none should be overlooked; e.g. solution, saturated solution, solubility, evaporation, crystallization, distillation, absorption, precipitation, filtering, etc. Children do not always find it easy to distinguish between what is soluble or what is insoluble and what is melted and such matters must be made clear.

Since the word compound will crop up, it is tempting to go into explanations and demonstrations to show the difference between elements, mixtures and compounds but this must be at the teacher's discretion. On the one hand we must bear in mind the idea of starting from a totality and, on the other, the terminology and concepts must be clearly understood. It could be pointed out for the moment that a compound contains several ingredients but that they are not individually recognisable. It may be a matter of some astonishment to learn, for instance, that common salt consists of a metal and a gas, but there is no trace of these in the crystals we spread on our food. The two ingredients of salt are poisonous by themselves but combined they form an entirely different substance which is a necessary part of the human diet and is a substance in its own right.

Equally astonishing, or even more so, will be the information that water is a compound of two gases known as oxygen and hydrogen. It can be said that these gases will shortly be studied and the secret of their combination revealed. The childrens' interest and appetite may thus be whetted.

It must also be demonstrated that chemistry is a practical science and has its application in the practical world. Thus, besides trying to explain the nature of a substance, one also explains its use and the various processes in which it is involved. Again, these may only be indications but sufficient interest will be awakened for some individuals at least to pursue the matter further and learn something for themselves.

Generally, chemistry seems to be a subject connected with flasks, jars, retorts, smells, isolated phenomena; the impression is given of remoteness from reality and this is something we should seek to avoid. Usually it has its own room. This may be essential at a later stage but in the class teacher period (up to age 14) and with a little ingenuity, the subject can quite well be taught in the ordinary classroom where it is not so divorced from other activities.

We have said elsewhere that science teaching should coincide with the onset of puberty, about the age of 12. The boy or girl of 12/13/14 wants to know how and why. A beginning is made with physics. Chemistry should be taken a year later. The reason for this is to give the child time to digest the "solid" world of physics and to become more mature and firmer within himself before this "solid" world dissolves, as it does to some extent in chemistry.

The child at this age is becoming more aware of the physical world. At the same time his thinking capacity is growing. Through a knowledge of chemistry, presented in the right way, the child can become much more conscious of his connection with the world; e.g. the breathing, nutritional and digestive processes, to say nothing of learning about the nature of substances and the tremendous discoveries which affect our everyday lives. The actual material and presentation thereof must be in tune with the child's awakening thinking capacity.

The ability to think intellectually is a fairly recent development in the history of mankind. It has led to the "scientific" understanding of the world and, in chemistry, to the idea of substances being composed of atoms, molecules, etc. In earlier times men were also concerned with substances but they spoke of their qualities, their virtues, their healing properties. The alchemists of old referred to world processes in terms of sulphur, mercury and salt. By sulphur the fire element was meant, that which strives back from the depths to the heights. Mercury was the power mediating between the depths and the heights, the liquid element. By salt was understood everything that leads to consolidation, to hardening, to the forming of the solid earth.

In connection with this is a very important matter touching the development of the thinking capacity of the adolescent. This is not to be confused with the actual acquiring of knowledge. We speak of carbon, oxygen, etc. and refer to substances. But there are occasions when we speak of substances in their functional value. For instance, if we speak of iron or oxygen in the blood, these are not present there as bits of metal or volumes of gas in the form in which we know them as elements. The mind therefore must go beyond the percept and grasp the concept or the idea of such a substance.

At a certain stage of growth children begin to feel grown-up and delight in using scientific terms. The long, new words will interest them and so will the chemical formulae, which for the present, can be used as a sort of alternative language.

As far as possible the first study of chemistry should be kept to what is directly perceptible. The new teacher is strongly recommended to practise the experiments before trying to demonstrate them in front of a class. As great care is needed in handling certain substances, he should also consult an experienced colleague.

The time which can be devoted to the subject in these years is very limited. The danger is that one thing can lead to too many others. It is therefore necessary to select carefully those substances and processes which are to be dealt with. What is here presented can only be looked upon as one way among many others. The main points we have in mind are:

1 To introduce the child to chemical concepts and processes in such a way that they are related to man and the rest of the world.
2 To show that there is wisdom and logic in the created world.
3 To present chemistry in such a way that the nature of substance is understood.
4 To present the subject matter in such a way that powers of observation and deduction are developed.
5 To show practical applications.

There will be about nine or ten weeks available in the two years, that is to say, three main lesson periods of three or four weeks each.

The order in which the material is presented to the children need not necessarily be the same as that shown here. Instead of taking the whole chapter on combustion, to be followed by the whole chapter on salt-formation, there is some point in showing the first combustion experiments and following them immediately with those of salt-formation, i.e. the lime process. The supporting material could then be taken or deferred until later but it must also be borne in mind that a great deal of work should be covered in the 3 or 4 weeks available. Some teachers might prefer to deal with the organic world before the metals.

The following is a suggested outline of work suitable for Classes 7 and 8 (ages 13/14).

To introduce the subject the children should be made more aware of all the substances and phenomena around them. Above and around is the atmosphere; spread over a great part of the surface of the earth is water; in the earth are rocks, metals and combinations of these; the rocks themselves are made up of an endless variety of substances. Every physical substance represents a sum of certain qualities. By combining qualities other substances are made. The children might make a list of all the minerals and rocks that they can think of and these might be discussed in a general way.

What has already been learnt in other lessons, in physics, geology, geography, mineralogy, history, the world of nature and of man, is related to chemistry and should be considered when introducing materials. Before a substance is used, it should be shown in its natural state as far as possible. Its connections with the rest of the world should be considered. It might be asked why history is included in the above list. The reason is that here is a human connection. Some person at some time made a discovery and applied it. Thus biographies and the historical periods concerned are also important. (The subject should be co-ordinated with history.)

To counteract any feeling of remoteness the teacher should, as and when appropriate, bring samples of the substances he intends to use into the classroom and speak about them. They should be observed and handled. Two things he does not need to bring are air and water but he should talk about them — the all-pervading, all-penetrating, life-giving and light-carrying air, winds, pollution etc. He might well indicate that there are mysteries in connection with air as with water, and that these also will be revealed in due course.

At some time he will be explaining the nature of lime. He should therefore show pieces of limestone, chalk and marble. He could also have some sea shells and explain where these things are found geologically and geographically. He will add that these substances are chemically similar, that they are all calcium carbonate. He could also say that in scientific circles this is known as $CaCO_3$ and that the formula will be explained at a later date. He may also produce some of the same substance in the form of calcite crystals.

If silica is to be discussed in the lessons, there are many interesting forms to be shown, of which flint, found in the chalk beds, is one. Others are the semi-precious stones: rose quartz, amethyst, chalcedony, jasper, agate, onyx, opal.

It is difficult to know where to draw the line. It is not likely that the properties of silica will be dealt with in these classes but it is a substance very abundant in the earth's crust and there is no reason why attention should not be drawn to it. It is present in nearly all rocks. For instance, the constituent parts of granite are quartz, feldspar and mica, but these are themselves compounds of other substances, namely, silicon, oxygen and various metals. Quartz is pure silica (silicon dioxide). It is used to make prisms and optical instruments. Silica and its near relatives are used in the building industry in the form of sand, cement and glass. Pottery and porcelain are made from clays containing silica. Clay is a silicate and, in the soil, clay provides the main reservoir from which plants draw water and mineral substances.

In a similar way the teacher can deal with other substances as they occur in nature, some of which will certainly appear again in the course of the lessons. Carbon is one of these. He may not be able to produce a diamond and in these days of push-button heating, he may have some difficulty even in finding a lump of coal or a bag of soot, but he may find a piece of charcoal in the art room. He can make a connection with geography by indicating the places where certain substances are to be found, as follows:

(The common and chemical names are given here together with the formula. Whether formulae are used or not at this stage is a matter for the teacher's discretion. It is too early to enter into explanations but it should at least be pointed out that the abbreviations are usually taken from the Greek or Latin names of substances. Sodium (English) = Natrium (Latin). Chlorine is derived from the Greek. Hence Sodium Chloride (common salt) = NaCl. The numbers concerned are a matter for the upper school.)

Chalk, Limestone, Marble, Calcium Carbonate, $CaCO_3$
All areas where there are chalk and limestone mountains or marble deposits.

Haematite, Iron Ore, Ferric Oxide, Fe_2O_3
Brazil, Venezuela, Labrador, Quebec, around Lake Superior.

Galena, Lead Ore, Lead Sulphide, PbS
Australia, North America, Cornwall.

Malachite, Copper Carbonate, $CuCO_3Cu(OH)_2$
(Owing to its attractive green colour this is sometimes used as a gem stone.)
Siberia, France, South West Africa.

Gypsum, Calcium Sulphate + Water, $CaSO_4.2H_2O$
France, Italy, England, Russia, North America.

Brimstone, Sulphur, S
U.S.A. Yellowstone Park, volcanic areas anywhere.

Salt, Sodium Chloride, NaCl
World wide, from natural brine, rock salt or the oceans.

Saltpetre, Potassium Nitrate, KNO_3
World wide, white crust on rocks, in caves.

Iron Pyrites, Fool's Gold, Iron Disulphide, FeS_2
Found in iron ore, Spain, Japan, U.S.A., Canada, Italy, Norway, Portugal, Czechoslovakia.

Epsom Salts, Magnesium Sulphate, $MgSO_4$
The name comes from the fact that this salt occurs in the waters of springs at Epsom in England; France, Spain, North America.

Green Vitriol, Ferrous Sulphate, $FeSO_4$
Green powder found on Iron Pyrites.

Chile Saltpetre, Sodium Nitrate, $NaNO_3$
Formerly found in Chile, hence the name. Now in North Africa.

It might be appropriate here to clarify the concept of "compound".

The teacher should show a piece of sulphur and explain that it is found in a free state in volcanic regions and more will be learnt about it later. Iron is well enough known.

For this experiment powdered sulphur and iron filings should be taken in the proportion of 4:7 by weight. Mixed together, the particles of each are clearly visible and if a magnet is applied, it will be seen that only the iron is attracted. The mixture is then put into a hard glass test tube and the Bunsen flame applied until a red glow appears in the tube. When it has cooled, the test tube may have to be broken to examine the residue. Now there is no sight of iron, no magnetic attraction and no sign of the sulphur particles. The two substances have combined to form a chemical compound known as Ferrous Sulphide. (Ferrum in Latin = iron). A chemical change has taken place.

Iron and sulphur by themselves are known as elements which means that they cannot be split into other substances. When elements are mixed without a chemical change taking place, they are known as mixtures and the contents can be in any proportion, but when a compound is formed, it only does so in a fixed proportion by weight. It is possible to split a compound into its elements but it is usually a difficult problem.

As information it could be added that there are about 92 elements in the world, of which the metals are good examples. There are thousands of compounds.

Attention can also be called to obvious chemical reactions in the everyday world such as rust on iron, green on copper. Detergents combine with grease to remove it; bleaching agents remove stains; milk turns sour; dough rises through the addition of baking powder; vegetable refuse and manure turn to soil; fallen trees rot; plants grow and their leaves turn green in the light; the human being eats, drinks and excretes. What happens when a fire burns? This sort of observation will excite interest in the subject and the pupils will have plenty of examples.

The teacher can then pass over to a consideration of the four elements (in the other sense) as they have been considered in earlier classes. Pupils who have been in the second or third class may have learnt something of the work of the elemental beings. They may have been fortunate enough to have learnt the choruses of the elementals published in the booklet "Miscellany". It is good to come back to these things and the teacher explains that what was once learnt in one way can now be understood in another. Thus there are the elements of fire, air, water and earth, and these four elements play a part in chemistry.

Two opposite chemical processes as primeval examples can then be shown. The one is the process of combustion which is the one recommended by Dr. Steiner as an introduction to chemistry. The other is salt-formation. Some consideration is then given to the metals and to the organic world. Studies will obviously be continued in later classes but some indication as to the nature of substance might be given as suggested in the last chapter.

COMBUSTION

Beginning with fire the teacher immediately has the opportunity of touching on aspects of ethics. Fire is purifying. Symbolically the flame and the light represent the intangible, the spiritual, whereas the ash is dead matter. The organic is spiritually imbued matter.

As with other subjects, one can borrow from literature to support and to extend the viewpoint. If the teacher can find a few poems connected with fire, they might be useful but unfortunately there seems to be a dearth of them. The verses of the fire fairies (in "Miscellany") could at least be recalled and spoken. (A little recitation is in any case a good beginning for the main lesson.)

The class may be reminded of the story of Prometheus, the significance of sacrificial fires, the St. John's fire, the burning of candles in church; also of the role of fire in cooking and heating. By cooking his food and keeping his buildings warm man saves his energies for higher purposes. We need only think how extreme cold can paralyse the will or how difficult it is to think in a cold classroom.

There is also fire in nature. The lightning strikes from above; the volcano erupts from below. In the rocks of the earth we find flints from which sparks can be struck. There is also a form of fire in the human being. We say a person is "fired" with enthusiasm.

Light is connected with fire. Light comes to us from outside but we also speak of eyes as "lighting up" and the light of wisdom.

The phenomenon of combustion clearly demonstrates chemical reaction and the transformation of material substance. Experiments should therefore now be made showing what is combustible and what is not. It

will be noted that only organic matter burns. (A few exceptions will be shown later.) A great selection of natural substances should be burnt one by one. A splendid opportunity is given to pupils to sharpen their powers of observation.

Things known should be presented first. It is to be assumed that children will be familiar with objects such as paper, but they may not know that paper is a product of wood and a few words on the subject should be said. Similarly they may know of the combustible liquids but an indication of their origin should also be given.

It should be noted how each substance burns, the type of flame it produces, and what is characteristic of the ash. With the reverence that one has for living matter, it might be better to restrict the burning to things from which the life force has departed, i.e. dry leaves and dead wood. It will be noticed how the dry leaves of deciduous trees burn differently from those of the conifers; how they both burn differently from pine cones. The twigs from different trees show different characteristics when burnt. Paper, cardboard, straw, hay, all burn in their own particular way. In some cases the residue retains the original shape of the substance; in others, it becomes a formless ash. It will be noted that roots produce more ash than the other parts of the plant and also that in some cases burning is not complete but a black residue remains. This is carbon.

Paraffin, methylated spirits, petrol (be careful) should be burnt. The presence or absence of smoke should be noted. When, for instance, paraffin or a paraffin wax candle burns, black smoke will be seen, and if a cold surface is held above the flame, there will be a black deposit, showing that the process of combustion is incomplete.

It can also be pointed out or demonstrated that a flame is not necessary in every case to produce combustion. A cigarette burns without flame. We can ask what happens if a hot iron is left on a wooden table. It can be explained that a haystack will set itself on fire through the heat generated in its interior if not properly built. We might ask why a match produces a flame, and we can put a match on a tin lid, heat it and see what happens.

(It might be appropriate here to remind the reader that in all science teaching the principle should be followed of showing the experiment one day, recalling the facts the next, then discussing them and drawing conclusions.)

In considering the experiments in combustion the following points will emerge — to be elicited from the pupils are far as possible.

When something burns a change of substance obviously takes place. In the burning process light and heat are emitted and an ash remains. We notice that, for the most part, only things that once had life in them burn. All life needs warmth and light and these have been absorbed from the sun. When something burns, it is as if the light and the warmth are released, striving upwards and outwards. The ash which remains is of the substance of the earth. The light and the warmth have bestowed the living quality to dead material. Light and warmth have no weight. Only the ash can be weighed. In physics we spoke of forces of levity and gravity, of the processes of expansion and contraction. We also meet them here.

In our earlier studies of the plant we noted how leaf and flower belong to the warmth, air and light elements, and the root, the earth. Now in the burning process we can see how little ash is left from leaf and flower, and how much more, relatively, there is from the root.

We see how chemical processes have been at work in the plant but chemical processes are also taking place in the human being. With possible memories of earlier studies the children can be reminded of the picture of man in a certain respect as an upside-down plant. The roots of the plant are the densest materially, but in man the corresponding part is the head. The part of the plant where the light/heat forces work the strongest is the flower, where pollination and seed formation take place. In man the functions of digestion and reproduction take place in the lower regions. In between are the rhythmic systems of leaf formation in the plant and breathing in the human being.

If the teacher feels able to take the opportunity, he might continue into the ethical/religious sphere. He could speak of the polarity of light and dark. As light dwells in the physical substance of the plant so do the soul and spirit dwell in the physical substance of the human body. At death the soul, like the flame, is released from the body and the latter turns to dust like the ash.

Having given some idea that the flame is the release of light which was imprisoned in matter, one can deal with the more physical-chemical aspect. One shows now how a flame reacts to air. Simple experiments which can be done in the classroom will show how a restriction or an increase of airflow affects a flame.

If a glass jar is inverted over a lighted candle, the flame will soon die away. If we hold the jar in the same position and place it over another lighted candle, this flame too, will be extinguished. If a candle is placed in the centre of a plate containing a little water, lit, and a jar placed over it, the flame will die out and the water be sucked into the jar. If coloured water is used, it is easier to see.

In the first two cases it it obvious that without an air supply there is no flame; in the third we see that some part of the air has been used up. Now we light a candle and observe the flame. Perhaps some bright pupil will be able to explain why there is no flame near the wick. If not, it is incumbent upon the teacher to do this.

It will be observed that the wick of a candle does not catch light immediately. The heat from the match has first to melt the wax which travels up the wick and is changed into vapour. It is the vapour or the gas which burns, not the wick. It only burns in contact with the air. That is why there is a dark central part of the flame which is unburnt vapour.

Now we can take a Bunsen burner (supplied from a cylinder if no gas is laid on). We describe its physical features and then demonstrate that when air is excluded the flame is yellow. When air is admitted, the flame turns blue and becomes hotter. A yellow flame will deposit carbon like the candle but the hot blue flame will burn it all up.

In these days when other forms of heating are so common, one seldom sees open fires, but in their heyday there was usually a pair of bellows hanging near. Their purpose was to increase the airflow and so stimulate the burning process. The best example of this is to be found, of course, in the blacksmith's forge.

In the case of an electric bulb we have the opposite example. Combustion is retarded by the absence of air or the substitution of a gas. The filament is heated by the electric current and the glow it gives is really a burning process. Without air, however, there is no combustion.

Since it is also part of the teaching to show practical aspects, it might be in place here to discuss the use of the flame. Obviously flame and heat are connected and in physics we have discussed heat, which is usually derived from a burning process. Now what of the flame? The yellow one provides illumination; the blue one, produced by an increased air supply, heat.

An early form of house illumination was to float a wick in oil. The burning wick produced the light. Torches, made of resinous wood or twisted flax and soaked in tallow, were another form. These could also be carried about and used out-of-doors. In the bad old days of London fogs, paraffin flares were lit in the streets. Not so long ago buildings and streets were lit by gas made from coal. As a flare the light was not very satisfactory but by directing a hot flame on to a substance such as lime, which would glow in the heat, a good light was obtained. Some such arrangement was used in the theatre and hence the expression "lime-light". A further invention was the incandescent gas mantle which works on the same principle.

With regard to heating – when a gas flame which is well supplied with air is burning, it is already hot, but by directing it on to a clay material, as instanced in the gas fire, the latter heats up and reflects the heat.

In connection with the use of the flame it is interesting to look at the miner's safety lamp, a very simple but useful device. When mining operations take place in a coal mine, a gas is released called "firedamp". This can explode if mixed with air and a spark gets at it. In 1815, Sir Humphrey Davy, a distinguished English chemist, discovered that by surrounding the flame of a lamp with gauze the mixture would burn inside but not outside unless the gauze became red hot, which was very unlikely. This invention saved countless lives and it is worth noting that Davy refused to patent his lamp on the principle that such a useful thing should be produced as cheaply as possible.

It should also be explained that there is a combustion process which takes place in the human being but that this is a matter for later study.

We said that for the most part only organic material will burn but there are a few inorganic combustible elements, for instance, sulphur, phosphorus and carbon. These substances should now be considered and the reason will be apparent in due course. Some description of them should be given if this has not already been done.

If anyone is acquainted with Rotorua in New Zealand, he will know that this town is actually built in the crater of an ancient volcano and that there are still signs of volcanic activity in the neighbourhood. There are hot springs, boiling mud ponds and jets of steam emerging from the ground.

Around these jets a yellow substance is deposited which is sulphur. It is a substance which is found everywhere where there is volcanic activity but in some parts of the world it also occurs as deposits and can be mined. It has the other name of "brimstone" derived from the German "Brennstein" which means "burning stone". The word "sulphur" means "sun-bearing". These names almost explain its nature.

As an experiment a little powdered sulphur can be placed on a stone or metal surface and ignited. A pale blue flame is observed which creeps over the surface. The substance melts, changes colour and gives off choking fumes which can be very unpleasant. Heat is given off but very little light. (The teacher who overdoes this experiment in his classroom will not be very popular with his neighbours.)

We now explain to the children that we have another substance which does not exist in its natural state but has to be manufactured artificially. This is phosphorus. The word means "light-bearer". Translated into Latin the word is "lucifer" and Lucifer is the name given to the fallen angel (Satan) who tempted Eve in the Garden of Eden. A match also used to be known as a lucifer.

Phosphorus has to be obtained from calcium phosphate, a mineral found in the earth. A piece of this substance can be shown. Phosphorus itself has to be kept under water and it must not be touched by hand. The reason will soon be apparent.

Using tongs a small piece is taken out of the water in which it is kept. Soon it will begin to smoke and must quickly be put on a fire-proof surface where it may burst into a bright flame.

NOTE. *Phosphorus is a very dangerous thing to handle, especially in a classroom situation where children may be excited and the teacher inexperienced. If, therefore, there is any question of danger, the matter should be approached another way. For instance, one could draw attention to the nature of phosphorus by referring to the glow-worm and the phosphorescence of sea creatures.*

Next we take some charcoal. We can use the sticks from the art room which are used for sketching. We refer to earlier lessons about the preparation of charcoal and its use in smelting iron. It is a relative of coal, which is also carbonised vegetable matter although in a less pure form. Like coal, charcoal has the capacity of burning, though differently. The chemical ingredient of charcoal is carbon which we met when burning a candle and which is also the residue left when a match is burnt.

A small heap of charcoal is ignited by means of a Bunsen burner or a blowlamp. We see no flame but only a persistent glow. Heat is given off.

The next day, as usual, these things are reviewed. The contrasts will be obvious. Sulphur comes from the interior of the earth and is connected with volcanic activity. It is a sun-like substance but it is not organic in origin. It looks like a piece of yellow stone. It burns and yields heat but not light. It is as if sun forces were active in it but these forces had been buried in the earth and they are only very reluctantly released.

Phosphorus is very different. It does not even exist in a natural state. We could almost say that the light forces in it are too strong for it to

materialise. We see that when it is exposed to the air it fumes and then bursts into flame. It is truly the light-bearer.

Carbon manifests a reaction which is something in between the other two. It does not flame but only glows when burning. It holds the balance.

Where do we find these things in nature? In man? And how do we make use of them?

We should remind the children that when we talk about sulphur, phosphorus, carbon, etc. in the organic world, these substances must not be thought of in their crude form.

Sulphur is contained in the pungent-tasting horse radish. It is in chamomile, a well-known herbal remedy for stomach disorders. Mustard is a condiment used as an aid to digestion and it is the sulphur content which is effective. Rape, a plant grown for animal feed, yields a sulphurous oil. The universal remedy for bodily ills not so long ago was brimstone and treacle. Sulphur tablets are given as a blood-purifying medicine. Their effect is volcanic. Sulphur soap is used in cases of skin eruption and sulphur baths for rheumatic conditions.

The effect of sulphur on the organism is to hasten the metabolism.

There are other uses. Sulphur is used as a cure for mildew on plants. It is used in making tyres since a small portion mixed with raw rubber gives greater elasticity. It is also used in the paper industry where its quality makes wood-pulp and paper strong and weather resistant. It is an ingredient of gunpowder. Sulphuric acid is very important in many industrial processes.

With regard to phosphorus, Henbane and Thorn-apple are two plants which specialise in the formation of phosphoric acid and both are used medicinally for treatment of nerves. The head is the centre of the nervous system and phosphorus is found in the brain. We can think of it in connection with the light. It is also in the bones giving them a quality of lightness in the other sense.

Phosphorus is an essential element in plant growth. Phosphates are present in most fertile soils and phosphates are used as an artificial fertiliser. (This is not necessarily a good thing and some people question the use of artificials in the soil, maintaining that everything can be provided by natural organic substances.) It is phosphorus which makes dials luminous in the dark.

Carbon belongs to the surface of the earth. It is one of the basic ingredients of vegetation. We shall see in due course how it is related to the rhythmic activity in the middle part of the body, i.e. breathing.

As an element carbon exists in many different forms. This quality is known as allotropy. The following are different forms of carbon.

Diamonds. Gem stones; used in industry for cutting glass; saws for stone-cutting have a diamond edge; also drills for boring through rock.

Graphite. A substance used formerly for writing. It is the black centre of the "lead" pencil.

Lamp-black. When oil burns, it gives off a deposit. Purified, this deposit is used to make Indian ink.

Charcoal. Used by artists for black and white drawing. Burning it will produce heat without flame and it is useful for cooking. It absorbs gases and is used in filter beds for purifying water.

Soot. Used sometimes as a low grade fertiliser.

N.B. Strictly speaking, lamp-black, charcoal and soot are different forms of graphite.

We could speak of these three substances, sulphur, phosphorus and carbon, as related to the three spheres of the world, the below, the above and the middle.

We see also that these three substances are intimately connected with a threefold activity in the human being – head, metabolism, and rhythmic system.

An example where all three substances are used in an external sense is provided by a match. The old type match was a small stick of wood, the head of which was dipped into molten sulphur. This was coated with a mixture of yellow phosphorus, sand and glue. When rubbed on a rough surface, the frictional heat ignited it. The safety match has a head containing a sulphur compound and another substance to generate oxygen and make it burn better. It is struck on a surface containing red phosphorus (a less dangerous variety), powdered glass and some sulphurous substance. As it burns the wood is carbonised but it has been specially impregnated and therefore it does not glow.

The next thing to consider is the role of air in combustion.

When we looked at the burning candle standing in water, with a jar inverted over it, we saw the light of the candle go out and the water rise. Obviously part of the air was used up. It must be this part of the air which supports combustion and if therefore we could get some of this by itself – a question to the class – how would things burn in it?

We also saw that the residue gas in a jar, after a flame had gone out, put out another candle. So what was left was a part of the air which would not support combustion. The greater part of this residue gas is known as nitrogen. In German there is a good descriptive word for this. It is "Stickstoff" which means "suffocating matter". Although it seems inert, it is extremely important and we shall learn more about it later on. The gas which supports the flame is known as oxygen. The air we breathe contains about 4/5 nitrogen and 1/5 oxygen and small quantities of other gases.

Here we need a supply of oxygen and come to the problem of the egg and the chicken. So far we have not dealt with any substance, apart from the air, which gives us oxygen. We could heat red lead or potassium chlorate but these things do not exist in nature and are therefore abstractions at present. We have not yet dealt with electrolysis and to do that at this stage is a deviation entailing many other explanations. However, it is to be hoped that in physics lessons the process of obtaining oxygen by liquefaction has been explained (see The Physical Sciences 1), and although there is then a little gap in the sequence of events, it might be best for the teacher to refer to this and produce an oxygen flask as a source of supply for the moment. The children must be reminded of how steam condenses to water, water to ice, through cooling processes, and how other gases can be treated likewise. They may then recall how the air can be cooled and nitrogen and oxygen separated out.

NOTE: *In setting out these indications on teaching chemistry the attempt has been made to proceed from the known to the unknown. It was mentioned in passing that water is a compound of oxygen and hydrogen but it was merely stated and not demonstrated. Since we need oxygen, shall need hydrogen soon and later speak of water as being constituted of oxygen and hydrogen, it would be logical here to show the electrolysis of water. Against this must be balanced the experience of the teacher and the receptive ability of the class. In some cases therefore it might be possible to show the experiment; in others the facts are simply stated with the promise of the demonstration in due course.*

If an oxygen cylinder is used, then great care is necessary and any instructions should be carefully followed.

If the teacher decides to produce oxygen otherwise, the usual laboratory method is to heat potassium chlorate with about a quarter of its own weight of manganese dioxide. The mixture is put into a test tube fitted with a delivery tube, the other end of which is passed into an inverted gas jar filled with water and placed on a beehive shelf in a trough of water. The manganese dioxide acts as a catalyst, that is to say, it helps the process without undergoing any change itself.

The drawback in using potassium chlorate and manganese dioxide is that we have had no introduction to these substances and cannot deviate too far. The same applies to other ways of producing oxygen. If one can tolerate this jump, an alternative is to put a little manganese dioxide in a conical flask, fit the flask with a two-holed cork through which passes a thistle funnel and a delivery tube. The other end of the delivery tube is passed into an inverted gas jar as above. Then through the thistle funnel hydrogen peroxide is poured very slowly on to the manganese dioxide and the evolving oxygen is collected in the gas jar over water. This method does not require heat.

Otherwise the gas jar is filled from the oxygen flask in the same way.

Whatever is in the jar is colourless, odourless and tasteless. If a glowing splint of wood is plunged into it, the splint will burst into flame.

We should now take a little sulphur on a deflagrating spoon, light it and bring it into a jar of oxygen. If will flare up creating heavy fumes. A piece of phosphorus (use only a very tiny piece) dealt with likewise, will flare up so that we have to turn our eyes away. This will also produce fumes. Charcoal, which only glowed in the ordinary atmosphere, will burn merrily but nothing visible is produced.

We now have to explain that in each case the oxygen and the substance put into it have combined to form what is known as an oxide. In the above cases the oxides are gases and their respective names are sulphur dioxide, phosphorus pentoxide and carbon dioxide. If water is added to the jars and the mixtures shaken, the gases dissolve, forming very important substances known as acids. The word oxygen really means acid-maker because it was thought at the time of its discovery that it was an ingredient of all acids but this was later found to be a fallacy. Acids have special qualities which we shall learn more about but for the moment we can note that they all taste sharp. A certain test for an acid is to use a piece of litmus paper. Litmus is a plant dye and an acid will always turn a piece of blue litmus paper red. Acids with which we are familiar are vinegar and lemon juice and acids in general are a group of substances with common characteristics. The liquids produced above are sulphurous acid, phosphoric acid and carbonic acid. When sulphurous acid is left exposed to the air, it attracts more oxygen to itself and becomes the much stronger sulphuric acid.

In the scientific language of chemistry the process concerning sulphur and oxygen is expressed thus:

$$S + O_2 = SO_2$$

(Sulphur Oxygen Sulphur dioxide)

$$SO_2 + H_2O = H_2SO_3$$

(Sulphur dioxide Water Sulphurous acid)

$$H_2SO_3 + O \text{ (from the air)} = H_2SO_4$$

(Sulphurous acid Oxygen Sulphuric acid)

Sulphuric acid reacts with common salt to form hydrochloric acid, an important material for industry. It is not recommended that the class teacher prepare this unless he is an expert or under expert guidance.

There is another very important acid which is a compound of oxygen, nitrogen and hydrogen. This is nitric acid, HNO_3.

Most acids, if they are strong enough, will have a burning effect. A drop of sulphuric acid will burn the skin or make a hole in cloth. Hence we can say that acids are related to the fire element.

When we burnt charcoal (carbon) in oxygen we produced a gas called carbon dioxide. A slight deviation might be made here to show another quality of carbon dioxide. If sufficient charcoal has been burnt the jar should be full of the gas. If a lighted taper is plunged into it, the flame will die out. We note that carbon dioxide does not support combustion.

If a jar of carbon dioxide is inverted over an empty jar, or rather one containing only air, and left for a time, it will be found that the carbon dioxide has sunk into the lower jar. It is obviously heavier than air. If a little petrol is placed in an evaporating dish (on a sand tray) and lit, the flames can be extinguished by pouring carbon dioxide over them, preferably using two jars together.

(If preferred these experiments can be done when the effect of acids on certain substances is shown. The effect of hydrochloric acid on marble chips is to produce carbon dioxide.) This principle (not the same substances) is used in certain types of fire extinguishers. A petrol fire cannot be put out by water. Contact with the oxygen of the air must be cut off and this is done by the heavy layer of carbon dioxide which chokes the flames.

We have seen how oxygen supports or enhances combustion and how, in combination with sulphur, phosphorus or carbon, it forms very "lively"

substances. It has many uses. In garages and engineering workshops we see men working in goggles, holding a jet with a bright flame and welding pieces of metal together. They are using oxygen together with another gas, acetylene, and the flame produced is hot enough to melt metals. Liquid oxygen is used as a rocket propellant.

When people have difficulty in breathing, either because they are ill or are at a high altitude in mountains or aircraft, oxygen is administered. For ordinary breathing however, oxygen in the air is important. As the flame dies when the oxygen in the air is used up, so would the human being die without oxygen. One reason why people feel tired in a city is that through the masses of people and the general pollution, the oxygen is in short supply. In Tokyo police on point duty have to retire occasionally to breathe oxygen.

Trees and vegetation restore the oxygen supply in the world through their chemical processes. This will be explained in due course.

When we considered the atmosphere, we spoke of nitrogen. So far all we have leant of it is that it is inert and, as such, the opposite of oxygen. It comprises approximately 4/5th of the atmosphere; it is breathed in and out by the human being without change. Nothing burns in it.

So the air itself contains polarities. On the one hand there is oxygen and on the other, nitrogen. They are mixed but not combined. Yet there could be no life without nitrogen. In oxygen itself, life would be quickly consumed so in a sense we could say that nitrogen carries the oxygen as liquid carries nutrients.

Yet there are occasions when the oxygen and the nitrogen of the air unite. This is when there is lightning. In the next chapter we shall see how, from this initial reaction, valuable substances for plant growth are formed. These substances are compounds of nitrogen and are known as nitrates.

A series of experiments should now be done to show the effect of acids. Since time is a limiting factor, they may have to be confined to the use of one acid, say sulphuric. We have seen how it is made and what are its constituent parts; so now, for the sake of convenience and purity, we may use some of the bought product.

Small pieces of paper, wood, cork, are placed in test tubes and concentrated sulphuric acid is poured on to them.

A little sulphuric acid is poured into water and stirred. (Never do it the other way round.)

Small pieces of metal are put into test tubes, concentrated sulphuric acid added and gently heated. (No boiling).

(The experiment mentioned earlier, hydrochloric acid on marble chips to produce carbon dioxide, could be inserted here).

It will be observed that the action of the acid on the paper, wood, etc. is to "burn" them. When acid is poured on water, heat develops. The sulphuric acid dissolves metals and a gas is given off. It can also be explained that sulphuric acid is used as a drying agent for gases because it absorbs moisture from the atmosphere.

Fire burns many things but acids will even burn metals. We have seen that the action of an acid on a metal is to produce a gas. Let us then collect the gas which is evolved. (In some circumstances we should not get what we require and the explanation is too complicated for the moment; we must therefore select.) We can use iron, in the form of iron filings (granulated zinc gives better results) and dilute sulphuric acid. The gas is collected by means of displacing water in a jar or test tube placed or held mouth downwards in a trough of water. It should have no taste, colour or smell although there may be some in our product due to impurities. Inverting the gas jar and applying a match, we shall get a "pop". The "pop" is a characteristic of the gas hydrogen, which is indeed the gas we have produced.

$$Fe + H_2SO_4 = FeSO_4 + H_2$$

DANGER. *The gas must be collected in another vessel and not ignited directly as it leaves the apparatus.*

Hydrogen is the lightest gas known and was formerly used in airships. It is however dangerous and helium was substituted later. The "pop" shows that it is explosive and hence must be treated with respect. It must therefore be explained rather than demonstrated that hydrogen burns with a very hot, almost invisible flame, which will easily melt glass. But it does not burn by itself, only when air (oxygen) is present.

Since a metal contains only one ingredient, it is obvious that the hydrogen must have been released from the acid.

This serves to confirm that the presence of hydrogen has something to do with the burning process.

Furthermore, it will be no surprise to learn that hydrogen is a constituent part of petrol, etc. These substances are a combination of carbon and hydrogen and are known as hydrocarbons, also a matter for study later on.

So far we have considered aspects of combustion. We should now look at the contrasting process of salt-formation.

SALTS AND SALT-FORMATION

In the early days of chemistry "salt" appears merely to have referred to what we now know as common salt. It was the solid substance remaining after evaporating sea water.

When, through heat, the liquid element of a solution is removed and an earthy substance remains, we have an example of an archetypal process. Perhaps a more interesting demonstration can be given by producing more distinctive crystals.

Using the same substances as for producing hydrogen, an experiment can be made as follows: iron filings are added to dilute sulphuric acid until there is no further reaction. When the undissolved iron filings are filtered off, a clear green solution of iron sulphate remains. If the liquid is evaporated to concentrate the solution and then allowed to cool, crystals will form, known as Green Vitriol.

In modern chemistry the term "salt" embraces a whole group of substances which are compounds and which have similar characteristics. As explained in the introduction we must dispense here with the idea of table salt or cooking salt and grasp the concept. Salts are a fundamental of the material world. Many exist in the natural state but it is also possible to manufacture them. Natural salts include a multitude of compounds which are well enough known although the chemical names may appear strange at first. There is, for instance, lime in all its forms such as limestone, chalk, marble. These are all calcium carbonate; similarly gypsum = calcium sulphate + water; brine = sodium chloride + water: Epsom salt = magnesium sulphate. The ash of a burnt plant contains potassium carbonate. Among others, substances designated as sulphates, chlorates, nitrates, carbonates, are salts and a metal is one of their constituent elements.

We have seen that an acid is related to the fire element, but the fire has become – to coin a word – inaquated. (Aqua = water). That is to say the fire is not incarnated into physical substance, but into the watery element. Salts result as a combination of this with "earth". The earth element is known as the base (basis). Whereas an acid tastes characteristically sharp and prickly, turning blue litmus red, a base is dull, slimy, insipid, and turns red litmus blue. When a base is soluble in water it is called an alkali. (Alkali comes from the Arabic and it means "ashes".) When by some means, the acid part is detached from a salt, the base remains. Reversing the process, when base and acid combine, a salt is formed.

It is not always easy to demonstrate these matters as substances vary in their reactions and strength of cohesion but lime provides an excellent example of the attributes just mentioned.

If they are not already familiar with them, the children can be shown or told about the many manifestations of lime – limestone mountains, chalk hills, marble, sea shells, stalactites and stalagmites, bones. Reference should be made to past lessons in geology.

It should be pointed out that all the above examples are solid matter but they owe their creation to the activity of water or a liquid. The chemical name of the substance of which they all consist is calcium carbonate, $CaCO_3$, a compound which consists of oxygen, carbon and a metal which does not exist in the free state, calcium. This lime substance is organic in origin. The limestone is a rock which has been formed at the bottom of the sea from the thousands of marine animals which have deposited their shells and bones there. At some time there have been great upheavals in the earth's crust resulting in the formation of the great mountain ranges. Chalk and marble are other forms of the same substance which are widely distributed over and under the earth. There is an old saying in Latin "Omnis calx e vermibus" – all chalk comes from worms. (By worms was meant the lower animals.) Where rivers flow through limestone country, they dissolve some of the chalk and carry it to the sea, and the dissolved chalk in the sea is taken up by the marine life. There is therefore a sort of lime cycle. A great deal of the earth's crust is formed of this substance but it is not only there that we find it. Man also owes his structure to it as it is contained in his bones.

We have observed the effect of combustion on organic matter. In calcium carbonate we meet an entirely different substance. How will this be affected by heat? Even if it owes its origin to the living, it is now a mineral, dead. The life quality has left it and it is now subject to the laws of the mineral world. The effect of burning therefore will be different from that of organic matter.

Unfortunately, it is not possible to demonstrate the effect of heat on calcium carbonate in the classroom or even in the laboratory unless a furnace is available. The matter has therefore to be described unless some other facility can be found. If a pottery kiln is available, that could be used or one might persuade the caretaker to be helpful. The point is to get a large piece of limestone or marble strongly heated for a day or two. When it has cooled it can be brought into the classroom. There will be no obvious change. Now water is poured on to it and the mixture will sizzle and get hot. We add more water and eventually have a milky liquid which is known as milk of lime. Filtering this we shall find a white substance on the filter paper and a clear liquid. The white substance is known as slaked lime and the liquid is lime water. What has happened is this: the original calcium carbonate, by the action of heat, has been changed into calcium oxide and carbon dioxide, a gas which has been driven off.

Calcium carbonate, $CaCO_3$ + heat (Chalk, marble, limestone) → Carbon dioxide CO_2 / → Calcium oxide CaO (Quicklime)

Calcium oxide + water → Calcium hydroxide $Ca(OH)_2$ (Slaked lime)

Calcium hydroxide + water → Deposit of calcium hydroxide and lime water

(Lime water is a solution of calcium hydroxide.)

If we dip a piece of red litmus paper into the lime water, it will turn blue, showing that we have an alkali (soluble base).

We saw that in the combustion process of plants etc. two diametrically opposed forces were revealed to which one might refer as gravity and levity. Similar forces manifest themselves, when, for example, chalk is burnt but it is as if much greater power is needed to drive them apart. Substances such as these then, limestone, marble, chalk which can disintegrate into two other characteristic substances are "salts".

In this particular case the separated substances both contain oxygen. The acidic carbon dioxide is driven out as the levity element. On the gravity side the residue is calcium oxide.

Let us now take a bottle of soda water or some of our own solution of carbon dioxide, which is the same thing, and taste it again. Now taste the lime water.

If we now mix the two liquids, the mixture will first become cloudy, then small white particles will be precipitated. The precipitation is no other than calcium carbonate. The original marble or limestone, $CaCO_3$, a salt, was split through fire into an acid and a base. The acid and base, united by water, form a salt. We shall see more examples when the metals have been studied.

If the intellectual capacity is sufficient we could now perhaps make a more exact definition from what has been learnt and say that a salt is a substance which, through the action of heat or other agency, disintegrates into two other substances, one of which is acidic and one basic. Alternatively, basic and acidic substances neutralise one another in the presence of water to become a salt.

In any case we can see that a salt is a combination of the element "earth" with "fire", influenced by water.

Salt + fire → acid (levity) / → base (gravity) — Fire severs

Acid + base (+ water) → salt — Water unites

In this example:

Calcium carbonate → Carbon dioxide / → Calcium oxide

Carbon dioxide + water = Carbonic acid

Calcium oxide + water = Calcium hydroxide

Carbonic acid + calcium hydroxide = Calcium carbonate

If we consider a plant, we see that the action of fire and water bring about similar results:

Plant plus fire → light (levity) / → carbon (gravity) — Fire severs

Light plus carbon (+ water) → plant — Water unites

We can remind the children that calcium carbonate is the chemical name for chalk and limestone and that these substances have been formed from animal skeletons. Calcium carbonate is a salt and therefore a "salt" process must be taking place in animal (and human) life in the formation of the bones.

The subject of acids, bases and salts is studied in much greater depth in Class 10, at the age of 16. For the moment it might be concluded by giving the following summary of characteristics:

Acids	Bases
Sharp taste and penetrating smell	Dull, insipid taste (only if soluble) no smell
Related to air and fire	Related to earth
Creates watery cloud	Creates dry solidity
Turns blue litmus red	Turns red litmus blue

The contrasts unite and become a salt

If the teacher feels able to use the analogy he might take the opportunity of giving a little moral slant to his instruction. He could point out that human beings sometimes overdo things in one direction or another but the balanced personality is the one who can achieve harmony.

Other studies can now be made, perhaps more picturesque and less intellectually demanding.

We can do an interesting experiment by exhaling through a tube into a flask containing lime water. We observe the same result as in adding soda water, i.e. there is a precipitation. This shows that we have exhaled carbon dioxide.

In the lungs there is also a sort of combustion taking place. We breathe in the air, for the most part consisting of oxygen and nitrogen. In the blood stream is carbon. When the oxygen and carbon meet, the oxygen is absorbed into the system, carbon dioxide is formed and breathed out with the nitrogen which is unchanged.

There is a "chalk" chemical reaction which takes place in nature.

When we add carbon dioxide to lime water, we notice a precipitation. If more carbon dioxide is added, there is a further chemical reaction. The calcium carbonate turns to calcium bicarbonate, $Ca(HCO_3)_2$, and this is soluble in water. In nature, rain water, passing through the air, dissolves some carbon dioxide, passes through the soil and vegetation and absorbs more. In limestone country the water and the carbon dioxide act on the calcium carbonate and calcium bicarbonate is formed, which dissolves in water. This mixture drips through cracks but releases some carbon dioxide, thus leaving tiny particles of calcium carbonate. The continual dripping piles up these particles and hence the formation of stalactites and stalagmites.

(This process lends itself very well to a little artistic work).

At this point it would be appropriate to explain practical uses of lime and to describe a lime kiln. Alternatively, it is something which the children can study for themselves. One can deal also with the problem of "hard" water.

One common use of slaked lime is to mix it with sand and water to make mortar. The lime takes carbon dioxide from the air and bricks, and becomes hard; that is, it turns into calcium carbonate. Lime is also used in steel processes, agriculture, for making bleaching powder and cement. Quicklime is used for burying diseased bodies.

The water in limestone country contains calcium bicarbonate and it is said to be "hard". One of the problems with such water is to get a

lather with ordinary soap. When boiled, carbon dioxide is driven off and the calcium carbonate remains. This is non-soluble and it is the "fur" which we find inside kettles.

$$Ca(HCO_3)_2 \quad = \quad CaCO_3 \quad + \quad H_2O + CO_2$$

This hardness is known as temporary but there is also a form termed permanent which has to be remedied by chemicals. Permanent hardness is usually caused by calcium sulphate which occurs naturally in the earth. It has to be treated with sodium carbonate. The chemical ingredients change partners, so to speak.

Calcium sulphate + sodium carbonate = Calcium carbonate + sodium sulphate.

These are insoluble salts and can be filtered off. The water is then "soft".

Something should also be said of the production and importance of common salt, which occupies a modest place in our kitchens and dining rooms, but has a great variety of other uses. ($NaCl$).

Salt can be extracted from mines, evaporated from sea water or underground lakes. If, as sometimes happens, salt is found on its own, underground and undissolved, water is pumped down to it. The brine is pumped back, evaporated and the salt remains. Huge deposits are found in Cheshire in England, in Poland, Spain and Germany.

It is used in the production of many useful things such as bleaching powder, disinfectants, washing soda, bicarbonate of soda (used in medicines and for baking powder), caustic soda (for making soap and glass), glazing material for earthenware.

It is essential for the proper nourishment of the human being. Salt is needed to replace that lost by perspiration and, if it were not added to our potatoes and vegetables when they are being cooked, they would be less tasty. In the days before refrigeration and other modern processes for preserving food, salt was used. It still is for some things, namely bacon and fish. Salt was so important in Roman times that part of a soldier's wages was paid in salt. (Latin, salarium). It is from this that our word salary is derived.

Yet too much salt kills. It has been found that there are hazards in irrigation in hot countries on account of the salt left in the ground when the water evaporates. The Dead Sea has 25% salt in it and it is practically lifeless. Hence its name.

(Economic and geographical aspects might be studied here at some length. Such matters can provide pupils with themes for individual projects.)

In the previous chapter mention was made of nitrogen and its compounds, nitrates, as important to plant growth. Another important compound of nitrogen in this respect is ammonia.

Ammonia, NH_3, is a gas which is formed naturally by the decomposition of organic matter and especially some of the matter in the excreta of animals. Near a manure heap or in a stall or stable we become very aware of it.

We said that in nature, under the influence of lightning, some nitrogen of the air combines with oxygen. Nitric oxide, NO, is formed. This absorbs more oxygen and nitrogen dioxide NO_2 is formed. Reacting with water this becomes nitric acid, HNO_3. Some of this nitric acid combines with atmospheric ammonia to form ammonium nitrate.

$$HNO_3 \quad + \quad NH_3 \quad = \quad NH_4NO_3$$

Very dilute nitric acid is washed down by the rain and enters the soil where it is acted upon by other agencies to form soluble, usable nitrates which can be taken up by the plants and which are essential for their growth.

A similar result can be achieved by a manufacturing process. This produces artificial fertilisers, the use of which certainly increases crop yields. Whether they are of ultimate benefit, either to the land, to the plant, or to those who eat the plants, is questionable.

THE METALS

In Class 6, in the geology period, some reference will have been made to metals. The study should now be continued in the direction of chemistry. At present, it will perhaps have to be restricted to the seven traditional metals and in any case it will be elementary. The theme is taken up again in the upper school.

As a beginning the various metals should be shown and handled; i.e. gold, silver, mercury, copper, iron, tin, lead. Various forms of some of them will be available – sheet, wire, filings, turnings, as well as consolidated pieces. Then also ores should be shown as they are found in nature. The link should be made with geography and geology and locations can be found by the children themselves by referring to charts and the atlas. As much information as possible should be extracted from the pupils from their own observation or reading with regard to the way in which metals are found, and their salient features.

The question should also be put as to the difference between metals and non-metals and it is to be hoped that something of the following will result:

Metals have a peculiar shine or lustre non-existent in other materials. They are found in the interior of the earth. The physics lessons may be recalled and the fact that usually metals are good conductors of heat and electricity. They give out a ringing sound when struck. Most of them have a high melting point. They are more or less malleable, tenacious and ductile. It may be noticed that with these metals, their ores or salts, an element of colour enters. Expand in heat, contract in cold

Gold is found in its natural state in veins in the earth or in the beds of streams as small particles or grains. It is the most malleable of all metals and can be worked with a hammer without heat. Gold can be hammered to a thin leaf and when held to the light, it appears green just the same as our blood when light shines through it. Gold does not tarnish or corrode and it

is virtually indestructible. It preserves a bright yellow appearance; it is a good conductor of heat and electricity. It forms scarcely any compounds and resists most chemical attacks. Its symbol is Au from the Latin Aurum.

Gold stands by itself. The other metals can be considered in pairs as they have opposite characteristics.

Silver is sometimes found in the free state but also as an ore, argentite or silver-glance, Ag_2S. (Argentum = silver). This is silver compounded with sulphur. It is also found as horn silver, argentum chloride, AgCl, and in ores which contain lead and copper (galena). On smelting its shining surface reflects the light in a peculiar way. It is a bright shiny metal but tarnishes in the atmosphere, forming a coat of black silver sulphide. Silver is resistant to atmospheric oxidation. It is the best conductor of heat and electricity.

The oxide of silver is brown and the carbonate a bright yellow.

Very different from silver is lead. Lead is found in mines in company with chalk in the form of lead sulphide and this compound is known as galena, PbS (Plumbum = lead). To extract the metal the compound has to be heated and then subjected to a process similar to that used to obtain iron, i.e. a blast furnace.

Although in actual fact gold and silver are heavier, lead gives the heavier appearance. A lump of lead is a picture of inertia and weight, dull and unattractive. It can be cut with a knife or scratched with a nail and the fresh surface is then a silvery blue. It soon tarnishes however. Due to the carbon dioxide in the air a carbonate is formed on the surface and this protects it from further reaction. It is a poor conductor and resistant to corrosion.

The oxides are yellow, red, black, brown and the carbonate, white.

Mercury or quicksilver is the most curious of metals. It is the only one which exists in the liquid state at normal temperatures. It is sometimes found in its natural state in isolated drops but more often has to be obtained from the ore known as cinnabar, which is a sulphide of mercury, HgS. (Hydrargyrum = quicksilver). The ore is a red or black mineral and the metal is obtained by heating. Sulphur dioxide is given off as a gas; the mercury comes away as a vapour which has to be condensed. It forms few compounds.

Although a liquid, mercury acts very differently from water. A little spilt on the desk will divide into tiny drops and run in all directions, but the drops will unite again on meeting, leaving no trace. Care should be taken not to lose any as it gradually gives off a poisonous vapour. It always needs careful handling. Like other metals it expands and contracts in heat and cold. It also conducts electricity.

The oxide is vermilion and the carbonate red or brown.

Tin is obtained from its oxide, cassiterite, which is stannic oxide, SnO_2 (Stannum = tin). It has to be obtained by the use of a furnace and removing the oxygen.

It is a tough, smooth, brittle metal, silvery white with a bluish tinge. When bent it crackles and this is known as "the cry of tin". It is durable under normal conditions but disintegrates in extreme cold. It can be worked cold.

The colours of cassiterite are red to brown.

Copper is sometimes found free but most of what we use has to be extracted from ores, as for instance, copper pyrites, $CuFeS_2$, and copper-glance, Cu_2S. (Cuprum = copper). The Latin name is due to the fact that the Romans found large quantities of the metal on the island of Cyprus, after which it is named. It is one of the most easily worked metals and hence probably its very early use historically.

Copper is tensile, malleable, ductile and can be hammered and rolled. It gives high conductivity to heat and electricity and it is not readily corroded. It is colourful and has a singular beauty and flexibility. Exposed to the air it turns green due to oxidation.

The whole range of colours is represented in copper compounds, green and blue being predominant.

In great contrast to copper is iron. This metal seldom occurs in the natural state but has to be obtained from ores using terrific heat. (A blast furnace should be described.) The usual ores are haematite, ferric oxide, Fe_2O_3; magnetite, ferrosoferric oxide, Fe_3O_4; siderite, ferrous carbonate, $FeCO_3$. (Ferrum = iron). It is due to the redness of iron ores that soil or rocks are sometimes red. Our red blood is also due to the presence of iron. Iron is found combined with other elements in hundreds of minerals. It corrodes in moist air, yielding the well-known rust. There are enormous quantities of iron in the earth's crust.

The chief quality of iron is its strength and the fact that by the addition of other substances or by regulating the heating and cooling processes an almost infinite variety of irons and steels can be produced. It is also the metal which has the relationship with magnetism.

The oxides can be black, brown or red and the carbonate is a pale green.

Having considered the metals in this way, the uses to which they are put should now be studied. Again this is a matter which the pupils can do for themselves or at least partly so. Collections and lists of various objects made of the different metals could be made. The uses of the metals will reveal something of their nature.

Gold. The original use of gold was in connection with religious worship, e.g. the sun cult in Mexico and Peru. It had no trading value. In Peru the Inca (king) had a golden throne and his room was lined with gold. The Christian church uses gold for crosses and other symbols. An echo of its original use is in the gold of the royal crown etc. Traditionally the wedding ring is made of gold. Ornaments are made of gold, as are works of art.

In that gold has come to be a measure of value, its use is debased. Men have fought for it. Its use has been for selfish purposes. Reference could be made to the Templars and Philip the Fair.

Silver. This metal has a particular relationship to the light. It is possible to polish silver so that it becomes a mirror. It is used for ornaments, coins, jewelry, cutlery and tableware. Because of its ability to conduct electricity, it is used for printed electric circuits.

Silver compounds are used for film and photographic plates. There are few silver salts.

Lead. In the past lead was used for pipes. It is a very durable metal and pipes laid by the Romans are still in existence. Lead has protective qualities. It can be used in containers to transport corrosive substances. It is used for roofing and it provides a sheath for underground cables. Sheet lead in walls is a sound insulator. It protects from radio activity. Lead is the basis for printers' type and it is used in storage batteries. It is a poor conductor. It melts before warmth or electricity can pass through it, hence it is useful for making electric fuses. Lead is poisonous. Its effect on the human frame is to harden the bones and the arteries.

Compounds of lead produce colouring material. Lead carbonate is used for making white paint.

Mercury. Since mercury will dissolve some of the other metals, it has been used with silver and tin to form an amalgam for filling teeth. However, this is not a healthy substance to have in the mouth continuously and other materials are now used. Mercury has a uniform volume expansion and, being a liquid, it is therefore useful in thermometers and barometers.

Tin. The main use of tin is to coat steel to prevent the latter rusting, e.g. tin cans. It is also an ingredient of solder. Together with copper it forms an alloy known as bronze. In former times there existed what is known as the Bronze Age because weapons and vessels were made of this substance. Today bronze is used for the bells which ring from the church towers.

Copper. All sorts of vessels, objets d'art, kettles and cooking pots are made from copper because of its special relationship to heat. Because of its conductivity it is much used for electric cables and also for hot water cisterns and pipes. (The pupils will probably be doing metalwork with copper in the craft lessons.)

Iron. This is, one might say, the most terrestrial of metals. The industrial revolution ushered in the iron age. Our present civilisation would be unthinkable without it. Trains, cars, weapons, machinery of all sorts are made from iron. Its relative, steel, forms the framework of our large buildings. In the house and garden our tools and implements are mainly products of iron. Its use is essentially utilitarian.

Having acquainted the pupils with the metals in some measure the latter can now be considered from the chemical point of view. First we can observe how the process of combustion affects them. Using the ordinary heat available, the Bunsen burner, we shall find that gold and silver are not affected. Mercury vapourises and the fumes are very poisonous. This therefore must be explained and not demonstrated unless special precautions can be taken. Copper (wire) will burn away slowly showing a green-blue flame producing a black deposit. Iron will get red hot and gradually flake away. Tin and lead will have to be put into a crucible where they will melt and eventually burn away.

We have already seen an example of how an acid acts on a metal to produce hydrogen, namely, dilute sulphuric acid on iron. The gas is given off and the residue is a salt.

ACIDS ON METALS

The action of acids on metals is however by no means uniform. No acid by itself attacks gold. Silver will be affected by hot sulphuric acid; mercury by nitric; copper, hot sulphuric and nitric; iron, sulphuric; tin and lead by most acids.

Recommended as colourful is the reaction of dilute nitric acid or concentrated sulphuric acid heated with copper, resulting in the formation of crystals, copper nitrate and copper sulphate respectively. The gas dissipates and the liquid can be evaporated, leaving the salt.

We shall have noticed that both base and salt have a metal ingredient. (Ammonium salts – not dealt with here – are an exception). When a base is treated with acid, the hydrogen of the acid is replaced by the metal and a salt is formed. We had the example of calcium hydroxide (calcium oxide + water) and carbonic acid to form calcium carbonate. It will be noted that calcium oxide is a compound of calcium (a metal) and oxygen. When a metal element combines with oxygen a basic oxide is formed. A non-metal element combined with oxygen forms an acidic oxide, e.g. carbon dioxide.

The following experiments might be done to show the reaction of a basic oxide with various acids:

Take three beakers and into each put a little black copper oxide (CuO – now called Copper II oxide).

Into the first beaker pour some dilute sulphuric acid and watch the change of colour. Pour some dilute hydrochloric acid into the second beaker and watch likewise. Do the same with dilute nitric acid into the third. In each case the acid should be poured slowly until the black powder just disappears. The solutions may then be evaporated and crystals obtained of the three different salts, copper sulphate, $CuSO_4$; copper chloride, $CuCl_2$; and copper nitrate, $CuNO_3$, respectively.

These demonstrations are further examples of the principle

$$\text{A base + an acid} \longrightarrow \text{salt (+ water)}$$

(1) $CuO + 2(HCl) = CuCl_2 + H_2O$ (2) $CuO + H_2SO_4 = CuSO_4 + H_2O$

THE ORGANIC WORLD

We should now look a little closer at chemistry in living processes and consider the cycle of plant growth from the chemical point of view. There is a danger here that the impression might be given that plant growth is due only to chemical reactions and therefore a larger view should first be taken and the wonder of growth emphasised. We might remind the pupils of Ruskin's words:

"The power that catches out of chaos charcoal, water, lime and what-not, and fastens them into given form, is properly called spirit; and we shall not diminish but strengthen our cognition of this creative energy by recognising its presence in lower states of matter than our own".

Let us call attention to the wonderful carpet of green vegetation which covers much of our earth. We shall have observed that plants are pale, or only a sickly green, in the absence of light and we must therefore conclude that the green world is really dependent on the light. Further we realise that the rest of the living world is dependent on the plant. Without the light there would be no vegetation, and without vegetation neither animal nor human life.

We might make a comparison here between the life processes in the plant and those in the human being. Man has faculties above those of the plant and we refer to the life of the soul. If a person gets excited, he may get red in the face; bad news sends him pale or causes him to faint. The life process is obviously affected by the experiences of the soul. Hunger, pain, fear, desire, all these can affect the organism. But man also has a higher member to which we may refer as the spirit and he also has a certain ability to overcome the influences of the soul.

In the plant we can see chemistry at work in a purely living way. In man chemistry is at work similarly but with his higher faculties he can influence his life processes.

In early classes the children will have heard about the work of the gnomes, the water, air and fire fairies and they will have seen how the plant lives between the forces of heaven and earth. Now we transform these ideas into a more scientific language appropriate to the ages of the children. We can speak of the four elements and of photosynthesis. Elements, in this sense of course, are not the elements of chemistry but earth, water, air and fire.

The earth is that which gives form and shape. Without earth there would be no solids and no individual substances as they would all merge into one another.

Water is the great unifying element. It unites all parts of the earth. It flows laterally and, in the rain cycle, vertically. It is essential to all life – vegetable, animal and man. The liquid element unites all parts within an organism (sap and blood).

Air is spread above the earth, around it and within it. In daytime the light shines through it; at night it is filled with darkness. In light and dark is the play of colour but air is also the medium of sound. It carries the sounds of nature – the wind, streams, birds and human voices.

Warmth and light stream to the earth from outside. They are also essentials of life.

The plant has an intimate relationship with all four elements. It is rooted in the earth and needs earthly substances. It needs water for its nutritional processes and it requires light and warmth. Our first experiments in combustion showed how little of earthly substance the plant really has. An experiment could now be done on a more scientific basis to demonstrate this.

Some fresh leaves could be weighed, dried and weighed again and the difference will tell us the weight of water extracted. The dried leaves can be crushed and carbonised and we can work out the weight of the volatile oils which have been driven off. With greater heat the carbon can be burnt away and only an ash remains. The result will show that the plant is approximately 72% water, 18% aromatic vapours, 10% carbon, and the amount of ash is fractional.

The class should be asked for observations on this process. The importance of water should be pointed out and the fact that apparently there is still liquid substance in the dried leaves, and that the ash, consisting of salts, is the only earthy part.

Further experiments can show the relationship of the plant to the air.

Text books often give the following two experiments to show how plants produce oxygen. Unfortunately for the teacher they do not always work as well as one could hope as they need time and sunshine. The latter commodity – in England at least – is sometimes in short supply. Therefore the advice must be repeated to try them out before demonstrating in front of the class and hope that conditions will be suitable when needed. A further difficulty is that the weed most likely to be useful may not be available.

We have seen that a candle burning in a closed jar uses up the oxygen. Take a large bell jar, place it in water with a floating candle and a small plant inside it. The candle is lit and the jar sealed. After a while the candle will go out. Now place the whole apparatus in the sunshine. After some time remove the cork and hold a lighted taper inside. It should burn, showing that oxygen has been restored – but this is something the children should be encouraged to think out for themselves.

The other experiment is to put some weed from a pond or an aquarium (Canadian pond weed, Elodea, is recommended) under water in beakers, with funnels over it leading into inverted test tubes full of water. One beaker is placed in the dark and the other in bright sunlight during the day and in artificial light during the night. After twenty-four hours we shall hope to find that the one which has been in the light contains oxygen. It can be tested with a glowing splint of wood.

A different result is obtained when we soak some peas or beans until they begin to sprout, then put them in a muslin bag and suspend the bag in a sealed jar which has a few inches of lime water at the bottom. The jar is put in the dark for a few days and when taken out we see that the lime water has turned cloudy. Why? Carbon dioxide has been given off.

What then is the chemical process taking place in the plant?

The atmosphere, as we already know, consists of nitrogen, oxygen, a small proportion of carbon dioxide and minute quantities of other gases. In the leaves of plants are tiny spores called stomata through which the carbon dioxide in the air is drawn into the plant. The greenness of the leaf owes its origin to a substance known as chlorophyll, which absorbs the light and gives the plant the power to transform the carbon-dioxide into other carbon compounds and oxygen. The carbon is absorbed into the structure of the plant and the oxygen released. This happens under the influence of light. During the night the activity of the plant changes; it uses oxygen and gives off a little carbon-dioxide. It is interesting to

note however, that for the main part, the plant breathes in the product rejected by man and animal, and restores what man and animal need.

Plants also use nutrients taken from the soil through their roots. This process however cannot take place unless water is present. In fact water is, so to speak, for ever flowing through the plant. It absorbs water and exhales a watery vapour. The process is known as transpiration. It can be demonstrated as follows:

A glass of water is covered by a plastic or rubber top and through a hole in this the stem of a leafy plant is inserted into the water. A bell jar is placed over the whole and it will soon be seen that drips of moisture form inside the jar.

At this stage it would be good to refer to allied matters connected with vegetation, e.g. the effect of wind on evaporation, the predominance of conifers in northern regions, the exuberant vegetation of the wet parts of the tropics, the deciduous trees of the temperate zones.

The carbon which is absorbed by the plant combines with the water flowing through it (hydrogen, oxygen) and forms substances which are known as carbohydrates. (Hudor in Greek means water.) Another substance, cellulose, is also produced by the plant and this is for its own structure. Oils are also produced by further condensation of the carbohydrates. Together with nutrients from the soil the plant also manufactures substances known as proteins. The carbohydrates, proteins and oils are the essentials for human nourishment. Animals use them also but some of them can digest the cellulose as well.

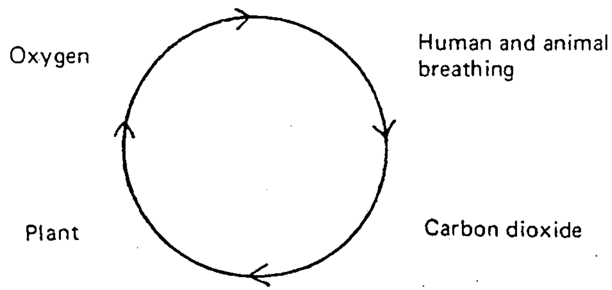
We see then that the whole environment is concerned in plant life. From above come light and warmth; from the surroundings comes carbon-dioxide; from below comes the water and mineral substances.

There is one special group of plants known as leguminous. These develop little nodules in the roots which are hives of bacteria and these take nitrogen from the air and transform it into a form which plants can use. The plants use some of it but much is left over to enrich the soil generally. Hence one of the reasons why a leguminous crop should be included in a rotation.

There are three cycles in plant growth:

First, the light, captivated by the plant, is drawn into the darkness and released again in the colour of the flower.

The second is as follows:



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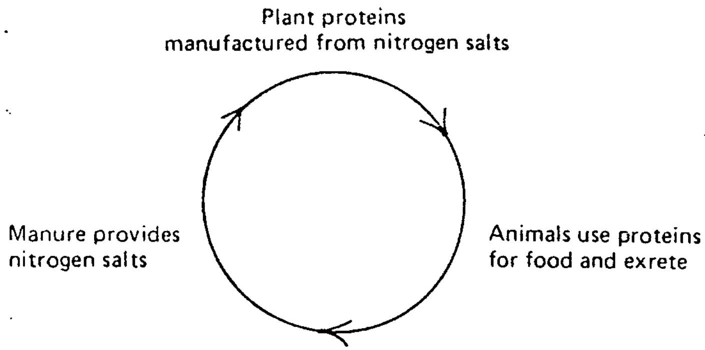

Two carbohydrates with which we are well acquainted are sugar and starch. These substances are in all plants but for our purposes, for manufacturing sugar or starch, we use those plants which have the richest content. The sugar on our tables comes either from the sugar cane or the sugar beet. Starch is made from potatoes or wheat.

If time allows it is interesting to say something about these substances, particularly the history of sugar. Also the manufacturing processes should be explained in whatever length the teacher feels able. Basically, sugar is prepared by beating the cane or shredding the beet, cooking it and crystallizing the juice. Starch can easily be obtained from a potato by grating it, mixing with water and sieving. The cellulose remains in the sieve; the starch granules pass through with the liquid which is sieved again and left for a while. The brown liquid is then carefully poured off, water added to the residue and left to stand for a while. Gradually a thin layer of starch settles on the bottom of the vessel.

One can now take a sample of sugar and show its characteristics. Its taste will be well known. It can be contrasted with salt. It is soluble but when the water evaporates, it crystallizes again. It can be pointed out that this quality is made use of practically in making icing, jellies, jam. Sugar burns. When open fires were in vogue and they needed a stimulus, a spoonful of sugar often helped.

When a little sugar is heated gently in a test tube, it melts. When it is heated on a tin lid, it puffs and boils and leaves a black, crunchy substance. In that it melts we see that sugar is related to the watery element; it gives off gases and is thus related to the air. It burns and shows its relationship to warmth and light. When the liquid and gaseous elements have been driven off, what is left? Carbon.

If we pour a little concentrated sulphuric acid on sugar, we shall observe the burning in another form. Carbon remains.

So we see that sugar is carbon and water and we know that water is a compound of hydrogen and oxygen. Liquid is circulating the whole time through the plant and this liquid is a sugar solution although it is very dilute. In the particular cases of sugar cane and sugar beet, we extract the sugar for

our own purposes but the sugar circulation is true of all plants.

Now we can take some starch or flour, which has a great starch content, and compare it with sugar. It has a different relationship with water. With the application of heat it does not melt but carbonises. When King Alfred burnt the cakes, he was creating carbon although he probably did not know it. Starch is then also a carbohydrate but it is less mobile than sugar.

In the plant the sugar solution becomes saturated and the wonderful power of the plant turns the sugar into starch, pushes it, so to speak, out of the sap stream and fixes it. This forms the solid part of the plant and particularly seeds and tubers contain much starch. At night, the starch is recomposed into sugar and taken into the sap again. Trees build up a store of starch in their trunks in summer and release it, transform it into sugar, when growth starts again in the spring.

It might be good here to speak about bread. Flour (starch) is the base (earth), water is added, the fermentation process introduces 'air', the heat of the oven consolidates it. Salt is a usual ingredient and in earlier times a spoonful of honey was included. Thus earth and heaven are further invoked. No wonder that bread is considered the staff of life.

In the human being too there is a continual circulation of sugar solution, i.e. a compound of carbon. It is in the blood but it does not form substances as in the plant. It is the provider of warmth and energy. When we eat starchy foods, there is first of all a chemical process which takes place in our mouths. By chewing and mixing with saliva the starch is changed into sugar and through the digestion process this is then absorbed into the blood stream. Carbon in the blood meets the air in the lungs. Oxygen is extracted from the air for bodily use; there is a chemical reaction and carbon dioxide is breathed out. This is the sort of combustion process in the human being mentioned earlier.

In the plant another substance is also expelled from the sap and this is the cellulose which forms the actual structure of the plant. We experience it if we try to eat tough cabbage or stringy beans. It builds the framework of the plant. Some plants have more of it than others and it is this characteristic which limits the number which we can use for food. We should have difficulty in chewing grass but cows can eat and digest the cellulose. Similarly oat straw can be used as a feed for cattle. On the other hand we do find a use for cellulose in that it provides fibres for our clothes. Rope and string are also made from plant fibre.

Sugar, starch and cellulose all contain carbon but with different characteristics and different functions.. Sugar is soluble, mobile and contributes to growth. Starch has a swelling, resting quality, is a reservoir and creates form. Cellulose is insoluble and fixed. It provides support and protection.

Strange as it may seem, the oils produced from plants are also compounds of carbon, hydrogen and oxygen, but they are formed more under the influence of air and warmth. E.g. sunflower oil is from the seeds; olive oil from the fruit.

It is a characteristic of oil that it does not mix with water. In the solid state it is known as fat and it forms a protection in some animals against the cold and the wet. Aquatic birds have a gland which secretes oil to smear their feathers which thus become waterproof. Whales and seals have thick layers of fat which keep out the cold.

We have spoken of sugar and starch as important for human nourishment. There is another substance in the plant which is necessary in our food but which in many instances today we obtain by eating the flesh of animals. This is protein. It is through the nitrates and minerals in the soil, combined with carbon, oxygen and hydrogen, that protein is formed. The formulae for proteins are very complicated.

A certain kind of protein is known as albumen. It is found in cow's milk. When milk turns sour, it is the albumen which coagulates and when it is strained, we are left with cream cheese. Milk can be artificially curdled in order to make cheese, using the juice from a calf's stomach known as rennet. The white of an egg is almost pure albumen. It consists of carbon, oxygen, hydrogen, nitrogen, with traces of sulphur, phosphorus and mineral salts. These are the substances which we have been considering both in this and in the previous chapters. From observation of their activity can we deduce their actual nature?

THE NATURE OF SUBSTANCE

In the foregoing some idea of chemical processes in the inorganic and the organic world has been given. It would be ideal now to say to the pupils: "You have now seen many demonstrations and you have been given much information. Now consider things a little further similar to the way in which we have already looked at sulphur and phosphorus. Consider the role of carbon a little more fully and that of other important elements as, for example, oxygen, hydrogen, nitrogen and the metals, and see if you can deduce the nature of these substances.

Something similar to the following might result.

Carbon appears in many forms and many aspects of it have been considered. A piece of charcoal retains its form for a long time when burning. When twigs are carbonised, they retain their shape. In the form of a diamond, carbon is the hardest known material. Carbon is the basic material substance of the plant. It is in the air in the compound carbon-dioxide, a heavy gas which plants use to build up their form. It has a special relationship with iron. The addition of carbon to iron results in steel which means that there has been a hardening and form-determining process at work. There are more different compounds of carbon, hydrogen and oxygen than all other compounds put together. Carbon is a constituent part of carbohydrates, together with oxygen and hydrogen. The two last named are gases but in a certain combination form water. The addition of carbon results in form. Carbon, compounded with oxygen, hydrogen, nitrogen and traces of other substances, forms protein.

We see then that carbon is concerned with form, shape, structure.

In various experiments we have seen how oxygen supports the processes of combustion and how essential it is for the human being. It is an ingredient

of water. It combines with most things resulting in oxides, sulphates, carbonates, nitrates. It is in all important rocks, in the tissues and blood of man and animal. It furthers the processes of decomposition and hence of further life. Its nature is active and chemical activity in the mineral kingdom is brought about by oxygen. It is an ingredient of many salts and therefore a forming quality must also be ascribed to it.

It could be characterised as the supporter of life and a formative agency.

Hydrogen is the lightest gas known and it burns with the hottest flame. It is the common element in all mineral acids which themselves can dissolve metals. It is contained in the volatile hydrocarbons.

Hydrogen combines with oxygen, the supporter of life, to form water. Water, among its other qualities has the ability to dissolve substances. Hydrogen works in water in a similar way as in acids. Seeds and oils from plants, the products of warmth, are rich in hydrogen.

Its nature then is that of fire.

Nitrogen, uncombined, is an inert gas. Its role seems almost to be that of keeping the brakes on. Oxygen by itself would be all-consuming. Diluted with nitrogen it is life-giving to man and animal. Nitrogen is breathed in and out without chemical change. It is as if nitrogen carries the oxygen as water carries nutrients.

But nitrogen itself is an essential for plant growth. We have seen the cycle of nitrogen. Again it is a sort of carrier. It also has other possibilities. Normally in the air nitrogen and oxygen are mixed. They can, however, be compelled to unite when the result is the powerful nitric acid. Nitrogen is also an ingredient of most explosives.

One could look upon it as a sleepy giant; normally in gentle movement but active when roused.

In the light of the above let us also cast a glance at plant substance, carbohydrates; and animal substance, protein. There is little protein in a plant but much more in the animal.

A carbohydrate is a combination of carbon, oxygen, hydrogen, — form, life and warmth. Protein contains another element in addition, nitrogen. Hence protein contains form, life, warmth and a quality difficult to characterise. Perhaps we could say movement.

With regard to the metals one might refer to ideas of former times as well as the results of modern research.

We think of the metals as belonging to the earth yet somehow they are interlopers in the earth's crust. The salts such as calcium carbonate (limestone) are the real earthly substances. The metals have a different character. They could be looked upon as something between the above and below. They can be heated to melting point and with sufficient heat to a gaseous condition. In this respect they resemble ice, water, steam. We could almost say that the metals belong to the liquid element of the earth, recalling the teaching of the alchemists; sulphur, mercury, salt. They become "earth" as oxides or salts.

Metals have a certain order of nobility.

Gold stands by itself and is chemically almost untouchable. Silver, copper, mercury are attacked only by the strongest acids, neither do they burn easily. The other three, iron, tin, lead are affected by weaker acids and also burn easier.

The alchemists considered that there was a relationship between the metals and the planets. The work of L. Kolisko confirms this.

Mythology connects gods with planets. We need no stretch of imagination to connect gold with the sun and sun-worship. The reflected light of the sun comes to us from the moon. Silver, the planet ascribed to the moon, is the great reflector. Mercury was the name of the messenger of the gods, hovering between heaven and earth and has the same name as the planet. The metal mercury has this volatile quality. If we think of the beauty of copper, the colours which it produces, its flexibility and gentleness, its feminine quality, we do not have to consider long to relate it to the goddess Venus and the planet of that name. By contrast iron is hard and strong. Mars was the god of war. What better metal can be equated with Mars than iron. Lead has a remote quality like Saturn and the god of that name who was dethroned. The god Jupiter was enthroned in the clouds. Jupiter as a planet is calm and shining. The metal related to Jupiter is tin.

If we consider the planets as viewed from the earth, the order is Moon, Venus, Mercury, Sun, Mars, Jupiter, Saturn. Considering the resonance and conductivity of metals the order is the same: silver, copper, mercury (in the solid state), gold, iron, tin, lead.

Sun and moon influence the earth. Some people believe that stars and planets also affect the earth. The thought therefore may not be too far distant that the metals on earth are representatives of planetary forces. It accords with the idea of the unity of the cosmos.

In learning about the nature of substances and the forces they represent we may have learned something of the garment of the divinity.

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- A Modern Art of Education
- Study of Man
- Practical Course for Teachers
- Spiritual Ground of Education
- The Kingdom of Childhood
- Essentials of Education

The above are published by the Rudolf Steiner Press, 38, Museum Street, London, W. C. 1.

A list of suitable background reference books for class teaching is available from E. C. Byford, The Librarian, Michael Hall School, Forest Row, Sussex.

This booklet is one of a series prepared by the author on the teaching of various subjects and allied matters. Details on request.

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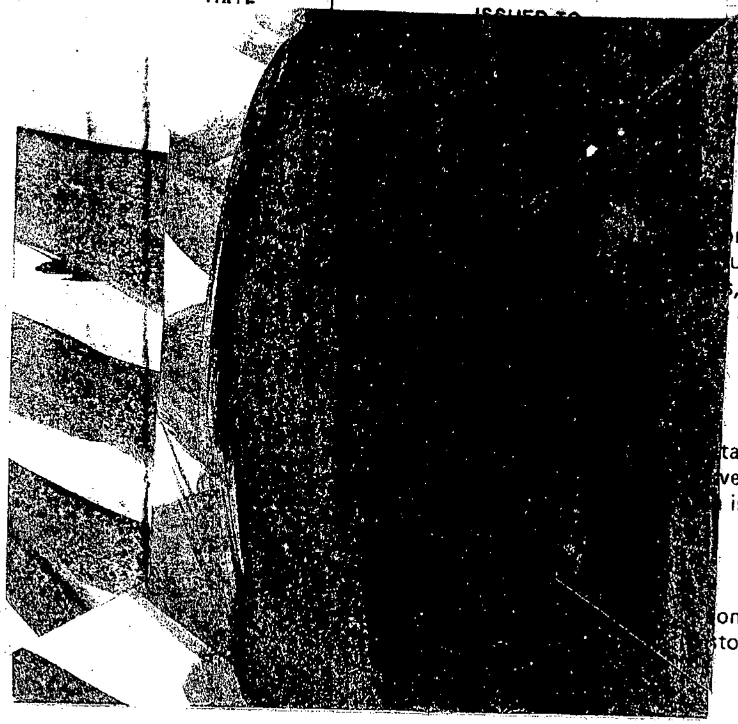

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