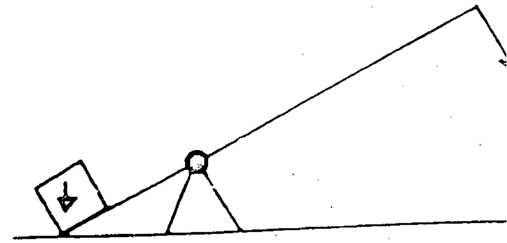
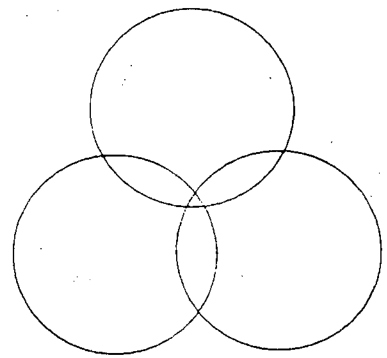
TEACHING PHYSICS

For age groups 12/13/14



CHEMISTRY

For age groups 12/13



ROY WILKINSON

RSCP

RUDOLF STEINER EDUCATION

PART I
TEACHING PHYSICS
FOR AGE GROUPS 12/13/14

Introduction
Sound
Light and Colour
Heat
Magnetism and Electricity
Mechanics including Hydraulics and Pneumatics
Meteorology and Climatology

Roy Wilkinson

RSCP

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.
The author wishes to acknowledge the assistance of specialist colleagues in offering suggestions and revising the text.

Note: Fractions such as one twelfth are sometimes represented in the text as 1/12.

TEACHING PHYSICS and CHEMISTRY
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INTRODUCTION

"The earth is the Lord's and the fulness thereof;
The world, and they that dwell therein."

Since physics is that branch of science which tells us about the physical world, it may be useful to be reminded that even the physical world is of divine origin as well as man and that they are inextricably bound up with one another.

The teacher of the physical sciences in the Rudolf Steiner school is faced with a formidable task. He cannot morally be present in the school and teach unless he has absorbed, understood, and is in agreement with Rudolf Steiner's basic conception of the world. This presupposes a spiritual origin of the physical world and a physical world permeated by spirit. Matter is looked upon as a result of spiritual creative activity. The book of nature is a script of the spirit. To deal with things from a purely materialistic point of view is to give a one-sided impression.

The history of mankind shows a development from spiritual perception to intellectual thinking combined with a consciousness of the material world only. Modern science considers the earth a mineral body and explanations are given from the material-physical aspect. Life is considered to have arisen by chance. But the earth and the human being have developed side by side. They have a common origin to which we may refer, if we use the old terminology, as God.

In the course of evolution man has acquired the faculty of being able to stand objectively towards the world. Hence he becomes capable of scientific investigation. He makes discoveries and invents things and penetrates further into matter with his intellect. He reads instruments and depends on these rather than on observations of the phenomena and his instincts. Thus, for example, dissection and analysis of a plant will furnish endless material information, but they say nothing about the being of the plant itself.

We may consider, by contrast, Goethe's method of research. This was to have confidence in the language of the senses and in contemplating something, to recognise in the phenomena themselves the relevant idea (the spiritual entity).

Material science and explanations cannot explain nature. Referring to plant growth, Ruskin expresses it thus:

> 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.

At one time it was firmly believed that God set the earth and planets in motion; present scientific belief is that they move in accordance with the laws of gravity and motion. The latter statement may be correct but it is only half the truth. The other half is contained in the former. The whole truth is not to be found in a one-sided physical interpretation of phenomena.

When Kepler found the laws of planetary movement, he realised that their harmony was an expression of divine creative powers and this afforded satisfaction to his soul.

The universe at the present time is being explored by scientific instruments which are sent out into space on voyages of discovery. But let it be remembered that these instruments can only record what they are programmed to record, just as our senses will only perceive that to which they are attuned. Possibly there are other factors in the universe which our instruments do not record and, equally possibly, there are other senses in the human being which can be awakened to give him an extended consciousness.

Divine power and human volition are factors which are sometimes overlooked. For example, in mechanics we observe cause and effect. One body causes another to move but who set the first in motion? It may be argued that this is a philosophical question unrelated to science, but science can only be understood with reference to the human being and the rest of knowledge.

A machine does not function by itself but only because human thought has been put into it. Similarly one might think of an agency which sets the world in motion. Our understanding of the world depends on our state of mind. At some stage it might even be possible to perceive the hidden side of matter.

Science gives us facts and few would dispute them but we must beware of dogma. The interpretation of facts is another matter. Darwin produced certain facts on human evolution and his followers produced the idea that monkeys are human ancestors. Is this really the case? It is arguable, yet the idea has been accepted as factual truth.

Science tells us that the soil needs certain nutrients for plant growth and that these can be supplied by chemicals. It may be true, but is it the whole truth? and what about side effects?

Let us consider the notion of gravity. The apple undoubtedly fell to the ground but how did it get up into the tree? What of forces striving away from the earth, in trees for instance, or in gases lighter than air, or buoyancy. Everything in nature has its counterpart so it might not be unreasonable to consider a force opposing gravity, i.e. levity. We learn a great deal about gravity but little about its opposite.

We learn that the tides are due to the gravitational effect of the moon. Ebb and flow, however, do not alternate once in the cycle but twice and there is an elevation of water on the other side of the globe opposite to that which rises below the moon. So perhaps the facts are not quite true as presented. Vegetation is also affected by the moon. A woman's menstrual period is a moon rhythm. These events tell us that some force is at work connected with the moon sphere but is it gravity? Is it gravity plus something else? Or is it something else entirely?

Furthermore, scientific explanations can be very constricting to the mind. If we were to consider the historical development of science we should note how theories change. We might, for instance, explain the idea of phlogiston to the pupils; we can tell them about the experts' view that flight in a heavier-than-air machine would be impossible; that medical science pronounced that travelling by train would shatter the nervous system.

Not so long ago it was heresy to consider the sun as the centre of the universe instead of the earth. In medicine, blood-letting was at one time the height of scientific practice. Formerly plagues and sicknesses were visitations of the divine will; now they are the result of microbes and viruses.

These matters might plant a healthy scepticism in the pupils' minds about present theories. One may be forgiven sometimes for thinking of the story of the Emperor's New Clothes. It is not that we should belittle the stupendous discoveries of modern science or refuse to learn what it has to tell us. It is merely that we should preserve an open mind and not allow scientific explanations to blunt the senses to other aspects of life.

There can be no understanding of the universe and man unless they are looked upon as a whole, interrelated and interacting. Although in teaching one has to isolate events to deal with them, they must eventually be brought together in the context of a whole. For instance, the constituent parts of water are hydrogen and oxygen. This in itself is an astounding revelation but to know this fact is to tell us little about water. It needs to be brought into connection with everything else we know about water, or, in the greater sense, the liquid element. The solid earth has originated from a fluidic state. The sea is not just salt and water but full of life (until we finally pollute it). The sea-creatures produce coral and limestone. The bones of the earth are formed through the liquid element. The waters course all over the globe in continual movement in tides and currents. In man, the chemical constitution of the blood closely resembles sea-water. The blood is the great carrier and dispenser of nutrients. In the embryo stage there are no bones. These too are formed from the liquid element

There is no growth without water. It circulates from heaven to earth and back again. For those who can accept it, there is a wonderful poem by Goethe which indicates the idea of reincarnation and compares the human soul to water:

> The soul of man resembleth water.
> From heaven it cometh, to heaven returneth,
> And then again to earth descendeth,
> Changing ever.

Water is not only in the seas but in lakes, rivers, brooks and the atmosphere. It has the power of dissolving substances and of forming endless combinations. It creates forms. It can be living and it can also be dead. It has a role in health and sickness.

All subjects should be dealt with similarly, that is, comprehensively, so that eventually the child has a wholeness of knowledge. He may be taught about light, heat and sound separately but these are not isolated phenomena and they should be related to man and the world in general.

For the human being to be interested in the world he must know his own relationship to it. Man stands at the centre. In the early classes, at the age of about 10 and 11, the child has learned something of his own nature through the study of animals, plants and minerals. Feelings of awe and reverence have been evoked which touch the deeper recesses of the soul. At the age of 12 (Class 6) the world of myth finally fades in favour of hard reality. But the hard reality also contains wonders and, as the child's sense perceptions are becoming more acute and directed to the physical world, so there can be new revelations to excite the mind. For the most part in our scientific age wonder has been abolished. Nature has been despiritualised, yet most children will still appreciate the rainbow. It is an experience of the child, or rather of the growing adolescent, to feel the enormous expanse of the world and his own very small place. It is still therefore possible to create an attitude of wonder, which is the opener of the gates of knowledge. It should be remembered that what are simple facts to the adult mind can be fascinating revelations to the still-open mind of the twelve-year old. He is beginning to stand opposite nature in a more objective way but he is aware of much mystery behind it.

There is also the wonder at man's capacities and achievements, the fact that there is so much knowledge in the world, so much that has been discovered, so much that has been created.

There is then a qualitative aspect to be considered. If science is to be taught educationally, it needs an approach which will engage the whole of the human being, not only his intellect, but also his feelings and will. Concepts which are merely intellectual may educate the head forces, but there must be participation of other regions of the human being, i.e. heart and limbs. There should be joy in the lessons, sorrow, wonder, reverence, activity. Let us always bear in mind that it is not the actual knowledge given that is significant, but the effect of that knowledge. There is a very pointed example of what a sole diet of scientific facts can do to a child's soul in Marie Corelli's book *The Mighty Atom*. The child concerned commits suicide.

Ruskin rightly states that the plant is something more than a transformation of substances. We would add that in teaching about plants, the colour, smell, taste, nourishing or medicinal quality and the aesthetic effect on man should be considered. A similar comprehensive survey should be taken of all subjects.

Let us again quote Ruskin:

> It is in raising us from the first state of inactive reverie to the second of useful thought, that scientific pursuits are to be chiefly praised. But in restraining us at this second stage, and checking the impulses towards higher contemplation, they are to be feared or blamed. They may in certain minds be consistent with such contemplation but only by an effort; in their nature they are always adverse to it, having a tendency to chill and subdue the feelings, and to resolve all things into atoms and numbers. For most men, an ignorant enjoyment is better than an informed one. It is better to conceive the sky as a blue dome than a dark cavity and the cloud as a golden throne than a sleety mist. I much question whether anyone who knows optics, however religious he may be, can feel in equal degree the pleasure and reverence an unlettered peasant may feel at the sight of a rainbow.

It is a fact of modern life that with all the knowledge available man cannot order his society reasonably. Enormous achievements have been made in the scientific field but social life continues to present a picture of increasing chaos. Science has given us tremendous knowledge and power but it has not given us understanding or morality. Scientific thinking has been divorced from feeling and the result is an impasse which can only be resolved by bringing the whole human being into play in the way we have advocated.

The time at school is the time to implant a feeling for the earth and its contents, a reverence and a respect which will arouse a feeling of responsibility and exclude mere utilitarian exploitation. This is extremely important in the science teaching.

For instance, whenever a road is made, it is a rape of the earth, however necessary it may be. Whenever marshes are drained, or cities built, wild life is disturbed and hence the whole ecology of nature is upset. Whenever there is death or destruction, particularly if these are the result of man's actions, they are matters which should be felt. An attitude should be inculcated that man has a moral responsibility for his deeds and inventions.

It is not being suggested that at this age one should enter into a discussion on these matters – it may well be that questions will arise which can be answered – but it is more a matter of speaking of the qualities of substances and elements, of discoveries and inventions in such a way that a moral-social element is conveyed indirectly. For example, when we speak of iron and describe the nature of the substance, we can also bring in expressions such as "man of iron", "iron will", "true as steel" and possibly refer to iron and its role in the blood. When we speak of explosives, we can also refer to the devastation they can cause.

This is one moral aspect. There is another. Much takes place around us of which we are not aware. We are manipulated in so many ways. We are in the grip of outside forces, not always conscious of what is affecting or motivating us. To counteract this we should be awake and seek to understand. As far as science is concerned, it therefore behoves us to learn the laws and principles of machinery etc. People drive cars, knowing that a certain manipulation will have a certain effect but not knowing how it is brought about. They are captives of the machine.

Similarly there is a social aspect. Many people in industry, in commerce, in agriculture, contribute to our welfare. It is right that we should learn how the rest of the world lives and works in order that we may appreciate our debt. Another matter touching social life is the effect of inventions and discoveries on the community and on the world in general, e.g. air travel, petroleum.

How is the teacher to deal with all these matters? Obviously he cannot launch out to his pupils with ideas of angelic or super-angelic beings and their influence in the physical world. He may have some idea of these things in his own mind but at the same time he has to present normally accepted scientific ideas. His own beliefs may colour his teaching but he too must avoid becoming dogmatic.

The teacher will, therefore, show the phenomena and where appropriate, give the accepted explanation but he may have to find some way of qualifying it by saying that it may not be the final truth. In some cases he may have to give two explanations.

To sum up, the essentials in teaching science are:

- The teacher should bear in mind that the material world is the end result of spiritual activity.
- Scientific facts should be presented as phenomena and not as dogma.
- The quality of "wholeness" should be preserved.
- The connection with the human being must be retained.
- Social and moral aspects should be considered.

These are the points which have been borne in mind, together with the practical indications, in compiling this booklet.

Structuring Science Lessons

As all teaching should be in accordance with child development, we can read from the child the proper age at which to give the different subjects. There comes a time when the youthful grace of childhood disappears and a certain awkwardness takes its place. Signs of puberty appear. These are stages of incarnation. The spirit is becoming more closely connected with the physical body and the child becomes not only more aware of his own corporeality but of the world of matter generally. At the same time the intellectual faculty is developing and so are moral ideas. The age of 1^ therefore is the right age to introduce physics as a subject.

It is always a good idea to give children a preview of what they will be learning and this applies particularly at the age of 12 when they are entering the fields of material science. The word physics has some element of magic and the magic does not have to be destroyed but it is just as well to give some idea of what the word means. It should be explained that studies of nature so far have been of plants, animals, minerals and man but in physics we come to the study of the nature of material objects and how different forces affect them. Simple illustrations, such as the way water boils when heated, or the fact that things fall when dropped, will provide an elementary introduction.

It is to be hoped that previous to this the children will have had an introduction

to the world of nature that was living. If they have learnt choruses such as those of the elemental beings in the play "The Golden Key" (see *Miscellany* booklet), they will have had an excellent preparation. They will have acquired an inner feeling for the spirit. They will also have learnt to love, and what is loved in childhood is understood later.

From a practical point of view there is so much to teach that selectivity is essential. Bearing in mind that it is not the quantity that is taught which is educationally beneficial but what can be effectively digested, we shall seek to give not a mass of facts but to show typical experiments. (At the same time since children of twelve are lovers of factual information they can be fed a fair quantity). The fact that experiments can be shown and performed by the children is of enormous help in teaching since there is immediate interest.

All teaching should be considered first from real life situations. The process is then to show the phenomena and make deductions later. In fact in all science teaching Dr. Steiner recommends the following order:

1. The experiment be demonstrated.
2. The apparatus is cleared away and the process repeated in thought or imagination,
3. The next day, after a night's sleep, it is discussed and deductions made.

It is obvious that there is great scope here for stimulating the thought and observation of the pupils. They should not be spoon-fed but encouraged to make their own discoveries and deductions. A great deal can be elicited from them. They should not be prejudiced by a description of what is to happen. The introduction of concepts, measurements, etc. belongs to the end of the process of instruction, not the beginning.

The first lessons in physics will deal with sound, light and heat. A week of main lesson period may be spent on each and a further week introducing the subjects of magnetism and electricity. The time available is extremely short; it is therefore all the more essential to deal only with fundamentals.

The schedule of science teaching for children aged 12/14 is somewhat as follows:

Class 6	Sound, light, heat, magnetism, electricity	3/4 weeks
Class 7	Above continued. Mechanics	"
	Chemistry	"
	Describe the work of factories and transport showing how physics, chemistry, geography, natural science are all involved and interweave.	
Class 8	Hydraulics, aero mechanics (pneumatics)	"
	Practical applications of what has been learnt in Classes 6, 7, 8. Meteorology, climatology.	
	Chemistry	"

Note. The time available for physics in Class 6 is very short. The intention is to give a survey of the whole field and to continue more detailed studies in the following classes. No period has been allotted above to the description of factory work, etc. These studies can be fitted in where possible and in related lessons.

Hydraulics and aero-mechanics are the subjects mentioned in the curriculum. The intention is to deal with the mechanics of liquids and gases. A certain amount of hydrostatics is included and "pneumatics" might be a more exact term than aero-mechanics. In the chapter headings we are using the terms hydraulics and pneumatics.

Mention is made here of chemistry only to complete the picture. Dr. Steiner recommends that chemistry and physics be taught together. The present booklet deals only with physics.

It may not be possible to cope with all the studies mentioned here in which case the work of Class 8 will overflow into Class 9.

SOUND

As wonder is the beginning of all knowledge, it is befitting to arouse this feeling for any school subject we like to take. In the parallel booklet on *Teaching English* the mystery of world creation from the element of sound was mentioned – the Divine Word. The poem there quoted might make a suitable introduction to the present study:

From harmony, from heavenly harmony,
This universal frame began:
From harmony to harmony
Through all the compass of the notes it ran,
The diapason closing full in Man.
(Song for St. Cecilia's Day by Dryden)

In Shakespeare's *Merchant of Venice* is the wonderful passage about the music of the spheres:

How sweet the moonlight sleeps upon this bank.
Here we will sit and let the sounds of music
Creep in our ears: soft stillness and the night
Become the touches of sweet harmony.
Sit, Jessica. Look how the floor of heaven
Is thick inlaid with patines of bright gold;
There's not the smallest orb which thou behold'st
But in his motion like an angel sings,
Still quiring to the young-eyed cherubins;
Such harmony is in immortal souls;
But whilst this muddy vesture of decay
Doth grossly close it in, we cannot hear it.

Descending from heaven to earth we can have a general discussion on sound. We can point out to the children how difficult it is to get away from some sort of sound entirely. We may have absolute silence in the classroom but a fly will be buzzing in the window pane. We many think we can experience quiet in the heart of the countryside but a bird will whistle, a bee will hum or the wind will rustle the leaves of the trees. We can call attention to all the contrivances which produce or broadcast sound.

It is however a faculty of the human being that he can "switch off". In the matter of seeing he can close his eyes or avert his head. He cannot physically shut his ears but he can listen or not listen. It is a matter of consciousness. (The teacher is in a privileged position to explain this.) It can be pcinted out how a person might get absorbed in a book or in work and become entirely oblivious of the world outside.

It is also a phenomenon that the air can be full of different sounds yet the human being can pick out the one he wants to hear.

It is also a matter of consciousness, together with experience, to recognise sounds and to understand them. The ability to recognise sound is very useful in practical matters. The blacksmith recognises the right temperature and consistency of his material by the sound emitted when he strikes it with his hammer. The wheels of a train can be "sounded" by a slight tap with a hammer to test their condition. A flick of the finger nail on a porcelain vessel will produce a flat note if it is cracked. A counterfeit coin will not ring true if bounced on a hard surface.

We can point out the fact that sound has an effect on the human being. Continuous unpleasant sounds are nerve-racking. Pleasant music creates a jolly mood. The song of the birds is uplifting but the growl of a dog instils fear. Too much sound or noise has an adverse effect. Physically a man's hearing can be ruined. Mentally, as would appear to be the case in some discotheques, the noise can deaden the senses. What one person may enjoy , another may dislike. We do not always appreciate the noise made by other people's radios or motorbikes.

Since children in the Rudolf Steiner schools are well acquainted with music, a more conscious experience may prove a good starting point in the study of acoustics. Teachers are reminded that demonstrations and experiments should precede explanations and the discovery of laws, and, as far as possible, children at this stage should try to find them for themselves.

It can be demonstrated that notes played on different instruments have different qualities. The scale can be played and the difference experienced between major and minor, consonances, dissonances, chords can be played. For the moment these things are merely experienced without much comment from the teacher although the children may have plenty to say.

It can be pointed out that these are sounds deliberately produced on instruments specially made but that there are many other sounds in nature and the class can be invited to name them – the whistling of the wind, the babbling of the brook, the roaring of waves, pattering of the rain, thunder.

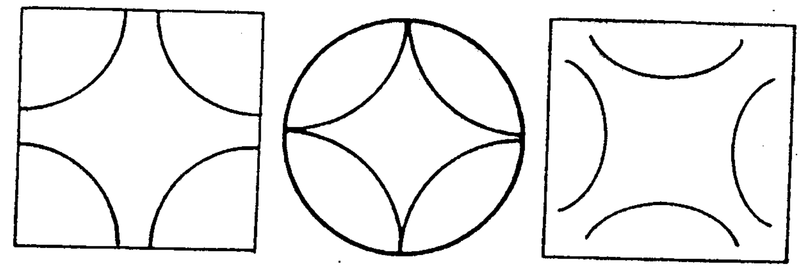
We can differentiate various categories of sounds. The mineral and plant worlds are silent but sounds are produced by their contact with one another. In the world of animate objects we hear the buzzing of insects but note that the sounds produced are still mechanical, i.e. the fluttering of wings. There are also the man-made noises, as of sawing, hammering. But the higher animals are capable of making sounds which originate within. They can express pain, pleasure, fear, desire. Think of a bird singing for joy or the same bird scolding if a cat is in the neighbourhood.

Then there is the world of sound as used by the human being: speech and song. While the animal expresses its emotion, the human being can consciously form his thoughts and utter them in speech. He can consciously put notes together to create music.

A game might be played by producing various sounds out of sight of the pupils and letting them guess what creates them. A coin, a piece of rubber, a pencil, a marble can be dropped on the table and each sound will have a different quality.

Having given this general qualitative introduction to sound we can proceed to the scientific details and show how sound produces vibrations which have a certain pattern. We can show in small compass what was expressed in Dryden's poem, i.e. the forming power of sound. This is done by means of the so-called Chladni plate. (Chladni was a German physicist who lived from 1758 to 1827.)

A round or square plate of brass or glass is fixed at its centre in an horizontal position, with salt or fine sand sprinkled on top. A violin bow is drawn across the edge until a steady note is produced. Through the vibrations of the plate the sand collects into certain positions, giving a definite pattern. By applying the bow at different points or damping with the finger, different patterns will be produced.



We see then a connection between note, vibration and form.

A further experiment is to make a so-called Monochord. This consists of a piece of gut or wire, a violin string or similar, stretched tightly over a hollow sounding-box. When the string is plucked the vibrations can be seen and the note heard. If the string is tightened, it vibrates faster when plucked and a higher note is heard; that is to say, the pitch changes. By means of 'stopping' with a little wooden bridge, it can be shown how the note varies with the length of the string.

A string of a different thickness, under the same conditions, will yield a different note. A thinner string gives a higher note and vice-versa.

If strings of different materials are taken of the same size, length, and with the same tension, they will yield different notes. In the case of metals it will be found that the lighter the metal, the higher the note.

In a wind instrument it is the air that vibrates and the same principle regarding size holds good – the smaller the pipe, the higher the note.

Other experiments can be made as follows:

- Play a recorder with all holes closed, then open.
- Demonstrate the Xylophone.
- Put different depths of water into test tubes and blow over them.
- Collect a series of different sized bottles and tap them with a stick.

It will be observed that objects of greater bulk produce the lower notes and vice-versa. It is a matter of the speed of vibrations.

Reverting to the Monochord we can now work out the numerical relationship between the note produced and the length of the string. If, for instance, the string is halved, the octave results; halved again, the next octave. Assuming a string to be 60 cm long this is the eventual result:

Note	Length of String (cms.)	Proportion
C	60	1
D	53.1/3	8/9
E	48	4/5
F	45	3/4
G	40	2/3
A	36	3/5
B	32	8/15
C	30	½

We have thus arrived at the mechanics of the scale, the notes of which we have heard already. The striking of a single note gives us some sensation but whether it is one or the other, if struck singly, it does not convey very much. It is another matter however, when the notes become related to one another; that is to say, the music really manifests in the intervals.

It can be pointed out that in Greek times a pentatonic scale was used, equivalent to our C D F G A C: that Indian or Chinese music is vastly different from ours. Why should this be? The only logical answer is that the experience of music is not the same in all peoples or all ages. As there is progression in ideas, arts, beliefs, so in music. The scale as we know it, with six whole tones and two half-tones, sounds right to us. Together with the study of music and eurythmy the nature of the scale might be explored. (It would be very good if the physics teaching could be co-ordinated with that of music at this point and the children should learn staff notation and something of the development of music, e.g. why the piano has seven octaves, and twelve fifths and why the keyboard is arranged the way it is.)

By striking the prime note each time and then the others in turn, one might characterise the scale as a sort of journey. The prime announces one's presence; prime, second, is a sort of question, a going hesitatingly forth, third, is a decisive stepping out; fourth, a halt; fifth, onward; sixth, boldly forward; seventh, there is some confusion but by the eighth (the octave) the goal is reached. It might also be possible to convey something of the quality of the different scales.

Since we now understand how sound is produced by the vibration of objects, we can look at a few musical instruments and see how they are made accordingly.

The children can make the lists for themselves:

Strings	Wood Wind and Brass	Percussion
Piano	Piccolo	Drum
Violin	Flute	Triangle
'Cello	Oboe	Timpani
Viola	Recorder	Cymbals
Guitar	Clarinet	Xylophone
Banjo	Organ	
Double Bass	Trumpet	
Zither	Trombone	
Lute	Horn	
Lyre	Cornet	
	Tuba	
	Euphonium	
	Bagpipes	

RESONANCE

If a tuning fork is struck and held in the air, a note is heard faintly. If the tuning fork is struck and the end of the handle placed on a board, the note is heard much louder. Why? Because the board vibrates in sympathy with the fork. When the body of a violin or any other instrument is constructed, this principle is taken into account. Not only the thin wood but the air inside vibrates and thus more sound is produced.

It is not so easy to make oneself heard in the open air as in a room or hall. Why is that? The fact that we hear better in a hall than outside is mainly due to the walls which reflect and concentrate the sound. On the other hand it is sometimes difficult to speak in a hall because the sound re-echoes round the walls. It is therefore important to get the right balance in a lecture hall or a theatre. The shape of the hall, the furniture, curtains, presence of people, all have an effect.

Temperature also plays a part in the production of sound. If tapped, a cold object yields a higher note than that same object warm. The case is different with air. A column of warm air vibrates quicker than the same column of cold air and therefore the note is higher. Bandsmen often have difficulty in getting the right note until the instrument is warm. That is why we see them puffing and blowing into their instruments before the concert begins.

HOW SOUND TRAVELS

We talk about sound travelling. It does not move like a ball or a car yet it certainly traverses space. A noise created in any one spot is heard by any human being in the globular radius provided there are no hindrances. The vibrations are projected into the air, extend in all directions and are picked up by the ear. If someone standing close to us speaks, we hear him. If he is standing further away, the sound is fainter as the vibrations disperse, and fainter still if there is a wall in between. In special circumstances the vibrations strike a wall or a rock and return. Then we have an echo. It is possible for a singer to shatter a wine glass some distance away by means of the vibrations produced by the voice.

Sound is obviously related to the element of air. The sounds of speech are a formation of the air stream. That sound is carried by the air we can see in the simple fact of shouting with the wind or against it, or trying to speak to someone on the opposite side of a bonfire. Sound created in a vacuum cannot be heard since there is no medium to carry the vibrations. This can be demonstrated experimentally by putting a clock in a bell jar and reducing the pressure.

If we are watching a cricket match, we can sometimes see the batsman hit the ball but we hear the clap a fraction of a second later. In a storm we see a flash of lightning and hear the thunder a little while afterwards. This shows that sound takes time to travel.

Sometimes we look into the sky and see an aeroplane but the noise it is making comes from somewhere behind it. Occasionally we may hear a bang caused by a plane which has broken the sound barrier. This will be explained later.

A bullet travels faster than sound and it is therefore comforting to know that we should not hear the sound of the bullet which hits us.

Some two hundred and fifty years ago there lived an English clergyman named William Derham. He wanted to measure the speed of sound. He had a telescope through which he could see a church tower exactly two miles away. He arranged for a friend to fire a gun from the tower while he observed the flash through his telescope and timed the interval before he heard the report. He found that it took 9½ seconds for the sound to reach him. That is to say that the sound had travelled 10,560 feet in 9½ seconds or about 1,112 feet per second. Nowadays we reckon it at 1,100 feet or 333 metres per second, 750 miles or 1,200 kilometres per hour. This reckoning can tell us what distance is needed to hear an echo. The minimum must be between 16 and 17 metres. If we shout one syllable, the vibrations travel 16 or 17 metres to the rock and 16 or 17 metres back, i.e. approximately 33 metres. At the speed of 333 metres per second, it has taken one tenth of a second, just about time to pronounce one syllable. Proportionately further away we could utter two or more syllables before the sound comes back. If we are nearer than 16 metres, our speaking and the echo are so near to one another that they blend.

We have been considering the speed of sound through the air. The speed depends a little on whether the air is hot or cold. Through warm air it travels quicker but it can also be carried by other materials and the speed depends on the material.

Perhaps the children will have seen a film where the cowboys (or the Indians) put their ears to the ground or to the railway line. They might hear better that way the approach of galloping horses or a train. If a tuning fork is struck and held between the teeth the note is to be heard more distinctly by the person concerned. If the central heating pipes are tapped, the noise is heard all over the house. A

string telephone demonstrates the same principle, namely, that sound travels better through solids than through air. It has been reckoned that it travels about fourteen times faster, though this is a little variable; for instance, where metals are concerned, it travels through iron four times faster than through lead. Sound also travels about four times quicker through water than through air.

If we are very high up in the mountains, we should find that not only are we a little short of breath but that the sound does not carry so well in the rarified atmosphere.

THE HUMAN VOICE AND THE HUMAN EAR

When we speak or sing, the human body is the instrument. In our throat is what is known as the larynx, sometimes called Adam's Apple and it can be seen very prominently in some men. The larynx contains the vocal chords and when we wish to speak or sing, we breathe out through them causing them to expand or contract and vibrate . Knowing what we want to say or sing, we activate our vocal chords and then form the sound with teeth, tongue and lips. Only the human being can do this and in this way the bodily organs become the servants of the spirit.

The ear is the receiver of sound. It is so attuned that it only receives sounds, i.e. vibrations, within a certain range. (A dog can hear a high-pitched whistle which is inaudible to man.) The outer part of the ear is shaped to catch the sound and lead it inwards. The vibrations beat upon the ear drum and are passed on to little bones further inside which transmit the effect to the brain. The sounds however which the ear receives would have no meaning if man did not possess a soul and spirit to translate them. These are matters for further study in connection with the human being.

(For further studies on sound see notes for Class 8 at the end of this book).

LIGHT AND COLOUR

It was mentioned already in the introduction that the teacher in the Rudolf Steiner School faces a particular problem with regard to science. This is very obvious in the teaching on light particularly in its connection with colour. While in the normally accepted Newtonian theory, colour derives from white light and spreads in waves, the teaching advocated here is based on Goethe's theory of colour which is founded on the eye's experience of colour, and brings in a qualitative factor.

It has already been explained too, how at this age particularly, the emotions should be engaged and it is therefore the qualitative aspect of light, as with sound and heat, which should be dealt with first.

Light reveals all things. It shows us the beauty of the world. We see separate objects; some things are more visible than others whereas in the dark everything becomes a shade of grey. In the rhythm of day and night we experience light and dark. Colours change in the light. All growth needs light. If we refer to the Bible, we read that the first Day was the result of the creation of light.

We also use the word light in an applied sense: "He saw the light" meaning that the person concerned understood. Dark is used for the opposite, meaning ignorant. We speak of the light of knowledge, the darkness of despair. Jesus Christ was called the "Light of the World".

The sun is the greatest source of light in our universe. Its light illuminates the whole earth although not all parts at the same time. The moon and planets reflect the light of the sun. The stars are other sources of light. Sometimes conditions in the atmosphere create light such as the northern lights or lightning. The lights on earth are man-made but they are usually made by burning substances which, in the final instance, have been created through the power of the sun, e.g. wood, coal, wax, paraffin, gas, electricity. Although electricity seems more remote, if we think of it being generated by coal or water power, we have a connection with the sun. In coal it is obvious, but the water which flows down our rivers can only do so because it is engaged in the eternal cycle of evaporation and condensation dependent on the sun's warmth.

Some people are frightened of the dark. To take a walk on a dark night is a vastly different experience from taking the same walk during daylight. Different senses are active. Where one cannot see, hearing becomes more acute.

It is of great benefit and interest to children to stimulate their own powers of observation and thinking. An experiment can be made of taking the children into a room from which all light can be excluded. They must be absolutely quiet. It can be quite unnerving simply to sit for a few minutes in these conditions. One by one they are then asked to walk a short distance. They are asked to go to a certain spot on the opposite wall or to put an object in a small ring in the centre of the room previously shown to them.

As a further experiment in the dark room, a torch is switched on and a patch

of light will be seen on the wall and (hoping the atmosphere is clean) nothing else. If a duster is shaken the particles will be seen floating in the air but once they have settled, nothing.

We can set up various objects in the room and, casting a light on them, or moving the light around them, observe the various shadows.

Bearing in mind the golden rule in teaching science at this age – do the experiment, let the children relive it in the imagination, then wait until the next day to discuss it and form conclusions – the matter will be considered the next day.

It will be obvious that in the darkness we need different senses. The question "Can we see light?" will provoke a lively response and it is to be hoped that the correct answer will be forthcoming. The fact is that light itself is invisible but it makes objects visible. In the same way as we do not see the force which makes the tree grow but we do see the result, so we do not see the light but its effects.

Belonging to light is shadow. When light falls on an object we see its shadow, the shape and size of which varies according to the position of the light. In the middle ages it was thought that ghosts and hobgoblins could be recognised by the absence of their shadows. In Indian mythology a princess recognised gods disguised as men by the absence of their shadows. The Greeks thought of the world of the dead as a world of shadows. When shadow is created by a cosmic event like an eclipse, it creates an eerie sort of mood.

Light and dark are polarities and we live between them as between day and night, sleeping and waking, breathing out and breathing in. (Some teachers might be inspired to continue from here into the aspects of good and evil. They could recall the story of Zarathustra who taught that life was a continual struggle between the forces of light and of darkness.) A balance is necessary for human well-being. In darkness we can become confused, but equally so if there is too much light. In polar regions there is the so-called white light when a strange radiance spreads over the whole landscape and there are no shadows, robbing a man of his normal senses. He can suffer from optical illusions such as seeing a ship floating upside down or people walking in the air, probably caused by refraction.

HOW LIGHT TRAVELS

Although we speak of light "travelling", the idea is, like sound, a little different from that of an object. Light radiates in all directions unless it is hindered or directed by some object. Some things, like glass, let the light through, and are known as "transparent". Substances like wood and stone which hinder the light are "opaque". Those materials like frosted glass, which let a certain amount of light through but are not clear, are known as "translucent".

Light spreads its radiance. If we observe the light from the sun shining through clouds, we see radiant beams. We see the beam and the edge of the beam as the result of light and shade. The edge of the beam appears to form a line but it has no more reality than the line cast by a shadow, i.e. radiating from the light but the idea of rays is a purely geometrical concept.

Light radiates and where it falls on an object we are observing, there is a line of vision between our eye and the object. Is this a direct line? The answer is yes, but under some circumstances it can be no.

Usually we think of straightness as a quality associated with light. An interesting experiment can be made with a pin-hole camera. This is very simple to make and the children will be able to do it quite easily.

> A dark box has one side removed and in its place is a piece of tracing paper. A small hole is punched in the centre of the side opposite to the paper, and this side with the hole is placed against the window pane. The whole of the window and the rest of the room is entirely blacked out so that the only light comes through the hole in the box. A picture of the outside landscape appears on the screen, upside down. Another way of doing the experiment is to set the box so that a candle or other light can shine through the hole casting a disc of light on the screen. The image will appear upside down. If a pencil is passed between the hole and the light the shadow will move in the opposite direction.

What does this tell us? It shows that the reflected light from the illuminated objects takes a direct path.

By experiment it has been worked out that light travels at 186,000 miles per second through the air, 139,000 miles per second through water, and 124,000 through glass.

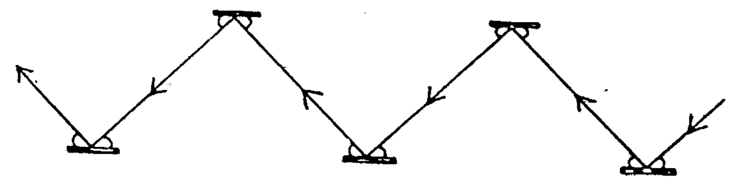
Light, unlike sound, will travel through a vacuum. If we reckon that light travels through space at the same speed as through the air, then the light of the sun takes about eight minutes to reach us. Astronomers reckon the distance of stars in "light years", i.e. the distance light travels in a year. By this reckoning our nearest star is 4 light years away.

REFLECTION

(In dealing with reflection, refraction, mirrors and lenses it is for the most part a demonstration of the phenomena in this class. The relevant mathematical concepts and explanations are dealt with in Class 10.)

If we bounce a ball exactly perpendicularly, it will return by the same path. If it is bounced at an angle, its upward path will not be the same as down but at the same angle to the ground as its downward path. It will also bounce further on a hard surface than on a soft. There is something similar with regard to light. We see that the "rays" proceed in a straight line. When they meet objects they bounce off but we call that "reflection". Something shiny and polished such as a mirror is the best reflector. If we take two mirrors, or better still a series of mirrors, we can reflect the

light from one to the other and we shall discover that the light leaves the mirror at the same angle at which it strikes it.



Why do some things appear brighter than others? If we take a number of objects and observe, we shall find that colour and surface make the difference. The brightness is due to the relative surface and colour of the objects.

REFRACTION

If we fill a bottle with water and look at some object through it, we see the object magnified. When the atmosphere is wet, the distant landscape looks closer than when it is dry. If we put a stick in water, it no longer appears straight. We can try an experiment as follows. Let us put a penny in a bowl out of our line of sight. Now put water in the bowl and keeping the same viewpoint, we see the penny. In the last two cases we speak of the phenomenon of refraction.

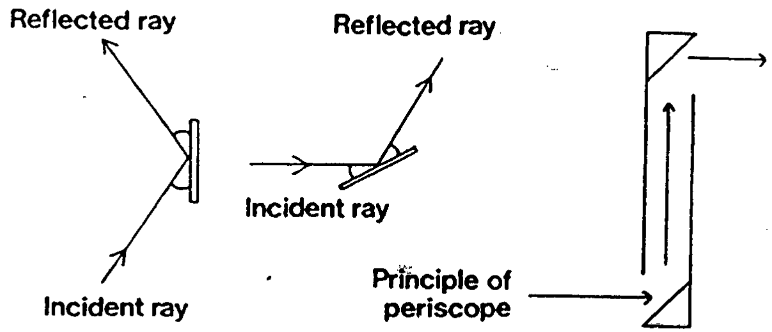
What happens is that vision through a denser medium appears to bring the objects closer. The stick appears bent and the penny becomes visible because the water has acted as a sort of magnifying glass. In the case of the penny it is as if the floor of the bowl is raised.

A similar case occurs when the sun is setting. We see the sun when it is actually below the horizon.

It is instructive to hold a magnifying glass at arm's length and look through it. Objects observed through the glass are in a different position from where they are in reality.

MIRRORS

If we take a plane mirror, catch the sun in it and move the mirror about, we can get a patch of sunlight to dance all over the wall. We can do the same with any light but if the light shines directly into the mirror it is reflected straight back and there is no dancing light patch. The principle is the same when we look into the mirror directly and we see ourselves in normal size. Our image appears as far behind the mirror as we are in front. If the mirror is held a little way away and tilted we can see round the corner or behind ourselves. The principle is that of the angle of the reflected ray equalling that of the incident ray. With an arrangement of two mirrors in a tube we can see over a wall. This is the principle of the periscope.



In curved mirrors the principle of reflection applies just the same. The light is reflected at definite angles depending on the curvature and the angle of incidence. If we look into a concave mirror from a short distance, we see a magnified image, but from some distance away, i.e. the other side of the focal point, the image is upside down.

A shaving mirror which gives an enlarged picture is concave. So are the small mirrors used by dentists. A practical use for a concave mirror is in a car headlamp. The actual light is fixed at the focal point and therefore a beam is projected straight forwards.

A convex mirror presents a smaller image.

LENSES

A lens is made of transparent material, usually glass, and it is curved in some way. Those that are thicker in the centre, whatever their shape, are known as convex; the others, thinner in the centre than on the outside, are concave.

Because of its curvature, a convex lens has the effect of concentrating the light as it passes through and creating a point of light, the so-called focus. The lens also concentrates the warmth and this is how we can light a piece of paper from the sun's rays.

This concentration of light produces the effect known as magnification. When we look at an object through a convex lens, we see it magnified if the object being

viewed lies between the lens and its focal point. If it is beyond the focal point, we see it upside down and diminished. A concave lens has the effect of making things appear smaller.

A simple experiment can be made to show the effect of convexity by standing a pencil in a half-filled jam jar of water and another pencil of the same size in a flat bottle.

A more detailed study of optics is made in the Upper School.

COLOUR

And God said: I do set my bow in the cloud and it shall be for a token of a covenant between me and the earth.

The rainbow is surely one of the most beautiful sights vouchsafed to man. There is no substance but only pure shimmering colour with a quality of unearthliness. Without colour our lives would indeed be drab. Although perhaps not conscious of it, we should miss colour were it absent. Anyone who has been at sea for a few weeks will appreciate the refreshment that colour affords when he lands again. Throughout the day and the year, the country-dweller, if not his town counterpart, has the opportunity to observe the splendid display of colour. The early riser will appreciate the many hues in the sky at sunrise and the spectator in the evening will see the magnificent colours of the sunset. The bird-watcher will note the variety of coloured plumage. The traveller will notice the different blues in the sky. Here in our northern clime the sky is a greyish light blue; towards the Mediterranean it becomes deeper and in the tropics a deeper blue still. Some people like colourful clothes and suitable colours are an essential in our homes. Those who enter one of our beautiful cathedrals when the sun is shining will appreciate the wonderful colour patterns of the stained glass windows.

Goethe saw the colours as a picture of the eternal struggle between light and darkness. His ideas were founded on the eye's experience of colour, i.e. qualitative. (To realise how the eye and colour are related the eyes can be exposed to intense light and then covered. There will then be a play of colour within the eyes). Goethe read the phenomena of nature to find where colours arise. He had realised by looking through a prism in a white room that colour only arises where light and dark meet. This is in contrast to Newton's belief which was that colours in their totality are contained in light. Colour as a quality is no essential factor in the scientific explanation of the spectrum.

The children in the Steiner schools have been given an experience of colour from the very first classes. It is now a matter of lifting these things into consciousness and approaching them from a more rational point of view. Simple experiments and observations can be made.

White is a picture of the light; black, of the dark. Light flows out; black concentrates. This can be seen by the simple example of an optical illusion. A white disc is shown on a black background, then a black disc of the same size on a white background. Invariably the white disc appears to be the greater.

We can show how a bright light becomes darker by lighting a candle and holding pieces of tracing paper in front of it. The more sheets of paper we can use the more the light turns from yellow to red. We can see a similar process in nature. At sunrise and sunset the colours radiating from the sun are stronger. This is because the light is traversing a thicker layer of atmosphere. If we look up to the sky at night we see it as black. During the daytime we see it through light and it becomes blue. This accords with Goethe's statement that blue is illuminated darkness, yellow is darkened light. Indigo and violet on the one side are heightened modifications and orange and red on the other. Where blue and yellow meet, green is produced. We see the same phenomena looking through water. If we look at the sea from above, we see blue (dark through light). Divers looking upward from the sea-bed see reds and browns, (light through dark).

A great deal of interest will be generated by the distribution of prisms. The colours shown by the prism have been known for hundreds of years. In the East it was highly valued in ancient times and the Chinese Emperor reserved its use for himself. The shape of the prism refracts the light in a special way and when we look at objects through it, we see colours which, according to circumstances, are red, orange, yellow, green, blue, indigo, violet – the rainbow colours.

A further experiment is to look through the prism at a black strip on a white surface. The light colours or the dark will appear at the top or bottom respectively according to the way in which the prism is held. If a pin is placed to mark the extremity of the colours and then the arrangement viewed with the or ordinary eye, it will be seen that the colours were projected on to a white space and a black space. This shows the refraction. The black is, so to speak, projected over the white, giving reds and yellows, and in the other instance white over black, giving the blues. The colours always appear near the edges of black and white.

If two heavy black lines are drawn fairly close to one another, the black and yellow will mix, giving green.

If the experiment is done with a white strip on a black background the order of colours will obviously be inverted. if two white lines are drawn on a black background, the colour between will not be green but a wonderful magenta.

COMPLEMENTARY COLOURS

It would seem that Goethe's statement that "the eye demands completeness and closes the colour circle in itself" offers the best explanation of the complementary colours. It is a fact of our nature that it seeks compensation and totality. After being awake for a time, we seek sleep; after activity, relaxation; after bright lights, shade.

A few experiments will demonstrate the above. If we gaze for a while at a bright sky with the light diffused somewhat by cloud, and then cover our eyes, we perceive a sort of greeny-black.

It can be established that by looking steadily at a red disc for a few seconds and then transferring the gaze to a white surface, the image of the disc appears as green. Similarly, blue gives orange, yellow, violet; or vice-versa. Any colour will yield the opposite. These are then the so called complementary colours. (Complementary = serving to complete).

The same phenomenon can be observed in black and white. If, for instance, the window frame is observed for a few moments in bright sunlight and then the eyes are directed towards the ceiling, the image will appear in the opposite colours.

It is obvious that the eye is not a mere passive receiver but actively produces its own colours after being stimulated by the light. It seems that not only beauty is in the eye of the beholder but also colour.

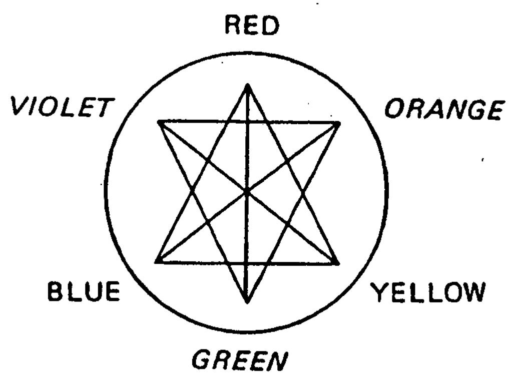
The same phenomena appear in colour shadows. Where the colour of the light is red, the shadow appears green; where blue, orange; yellow, violet. In painting, red, yellow and blue are known as the primary colours. Where two primaries are mixed, as in water colour painting, we obtain the secondary colours, orange, green, violet.

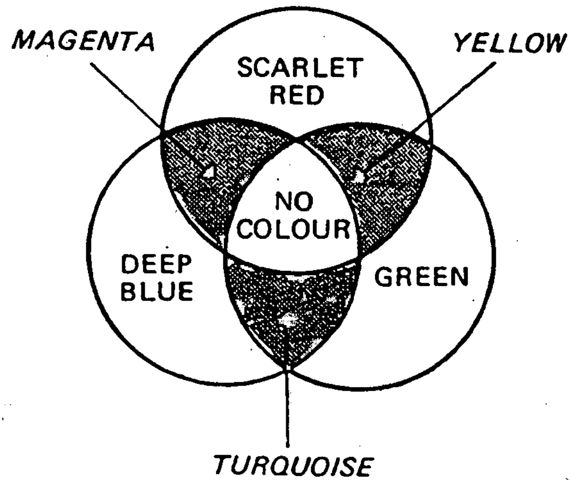
The case is different when colours are projected, as for instance, in stage lighting. Two circles of colour, e.g. yellow and blue added together in one projector, will produce green. If, however, two projectors are used and the colours overlap on a screen, pink is produced. If three discs of colour are projected, the results are as shown in the diagram.

In the mixing of colours on paper the tendency is to darken the light; in projecting colours, darkness is lightened.

It is interesting to look at objects or the landscape through a coloured glass. Those things related to the colour will stand out; the complementary colours will be dark. Thus if we look at red through a red glass, everything that is red will be enhanced. Green will merely look dark and almost colourless.

Colour speaks, but what does it say? Undoubtedly it enriches and enhances life. It opens up another world to the soul. And the individual colours? What do they say? What is their nature? The children have already been expressing these things in their paintings but now perhaps they will become more aware. Red is strong and powerful. Blue draws one into the distance. Yellow provides the merry, happy element. Looking at a green landscape the eye is rested and the green creates a peaceful effect. Orange is jolly, while violet lends an air of dignity. It could be pointed out that colour, like music, has a therapeutic effect. It speaks to our feelings.





HEAT

Heat is something that we so readily take for granted that perhaps the first object in teaching about it should be to awaken a sense of mystery. We might recall the story of Prometheus who stole the fire from the gods. We could think of fire-worship and the old beliefs of gods being active in the fire. There is also the story of Moses and the burning bush.

We are all familiar with hot objects, but what is heat itself? The old idea of considering it a form of substance, Caloric, is no longer accepted: the new idea that it is a form of energy is not particularly satisfactory either. There is something in both ideas but the fact remains that we have great difficulty in defining it. At this stage it is probably just as well that we do not try. We leave the children with an open mind. We can discuss and show the phenomena and remember too, that there is another aspect of heat, namely, cold.

Most of our heat comes from the sun or from substances in which the sun's heat has been stored, albeit transmuted. In this connection we can think of wood, coal, petroleum, even electricity because the production of this commodity depends on substances like coal and water-power which are within the cycle of nature. Nuclear fission falls into a different category. There is also heat within the earth but this may also be connected with the sun if our minds can grasp the whole process of earth evolution. Factually the temperature rises by nearly 1°C every 30 metres in depth.

Another form of heat is produced by compression. Anyone who has tried to blow up a bicycle tyre with a handpump will have experienced this.

We can generate heat in various says. In burning a substance we are releasing the heat which has been, so-to-speak, absorbed from the sun and stored. It may be interesting to know the relative heat emitted by burning substances. Taken weight for weight the order is: soft wood, hard wood (dry), brown coal, coke, charcoal, anthracite, paraffin, petrol, methane. Gas is high on the list but varies according to its composition.

Rubbing materials together, friction makes them hot. Certain substances react together chemically and become warm. Nuclear fission generates terrific heat.

This sort of heat we feel physically through our skin, over the whole body but there is another sort of heat. We speak of a cold or a hot-blooded person, or, a warm-hearted one. We use expressions such as "giving the cold shoulder". We speak of heat in anger and of cold indifference. We talk about a lukewarm reception and the fire of enthusiasm, We speak also of the fire of purification. Joy produces warmth of heart; fear, cold.

Warmth makes a difference not only to the environment but also to the human being. It is an essential ingredient of life processes. When the weather is hot and the sun shines, and there is sufficient moisture, we observe the rapid growth in plants. Warmth is especially necessary for the formation of fruit and seed. On a world scale we note the luxuriant growth in the tropics and the stunted or non-existent vegetation near the poles.

In warm weather most people feel relaxed and expansive. Intensive cold paralyses the will. In warm climates people on the whole are much more volatile than the taciturn types of colder regions.

The human body has its own heating system but within it there are slight variations. The head is the coolest part. The limbs are warm but the hottest parts are the inside organs which transform nourishment into blood. The temperature of human blood is normally 37°C. whether it is cold or warm outside. Any variation is a sign of illness. The sense of warmth can be local in our bodies, i.e. if we take a hot drink, the mouth feels the heat first; if we touch something hot with a hand, the sensation is felt there; but of course the sense of warmth pervades the whole being and to feel comfortable we need a certain warmth. Where the climate does not provide a sufficiency, we have to wear clothes and keep our houses warm. It is interesting to note that only man and the higher animals supply their own bodily heat; the lower ones fit in with their environment.

After some general discussion on the lines indicated above, and after eliciting as many facts and as much information as possible by questioning, the teacher can proceed with experiments, remembering the procedure. (See note on page 7).

We can find from experiments, or we know from observation, that hot water flows quicker than cold, that oil does likewise, that the surface of cold water is firmer than that of hot, that dirt comes off the hands easier by using hot water rather than cold. Butter melts in the sun; honey becomes thinner; a candle melts when it is lit; sugar dissolves quicker in hot water than in cold; lead, a solid metal, easily becomes liquid on heating; ice turns to water.

> An interesting experiment can be made with regard to the human sense of warmth by taking three bowls of water, one hot, one warm and one cold. Put a hand in the cold water, then in the warm. Now put the same hand in the hot water, then the warm and note the sensation.

Further experiments will show the behaviour of certain materials under the influence of heat. It can be demonstrated how a metal bar expands; how a metal ball will slip through a ring cold, but not hot; how a screw top on a jar can be more easily moved if heated. In this connection it will be interesting to learn that the Forth bridge, over one and a half miles long has a movement of some eight feet or two and a half metres in expansion and contraction; Concorde is thirty cm longer in flight than on the ground; the Eiffel tower is 15 cm higher in hot weather than in cold.

If a metal is continually subject to rhythmic stressing and relaxing with alternating heat and cold as a contributory factor, it becomes tired. This is known as metal fatigue and its inner structure is weakened. Railway lines are an example They have to be replaced at intervals. Another example is when we break a piece of wire by bending it backwards and forwards. We note it becomes hot (friction) and then breaks.

Different substances react differently to heat. Some burn, some evaporate; metals melt, but each metal has a different constitution. Tin will melt at a higher temperature (centigrade) of 232°, lead at 327°, but the noble metals all require much higher temperatures: silver 960°, copper 1083°, gold 1063°, platinum 1760°. The metal mostly in use, iron, melts at 1535°.

If a flask is filled with water, a cork inserted with a small glass tube through it, the hands placed round it and the mouth of the tube placed under water small bubbles will be seen coming from the tube. If the flask is placed on a tripod and heat from the bunsen applied, there will be a momentary drop in the level (the flask has slightly expanded) then the water will rise in the tube. This is the principle of the thermometer.

The process is, of course, reversed when things are cooled. For instance, in an iron foundry, it is necessary always to have a measurement in excess of that required in the finished article because the metal contracts on cooling.

There is one great exception to the rule of expansion and contraction by heat or cold. This is in the case of water and ice. Water expands when heated but contracts when cooled nearly as far as freezing point and then expands again as it turns to ice. This is why the old lead water pipes had a habit of bursting. Ice is also lighter than water, thus we see it floating on the top of lakes and ponds.

Water provides us with an excellent subject for studying the effects of heat. In different forms it illustrates the three states of matter. As water, it is liquid; as steam, gas; as ice, solid. Rain, snow, ice, dew, mist, fog, vapour, steam are water at different temperatures.

If we observe a kettle full of boiling water, we see nothing near the spout. Only when the vapour reaches the colder air do we see it and then it is beginning to condense. We may also see, as James Watt did, that the lid lifts. We define the boiling point of water as 100°C. At this temperature steam comes off but the water cannot absorb more heat and its temperature remains constant. Water converted to steam means developing a great expansive force. The volume of steam produced from water is in the ratio of 1700:1. It is because of this that steam can be used for motive power.

Other liquids boil at different temperatures and, at the other end of the scale, their freezing points also vary. Milk freezes just below zero, but a volatile substance like petroleum requires extreme cold.

Similar variations apply to gases, which, under the influence of cold, can become liquid and even solid.

Steam comes off water when a fair amount of heat is applied but there is a slower process, also due to warmth, which we call evaporation. When there has been dew on the ground and the sun shines on it, we see a mist slowly rising. If we rub peppermint leaves together, the aroma which escapes is an evaporating process. When we smell paraffin or any other liquid, it is not really the liquid we smell but the vapour which it gives off. Petrol evaporates in the carburettors of our cars, mixes with air and becomes a gas which, by a complicated process, drives the car along.

Evaporation creates a cooling process because the evaporating liquid takes heat from its surroundings and conveys it to the air. This is why we feel cooler when perspiring.

There are some substances which do not have an intermediate liquid state. For instance if we put a crystal of iodine into a test tube and heat it, a gas comes off immediately. Camphor is another such substance. We hang bits of it in our wardrobes where it slowly turns into a gas and keeps the moths away.

It will be understood that heat is the great transformer; also that where there is no heat, there is no life.

CONDUCTION, CONVECTION, RADIATION

Experiments can be made to show how heat travels. A piece of wood can be heated while the other end is held in the hand. A glass rod and a metal bar can be dealt with in the same way. It will be observed that the metal becomes hot where it is held; the glass, warm. The wood is unaffected. The process of heat transference in this way is known as conduction. The same phenomena appear in the intense cold. A piece of wood can be held normally in the hand but a piece of metal conducts the heat from the body to such an extent that it will take off the skin.

If we stand on a cold bathroom floor in bare feet the floor feels cold until it has absorbed sufficient heat from our body.

If we put a few potassium permanganate crystals in a flask of water and heat it, we shall see how the water circulates in a sort of fountain. This way of distribution of heat is known as convection. It applies also of course to air currents.

When we allow ourselves to be warmed by sitting in the sun or in front of a fire, the heat reaches us by the process known as radiation.

In the phenomenon of radiation we can see that warmth is closely related to light. Light radiates. If light strikes a white object, it reflects it but a black object does not. The case is similar with heat. If the sun is shining and we put a thermometer under a black cloth, it will register a higher temperature than under a white one.

Heat is conducted, convected or radiated at different rates according to the substance carrying it. Water conveys it some twenty times quicker than air. If we go for a swim in water which has the same temperature as the air, we might ask how it comes about that it feels cooler and refreshes us. The answer lies in the above statement. The water takes our body heat away quicker. But why then do we feel the cold when we come out of the water into the air. The reason for this is that the

water on our body vapourises and extracts the heat from our bodies to do this.

The metals are the best conductors of heat. Iron carries it approximately 2,000 times quicker than the air, and copper over 15,000 times. That is why copper is such a good material for making kettles and saucepans. Silver would be even better but may be a little too expensive.

We see then that heat changes the characteristics of things. A piece of wood does not contain heat by itself but it has acquired certain characteristics under the influence of heat. When it burns these change and heat is released. It is as if heat has been absorbed into a certain form but it is freed when the form dissolves.

If we drop small amounts of molten lead into water, they take on the most varied shapes. In winter vapour may freeze on the window panes and we have the most marvellous designs. When water containing various substances is cooled, we find crystals. We could say that, under the influence of cold, movement is frozen into form.

The Greeks looked upon nature as containing four elements, earth, water, air and fire. By earth they meant everything of solid physical matter; water included everything that was liquid; air was the gaseous substance and fire included warmth and light. Heat and cold are forming forces of nature. They take part in the eternal change of becoming and decaying.

When Goethe lets Faust invoke the Earth-Spirit, the latter appears in the form of a flame and expresses his nature thus:

In the tides of Life, in Action's storm,
A fluctuant wave,
A shuttle free,
Birth and the Grave,
An eternal sea,
A weaving, flowing
Life, all-glowing.
Thus at Time's humming loom 't'is my hand prepares
The garment of Life which the Deity wears.

MAGNETISM AND ELECTRICITY

In dealing with these matters a different sort of wonder can be aroused in the child's soul. It is a wonder tinged with apprehension. Here in these fields we are delving into matters and using forces the nature of which is not fully understood.

In the introduction mention was made of an eventual assessment of the way in which the world has changed through man's inventions and discoveries, with particular reference to morality. The advent of electricity has meant perhaps a more profound change than any mechanical discovery. This then is to be borne in mind as well as the actual technicalities.

There are many mysteries in the world not yet solved. In recent years there has been some research in England on the so-called ley lines. These seem to be the manifestation of some sort of force in the earth, so far undetermined, but it has been found that series of churches or holy places are constructed in definite geographical locations all in a straight line. Some of them converge in a spot which has become particularly famous, such as Glastonbury in Somerset.

As ancient peoples had a different attitude towards life and disposed of different human powers, so it is to be assumed that these ley lines were experienced in some way. Modern man, with his faculty of thinking, his interest in the material world, and his inventions, has lost this faculty.

Even today, however, there are some people who have a particular sensitivity towards what is in the earth – about one in ten thousand in England – and they can detect water or metals. These people are called diviners and with the help of a hazel twig or a small pendulum, they can say where certain things are within the earth's crust.

We also know, from certain experiments that have been carried out, that the moon and even the planets have some influence on plant growth. That the sun affects everything on earth is obvious.

Thus we can perhaps appreciate that there are many forces at work in the world of which we are not always conscious.

Among these forces is the one which we call magnetic and this has a particular relationship with iron.

Tradition has it that a certain magic stone was used by the Chinese in ancient times to show them direction. It was also known to the Greeks, Romans and Arabs. If a piece of this stone were suspended freely on a piece of string or something similar, it would always come to rest in a particular direction. One end would point to the north, the other to the south. Perhaps for this reason it received the name of lode – or loadstone, which means the "lead" stone.

Magnets, obtained by rubbing a piece of steel with a lodestone were in use as compass needles in Europe about the year 1100.

The lodestone, which is a form of iron, also has the property of attracting other pieces of iron to it.

There is a story which tells of a shepherd in Greece who had difficulty in walking in a certain district because his iron-studded sandals were sticking to the rocks. We certainly know that stones of this type, called magnetite, are found in a district of ancient Greece known as Magnesia, from which the name magnetite is obviously derived, as well as the word magnet.

By contact with other pieces of iron this property of attraction can be transferred and our magnets have developed in this way. Since one end of a magnet is always attracted to the north and the other to the south, the two extremities are known as the poles. Pole is from a Greek word which means axis and geographically the poles form the axis on which the earth turns. There is, however, a difference between the geographical poles and the magnetic. The latter are in the same region but do not coincide, and the position of the magnetic poles varies from time to time.

Today magnets are made in all sorts of shapes. There is also the electromagnet but this is something a little different from the natural one.

By taking a magnet and experimenting a little we shall soon discover what sort of materials it attracts. We shall find that it only attracts other pieces of iron or derivatives therefrom. If we put a nail close to a magnet, it will be drawn towards it and will stick to it. We note that the force of the magnet extends beyond its physical form and can be transferred through space and even through other objects. If, for instance, we put a magnet on the table, hold one end of a nail a short distance away from it, and put some iron filings near the other end of the nail, the iron filings will attach themselves to this end. If we put iron or steel objects on paper, glass, leather, plywood, we can move them about with the magnet underneath. It is, of course, only effective within a certain distances.

Iron which has been in contact with a magnet becomes temporarily magnetic itself. Soft iron quickly becomes magnetic but loses the force quickly. Steel takes longer but retains the power longer.

Stroking conveys the magnetic force and this will then last longer. If a needle is stroked some twenty or thirty times (the whole length, with the same pole, and in the same direction) it becomes magnetic and if pushed through a cork and floated on water, it will become a primitive compass, showing always the north/south direction. If it has been stroked with the north pole, it will become south-seeking and vice-versa. We shall find, however, that if a magnet is brought near it, it will be affected.

If a piece of steel wire is magnetised and then cut in two, we should find ourselves with two magnets. Each has a north and south pole,

By placing a nail at various points on a magnet and picking it up again, we shall notice that the forces are strongest at the ends, i.e. the poles. The north and south poles will attract any non-magnetic piece of iron but if we take two magnets we can see how the opposite poles attract one another but like repels like. The two poles acting together exert a stronger force than each singly, hence the frequent horse-shoe shapes of a magnet.

If we place a piece of paper or glass over a magnet and sprinkle it with iron filings we shall see the lines of force or the magnetic field. The pattern will vary according to the way in which the magnet or magnets are positioned.

The power of a magnet can be destroyed by heat, by hammering or even by dropping it too frequently on the floor.

The magnetic field with the iron filings shows us in a minute way something which is spread out over the whole earth; for the whole earth has a magnetic field with north and south as the focal points. Therefore no matter whether we are in Europe or China, Australia or South America, the compass will always point north/south. The magnetic influence is not constant over the whole earth but varies from place to place.

It used to be thought that magnetism was a force in the earth but at a high temperature magnetism is destroyed and the very high temperatures inside the earth are sufficient to do this. It has been observed that variations in the earth's magnetic field coincide with the activity of sun spots and therefore it must be assumed that magnetism is connected with the setting of the earth in the whole universe.

ELECTRICITY

Electricity, or rather the use of it, is something relatively new and yet in our civilisation it is something with which we are very familiar. In presenting a study of it to the children one could perhaps consider all the points at which it touches our lives, and compare it with other forms of energy. In the latter respect it is obvious that it has quite a different (and almost uncanny) character. There is something essentially honest about a fire and steam but by contrast electricity has a very subtle quality. A burn from a fire is something very different from an electric shock.

The use of the electric light is almost universal. Electric heating is found in many buildings. In the house electricity has innumerable uses: mixers in the kitchen, hairdryers, vacuum cleaners, water-pumps in the central heating, radios, television sets, record-players, telephones, shavers, sewing and washing machines. Its presence in the car is vital. In industry and transport its use as motive power is widespread. The electric motor is simple, quiet, easily worked.

As a source of power and as a source of light electricity is different from others in that production and consumption do not take place in the same spot. If we consider the electric lamp or fire in our room, there is no immediate burning process as with other fuels. A simple piece of wire brings us the energy from the distant

works where it has been produced. In some cases this is an advantage. In the case of transport, in the locomotive, for instance, it is not necessary to carry the means of producing energy with it. It is supplied through a wire from the place of production and the same generating station can supply a whole series of other locomotives as well. The disadvantage is that if the central works breaks down, then all the individual units are immobilised.

Only certain substances will conduct electricity, chiefly metals, of which copper is the most useful. Glass, china and rubber are non-conductors and are therefore used as insulators.

Electricity is also different from other sources of power fuels in that it cannot be stored in any quantity. There are such things as storage batteries and accumulators but in the main electricity is produced and used at the same time. This causes certain difficulties as the demand varies from time to time. There are the so-called peak hours and the non-peak. A peak hour occurs for instance in England in the winter when it begins to get dark towards the late afternoon. The factories are still working but people also switch on the electricity in their homes. The quietest time is during the night. These ups-and-downs can only be met by bringing in more generators or shutting some of them off.

An ingenious way of helping this situation has been devised by the use of dams. At off-peak periods the electricity is used to pump water into dams and when the peak period comes the water is released to drive generators to produce the extra supply.

If there is a grid, i.e. a linked-up supply, over a large geographical area, this also helps since the peak periods vary.

Experiments should now be made to show the different types of electricity and also the connection with magnetism.

A piece of amber, rubbed with a piece of cloth, will have the capacity of attracting to itself small pieces of paper. Amber, a fossilised resin, is called in Greek "electron" and it is actually from this that our word electricity comes. A similar phenomenon can be observed by rubbing a balloon with a woollen cloth and holding it over someone's head. The hair will stand on end. A piece of glass can be placed on short supports with small scraps of paper underneath. When rubbed, the paper scraps will dance. There is also a child's toy with dancing clowns which works on the same principle.

This phenomenon is known as frictional or static electricity.

It may be that on a hot day someone may touch a car which has been travelling and will get a shock. This is also "static" electricity.

In 1799, Volta, the Italian physicist, realised that electricity can be produced by certain chemicals acting on one another. Working on this principle is the Leclanché cell, named after its inventor, a French chemist, who produced it about the year 1865.

A glass jar is filled with sal-ammoniac solution (NH_4Cl). Into this is placed a zinc rod and a porous jar containing a carbon rod, powdered carbon and manganese dioxide. A chemical reaction takes place giving rise to the production of sufficient electricity to light a small bulb. The terminals are the zinc and carbon rods. A similar result is obtained by inserting zinc and copper rods in diluted sulphuric acid. This is known as a Daniell Cell.

The modern dry cell, used almost universally in flash-lights and radios, is an adaptation of the Leclanché cell. The sal-ammoniac is made into a solution which is near solid; the porous jar is replaced by a muslin bag; the glass jar is replaced by a zinc cylinder which displaces the zinc rod. In a flash-lamp battery therefore, the terminals are the carbon rod in the centre and the zinc outer casing.

Electricity produced by these and similar means is known as chemical electricity and it is a very useful source for small purposes. However, most of the electricity we use has to be generated and other sources of power are needed to drive machines to produce it. These may be coal, water, gas, nuclear reactors. The machines are known as dynamos and the place where they are situated is usually known as a generating station.

We should show here the connection between electricity and magnetism.

Three names appear in historical sequence in this connection. In 1819, Professor Oersted of Copenhagen found that if an electric current were passed through a wire parallel to a compass needle, the needle was deflected.

In 1821 Ampère, a French mathematician and philosopher, discovered that if a wire is wound into a coil (solenoid) and an electric current passed through it, a single strong magnetic field is formed through its centre. A steel needle put in the centre is permanently magnetised. Soft iron loses its magnetism.

In 1831, the English chemist, Faraday, found that a magnet pushed in and out of a solenoid produced electricity in the wire.

These things can be demonstrated and the following apparatus constructed.

> A length of covered copper wire is wrapped round and round the length of a piece of iron, say an iron bolt, possibly two or three layers. When an electric current from a small battery is passed through the coil, the bolt becomes magnetic. This device can be used to make an electric telegraph. If the bolt is suspended over a small hinge, one side of which is fixed, the other is lifted towards the magnet when the current is switched on and the result is a little click. By making and breaking the circuit it is possible to tap out messages in Morse. The pupils will take great delight in making such an apparatus: and possibly in learning the Morse code in which the most famous signal is · · · – – – · · · S.O.S.

The electric telegraph was one of the earliest mechanical devices for

transmitting messages. Originally, an operator, by controlling the current, could make an electromagnet move a pointer which indicated letters of the alphabet on a chart. Morse was the next development.

In generated electricity we are dealing with the opposite case. Electricity in the dynamo is produced by spinning a coil of wire in a magnetic field. The actual explanation of the dynamo belongs to a later class but the simple fact that a compass is deflected if a wire containing an electric current is near, shows the principle. An experiment can be made as follows.

> Insulated bell wire is wrapped round two separate tubes of thin cardboard so that the wire is continuous. Into one is placed the compass with the needle on the north position and the coil orientated in the same direction. The other coil is placed some 18 inches away and a magnet held in it. It will be seen that the compass reacts.

On the one hand then we have a magnet produced by an electric current and on the other, an electric current produced by a magnet and a piece of wire. Thus the dynamo and the electric motor are a sort of reversible machine.

An example from another sphere may make it clear. If we turn a rotating fan by hand we create a draught. If the wind blows a fan round, the shaft rotates. The dynamo produces electricity but by the same principle, electricity turns a motor. (These things are dealt with in detail in Class 8).

Something of a mathematical nature belongs to electricity. Certainly calculations have to be made. In this connection simple mathematical problems could be set, based for example, on Ohm's law.

If time allows, it would be extremely rewarding to deal with the development of electricity in its historical sequence. In fact some teachers may prefer this approach altogether. To some extent the work can be coordinated with the history lessons because the history in this class deals with inventions and discoveries in the natural scientific field. Biographies of the great scientists should be studied in any case.

MECHANICS

CLASSES 7 AND 8, AGES 13 – 14

In teaching this subject the procedure should be the same as with all physics teaching: first demonstration by experiment; remove the apparatus and review the experiment in the imagination; consider the matter the next day and come to conclusions. There are many aspects of mechanics but as far as the Rudolf Steiner school is concerned the following is a general outline of the work to be done in Class 7, at the age of 13, extending possibly into the next year. As well as dealing with solids, it deals with the mechanics of liquids (hydraulics) and of gases (pneumatics).

The slogan of "let the children find out" has its application here. Let the children observe and make experiments for themselves. Let them discover the laws themselves from an observation of the phenomena. The teacher should not be too ready with explanations. There will also be ample opportunity for working out mathematical problems in connection with the work.

The word Mechanics comes from a Greek word which means contrivances. Our word machine is related to it. It is the study of mechanical devices. But as every object exists with forces working on it, the study of mechanics is also the study of the conditions under which objects move or rest.

As an illustration we might speak of the earth which is like a huge magnet. We know that the earth is round and when we first learn that as children, we wonder why people on the other side do not fall off. But they do not and the force which holds things to the earth is known as gravity. If we pick something up we are exerting a contra-force.

We might ask the pupils to list all the forces they can think of and with good fortune and the teacher's promptings we might include: gravity, wind, light, heat, sound, pressure, suction, friction, expansion, contraction, magnetism, electricity, growth, human will.

We see houses, skyscrapers, bridges, which have to be built to carry enormous loads and they must all be constructed in accordance with certain laws or they will fall down.

It is obvious that when things are moving they are under the influence of some force but stationary objects are similarly affected. A stone does not move of its own volition. Some force holds it in place unless another and greater moves it. If a bridge did not stay in position, it would be catastrophic. (Tay bridge disaster). That branch of mechanics which deals with things at rest is known as Statics. When objects move, they do so according to certain laws. They may move uniformly or at varying speeds. An aeroplane needs a certain speed to take off. If it is flying and suddenly loses speed, it will crash. Mechanics is also concerned with motion. This branch is known as Dynamics. Statics then is the study of immobile forces. It concerns itself with forces in equilibrium. Dynamics is the study of forces causing

movement.

It is interesting to study the difference between natural movement as performed by man and animals, and mechanical movement. The human being walks, sits, lifts things, turns his head, balances on two feet. He does these things in obedience to his thoughts, feelings, will, or instinctively. Different animals move in different ways. Most four-legged animals move the foreleg of one side with the hind leg of the other, but elephants, giraffes and camels move both legs on the same side together. Trotting and galloping are other variations of movement. Kangaroos leap.

Insects are always supported on three legs. The fore- and hind leg on one side move with the middle leg on the other. A snake crawls; worms move by expansion and contraction.

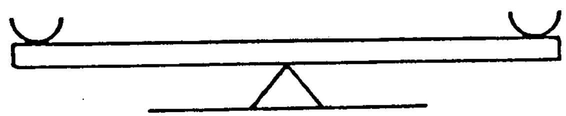
Birds fly by flapping their wings and making use of air currents. In the water aquatic birds paddle.

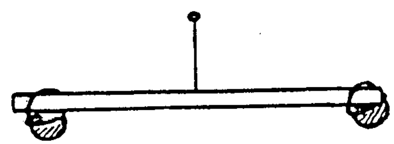
Most fish make side-to-side strokes with their tails. Eels move by undulation; the medusa by water jet propulsion.

Yet the actual actions follow the physical laws of mechanics.

In machines, the parts turn, move up or down, slide backwards or forwards. All the movements conform to certain laws.

One of the simplest contrivances is the scales, the old-fashioned type consisting of a bar, balanced in the middle with a pan on each end. We can easily make one by balancing a small piece of wood on a pivot or suspending the metre rule at the centre from a piece of string.





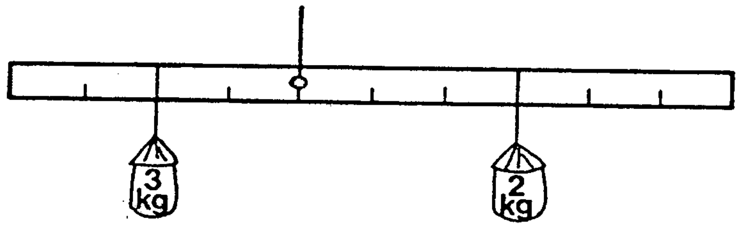
If the balance is right, the beam will be horizontal. If an equal weight is put on both ends, it will remain in that position. If one side is heavier than the other it will sink and the opposite will rise. We can however restore equilibrium by changing the distance of the weights from the fulcrum (the pivot). We know the idea from the see-saw. If a light person is sitting at one end, the heavier person will have to sit nearer the point of balance.

Using the metre stick the children will discover the law or the formula governing equilibrium. Experiment will show, for instance that if a weight of 2 kg. is hung on one side of the fulcrum at a distance of 20 cms., it can be balanced by a weight of 1 kg. hung 40 cms. from the pivot on the other side:

Weight x distance = Weight x distance
2 x 20 = 1 x 40
40 = 40

What happens if the point of balance is not in the centre? We can achieve equilibrium by manoeuvring the weights. Suppose the balance is suspended at the 40 cms. mark. A weight of 3 kg. hung 20 cms. away from the fulcrum on the one side, will be balanced by a weight of 2 kg. 30 cm. away on the other.

3 x 20 = 60
2 x 30 = 60



Weight in these instances is looked upon as a force. The product of force and distance (weight x distance) is known as the Turning Moment of the force. (The weight of the ruler in this instance is not considered).

Many weighing machines are constructed on the above principle. A heavy object can be weighed by a small movement of small weights.

Another contrivance or a simple form of machine is the lever and its application is to be found everywhere.

Give me a place on which to stand and I will move the earth.

These are words spoken by the Greek scientist Archimedes in the third century B.C. He was referring to the power of the lever.

A small force is used to lift a big weight. As the distance between fulcrum and the point of effort increases, the actual effort required to move a given load becomes less but the movement greater. The help gained by the use of a lever is called the "Mechanical Advantage" and this can be expressed mathematically:

Mechanical Advantage = Load/Effort

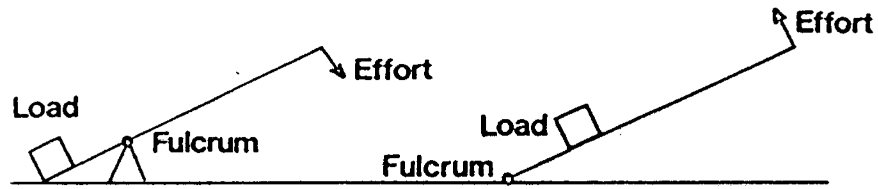
Thus if an effort equal to 10 pounds is needed to move a load of a 100:

$$\text{Mechanical Advantage} = \frac{100}{10} = 10$$

The greater movement required by the effort in relation to the movement of the load is known as the Velocity Ratio.

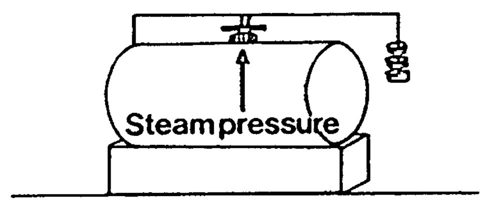
$$\text{Velocity Ratio} = \frac{\text{Distance effort moves}}{\text{Distance load moves}}$$

If the effort moves 1 metre (100 cms.) and the load 20 cms., then the velocity ratio is $\frac{100}{20} = 5$

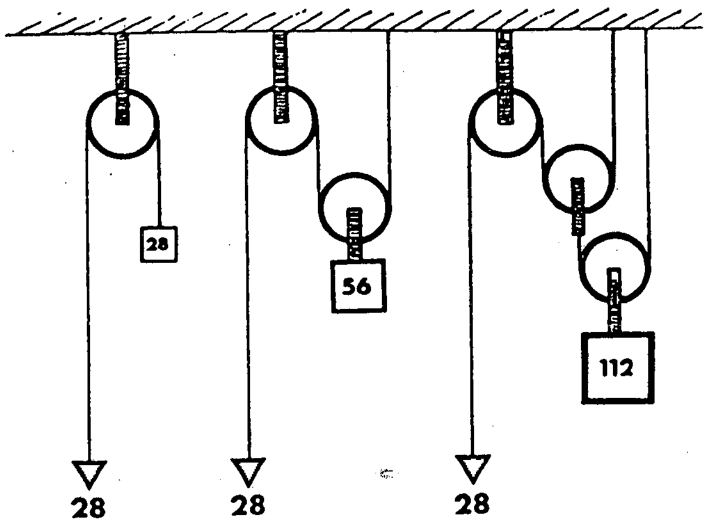


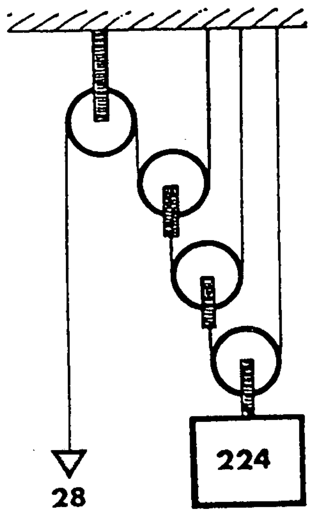
The class can now have the task of finding examples of things in everyday use where the principles of these levers are incorporated: pliers, pincers, claw-hammer, tyre lever, spade, wheelbarrow, nutcrackers, cars, typewriters, pianos, sugar tongs, canoe paddles.

The above illustrates the first two orders of levers where a mechanical advantage is to be gained. There is a third order where the mechanical advantage is less than one but a different advantage is achieved in that a load can be moved a long way by relatively little effort. In this order the effort lies between the load and the fulcrum. When, for instance, we raise a ladder, the effort is where we push but the end of the ladder travels a long way. The same principle can be used to stifle effort if necessary, as for instance in the old type steam safety valve.



An adaptation of the lever, using the same principle, is the pulley.





A grooved wheel turning on its axle in a fixed framework is called a pulley. If a rope is threaded through the groove and the pulley fixed high up, e.g. on a wall, then by pulling one end of the rope down, a load is hoisted up on the other. There is effort on one side, a load on the other and the axle is the fulcrum. One could think of the diameter as the lever. In this particular case not counting the weight of the rope, the mechanical advantage is 1. If the rope moves a certain distance, the load does likewise. In the case of the single pulley the rope moves the same distance on both sides. This is the Velocity Ratio, which in this case is also 1.

$$\text{Velocity Ratio} = \frac{\text{Distance effort moves}}{\text{Distance load moves}} = \frac{1}{1} = 1$$

An arrangement of pulleys can be a matter for further experimentation and discovery on the part of the pupils. it is best demonstrated as shown on page 38. For classroom use small pulleys and small units of weights may be more practicable.

With a single moveable pulley it will be found that a load can be moved twice the weight of the effort; with two pulleys, four times; with three, eight times. Thus a man using three pulleys, could raise a load eight times heavier than himself. The length of rope to be pulled is of course greater each time. Suppose we take an effort equivalent to the weight (force) of 28 kg. and the distance 12 metres, then according to the number of pulleys the following loads could be moved: 28, 56, 112, 224 kg.

M A	$\frac{28}{28} = 1$	$\frac{56}{28} = 2$	$\frac{112}{28} = 4$	$\frac{224}{28} = 8$
V R	$\frac{12}{12} = 1$	$\frac{24}{12} = 2$	$\frac{48}{12} = 4$	$\frac{96}{12} = 8$

In the above example the numerical values of mechanical advantage and velocity ratio are the same but this is not necessarily the case. For instance, with a single moveable pulley, the load might be 50 kg. and the effort 30, then the mechanical advantage is $\frac{50}{30} = 1.66$.

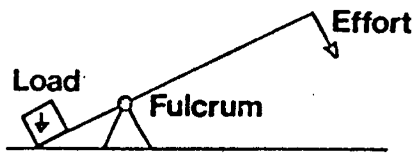
The velocity ratio is 2.

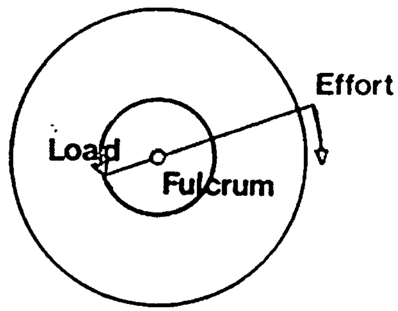
In reckoning mechanical advantage above, no account is taken of the weight of the rope or the moveable pulleys or of friction. The velocity ratio is not affected by these.

For practical purposes the pulleys are arranged in what is known as block and tackle. Such things are often to be seen on sailing boats.

THE WHEEL AND AXLE

This is another useful appliance. A large wheel is fixed to an axle or drum and revolves with it. A ropo fastened to the axle carries the load and the effort is applied to the wheel by a ropo wound in the other direction. The principle involved is that of the lever of the first order.





$$\text{Mechanical Advantage} = \frac{\text{Load}}{\text{Effort}} = \frac{\text{Axle Load}}{\text{Force applied to wheel}}$$

In many practical applications the crank handle replaces the wheel. The formula therefore becomes $\frac{\text{Axle Load}}{\text{Force applied to Crank Handle}}$

Supposing a 20 kg. load is being hauled up a well with a force on the handle equal to 10 kg., then the mechanical advantage is $\frac{20}{10} = 2$.

The velocity ratio is: $\frac{\text{Circumference of Wheel or Path of Crank Handle}}{\text{Circumference of Axle}}$

As circumference equals 2 π r the formula can be reduced to

$$\frac{\text{Radius of Wheel or Length of Crank Handle}}{\text{Radius of Axle}}$$

We shall see in due course how from these figures the efficiency of a machine can be computed.

Examples: Well, coffee mill, mincer, water tap, the now-obsolete starting handle of a car.

As the circumference of a big wheel covers a greater distance than that of a small one, the above arrangement can be reversed (provided power is available) to gain speed.

The old Penny-farthing bicycle is a good example of this. The modem bicycle works on the same principle but the transmission is via chain and sprockets. The circumference of the wheel is greater than the circumference described by the pedals. They turn at the same speed; therefore the circumference of the wheel travels further with a relative increase in the speed of the bicycle.

TRANSMISSIONS

When, through some mechanical device, one type of movement is changed into another, or when the direction of a movement is changed, we speak of transmission.

When wheels are on the same axle, the number of revolutions is the same. The speed of the circumference is different according to the size of the wheel. The greater the wheel, the greater is the speed at the circumference. When wheels on different axles are connected by cogs, belts or chains in different relationships, they are referred to as gears. Mechanical advantage or velocity is gained according to the arrangement of the wheels.

Gear wheels can be used in three ways to obtain:

1. A change in direction
2. An increase in speed
3. An increase in power

As an example, the high speed of a car engine cannot be connected directly to the driving wheels. The transmission therefore goes through a series of gears. The arrangement is such that they can cope with varying loads.

When the effort (engine-power) is applied to a small wheel which reacts on a large one, the latter turns slowly. This is then the arrangement when there is a heavy load, i.e. when the car moves from a stationary position or goes uphill. When the car is running and is moving, more equal-sized wheels will give greater speed or the same speed with less effort. As movement increases the effort is switched to a bigger wheel turning a small one faster, to give more speed or less effort.

In a watch or a clock are very fine examples of gearing. The spring, which would expand in a second if released directly, is made to expand slowly – in twenty-four hours, seven days or even longer, by means of gears. By a most intricate relationship of cog wheels, the three distinct hand movements (second, minute, hour) are worked from the same source of power. The old grandfather clocks and some church clocks also work through a series of cogs but the motive force is not a spring but weights.

In our own bodily movements we are continually making transmissions. When a man walks, he translates the rhythmical movement of stepping into a progressive movement. He does the same when he saws a piece of wood or hammers in a nail. When he plays a violin, he changes a progressive movement into a rhythmical one. The animal also changes a rhythmical movement into a progressive one – the bird flaps its wings to go forward, the dog trots.

But it is in the field of machinery where we find the most and best examples. The mechanism of a machine allows three distinct movements of which one can be transmitted to another. There is the obvious circular movement, the straightforward progressive, and the repetitive or rhythmical movement.

There is a golden opportunity here for children to develop their own powers of observation and thinking and it is to be hoped that they will discover at least some of the following:

Circular movement or Rotation	**Progressive or Linear**	**Rhythmical or Oscillating**
Rim of wheel	Car	Pendulum
Hand of clock	Bullet	Piston
Roundabout	River	Tides
Turbine	Light	Swing

It is obvious that with two linked cog wheels the circular movements will be in opposite directions. A belt drive will turn wheels in the same direction but reverse the second if crossed.

A circular movement can be changed into a rhythmical and vice versa, e.g. sewing machine, piston and wheel of a steam locomotive or the up and down movement of the pistons in a car.

The progressive movement of a stream can produce the circular movement of the water wheel. Similarly the wind turns the sails of a windmill.

The circular movement of the wheels of a vehicle produces a progressive movement. Lifts, propellors, the paddles in paddlesteamers are other examples.

The Inclined Plane

According to Herodotus, the Greek traveller, the Egyptians built their pyramids by hauling the great blocks of stone up artificially built slopes. He called these slopes machines. We refer to them as inclined planes.

When we climb a hill, we can either go straight up a short, steep path, or we can take a longer, easier, roundabout route. Whichever way we go the work is the same: either a great effort over a short distance, or a less effort over a longer distance.

Examples: Slipway, wedge, screw, propellor, vice.

Measurements of Work and Power

The measurement of power known as horse-power is in actual fact based on the strength of a horse. James Watt wanted to find some standard by which his

customers, who were used to horses, could understand the power of his machines. He found by experiment that if a weight of 100 lbs were suspended over a pulley down a shaft at the end of a rope, a cart horse could pull it up at the rate of 2½ miles per hour, which equals 13,200 feet. He called one pound raised one foot a unit of work and this is known as the foot/pound or written as ft/lb. The horse was therefore performing 100 x 13,200 ft/lbs work in an hour, = 1,320,000. In a minute this would be: $\frac{1320000}{60}$ = 22, 000 ft/lbs.

To allow for friction and to give his customers good value, he increased this measurement by half to 33,000 ft/lbs per minute or 550 ft/lbs per second. This he then designated 1 horse-power, 1 hp.

On this scale we might like to know the capacity of man, animal and various machines. A man can develop up to 1.3 hp, horse 0.5 to 5; motor cycle, 6 to 7; medium car, 30 to 40; lorry, 80 to 100; locomotive, 1000 to 6000; four-engine jet, 25,000; a large ship, such as an aircraft carrier, 200,000.

Efficiency of Machines

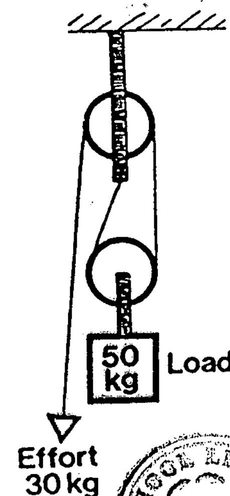
At this age it would be difficult to work out the efficiency of our modern sophisticated machines but for simple mechanisms such as we have considered, the efficiency can be worked out roughly as follows:

$$\text{Efficiency} = \frac{\text{Work Achieved}}{\text{Work put in}}$$

or

$$\frac{\text{Load x Distance load has moved}}{\text{Effort x Distance effort has moved}}$$

Example:
A load of 50 kg. is moved 1 metre by an effort of 30 kg. which moves 2 metres.
Efficiency (%) $\frac{50 \times 1}{30 \times 2} \times 100 = 83.3\%$



Another formula for reckoning efficiency is
$\frac{\text{Mechanical Advantage}}{\text{Velocity Ratio}}$
In this example,
Mechanical Advantage $\frac{50}{30} = 1.66$

Velocity Ratio $\frac{2}{1} = 2$

Efficiency (%)} $\frac{\text{M.A.}}{\text{V.R.}} = \frac{1.66}{2} \times 100 = 83.3\%$

These formulae give the possibility of doing more practice in mathematical calculations, possibly in the mathematics lesson.

Pupils can work out what work they do (in this sense) when they climb the stairs, run a mile, etc. They can work out their own horse-power.

Forces affecting Motion

We have already referred to the force of gravity which attracts objects towards the earth. Unless moved by another force, the object continues to rest. When we pick something up we overcome the force of gravity but when we let go, gravity asserts itself. We may ask if there is any particular way in which things fall to the ground. Certainly they drop vertically but at what speed?

If an object is projected through the air or along the ground, is the speed constant and if not, why not?

In order to measure speed we need a unit of distance and a unit of time. These are usually: miles per hour; feet per second; kilometres per hour; metres per second.

It is interesting to compare relative speeds – all in metres per second.

Snail	0.0025
Pedestrian	1.3
Cyclist	4 to 5
Car	28 at 100 km/hr or 60 mph
Messenger Pigeon	40
Aeroplane	222 at 800 km/hr or 500 mph
Sound	333 in air
Light 300,000,000	

These are average speeds or constant speed, but speed is usually not constant, i.e. travailing by car we go faster or slower according to conditions but we regulate the speed by means of the engine and brakes. If, however, we travel down a slope by sledge, on skis, or on a bicycle, our speed increases towards the bottom, levels off and we come to a stop ascending the opposite slope. This variation is due to gravity. We speak of acceleration and deceleration. The rate at which a body moves is called its speed or its velocity.

Just as a body at rest will stay until moved so a body in motion will continue to move unless it is stopped by something. This is known as inertia. If anyone is riding a bicycle and happens to run into the fence, the bicycle will stop but the person riding it will fly over the handlebars, not being a part of the machine. If we are standing in a vehicle which suddenly moves we have the tendency to fall over. If we are travelling and the bus suddenly stops we have the same problem. If we have a pile of coins we can knock out the bottom one by a short sharp blow and under the force of gravity the others will retain their position.

When objects are in motion they are usually stopped by friction unless by an absolute barrier like the fence in front of the bicycle. Friction means the the resistance an object meets in passing over another. It is more difficult to slide our hand over a rough surface than a smooth one. In vehicles friction has to be overcome as far as possible for them to move, but applied as great as possible to stop them. But there is also an odd contradiction in that friction is also necessary for any movement to take place.

If we try to push a car with its brakes on, there is tremendous friction between the tyres and the ground. When the brakes are released, the friction is transferred to the axle where there is little. If the action is transferred through ball-bearings the friction is fractional and oil or grease will reduce what little there is. When the vehicle needs to stop, friction is applied through the brakes, i.e. the brake shoes on the wheel. In the old horse carts a block of wood was applied on the outer edge of the wheel. Sand on an icy road creates greater friction. On an aeroplane wing flaps are manoevred to provide air resistance when slowing on the runway. Friction produces heat which sometimes has to be dispersed.

In anticipation of more detailed study in the Upper School we might now glance at the three Newtonian laws of motion:

1. An object will remain at rest or will continue in a given state of motion until some outside force acts upon it. An example would be when, in a free-fall parachute descent, the parachutist accelerates to his terminal velocity whereupon the upward thrust due to the air balances the downward force due to his weight and he falls at constant speed.

2. An object accelerates in the direction of the force pushing it. The greater the force, the greater is the acceleration; the greater the mass acted upon by the same force, the less is the acceleration. Throwing stones demonstrated the latter part of this statement. As for the former, a projectile fired from a gun follows a curved path because, in addition to the force propelling it, there is also the effect of gravity bringing it back to earth. In actual fact the path can be calculated so that it will be known where the shell will fall.

3. Every force has a reaction that is equal and opposite.
The jet engine is a good example; also the recoil when a gun is fired.

A few definitions might be noted as applied to the study of mechanics:

Force:	That which produces, alters or stops the motion of a rigid body, or changes the shape of an elastic body. Measured in units of weight.
Work:	Result of the action of a force.
Energy:	Capacity for work.
Power:	Rate of working. Work performed in a certain unit of time.

The distinction between mass and weight should be made clear. Up to the time of Galileo it had been assumed that heavier things would fall faster than light ones. Although some historians question the story, it is said that Galileo dropped two bags of lead shot, one weighing one pound and the other ten, from the top of the leaning Tower of Pisa and that they hit the ground together.

Where possible some similar experiment should be done, also dropping things through a vacuum. In actual fact objects will fall at the same acceleration through a vacuum, be they of lead or of feathers, but in the open, air resistance may play a part. In the case of the lead shot air resistance is negligible It would be the same if we used ball-bearings or something similar.

Experiments should also be made, dropping for instance a ball-bearing from different heights, using a stop watch to measure the time taken. It will be discovered that the speed of the fall increases. This is something that can be plotted on a graph.

A free falling body accelerates, i.e. changes its speed under the influence of gravity at the rate of 10 m/sec every second. Thus a body falling from rest will be travelling at 10 m/sec at the end of the first second when it will have fallen a distance of 5 metres while gathering speed. Since the object changes its speed by 10 metres per second every second, then its actual speed after any determined time (number of seconds) will be 10 x the number of seconds, i.e. after 2 seconds 2 x 10 = 20, after 3, 3 x 10 = 30. (See Chart on page 45).

The average speed during any particular second will be the average of the speeds at the beginning and end of that second, i.e.

$$\frac{\text{Speed at the beginning of that particular second + speed at end}}{2}$$

Thus in the third second: $\frac{20 + 30}{2} = 25$ m/sec.

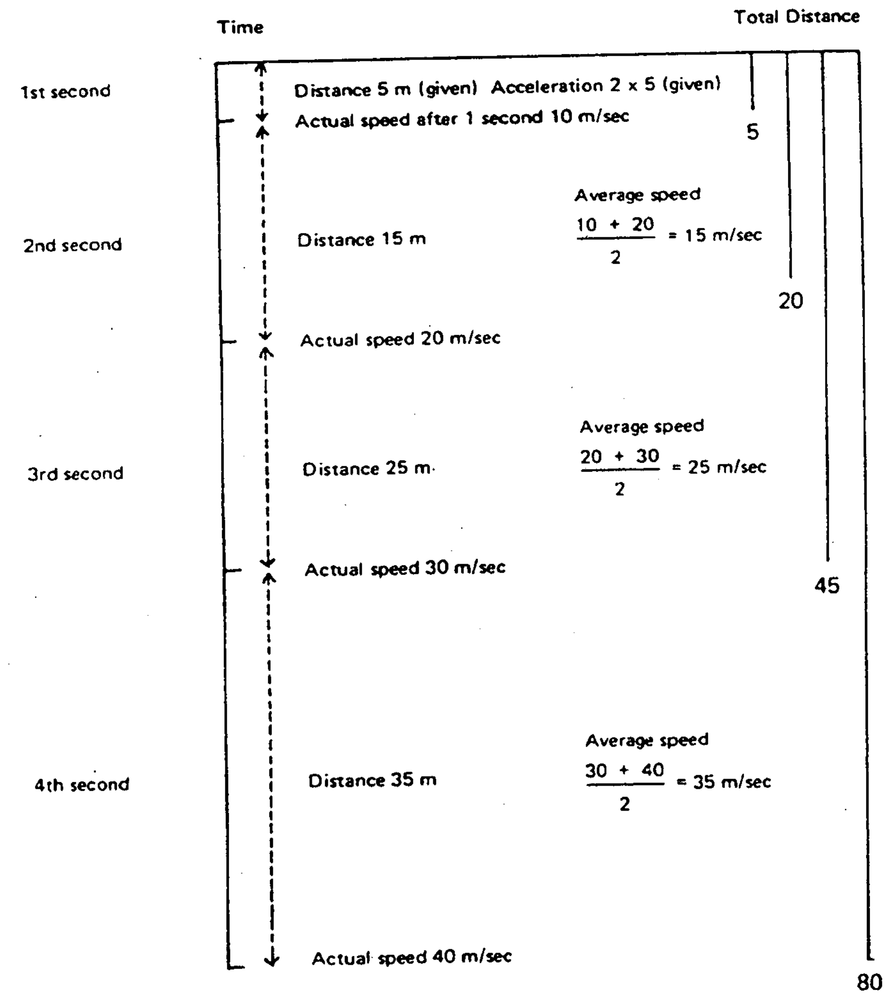
The distance fallen is: average speed m/sec) x time. Thus the distances (in metres) fallen during each second are:

1st second	5 x 1	Total distance 5
2nd second	15 x 1	Total distance 15 + 5 = 20
3rd second	25 x 1	Total distance 25 + 15 + 5 = 45
4th second	35 x 1	Total distance 35 + 25 +15 + 5 = 80

A formula for reckoning total distance fallen from rest in a given time is:
Average speed (m/sec) x total time (seconds)

$$\frac{10t}{2} \quad x \quad t$$

$$= \quad 5t \quad x \quad t \qquad \text{or} \qquad 5t^2.$$



These matters should be coordinated with the teaching of mathematics. Graphs are an obvious relation but problems such as the following should also be worked out if the children have sufficient understanding. Otherwise this work can be taken later.

In any case a more intensive study of these matters is taken in Class 10, at the age of 16.

1. What is the speed of an object which has been falling for 20 seconds?

   Speed = 10 x number of seconds
   10 x 20 = 200 m/sec.

2. What is the average speed of an object during the 20th second of fall?

   Average speed $= \frac{(19 \times 10) + (20 \times 10)}{2}$ = 195 m/sec.

3. A parachutist opens his parachute after 12 seconds, 200 metres above ground. How high was the plane?

   Height = Distance to ground + Distance already fallen
   $= 200 + (5 \times t^2)$
   $= 200 + (5 \times 12 \times 12)$
   = 920 metres.

4. If a stone is dropped down a well and a splash is heard after 4 seconds, how far is it to the surface of the water?

   Distance $= 5 \times t^2$
   $= 5 \times 4^2$
   $= 5 \times 16$ = 80 metres.

If an object is thrown or shot straight upwards how does it behave? This may not be measurable in the classroom but it is at least observable. It leaves the ground with a certain velocity, slows down as it gets higher, reaches a zero point and begins to descend with accelerating speed. The law states that an object projected upwards takes exactly the same amount of time to climb as to descend. Example:

If a cricket ball is hit into the air and meets the ground after three seconds, what height did it attain? (Discounting the measurements of the batsman etc.)

Total distance $5 \times t^2$
$= 5 \times 3^2$
$= 5 \times 9$ = 45 metres.

Taking the same time to rise as to fall

Height attained $= \frac{45}{2}$ = 22.5 metres.

At what speed was it projected or what was its initial velocity?

Initial speed = End speed

End speed $= 10 \times t$
$= 10 \times 3$

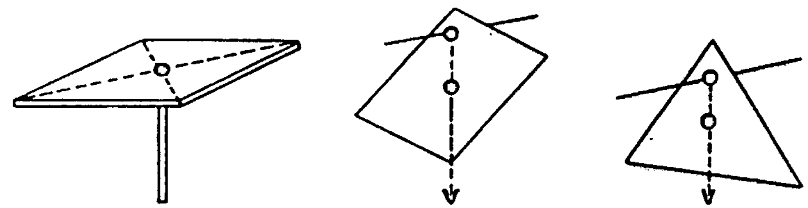
= 30 m/sec. Initial speed 30 m/sec.

When an object, such as the cricket ball, is projected obliquely into the air, it describes a parabola. This again is something to be dealt with in the mathematics lesson.

The Centre of Gravity

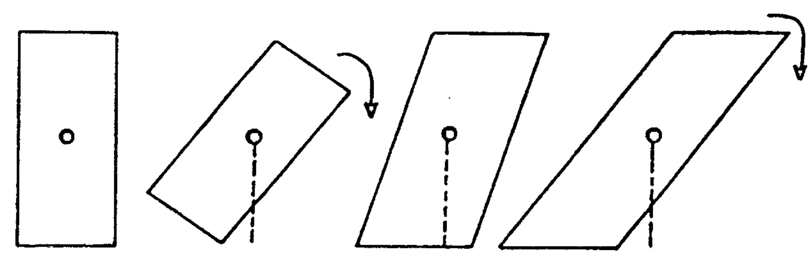
In Pisa, in Italy, there is a famous leaning tower. Why does it not fall over?

A few experiments can be done with various objects to see if the law can be discovered. At the same time experiments can be carried out with pieces of cardboard or wood to find the place at which they can be balanced on a point. This point is known as the centre of gravity. From whatever position the card is hung the centre of gravity will always be in a straight vertical line with it.

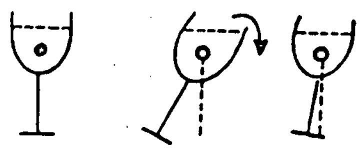


If the centre of gravity is below the point of suspension, the object is stable. If it is at this point, it is indifferent. If below, then the object will turn where possible to the first position, otherwise it is insecure.

If an object is standing, it will remain firm as long as the centre of gravity is above the area of support. It falls over as soon as the centre is not vertically supported. The leaning tower of Pisa is still safe although it is reported to be gradually moving further over due to ground subsidence.



It is obvious that the greater the base on which an object rests, the safer it is; also that the lower the centre of gravity the more stable the object. This principle is of great significance in building cars.



The Pendulum

A weight on the end of a string will form a simple pendulum. Given a little momentum it will swing back and forth under the influence of gravity. As an experiment the swing can be started from the horizontal position and the number of oscillations per minute counted. It can then be started from an eight-o-clock position and again the number in a minute counted. It will be found that the numbers coincide, provided the string is kept the same length.

This is the particular property of the pendulum, i.e. that the interval of time for each complete swing to and fro, called the period, is constant. The same conclusion can be reached by the use of a stop watch.

It was Galileo, the Italian scientist, who first noticed the constancy of a pendulum's movement by comparing the movement of a swinging lamp in a Pisa cathedral with his pulse rate.

If the weight is changed, it does not affect the number of oscillations, neither does the distance of the swing. The string may be lengthened or shortened and it is this which affects the number. We might by experiment find a ratio between the length of the pendulum and the period:

Length of Pendulum	Periods per Minute	Length of Period
11 cm	180	60 ÷ 180= 1/3 sec.
44 cm	90	60 ÷ 90= 2/3 sec.
99 cm	60	60 ÷ 60 = 1 sec.

In order to double the period the pendulum must be 4 times longer; 3 x period, 9 times longer; 4 x period, 16 times, etc.

Because the earth's gravitational field varies in different parts of the earth, there may be slight variations. In England the pendulum should be 99.4 cms. long to achieve a period of one second.

Such a fine instrument can obviously be used to measure time, hence its application in clocks. In a clock the pendulum is often a metal bar mounted on a knife edge to reduce friction and it is given momentum by a spring or a weight. It

has to function, however, through an ingenious sort of cog so that the motive power is not used up immediately.

Centrifugal and Centripetal Forces

This is a difficult chapter and the class teacher who is already feeling overburdened may like to leave it to his specialist colleagues in the Upper School, particularly if his class shows no great relationship to these matters. Nevertheless a mention might be useful at this stage.

By definition, centrifugal force is that force which acts outwards on any body that rotates and is directed away from the axis of rotation. Centripetal force is that force which acts inwards on any body that rotates and is directed towards the axis of rotation.

In actual fact the important force is the centripetal one because this is the cause of the motion. An object would move straight on were it not for a force acting towards the centre of the circle pulling the object round. If it is released at any moment it flies off at a tangent. We can observe this action if we see a car starting or travelling on a loose surface when the gravel is thrown out by the revolving of the wheel.

If we have an object on the end of a piece of string and whirl it round, the object will travel approximately in a circle. In this instance we ourselves are the source of the motion and we experience the resulting tension in the string as a force pulling us radially outwards. This is the centrifugal force. It does not exist as an independent force. This is demonstrated by the fact that if the string is released the object does not fly out along a radius, but along the tangent. An example of centrifugal force in action is to be seen (and experienced) in the Rotor at a fair.

When we think of the earth rotating, there is no centrifugal force at the poles but a great deal at the equator. For this reason a man weighs less at the equator, something like half a pound or 230 gm, and the earth itself is flatter at the poles. One might think that with the earth spinning as it does – the speed at the equator is over a 1,000 miles or 1600 kilometres per hour – the centrifugal force would throw everything off the surface. Working against this tendency to fly off is the force of gravity. The same point of view can be extended to the movement of the moon and planets and according to Newton, it is the balance of forces which keep earth, moon and planets in their courses. The fact that Newton did not explain how they got there in the first place may open up the field for discussion of other points of view.

At the same time the fact that physical existence is dependent on a balance of forces gives the teacher the opportunity to draw parallels. The human being is also subject to physical forces and he too must maintain a balance. But a healthy human being requires balance in other respects. He can direct his forces outwards and inwards. Outwardly he can create or show sympathy; inwardly he can develop mind and soul.

In addition to the foregoing there should be, in Classes 7 or 8, descriptions of the work of factories or installations showing how manufacture, transport, physics, chemistry, geography, natural science are all interwoven. (Visits of course are also instructive). In the present technological age the possibilities of such studies are endless. The teacher is naturally free to take whatever he pleases but this is an area which lends itself very well to individual projects. Children should be learning to work individually and here is an opportunity for encouraging them to do so. Each individual may then also contribute some knowledge to the whole.

The following is a random selection of suggestions:

The production and distribution of gas (from coal), electricity, petroleum.
The manufacture of cars, bicycles, aeroplanes bridges, any piece of machinery; building of ships.
Textiles. The water supply. Sewage system. Light houses.
Printing and colour printing. Coal mining. The Work of divers.
Plants in industry (Jute for sacks; sisal, ropes; coconut palm, soap).

HYDRAULICS

Hydraulics is the science of conveying liquids through pipes and also of using them as forces. The word is derived from the Greek 'hudor' wafer and 'aulos' pipe. It concerns the mechanics of water.

With the idea of comprehensiveness in mind the subject could be introduced by inviting general observations on liquids, particularly that most common of all liquids, water, amplified by the teacher where necessary and referring to what has been learnt in geography and other allied subjects. The remarks made on water in the introduction could be used here as well as such oddments as the following:

Two thirds of the earth's surface is covered by water. Milk is 87% water. Every day, in England, each person uses about 10 gallons excluding baths. A cow drinks 20 gallons of water for every gallon of milk produced.

The siting of villages in the past has been dependent on the water supply. For instance, the Anglo-Saxon villages along the lines of the North and South Downs are all at the foot of the hills where water is available.

It is instructive to watch the tides filling up nooks and flowing around the jetties in a harbour. There is a fascination in watching the movement of the waves. It is interesting to observe how a brook or a river has carved out its bed and how the currents actually flow. Water seldom takes a straight course but it meanders. It finds the easiest route and hence makes a curve round anything resistant; but the curve means increasing wear on the outside bank, thus increasing tire snake-like pattern of the bed. Within the main flow of the water, swirls, eddies and minor currents can be observed some even flowing in an opposite direction. A limestone cave gives a wonderful opportunity of seeing the effect of the sculpturing power of water. One can observe the directions in which the water has flowed from the formation of the rock.

Not only do rivers shape the landscape in their meanderings but they also shape and reshape their own bed. This is particularly obvious in mountain streams where the fall of the water creates steps. Waterfalls retreat. It has been estimated that the Niagara Falls are now 8 miles further upstream than they were 20,000 years ago. In areas where the water can spread, the flow is slow but where it passes through gorges, the same volume attempts the passage and therefore the current flows faster. As a river approaches the sea the fall is very often extremely small yet tremendous masses of water are moved.

Water flows downward naturally under the influence of gravity but even if it is pumped through pipes, it still does not lose its flowing characteristics. Man makes use of the natural downward flow in harnessing water power to drive turbines in hydro-electric works. The same power was formerly used for driving mills and other machinery. An ingenious invention of earlier times was the water clock. Without any mechanical arrangements the current in rivers can be used, for instance, in floating logs from forests to the timber yards.

We usually think of water as having a level surface but this is correct only to a degree. In actual fact the water level in nature follows the curvature of the earth. Every point on the surface is vertical to the force of gravity

Liquids are heavy. That will be obvious to anyone who has had to carry a bucket of water or a can of petrol.

The liquid element is also very present in the human being. He quickly becomes ill if the gland systems do not function properly. It is the blood which is the great carrier and distributor of all the nutrients necessary to all parts of the body.

The essential nature of a liquid, by contrast to that of a solid, is that it has the quality of flowing. If we observe a lorry and a road tanker being unloaded we note the effort required if the goods are solid and the ease, simply by fixing a pipe, if they are liquid.

Increasingly liquids, particularly petroleum, are being transported by pipe line. Think of the number of wagons, or the number and size of ships required if no pipes were available. Think of the transport required to bring oil from Alaska, as well as other difficulties, if no pipe line could be laid.

The pipe makes things relatively simple. In older times water had to be carried into the house from the well or pump. Now we turn a tap and out it gushes through a pipe. Our waste, too, is also carried away through pipes.

Liquids are very mobile, flexible substances. They flow round corners without difficulty; they spread themselves easily. The moving parts of a machine would soon be worn out or seize up if they were not lubricated by a substance, oil, which retains it mobility and flexibility.

A few simple experiments will demonstrate the characteristics of liquids.

A rubber tube is fitted with a funnel at one end and a glass tube at the other. The funnel and glass tube are held level and water is poured into the funnel until it appears part of the way up the glass tube. When the funnel is raised the water in it sinks but rises in the tube and vice versa.

A vessel is filled with water and one end of an empty tube placed in it. The other end hangs over into another container. Nothing happens until the tube is filled with water. Then the water flows until the levels are equal.

We see that water in connecting vessels finds it own level.

Applications: When a spring bubbles out of the ground, it is because its source is on higher ground. This is true even if the spring is high up on a mountain and there are apparently no higher mountains around it. The source may be hundreds of miles away.

The same principle holds good for reservoirs and the water which flows from our taps. In cases where the reservoirs are lower than the houses, a supply is pumped into so-called water-towers from where it is distributed. Where a house has its own water supply it is usually pumped up into a tank for easy distribution through the taps. In central heating and hot water systems a tank has to be installed high enough in the building to supply a sufficient "head" of water. In an artesian well the same principle applies although here a boring has to be made through an impermeable stratum.

When tea is made in a teapot the level of liquid is the same in pot and in spout. When the pot is tipped so that the opening of the spout is below the level in the pot, the tea flows.

If we look under the sink or in the bathroom, we see "elbow" bends on the waste pipes. Water is retained in these and forms a barrier to unpleasant smells which may otherwise come into the house.

The fact that water in connecting vessels finds its own level is used in canal locks to raise or lower barges or ships to different levels.

Experiment: A can with holes punched in the side at different levels is filled with water. From the bottom hole the water is projected much further than from those higher up.

We see that pressure increases with depth.

Applications: Divers need special protection. Submarines must be built to withstand the pressure. (In a specially constructed vessel, known as a Bathyscaphe, Professor Piccard descended in 1960 to a depth of 35,802 feet, 6¾ miles, in the Mariana Trench in the Pacific.) Water power for generating electricity. The shape of a dam.

Experiment: A rubber ball with one small hole is filled with water. Holding the thumb over the hole, the ball is squeezed.

A rubber ball with several holes is filled with water and squeezed from the top, then from the bottom or the sides. In each case the water spurts out from the holes with equal force.

We see that a liquid cannot easily be compressed and that pressure on a liquid is felt everywhere throughout the liquid. The latter fact was discovered by the French physicist Pascal, (1623 - 62). He stated: If a closed vessel filled with water has two openings, one of which is a hundred times larger than the other, and if each opening be fitted with an exact fitting piston, a man pushing in the small piston could balance the efforts of a hundred men pushing in the other, and he could overcome the force of ninety-nine men.

Obviously the piston in the smaller cylinder will travel farther than that in the large one, on the same principle as lever and pulley.

Applications: hydraulic press, lift, jack. Hydraulic brakes, (pressure applied to the master cylinder exerts pressure equally on all the wheels.) The suspension, braking, retraction on a Jumbo jet are all controlled by hydraulic power

In the depths of the ocean there is enormous pressure but objects do not immediately disintegrate because the pressure acts on all sides. The deep sea fish have water in their bodies which counterbalances the pressure from outside.

When an object is placed in water, it is subject to pressure from all sides. As it sinks the pressure from below upwards increases. When this pressure balances its weight the object floats.

A law relative to this was discovered by the Greek scientist Archimedes. He found that a body immersed in liquid is subject to the upward pressure of the liquid and this pressure or apparent loss of weight of the body is equal to the weight of the fluid displaced. Stated another way: a body loses as much weight when in water as the weight of the water it displaces.

A famous story about Archimedes concerns his way of determining whether a king's crown was of pure gold, as it was purported to be, or whether it was an alloy.

Hieron, King of Syracuse, suspected that his crown was not of pure gold and gave Archimedes the task of finding out without destroying it. It is said that Archimedes hit upon the solution to the problem by noticing the rise of water when he got into his bath. He is supposed to have jumped out in his excitement and run down the street naked, shouting "Eureka, eureka" (I have found it.)

He obtained an amount of gold and a similar weight of silver. Since silver weighs less per volume than gold, it displaces a greater amount of water when immersed. He put the crown in water and noted the displacement. If the crown were pure gold, a weight of gold equal to the weight of the crown would displace the same amount of water, but he found that the crown displaced more. Hence it could not be of pure gold and by various measurements with the two metals, he was able to determine the proportion.

From the incident in the bath he is also said to have derived the principle of buoyancy, stated above.

Although liquids have similar characteristics, they also have differences. Some will support objects easier than others. E.g. If a fresh egg is placed in a jar of fresh water, it will sink. In a jar of salt water, it will float. It is easier for the human being to swim in salt water than in fresh. In the extreme case of the Dead Sea there are so many minerals dissolved in the water that it is impossible for the human body to sink in it.

The difference between the two liquids is one of density. Density means mass in relation to volume. (Mass is the quantity of matter in a body and this quantity is

measured by its weight). One cubic centimetre of water has a mass of one gramme (at 4°C). Density equals mass divided by volume. We define the density of water as one gramme per cubic centimetre. This is the standard by which other things are measured. Salt water has a greater density than fresh. Objects with lesser density than the liquid into which they are placed will float in that liquid; with greater, they sink.

One cubic centimetre of lead weighs 11.3 grammes. Its density is 11.3 gm. per c.c. It will therefore sink in water. One cubic centimetre of wood weighs 0.8 grammes; it therefore floats.

As well as density it is useful to know, as a standard, the ratio of the weight of any volume of a substance to the weight of an equal volume of water. This is known as the "specific gravity". In metric measurement this is the weight of one cubic centimetre of a substance relative to the weight of one cubic centimetre of water and numerically the figures are the same as those for density. Thus the specific gravity of lead is 11.3 and that of wood 0.8.

The human body has an average specific gravity of less than one, but only just so, and that when the lungs are full of air. It will float therefore in water but if upright only sufficient for the top of the head to be above the surface. If water gets into the lungs, the specific gravity becomes more than one, and the body sinks.

It may seem strange that when we throw a piece of iron or steel into water, it sinks, yet a ship containing many tons of steel will float.

Wood is naturally buoyant and it is therefore no surprise that a wooden ship will float. A piece of iron sinks because its density is greater than that of water. On the other hand a ship floats because its density is less. A ship is not solid. Even though loaded with cargo, there is plenty of air space. It has a large volume relative to its weight.

If a ship weighs 40,000 tons, it will sink in the water until the weight of water displaced is 40,000 tons, then the upward thrust of the water (buoyancy) makes it float.

All ships have a "plimsoll" line. This shows the safe depth to which they can be loaded both in fresh and salt water.

PNEUMATICS

Pneuma is the Greek word for wind or air. Pneumatics is a word which has become well known in connection with air-filled tyres but in the sense used here it is the science which concerns itself with the mechanics of air or gases.

As with hydraulics the study should begin with a few general observations extracted as far as possible from the pupils.

The atmosphere around us is not, as one might suppose, mere emptiness. Neither does it reach out into the infinite. The average height of the earth's atmosphere is seven or eight miles. It consists of what we call air but air itself is a mixture of substances, including water vapour.

Air is something vital to life. All living creatures need it. From the moment a human being is born to the moment he dies he needs air. When he dies, we say he expires, i.e. he breathes out. The element of air also appears in other figures of speech. The politician talks "hot air". To be deflated is "to have the wind taken out of his sails".

When the wind blows, air is in motion. When we pump up the car tyres, we compress air. When we climb high mountains, we have difficulty in breathing because the air in the upper reaches of the atmosphere is rarified, i.e. thinner.

We use air, directly, for driving windmills and sailing boats. We use it, indirectly, in various machines as, for example, a pump.

When air is compressed we speak of high pressure; when thinned, low pressure. In our breathing process we continually create small areas of high and low pressure. When we breathe in we form a low pressure systems in front of our nose. In breathing out we pressurise the air, making a small high pressure system.

This is the characteristic behaviour of air and gases. Unlike solids, which remain constant in form and volume unless acted upon by outside sources, and unlike liquids, which adapt their form according to their surroundings under the influence of gravity but remain constant in volume, the nature of air or gases is to expand to fill the available space but they move according to pressures which are created by other agencies. Liquids are contained by preventing their flow downwards but gases have to be contained on all sides. We can easily note how a gas expands if we turn a gas tap on a moment before applying the light, or, if there is a small gas leak, the whole house smells.

Various experiments can be made to show that air is a substance and has definite characteristics. Breathing in and out is one, or fanning the face.

Experiments. A toy parachute can be made with a handkerchief. When thrown into the air, it will float slowly down to earth.

A jar filled with water is held mouth downwards under water. Another empty jar is pushed into the water mouth downwards and the air enclosed in this is

poured upwards into the other jar.

A small tube and stick can be made into a 'potato shooter', The tube is plugged at both ends with potato. When one piece is pressed further in with the stick, the other shoots out.

These experiments show that air is a substance.

Experiments: A thin lath is laid on the table with a few inches overhang. The part on the table and all around it is covered closely with newspaper. When the end of the lath is struck sharply, it breaks. Without the paper it bounces.

A balloon is put inside a bottle and the neck of the balloon is stretched over the neck of the bottle. It is impossible to blow it up.

A sucker is pressed to the wall. It stays there.

A jar is filled with water so that there is no air space, a cover put over it and the jar quickly inverted. The cover stays in place.

A tube is filled with water. As long as it is kept closed at the top, the water does not run out. (Pipette).

If air is compressed, as in a bicycle pump, it gets hot. When it expands, it cools.

Torricelli's Experiment: Torricelli was a friend of Galileo. He took a glass tube about one metre long, sealed it at one end and filled it with mercury. He then put the open end in a bath of mercury, held the tube upright and noticed that a small space showed at the top, obviously a vacuum.

If such a tube is observed from time to time, and in different places, it would be noticed that the space varies. Further observation would confirm that it changes with the weather, i.e. with atmospheric pressure.

This is the principle on which the barometer works.

The same thing could be done with water but the column of water would have to be about ten metres high.

These experiments demonstrate the weight and pressure of the air. In actual fact the atmospheric pressure can be measured. Ten metres of water resting on one centimetre surface is the same as a thousand cubic centimetres, a thousand grammes or one kilogramme. Hence the measurement of kilogramme per square centimetre. This is equivalent to about 15 pounds per square inch.

The modern way of expressing pressure is in millibars. One millibar is equal to about one thousandth of the pressure of the atmosphere operating on an area of one square centimetre. The pressure in England varies between 960 and 1,040 millibars. The highest recorded pressure in the world is 1,083 millibars and the lowest 877.

Experiments: A long strip of thin paper is held over the top lip and the breath blown out. The paper becomes horizontal. It is held beneath the lower lip and the action repeated. Again it becomes horizontal.

Two strips of paper are held several inches apart and the breath directed between them. They come together.

The reason for these apparent contradictions is that, by blowing, areas of low pressure are created and the higher outside pressure forces the object or objects towards the low pressure areas.

Applications: Aeroplanes and sailing ships make use of these principles.

When roofs are lifted in a storm it is due, not as might be supposed, to meeting the wind directly, but due to a low pressure area created by the wind in passing. When hurricanes blow, it is the walls on the not exposed side which collapse for the same reason.

When a vacuum cleaner is working, a low pressure area is created inside it which causes the suction.

If we go climbing in the high mountains, we have difficulty in breathing. We say the air is rarer, or the atmospheric pressure is reduced.

If therefore we boil water at a high altitude, there is less pressure on the surface and the water will boil at a lower temperature. Alternatively, below ground, the boiling point is higher. If water is confined to a boiler, it will boil at a higher temperature and the steam comes under pressure.

When pressure is reduced to nothing we have a vacuum. Is it possible to imagine "nothing"? One speaks of the horror of a vacuum. It was thought at one time that natural phenomena were brought about by the "horror vacui". Nature feared empty space and would go to any length to avoid it. "Nature abhors a vacuum".

The Magdeburg Experiment: In 1654 the Burgomaster of Magdeburg in Germany conducted an experiment which has become famous. He had two large hemispheres of copper made, fitted them together closely and then extracted the air by a device of his own invention. A strong horse was then attached to each of the hemispheres and the attempt made to pull them apart. To the amazement of the good citizens it proved impossible. When a valve was opened to admit air, the two halves fell apart easily.

It is possible to harness the power of a vacuum as, for instance, in vacuum brakes. As it does not conduct heat, a vacuum is incorporated in a Thermos flask.

In earlier experiments we have seen how gas expands under the influence of heat. This fact is made use of in gas turbines and jet engines.

Steam is of course also a gas which can be heated and its power of expansion is used in the steam engine. It is steam power which activates the geysers to be found in North America, Iceland and New Zealand. It is steam power which produces the noise in a whistling kettle.

Air or gas can also be cooled. The Montgolfier brothers floated a balloon in 1783 by means of hot air which rises. We know how water turns to steam under the influence of heat and we know by a cooling process that steam turns to water. If we can lower the temperature sufficiently, air itself condenses to form a liquid. It does this at a temperature of about -200 °C. Some gases such as chlorine and ammonia will liquify by compression, but air and the gases in it have to be cooled. When liquid air is exposed, it boils, but the gases in it boil at different temperatures. By careful supervision it is therefore possible to draw off the different gases. Oxygen remains liquid up to -182 °C. This is the process by which liquid oxygen is produced. It has to be stored in special flasks known as Dewar flasks, which incorporate the same principle as the Thermos flask. Oxygen is used for welding, in rocket engines and also for medicinal purposes.

Another gas which is produced in a similar manner is neon, which is the gas used in the lighting strips.

We have seen that air can be thinned. Every time we use an air pump we see that air can be compressed. The caissons used in underwater construction are full of compressed air to keep the water out. We use compressed air in the pneumatic drill, in bellows, an accordion, hovercraft, football. Compressed air in pneumatic tyres smooths the ride in our cars. We know well enough that if we have a puncture, the air escapes. If we take a bicycle pump, seal the end with a thumb and push the handle down, we can feel how the air is being compressed and how it pushes the handle back when we let go. All gases have this quality.

When air or gas is suddenly released, an explosion occurs. This is why we can "pop" a paper bag The expanding property of gas is exploited in every explosion. Through chemical means a tremendous pressure is released in a limited space. When gunpowder explodes, the increase in volume is nearly four thousand fold.

When an explosive ignites the temperature may rise to 6,000°C, and the ratio of volume in a modern explosive can be as high as 1:12,000. It is the expansive power of gas which is used in a rocket engine.

One surprising use of an explosive is to blow out an oil well fire, as we blow out a candle.

Summary of properties, qualities, characteristics of substances and terms used to describe them.

Solids:	Fixed volume and shape. Rigid.
Liquids:	Fixed volume taking on the shape of receptacle holding them. Fluent.
Gases:	No fixed shape or volume. Evanescent.

Compressibility:	A quality only really applicable to gases.
Elasticity.	The ability to resume normal bulk or shape after distortion.
Ductility:	The property of certain solids (metals) to be made into fine threads.
Malleability:	The property of metals to be beaten into thin leaves, especially applicable to gold.
Viscosity:	Resistance to flow in liquids.
Conductivity	The ability of a substance to transmit heat (thermal) or electricity.

CLASS 8

The greater part of the physics period will be devoted to studying the practical working of what has already been learnt. Mention of many things will have been made already but they can now be examined in more detail and with greater understanding. Here we list the sort of things to be studied or constructed in Class 8, possibly extending into 9. It is not suggested that the whole field can be covered. Social/moral aspects should not be overlooked.

Record-player, echo-sounding equipment, megaphone, loudspeaker, sound barrier, acoustics of a hall, measuring noise, noise insulation.

Spectacles, telescope, microscope, periscope, cystoscope, photography, cinema, lighthouses, candlepower, stage-lighting, manufacture and technicalities of lenses, sundial, astronomical light year.

Metal tyres, straightening walls in old houses, gaps in steel bridges, automatic fire alarm, thermostat, thermometer, ferro-concrete, old type central heating (without pump), different types of steel, refrigeration, the ice-rink, steam engine, Newcomen's atmospheric engine, why a boiler bursts, car cooling system, efficiencies of fuel and heating systems.

Use of magnets – drawing metal particles from the eye in accidents, sorting metals, cranes, closing cupboard doors.

Electric lighting, heating and all domestic uses, electric motor, generator, electrics in the car, telephone, radio, arc lamps, metal plating. Comparison of electric motor with internal combustion engine.

Gears, transmissions, turbines, Screw of Archimedes, hydraulic press and lift, caissons, lavatory cistern.

In the study of the internal combustion engine, in this class or the next, there is much to be observed relevant to past teaching:

Engine, direct movement into rotary
Cylinders, expansion of gases
Dynamo, magnet and coil to produce electricity
Cooling system, convection
Radiator, dispersal of heat through large surface
Carburretor, evaporation
Transmission, one circular movement into another
Gears, velocity ratio and mechanical advantage
Rod or cable brakes, levers
Hydraulic brakes, fluid pressure
Friction, grip of tyres

METEOROLOGY AND CLIMATOLOGY

In so far as the weather is also connected with physics, it becomes a subject for study under this heading. A few notes are appended here on the teaching of meteorology and climatology put for the most part the necessary information can be obtained from suitable text books. The teacher should bear in mind the idea of comprehensiveness and the various points enumerated in the teaching of science. A short resume of the principles concerned should be given.

It may be that some reference to earlier lessons will set the mood. Something like this may be said: In Classes 1, 2 and 3 you heard something about the elemental spirits at work in nature; in Class 4 you learned about your surroundings and listened to Norse stories, in Class 5 you studied plants and heard stories from Greek mythology. In many of the poems you have learned and the tales you have heard, there has been a mention or description of nature spirits. In Classes 6 and 7 you have bean learning about the laws of the physical world. Since Class 5 you have been learning history and now you may realise (although this is really a study for the upper school) that men's minds have not always functioned in the same fashion.

People of earlier times, just as you did when you were vary small, thought of elemental beings activating nature, or of monsters and dragons in the winds. We may think now that we know the answers through physical laws but there is still the question of who fashioned the law in the first place.

The children may be reminded of the story of the cloud (the rain cycle). Now it can be put in another way. The rain comes down; a third runs off into the rivers etc., a third sinks into the ground, and a third evaporates as vapour from the ground, from living things, from animals. It rises, condenses, forms clouds, and returns.

In the matter of "wholeness" these subjects should be co-ordinated with geography and with the study of man Things to be considered are: the effect of warmth and cold in nature. There is abundant life in the tropics, low levels in arctic regions. What is the seasonal effect in the temperate zones?' How are warmth and cold distributed through the air and the seas?

There is, too, the effect of warmth and cold on the human being. Excesses in either direction create disturbances. We might further consider racial differences mentioned already in the chapter on heat. Has the happy-go-lucky nature of the Italian any connection with the sunny Mediterranean and is the Scotsman so dour because of the inhospitable climate in which he lives?

Reference was also made earlier to the effect of heat and cold on the individual, and to the significance of these terms in the applied sense. Is it true that most people feel happier and better when the sun shines and sink into themselves when the weather is adverse. Does the sun stimulate and cold paralyse the will? What does it mean when we say "getting hot under the collar", a hot temper; cool as a cucumber; a cold fish.

The majesty and power of the elements should also be appreciated by the artistic side of the human being as well as his intellect. For this purpose perhaps poems and descriptions from literature can be useful. Typical would be Shelley's poems: *The Cloud*; *Ode to the West Wind*.

It should be possible to make a study of the snowflake, to appreciate the wonder and the beauty of its form as well as considering the effect of a snow blanket on the earth.

The power of the elements is well documented. For instance in 1961 a hurricane hit the coast of Texas over a distance of 350 miles at a speed of 200 miles par hour. Houses, furniture, tractors were tossed into the air. (We can consider the derivation of the word "hurricane". Hurrican in Carib Indian means an evil spirit.)

Some fifty years ago a typhoon struck Japan and a ship was lifted bodily out of the harbour and deposited on land.

The weather also has to be considered in constructing roads and railways.

The uses of weather forecasting should be pointed out, for farmers, ships and aircraft, as well as helping us to decide whether to spend a day at the seaside.

The responsibility for the earth, which touches social and moral aspects can be brought home by considering how the cutting down of forests can change a weather pattern and how the existence of a big city influences the weather. Pollution, aerosol sprays may be affecting weather.

There follow the scientific explanations based on what has already been learned, or which are otherwise readily available in reference books. Subjects will include:

Climate and reasons for it on a world scale.
Local weather patterns.
Cloud formations and the different types of clouds.
Fog, mists, ground mist, dew, frost. snow.
Tornadoes, hurricanes, typhoons, cyclones, whirlwinds, waterspouts.
The Beaufort scale.
Barometer, aneroid barometer, anemometer, rain-gauge.

An added interest would be to make weather forecasts from observing the wind direction, cloud formation, etc. without the use of instruments.

It may be possible sometime to observe a glider or hang glider and read from its movements the direction in which the wind hits the hills, or how thermal pockets arise over a ripe cornfield or a paved road.

Factual information on such matters as extremes will be of interest.

E.g. Hottest part of the world, San Luis, Mexico, 56°C in the shade
Coldest, Antarctic plateau, – 88°C
Driest, Atacama desert, Chile. No rain at all
Wettest, Cherrapungi, Assam. 2646 cms per annum.

RUDOLF STEINER EDUCATION

PART II
TEACHING CHEMISTRY
FOR AGE GROUPS 13/14

Roy Wilkinson

RSCP

INTRODUCTION

In the parallel booklet "The Physical Sciences" 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 practice 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.

Suggested outline of work suitable for Classes 7 and 8 (ages 13 to 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 CaCO3 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, CaCO3
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 as 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 is 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 "limelight". 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 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 he 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 (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 learnt 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 section 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, CaCO3 + heat → Carbon dioxide CO_2
(Chalk, marble, limestone) → 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 carbonate → 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)
Plant plus fire → 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 now non-soluble and it is the "fur" which we find inside kettles.

$$Ca(HCO_3)_2 \longrightarrow CaCO_3 + H_2O + CO_2$$

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.

$$HNO_3 + NH_3 = NH_4NO_3$$

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.

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 copperglance, 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.

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:

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

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.

Textbooks 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 men 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, forever 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;

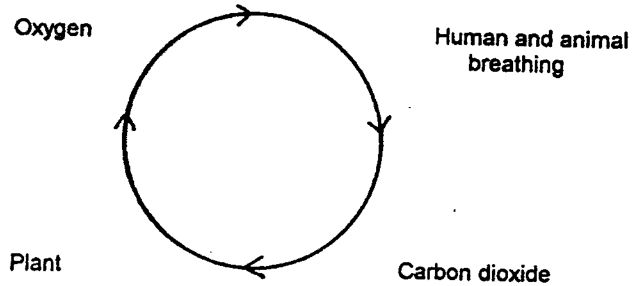
from below comes the water and mineral substances.

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.

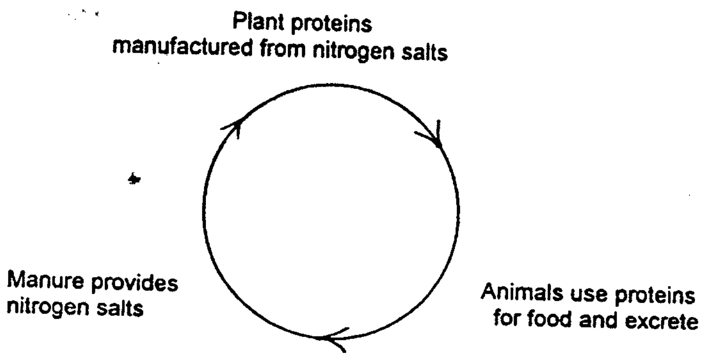
There are three cycles in plant growth:

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:



The third:



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 rôle 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 me 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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