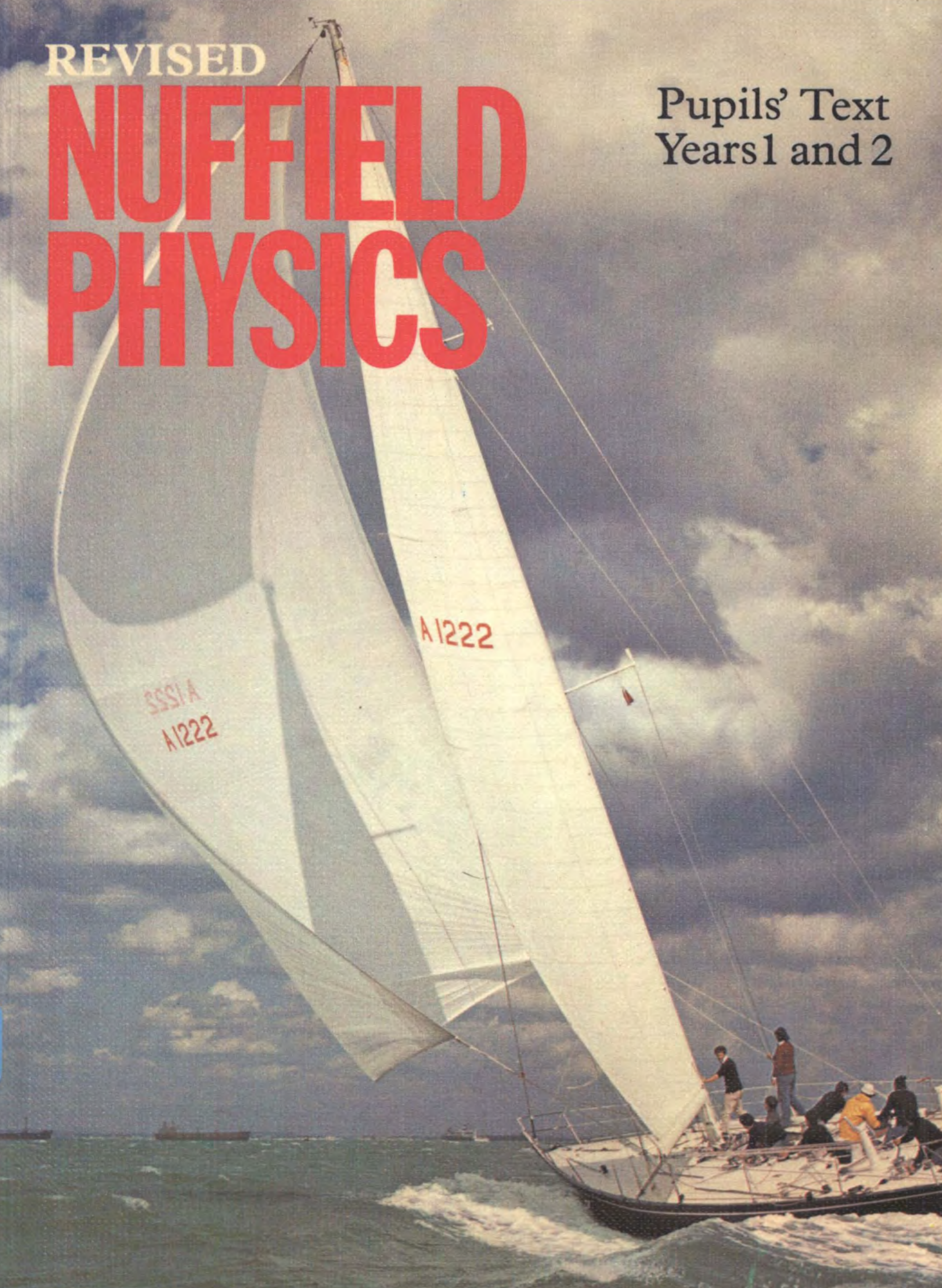
REVISED

NUFFIELD PHYSICS

Pupils' Text
Years 1 and 2



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Nuffield Physics
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General Editors
Eric M. Rogers
E. J. Wenham

Contributors
H. F. Boulind
Margaret Fawcett
Reinet Fremlin
Gwen Jones
Hilda Misselbrook

Cover photograph

Fortuna, a Class One Ocean Racer from Argentina, racing at Cowes for the Admiral's Cup.

Photograph, Beken of Cowes

REVISED

NUFFIELD PHYSICS PUPILS' TEXT YEARS 1 AND 2

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Foreword

In the early 1960s the Nuffield Foundation commenced its sponsorship of curriculum development in the sciences. Specific projects can now be seen in retrospect as forerunners in a decade unparalleled for interest in teaching and learning, not only in, but far beyond, the sciences. Their success can best be measured by their undoubted influence and stimulus to physics amongst teachers—both convinced and not-so-convinced.

The examinations accompanying the schemes of study, which have been developed with the ready co-operation of the Schools Certificate Examination Boards, have provoked change and have enabled teachers to realize more fully their objectives in both classroom and laboratory. The changes continue and the nation is currently engaged in discussion of further alterations to the pattern of examinations. Whatever the outcome, we are confident that these Nuffield studies will continue to make important contributions to the teaching and learning of science. In these volumes we have attempted to produce materials to meet the needs of particular classroom situations. Where curriculum development is not capable of adaptation and renewal, it impedes, rather than encourages, innovation and it commits the very sin it sets out to avoid.

The opportunity for local curriculum study has seldom been greater and the creation of Schools Council and teachers' centres has done much to contribute to discussion and participation of teachers in this work. It is these discussions which have enabled the Nuffield Foundation to take note of changing views, to correct or change emphasis in the curriculum in science, and to pay attention to current attitudes to school organization. We have learned from many, particularly those in the Association for Science Education, who, through their writings, conversation, and contributions and in other varied ways have brought to our attention the needs of the practising teacher and the pupil in schools.

This new edition of the Nuffield physics material draws heavily on the work of the editors and authors of the first edition published in 1966. An immense debt is owed to them. The physics programme was inaugurated in May 1962 under the leadership of Donald McGill. It suffered a severe setback with his tragic death on 22 March 1963, but those who were appointed to continue the work have done so in the spirit in which he initiated it, and in the direction he foreshadowed. He was succeeded as organizer by Professor E. M. Rogers. Together with the associate organizers, John Lewis at Malvern and E. J. Wenham at Worcester, the assistant organizer, D. W. Harding, and the deviser of the *Question Books*, the late H. F. Boulind, the teams of teachers led by Eric Rogers produced teaching ideas that have influenced profoundly curriculum discussions and physics at a time of major educational change.

The new volumes draw in many ways on the original *Teachers' Guides* and *Guides to Experiments* and *Question Books*. Their contribution in providing a firm basis for these further developments is gladly acknowledged here. It is a pleasure to praise the part played by the large number of teachers who have helped in discussion, feedback and persuasion but it is once more to Eric Rogers who, with an extraordinary vitality, has led and completed this work, that we especially record our thanks.

Our thanks go with equal appreciation to Ted Wenham. As well as editing *Teachers' Guide Years 1 and 2* in the new edition and writing the new *Pupils' Text Years 1 and 2*, he has continued to act as a very wise and helpful consultant on all aspects of the programme. His judgement and knowledge have been welcome and essential throughout.

Lastly I should like to acknowledge the work of William Anderson, our Publications Manager, and his colleagues, and of course our Publishers, the Longman Group Ltd, for their continued assistance in the publication of these books. The editorial and publishing contribution to the work of the projects is not only most valued but central to effective curriculum development.

K. W. Keohane
Co-ordinator of the Nuffield Foundation Science Teaching Project

General Editors' Preface

Many years ago the Nuffield Foundation, following requests from teachers who suggested changes in O-Level Physics teaching, gave a large grant for studies of needs, development of apparatus and the provision of printed materials to offer a new teaching programme to schools who liked to try it.

The essence of that programme, as it emerged from consultations, visits to schools, discussions in groups of teachers—was a change from teaching hampered by insistence on rote learning towards even more learning for understanding which, it was felt, would provide greater chances of pupils' learning of science being transferred towards long-lasting benefits.

By now, pupils of many schools have tried that programme – we believe with enjoyment and some success. As pupils reached the end of the five years to face an O-Level Examination, the teaching proved justified by the admirably relevant Nuffield Physics papers produced by the Oxford & Cambridge Schools Examination Board (acting on behalf of all Boards). The number of candidates for that Nuffield O-Level Physics Examination is now over 20,000 each year.

Those Nuffield papers were set with the aim of testing the teaching and learning that we suggested; and they received sympathetic marking which looked for understanding in candidates' answers.*

Many teachers have followed some general suggestions:

1 Let pupils work in the lab in small groups, often pairs, and leave them alone to make their own mistakes and find their own solutions, except where rescue is needed. That seems to us near to professional science.

2 Use stimulating questions as principal learning aids to encourage discussion, reasoning, and imagination.

In making the revision for this new edition we received a general directive from the Foundation; that we should try to maintain the same standard of enquiry, and learning of science for understanding, and not change the programme in a way that would 'lose the Nuffield spirit'. The Foundation recognized the changes in school structure but considered that other programmes, such as Nuffield Secondary Science, provide better for other levels of treatment than a heavily diluted version of our programme could do.

We started the revision by consulting some 200 teachers, some of them in person, many by profuse enquiry forms. We also visited a considerable number of schools to see Nuffield classes in their present form. Again, those visits influenced us very profitably in our revision.

We changed Dr Henry Boulind's excellent Questions for thinking and understanding to simpler wording, but retained their essential enquiry. In response to pleas from teachers, and to the needs of the new schools structure, we added Progress Questions to provide a different and easier approach.

Our most important change of all in the revision has been the production of the *Pupils' Text* in four volumes, to provide young scientists with help for experiments and some discussions of ideas, also thinking questions and progress questions. Thus for many pupils this book should act as a complete substitute for work cards.

On behalf of teachers and pupils who will use these books, we owe thanks to many people: to our consultant teachers, without whose advice we could not have envisaged the needs of the project; to Professor R. A. Becher, who was our chief inspiration and guide in the original project, to whom we still turn for wise advice; to Professor K. W. Keohane as our co-ordinator with counsel

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*Two small examples may illustrate that:

i The Board prints on the front of the Examination paper all the formulae likely to be wanted – this is an assurance to both teachers and pupils that just 'memorizing formulae' is not so important. Candidates realize that memorizing definitions and formulae is not very profitable. On the other hand, the Examiners expect a candidate to understand the origin and uses of some formulae and their limitations – like a capable craftsman. And they expect a candidate to be able to describe physical quantities and relationships in his or her own words.

ii In marking scripts for O-Level, the Nuffield Examiners have not felt themselves restricted by a fixed marking scheme. They read with a flexible attitude, looking for good knowledge, imagination, and interesting suggestions too – which they award with bonus marks.

concerning Physics and teaching and people; to John Maddox, Director of the Foundation, for past interest and care, and now special encouragement. Both teachers and pupils will owe much to the five teachers who constructed the Progress Questions – forged and tempered them. Anthea Arnold, Margaret Fawcett, Reinet Fremlin, Gwen Jones and Hilda Misselbrook.

We would also like to thank the following: Michael Spincer of the Longman Group who gave much valuable advice at various stages in the planning and production of these books; the editors who saw them through the stages of production, Hendrina Ellis and Richard Shaw; our artist, Rodney Paull who is responsible for all the illustrations; the designers and art directors, Ivan and Robin Dodd; and Deborah Williams who carried out the picture research.

Eric M. Rogers, E. J. Wenham
General Editors

TO THE PUPILS WHO USE THIS BOOK

This book is about some physics experiments and observations. If you enjoy *doing* experiments and *thinking* about them as you do them you will understand some science and you will able to use your science.

This book also has lots of questions in it. They are to help you to think about the science you are learning and to help you to use your knowledge.

Some are clear and easy like this one:

QUESTION Which form of matter (solid, liquid, or gas) is easiest to make smaller by squeezing?
ANSWER. A gas. (Think of squashing air into a bicycle tyre.)

Others are more difficult – you will need to think carefully about them.
QUESTION A small stoppered bottle is half-full of water. Is it correct to say that the bottle is half-empty?
ANSWER Water fills the lower half. What is there in the top half? Air. So the bottle is also half-full of air. It isn't really half-empty.

Here is another example.
QUESTION Twelve boys weighed the same piece of metal on the same balance (which weighs to the nearest gram). The twelve results were:

173	173	174	173	173	172 grams
173	171	173	174	172	173 grams

One of the boys added all these and got 2074. He then divided 2074 by 12 and got to one decimal place, 172.8 g.

This is correct, but how would you have got the same result much more quickly, without nearly so much arithmetic?
ANSWER You could guess the average, say, 173. That number occurs 7 times. The other numbers were $(173+1)$, $(173-1)$, $(173-2)$, $(173+1)$ and $(173-1)$. That is five more 173s minus 4 plus 2. So the average is

$$\frac{(173\times 7)+(173\times 5)+(1-1-2+1-1)}{12}$$

which is

$$\frac{(173\times 12)-2}{12}$$

or
$173-\frac{2}{12}$
$= 172.8$ (to one decimal place).

QUESTION *(Following from the last question)* One boy wonders whether the balance is really correct, and to test this, he puts on it the following weights taken from a set of weights which has been tested and which is known to be accurate to much less than 1 gram. The weights are: 100 g, 50 g, 20 g.

They are put on the balance together and it reads 168 g. Several people agree about this. What do you think is the 'best' value (to the nearest gram) for the piece of metal?

ANSWER When the three weights are put on the balance it reads 168 g instead of the correct 170 g. So the balance is like a clock which is running a little slow – by 2 g in 170 g. To the nearest gram, the piece of metal must weigh $(173-2)$ g, or 171 g.

YEAR 1

CHAPTER 1
Materials and molecules
About solids, liquids, gases; about crystals, how they grow, how they dissolve; about the way we measure things

1 Experiment
Exhibition of materials

Look at an exhibition of common materials. Some of these will be natural; some are man-made; some are crystals; some have a smell; some are liquids; . . . .

Without looking at the labels, how many can you name?

You could sort out the pupils in your form by the colour of their hair and list them in groups headed FAIR, DARK, RED, . . . Or you could sort them by the colour of their eyes and list them in groups as BROWN, or BLUE AND GREY. *Can you do something like that for the materials in the exhibition?* For example, some of them are rocks; some are metals.

Progress questions

Most of these progress questions should be answered in the laboratory with the experiment in front of you. In many cases the questions will help you to see the point of an experiment.

1. In your Physics lesson you looked at an exhibition of materials.

What did you find most interesting?

2. Some materials have to be kept in dishes or they spread all over the bench.

a. Make a list of twelve materials like this you have seen.

b. Choose six of them and say how a blindfolded person could tell which was which.

3. Imagine that you have two balloons exactly the same and a way of filling a balloon with natural gas. You blow one up yourself and fill the other with natural gas. How could you show someone that natural gas is lighter than air?

Do you know what the balloons that people fly in are filled with? There are two kinds. Can you describe how they work? If you don't know find a book, probably an encylopaedia, that will tell you.

4.

a. Name six materials *in your home* that are soft enough to be marked by a finger-nail.

b. Name six materials *in your home* that are too hard to mark with your finger-nail.

5. Look at this list of materials:

air, alum, aluminium, alcohol, brass, copper sulphate crystals, carbon dioxide, cotton, flour, glass, hydrogen, iron, marble, mercury, nylon, olive oil, Perspex, red rubber, salt, sand, silk, sugar, natural gas, vinegar, water.

Make lists of:

a. the metals;

b. the things you can eat;

c. the ones which are transparent (you can see through them);

d. three which are hard to the touch (you could not stick a pin into them);

e. three which are natural substances (not man-made);

f. the ones from which you could make saucepans.

6. Make headings in your book like this:

Solid *Liquid* *Gas*

and write a list of materials under each heading.

You may use the list of Question 5 if you like, but also add other materials.

Questions

7. *Experiment* Put on a tray about ten different solid substances; e.g. a stone, a cork, a piece of iron, a piece of aluminium, an india-rubber, a piece of sponge rubber, a steel ball, a piece of plasticine, some sugar, salt, sand, and a piece of chalk.

Feel their shape, weight, texture, temperature, squeeze them between your fingers, smell them.

Now shut your eyes while someone turns the tray and moves some of the things. Keep your eyes shut, and try to decide what each is by feeling it or smelling it. Open your eyes. Make a list of all the

Q.7 *continued*

objects and write against each one the property or properties by which you recognized it.

8.

a. A small stoppered bottle is half-full of water. A second bottle is half-full of bicycle oil. And a third bottle with golden syrup (or treacle). What difference would you expect to notice when each bottle is slowly turned upside-down?

b. A garage mechanic says, 'Motor oil is thicker than bicycle oil.' What does that mean? Give your own scientific description.

9.

a. Is it quite correct to say that each of the bottles in Question 8 is half-empty. If not, why not?

b. You could say that each bottle is half-full of the same substance. What substance?

10.

a. Here are four substances: glass, diamond, putty, your finger-nails. Write them in a 'scratch order', that is, so that No. 1 scratches No. 2 but is not scratched by it; No. 2 scratches No. 3 but it is not scratched by it; and continue like that for the third and fourth.

b. Would the first scratch the third and fourth?

c. A steel pin scratches wood, but a sharpened wooden stick does not scratch steel. So we say 'steel is *harder* than wood'. Which is the hardest of the four substances mentioned in (a), and which is the softest?

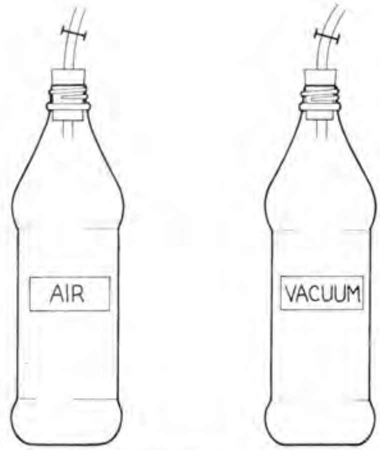
d. Write out and complete the following sentence, which explains what is meant by 'harder'.

'A substance X is harder than a substance Y if X . . ., but Y . . . .'

Transparent things Some of the materials are transparent (that is, you can see through them clearly). You will find two bottles in the collection with the labels AIR and VACUUM. The labels are correct. Suppose the labels had come off. *Could you tell which is which by looking at them?* Remember, one of them is 'full' of the air you breathe whilst the other is 'empty' of air.

Progress question

11. Here are two bottles which look alike. Each is closed by a clip on a tube. One is labelled AIR and the other is labelled VACUUM.



a. What does the word VACUUM mean? (Answer in three or four words.)

b. What happens when you put the bottle full of air and its tube under water and open the clip?

c. What happens when you put the bottle labelled VACUUM and its tube under water and open the clip?

Questions

12. You are given two tightly stoppered lemonade bottles. Both *look* alike and both look empty. One is labelled AIR and the other is labelled VACUUM.

a. When you weigh them you find that the bottle marked VACUUM weighs $\frac{1}{2}$ gram *more* than the other. Are you surprised? If so, what do you think is the most likely explanation? (You may take it that the labels are correct.)

b. How could you show to a younger brother or sister the difference between the contents of the two bottles? (You may now open them.)

c. What experiment would you do to show that your explanation in (a) was correct?

13.

a. You open a bottle which has nothing (a vacuum) inside and air goes in. Does this mean that there is less air somewhere else? Where has the air become less?

b. What happens when a bottle with no water in it is opened underneath the surface of the sea?

14. A can of lemonade has *two* places marked on the top where you should make holes to pour out the lemonade. Why two?

15. Three blown-up balloons, A, B, and C, look alike but A is known to be filled with air, B with carbon dioxide, and C with hydrogen. The material of the balloons is very light, and they do not carry strings.

The balloons are released and pushed over the edge of the bench all at the same moment. Two fall slowly to the floor. One of those reaches the floor before the other. The third goes upward and has to be fetched down from the ceiling. Which is which? And how do you know?

16.

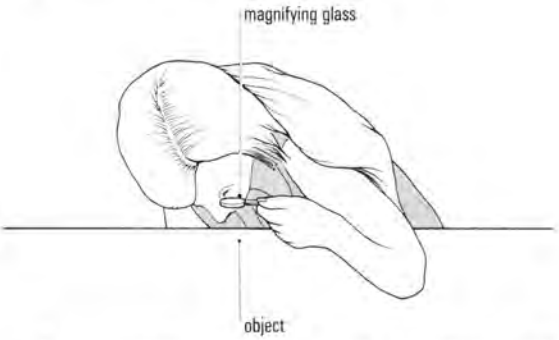
a. You are given two dice that look exactly the same, but one is loaded with a lead plug under the face marked 1. When placed in water, both sink. You drop each die gently into a glass of water several times. Could you tell by watching them carefully which was the loaded one? *How* would you tell?

b. Suppose one die is 'loaded' just under the face marked 1 and the other has an equal lead plug at the centre. How could you tell which is which, using a glass of water?

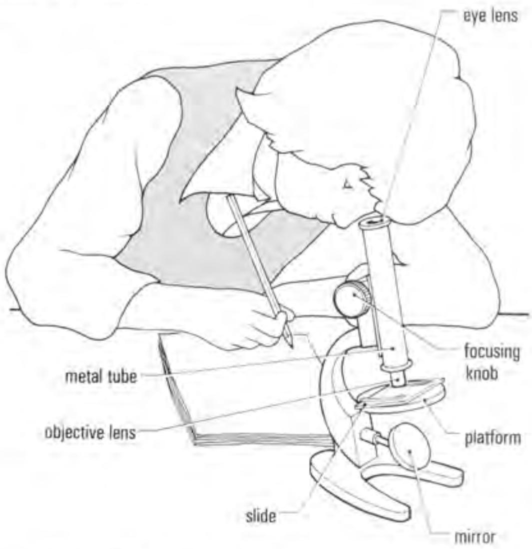
c. How could you tell which is which of the dice in (b) without water or any other liquid?

1a Experiment
A closer look

You may wish to have a closer look at some of the materials in the exhibition. Try using a magnifying glass. It is best to hold it close to your eye and then move nearer to the piece of material until you can see it clearly through the glass.



A microscope will give you an even closer look. First you must get used to making a microscope work. Try to look at, say, a pencil mark on a scrap of paper, or a grain of sand, or a hair from your head. Place what you want to look at on a glass slide. Put the slide on to the platform (= 'stage') of the microscope. Tilt the mirror under the stage to reflect light up through the slide into the microscope's tube.



DANGER

You must avoid letting the lens at the bottom of the tube (the objective lens) crash into the slide. The lens might get damaged. Therefore, to focus the microscope first look at the tube and the stage FROM THE SIDE. Turn the focusing knob so that the lens and your specimen are very close together but NOT touching.

Then look down the tube from the top and turn the focusing knob very gently so that the lens moves AWAY from the specimen, until you see the specimen magnified many times.

Things that show orderly arrangement Some of the materials have been cut to a regular shape. Others, called crystals, form in regular shapes of their own accord.

2 Experiment
Crystals

Look at some crystals of sugar to see how regular they are. Or look at 'hypo', the crystals of the material used to 'fix' photographic films and plates. The magnifying glass may help.

3 Experiment
Watching crystals form quickly

'Hypo' crystals are especially interesting because

3 E. *continued*

they can form quite quickly. Ask for a tube containing 'hypo' that has been melted to liquid. Drop in one tiny 'seed' crystal. *What do you see? Why is the crystal which you dropped in called a 'seed'?*

4 Experiment
Crystal growing

You need a jar (preferably with a loose paper cap) and some very strong solution of a crystalline substance in water. Alum is a good choice. Choose a

tiny, well shaped 'seed' crystal and tie it, using a slip-knot, to a short length of fine thread. Hang it from a stick or pencil placed across the top of the jar. Carefully place the jar in a place where it will stay at a fairly steady temperature – and wait. Do not disturb! You may have to wait for several days.

5 Home Experiment

You may try this at home too. You could use salt or sugar, or even Epsom salts. Start by dissolving some sugar in a little hot water in, say, a jam jar. Go on adding crystals until no more will dissolve. Pour off the clear solution into another jar and let it stand until it is cool. Then hang a short length of thread from a pencil across the top of the jar so that the thread is dipping into the solution. Watch it every day. That way you may be able to get a very good 'seed' crystal which you could grow to a larger size. If you try salt rather than sugar, don't use hot water, for that doesn't help salt to dissolve although it does help sugar.

6 Experiment
Watching a crystal grow under a microscope

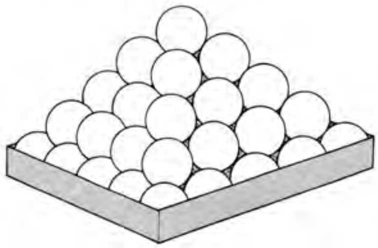
Take a clean microscope slide and warm it gently over a small Bunsen flame. Then place a tiny drop (about the size of a pin-head) of brine (= salt-water) on the slide; transfer the slide very carefully to the microscope stage and adjust the microscope as before until you see the drop magnified. Watch carefully. *What do you see?*

CRYSTALS AND ATOMS

All sugar crystals have the same shape as any other sugar crystals. All salt crystals have the same shape as other salt crystals. When crystals of a substance grow they are always the same shape – for that substance. They always have the same angles at the corners. This is a little like the square corners which always occur when children's bricks are piled up into larger shapes; or when piles of cannon balls are left ready near an old gun. See the photographs opposite.

7 Experiment
Building with marbles

You will need a tray made of wood or card, that will just hold 25 marbles – five on each side. That layer will take another 16 marbles on top of it.



How many marbles are there in the next layer? And in the next? And the next? What can you say about the angles of the pyramid you have built from the marbles?

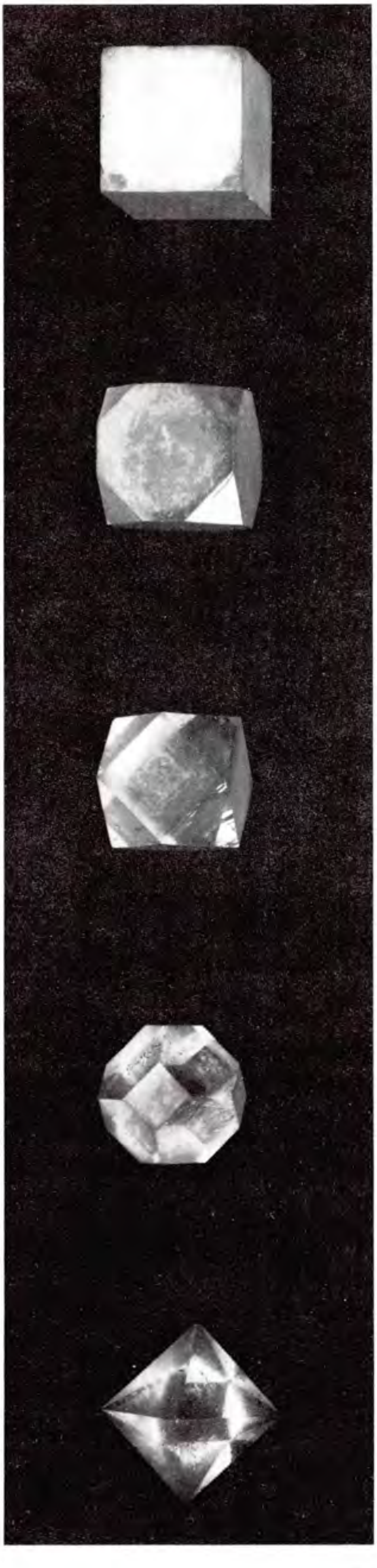
8 Demonstration

Look at some larger models made with larger balls which have been arranged in different ways.

You may be wondering what these models have got to do with crystals. The models show how regular crystal-like shapes can be built up from similar building units (round balls in this

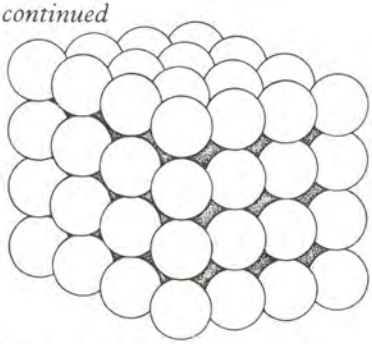
A. Crystals of granulated sugar (×10)
Photograph, Tate & Lyle Ltd.

B. A scanning electron micrograph of sodium chloride crystals (×2275)
Photograph, RHM Foods Ltd.



C. Alum crystals, showing change of form. Each crystal is about 2.5 cm across.
Photograph, lent to the Science Museum, London, by Peter Spence & Sons Ltd, Farnworth, Lancashire.

8 D. *continued*

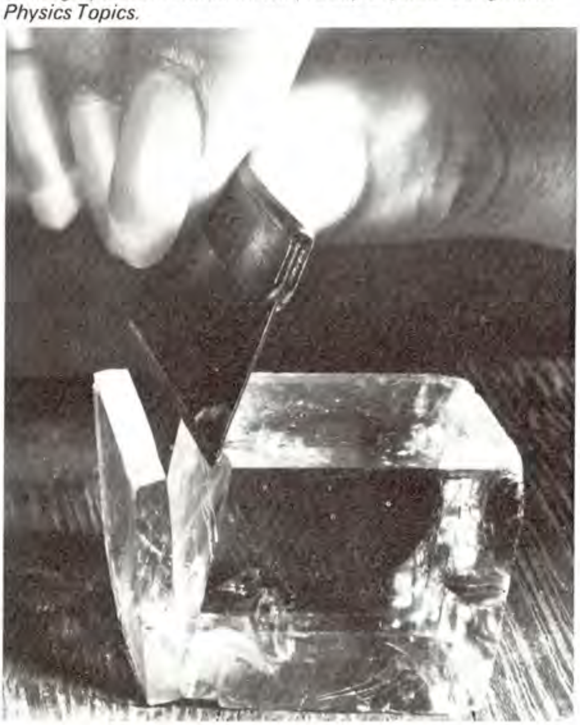


case). Perhaps crystals too are made up of tiny units of matter, all similar to one another, fitting together so that the regular crystal shape always appears. These tiny units of matter are called molecules (= small family groups of atoms).

9 Demonstration
Cleaving a crystal

There are certain directions in which a crystal easily splits (or 'cleaves') into two parts, giving two small crystals. You should see this done to a large crystal of calcite, which is a crystalline form of chalk. A light tap on a sharp blade held at just the proper angle is enough to cleave it in two.

Cleaving a calcite crystal.
Photograph, from Hurst, M. M. (1969) Crystals. *Longman's Physics Topics.*



Progress questions

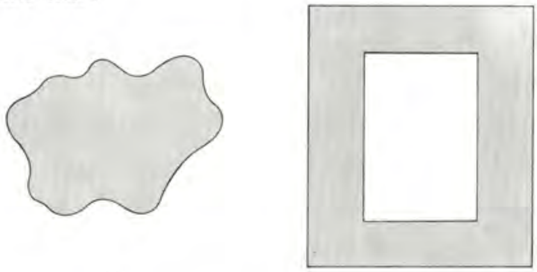
Crystals

17. Make a list of some *crystals* you have looked at. Draw the shape of some of them.

18. Write 'true' or 'untrue' for each of the following statements. All the crystals of *one* particular material are the same:
a. colour;
b. size;
c. length;
d. in the shape of their corners.

19. Hypo and alum both come as colourless crystals. If you drop a hypo crystal into a dish of alum crystals why is it easy to pick it out again?

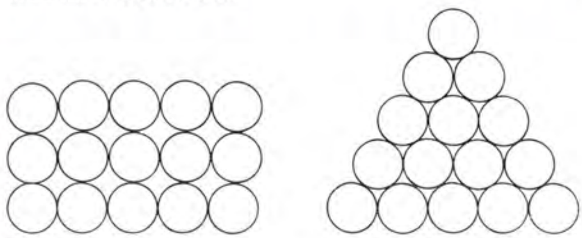
20. An aeroplane pilot flying high can see a crowd of people as a dark blotch on the ground. Suppose he sees two such dark patches, shaped like this:



A B

What do you think the people in patch B might be doing to make such a regular patch?

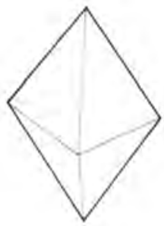
21. Some polystyrene balls or marbles have been put together, and here are two of the shapes that have been built.

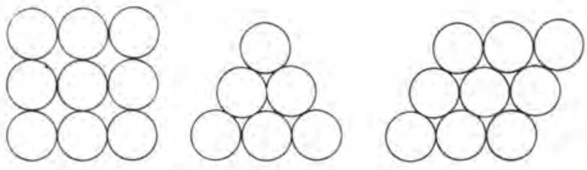


Copy these out very carefully. Then add one or more rows to each.

22. Here is an alum crystal (top right). Look at salt again to recall the shape of a *salt* crystal.

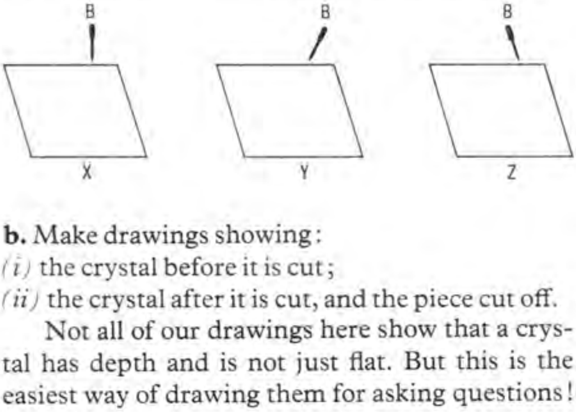
Diagrams A, B, and C show possible ways that molecules can be built up to make *one* face of





a crystal. Say which you think is likely to be a model of:
(i) salt molecules; and
(ii) alum molecules.

23. Someone wants to cut a neat slice off a crystal. He holds a razor blade against the crystal, and taps the back of the blade with a hammer.
a. Which of the following diagrams shows the best way to hold the blade (labelled B) before hitting it? (Think of splitting a piece of wood with an axe.)



b. Make drawings showing:
(i) the crystal before it is cut;
(ii) the crystal after it is cut, and the piece cut off.

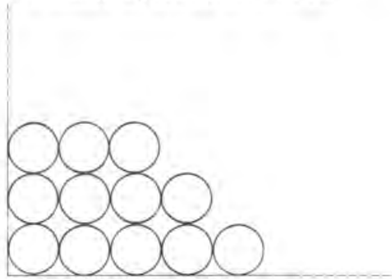
Not all of our drawings here show that a crystal has depth and is not just flat. But this is the easiest way of drawing them for asking questions!

Questions

24. *Experiment* This is something you can try at home.
a. Fill a large cup or can exactly to the brim with clean, perfectly dry sand. Tip the sand into a basin, add about one-tenth of a cup of water. Stir it up so that all the sand is evenly damp. Put the sand back in the original cup.

Can you get it all in? Look at the sand with a magnifying glass. Suggest something to explain your discovery.
b. Try making the sand *very* wet by adding a lot more water. Will it all go into the cup now? What has happened this time?
c. How is sand used in building houses? How might the results of this experiment be important to a builder?

25. A box is nearly cubical in shape but not quite. Its base measures 30 cm × 28 cm *inside*, and its height is 28 cm. Suppose you are given a large number of balls, each of diameter 4 cm.
a. How many of these balls can you fit along a 28-cm side? How many along a 30-cm side?
b. How many can you fit inside the bottom of the box, so as to form a layer one ball thick?
c. If layers are fitted on top of each other as in the figure, how many layers fit in the box?



d. Packed like this, how many balls go in the box?
e. Is any space wasted? If so, where?
f. The answer to part (d) is *not* the *largest* number of balls that can be fitted into the box. How could they be packed so as to get more in? Give a diagram. (You need not draw large numbers of balls; a diagram like the figure for part (c) but showing a different arrangement will do.)
g. Suppose you have a large number of small spheres, beads, for example, which you pour into a box or bag. Would they be more likely to settle down in an arrangement like the figure for part (c), or would they settle so that they were more like your answer to part (f)? Give a reason for your answer.

26.
a. You may have seen a demonstration of a crystal being cleaved. What happens when you cleave (split) a calcite crystal 'in the right way'? Explain what you do, and draw a diagram showing what is meant by 'in the right way'. (It would be better to say 'with the right orientation'.)

Q.26 *continued*

b. *(i)* What happens if you have the 'wrong' orientation, though you are using the 'right' tool (razor blade or sharp knife)?
(ii) What happens if you have the right orientation but the wrong tool, that is, something blunt?
(iii) Draw a diagram illustrating *one* of your two answers.

27. What do your answers to Question 26 suggest about the way crystals are made up? (That is, how do crystals differ from something such as glass or plastic?)

Do you know any other kind of crystal besides calcite which can be easily split? If so, name the crystal and say how you would split it.

28.

a. One pupil tried cleaving cubes of sugar with a knife. The results were unsatisfactory. In whatever way he held the knife the sugar-lump broke, sometimes into two pieces, sometimes into many pieces. So he said 'sugar is not crystals'. What do you say to this?

b. That pupil then found a small cube of wood. He tried two sides of the cube with a knife but only made a small cut or dent. Then he tried another side, and the wood split easily. So he said 'wood consists of crystals'. What do you say?

29.

a. What do all the following have in common?
threads in linen cloth;
seats in a cinema;
steps on stairs;
ripples on water;
fruit in an orchard;
a crystal.

What, in a crystal, corresponds to threads, seats, steps, ripples, trees? Suggest two more to add to this list.

b. *(Advanced)* Actually, there is one way in which the crystal differs from the other five, though it resembles the arrangements of spheres in Questions 25 and 26. In what way does the crystal differ from the other five?

30. You have seen crystals (of hypo) form quickly in a glass tube.

a. What did you do to make that happen? (One sentence.)

b. What did you see happening?

c. Did you *feel* anything happening, and if so, what?

d. Draw two sketches of the tube, one 'before' and one 'after'.

31. You have grown crystals, allowing them to form slowly.

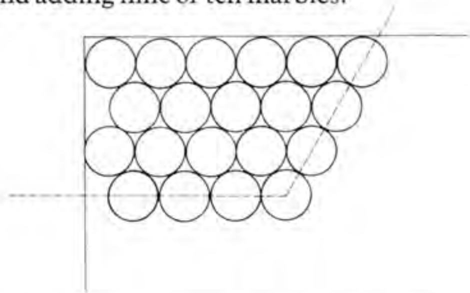
a. How did you do this? (About three sentences.)

b. What happened? Draw a picture of the crystal you grew, or if you made several, draw a picture of the one you liked best.

32. *(Advanced)* Explain as far as you can why crystals that are grown quickly look so different from crystals grown slowly.

33.

a. The diagram shows one corner of a square wooden tray like the one in which you put marbles. Twenty marbles are shown in this corner. Suppose you add nine or ten more, where are they likely to go? Answer this by copying the diagram and adding nine or ten marbles.



b. In the diagram two dotted lines are drawn joining the centres of the outer rows of marbles. Do the same for *your* diagram, which has extra marbles added.

c. What can you say about *your* lines (with the extra marbles) and the original lines in the diagram?

34.

a. You make a pyramid out of 14 balls in 3 layers. How many balls in each layer?

b. You then add more balls in order to make a 4-layer pyramid with a 4×4 base. How many balls does this need altogether?

c. Next you make the pyramid into one with a 5×5 base. How many balls altogether?

35.

a. What can you say about the angles between the faces of the 3×3 base pyramid, the 4×4 pyramid, and the 5×5 base pyramid in Question 34?

b. What resemblance is there between a crystal and the pyramid you have built up with the balls?

Molecules moving into each other

10 Experiment
Dissolving crystals

Watch a pinch of salt dissolve in a little water. *What happens to the crystals?*

The molecules have left the crystal. But we know we can get the salt crystals back by driving the water away; so the salt must still be in the beaker mixed up with the water.

11 Demonstration
Salt dissolving

You should see the demonstration sketched. *What happens to the total space taken up by the salt and the water? Where have the molecules of salt gone?*

Progress questions

36.
a. Describe how you grow alum or copper sulphate crystals.
b. What happens to a crystal of alum or copper sulphate if you put it in water?
c. What happens to a crystal in its solution if the room becomes much warmer?

37. You have half a cupful of water and add a tablespoon of salt to it. Then you stir hard.
a. Does the amount of salt crystals you can see in the cup stay the same or get less?
b. Does the taste of the water change?
c. If there is still some salt not yet dissolved, how can you make the rest dissolve?
d. What do you think happens to all the little bits (molecules) of salt which were in the salt crystals to start with?

Questions

38. Building up a pyramid of balls is like growing a crystal in a saturated solution. Suppose you take balls away from the pyramid. That is like something that can happen to a crystal. What? Describe (two or three sentences) an experiment which shows this happening to a crystal.

39. What is the most interesting thing, *except crystals*, you have seen through a microscope? Draw a diagram of what you say, and label it. (Do not spend much time on this.)

40. You have seen, through a microscope, salt crystals growing on a microscope slide. Draw two sketches to show:
a. the appearance when about one-third of the liquid has crystallized,
b. the appearance of the same crystals and liquid a short time later, when about one-half has crystallized.

41. Suppose you have a grown-up friend, who is intelligent and interested and has time to spare to try out new ideas. He did not do any physics when he was at school, so you have to explain things clearly to him, in your *own* words.

You have told him about your work on crystals and you showed him some cooking-salt under a lens, and he agreed that the salt consisted of small cubical crystals. 'Sugar is the same', you say, 'look at some through the lens'. 'Right', he says, and fetches *icing sugar* from the cupboard. Under the lens it still looks like powder.

'All right', you say, and next day you borrow a microscope so that he can look through that. The icing sugar still looks like nothing but powder. You cannot borrow a more powerful microscope.

Your friend is willing to be convinced by any reasonable experiment and argument. How would you convince him that icing sugar consists of crystals? (In addition to icing sugar, the cupboard contains granulated sugar, castor sugar, and demerara sugar.)

Weighing and measuring solids

12 Experiment

Some of the materials in the exhibition had been cut to a regular shape. Put them in order of weight

12 E. *continued*

by simply lifting ('hefting') them. Weigh these next on a balance and record the weight of each. *Were you right?*

13 Experiment
Weighing and measuring solid blocks

There are some blocks of a number of solid materials available. Some are the same size; some are not. Weigh each of the same sized blocks (which may be of aluminium, iron, soft wood, paraffin wax, or polystyrene foam). Measure their sides. *How many sides?* Try arranging them in order of weight as you did before. *What are you going to do about the polystyrene foam?* Next weigh and measure the other blocks. *Would it be a good idea to include their weights in a table of weights of the similar sized blocks?*

Progress questions

42. Here is a list of units which can be used for measurements:

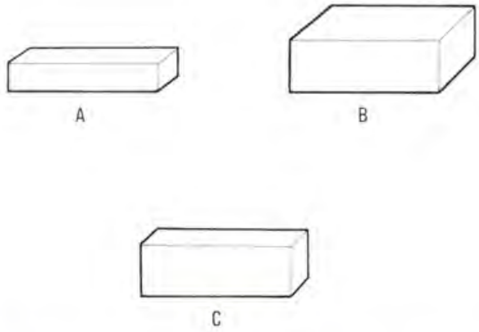
pounds, miles, seconds, grams, kilograms, ounces, minutes, metres, hours, centimetres, days.

a. Write out which of these are for measuring *length*.
b. Write out which of these are for *weighing*.
c. Write out which of these are for measuring *time*.
d. Add one more to each of your lists.
e. Go back to your answers to (a), (b), (c), and underline the ones that are METRIC units.

43. In the following list, pick out a distance which is:
a. *roughly* 1 millimetre long;
b. *roughly* 1 centimetre long;
c. *roughly* 1 metre long.

The height of a room; the height of a bench; the thickness of a biro; the thickness of a 10p piece; the length of a table knife; the thickness of a pencil lead.

44.
a. Someone says, 'I want a rubber 3 cm long.' Which of the drawings A, B, C, would fit what he asks? Only one of them? Or all three of them?
b. He then says, 'I mean 3 cm long and 1 cm high.' Which of the drawings look as if they would fit now?



c. He then says, 'I really mean 3 cm long and 1 cm high and 1 cm wide.' Which would fit now?
d. Which of them has the *most rubber* in it?

45. You have a piece of iron, a piece of wax, and a piece of aluminium, which are all the same size. Which weighs the most? Which weighs the least?

46.
a. 1 kilometre = 1000 metres = 100 000 centimetres = 1 000 000 millimetres. Write the following as METRES:

10 centimetres
100 millimetres
10 kilometres
1 centimetre

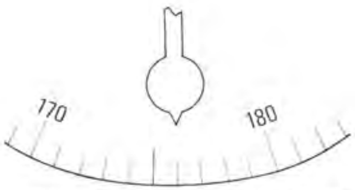
If you find this difficult make a list for yourself like this. You will have to continue it to answer the question.

km	m	cm	mm
1	1000	100 000	1 000 000
0.1	100	10 000	100 000
0.01	10	1 000	10 000
0.001	1	100	
0.0001			

b. 1 kilogram = 1000 grams = 1 000 000 milligrams.
Write the following in kilograms:

1 gram;
1 milligram.

47.
a. Copy this diagram of part of a balance scale, which reads in grams. At what number of grams is the arm pointing?
b. Copy the sketch (top of next column) and show the arm pointing at 179 grams, and 174.5 grams.

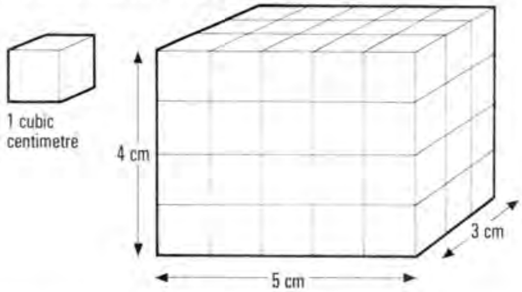


48. Suppose I have two blocks of the same size. One is brass; one is pure gold. The gold block weighs twice as much as the brass one.

I have two rings for my finger. They are exactly the same size and look alike. One *is* gold; the other may be brass or gold. How would you find out?

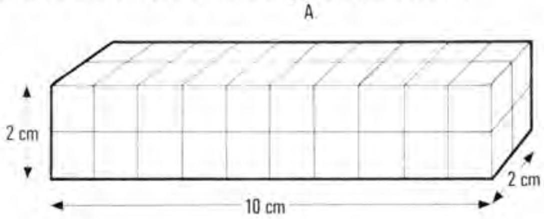
Counting the cubes

49. If we have some dice, and each one measures 1 cm × 1 cm × 1 cm, we say each one is 1 cubic centimetre. Now suppose we have a block measuring 5 cm × 4 cm × 3 cm. How many cubic centimetres are there in the *top* layer of the block? How many layers are there? So how many cubic centimetres are there altogether?

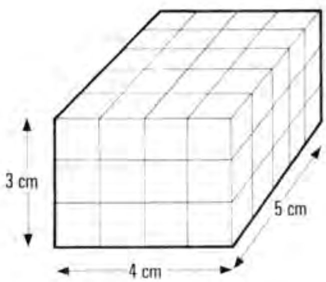


50. How many cubic centimetres are there in each of the blocks A and B pictured below?

A



B



51. Think of a box measuring 10 cm × 10 cm × 10 cm outside.

a. How many of these boxes put in a row would fit into 1 metre length?

b. A room is 5 metres wide. How many of these boxes would fit in one row across this width.

c. The room is 8 metres long. How many *rows* would you need to cover the floor with these boxes?

d. The room is 3 metres high. How many *layers* of boxes would reach from floor to ceiling?

e. So how many boxes altogether would completely fill the room?

If you have any difficulty in imagining this, draw a diagram like the ones in Questions 49 and 50 or use small cubes to represent the boxes.

52. If you have an answer to Question 51 try this one.

a. A box 10 cm × 10 cm × 10 cm holds 1 litre of air. So how many litres of air are there in the room?

b. One litre of air weighs about 1 gram. So how much does all the air in the room weigh?

Questions

Counting the cubes

53. *The problem of the grapefruit.* A fruit grower who grows grapefruit packs them and sends them to a market in London. The fruit have to travel a long way. The grower wants to make sure they do not get damaged. So he packs them in a big box with sheets of cardboard between each grapefruit and the next. Then each of them is in a small box of cardboard, *like a cube.*

The little cardboard box that holds each fruit is 10 centimetres long, 10 centimetres wide, and 10 centimetres high.

(The cardboard used to keep the fruit apart is too thin for its thickness to matter when you answer the questions below.)

a. Suppose instead of his big packing box the fruit grower has only a little box 20 cm long by 10 cm wide by 10 cm high. How many grapefruit will that hold? (If you are not sure, draw a sketch and divide it up into single 'grapefruit cubes'.)

b. Suppose he sends grapefruit in several small boxes, A, B, and C.

Q.53 *continued*

Box A is 30 cm long × 10 cm wide × 10 cm high.

Box B is 30 cm long × 20 cm wide × 10 cm high.

Box C is 30 cm long × 20 cm wide × 40 cm high.

How many grapefruit does each of those boxes hold?

c. Now suppose the grower measures his big packing box and finds it is 100 cm long inside, 50 cm wide, and 40 cm high. How many grapefruit?

54. Did you get the right answer to the last question? How did you get it? Suppose you were going to work for that fruit grower and had to find out how many grapefruit could go into each packing box, and you had many different sizes of box but only one size of fruit.

Would you have to think out very carefully for each box how many grapefruit fit into the length, how many grapefruit fit into the width, how many grapefruit fit into the height; and then think out very carefully how many rows and layers that would make? Or could you give yourself a simple rule that you could use for every box.

There *is* such a rule. What is it?

55. *(Make sure you are successful with Question 54 before you try this.)*

The problem of the atoms. Scientists can measure the size of a single atom. An atom of iron is so small that if you put it into a small cubical box that would just hold it the box would be about $\frac{2}{100\,000\,000}$ cm wide, and the same thick and the same high. Think of the iron block that you handled. It probably measures 5 cm long × 4 cm wide × 3 cm high. Suppose that the atoms are arranged very simply in it in a simple cubic pattern like the grapefruit.

a. How many atoms would there be in the length of your iron block? How many in the width? How many in the height?

b. How many atoms would there be in one layer 5 cm × 4 cm?

c. How many atoms would there be in the whole block?

d. Suppose your block has 450 grams of iron in it. How much iron would there be in one single atom?

NUMBERS, LARGE AND SMALL

(Optional now) (but very useful later – for O-level)

That last problem had some very small numbers in it, as well as some very large ones. In science we often find very big numbers and we often find very small ones – so often that scientists use a shorthand form. That shorthand form also helps to make multiplying and dividing these numbers much easier. Try this:

You could say that 100 is figure 1 and two zeros.

Make a column for the figures and the zeros like this:

	Figures		*Zeros*
10 is figure	1	and	1 zero
100 is figure	1	and	2 zeros
1000 is figure	1	and	3 zeros

You know that 1000 is ten times larger than 100. So multiplying numbers like this could be written

100	1	2
× 10	× 1	+ 1
	1	3

which means 1000.

Try some larger numbers. For example,

240 000 000	24	7

Suppose you wanted to multiply that number by 200 000. You would write

240 000 000	24	7
200 000	× 2	+ 5
	48	12

And this is 48 000 000 000 000.

Instead of writing the two columns we can tell the story told by the column of zeros in another way. The 7 in the second column of zeros means 7 zeros; but that really means 7 lots of multiplying by ten. There is a professional way of saying 'multiplied by ten seven times', that is, 'ten to the seven', written 10^7. If we use that we can write 240 000 000 as 24×10^7 and 200 000 as 2×10^5. Multiplying these together,

$24 \times 10^7 \times 2 \times 10^5 = 48 \times 10^{12}$.

Remember 10^7 is just shorthand for

$10 \times 10 \times 10 \times 10 \times 10 \times 10 \times 10$.

Questions

56. The Sun is 149 000 000 kilometres away. Write that number in the new form.

57. The speed of light is 3×10^8 metres per second. Write that number out in full. Now write the speed of light in centimetres per second in the shortest way you can.

58.
a. The Earth's radius is 6 400 000 metres. Write that number in the shortest form.
b. How many kilometres is that?

59. What number comes after
25 in the set 5, 10, 15, 20, 25, . . . ?
6 in the set 12, 10, 8, 6, . . . ?
3 in the set 12, 9, 6, 3, . . . ?
-1 in the set 3, 2, 1, 0, -1, . . . ?
10^1 in the set $10^4, 10^3, 10^2, 10^1$, . . . ?
What number is that in the last set?

60. What number follows 0.1 in the set 1000, 100, 10, 1, 0.1, . . . ?

The shorthand form you have used for the very large numbers can be extended to very small ones. Dividing by 10 once moves the decimal point one place to the left – one-tenth of 1 is 0.1; two lots of dividing by ten move the decimal point two places to the left – one-tenth of 0.1 is 0.01; and so on. The shorthand for one-tenth is 10^{-1}; for one-hundredth is 10^{-2}; for one-thousandth is 10^{-3}, and so on.

Question

61. What is $10^2 \times 10^1$? It is 10^{2+1} or 10^3. What is $10^2 \times 10^{-2}$? Discuss that with your teacher. What is $10^6 \times 10^{-6}$?

A hundred millionth part of 2 cm is $\frac{2}{100\,000\,000}$ cm or 2×10^{-8} cm. That is about the size of an iron atom. *How many atoms of iron are there in the length of a block 5 cm long?* The number of atoms is found by dividing the size of one atom into the length of the block. That is $\frac{5}{2 \times 10^{-8}}$. Now keep the value of that the same by multiplying top and bottom, each by 10^8, to obtain $\frac{5 \times 10^8}{2 \times 10^{-8} \times 10^8}$ or 2.5×10^8. So the number of atoms is 2.5×10^8.

Questions

62. How many atoms are there in the width of a block of iron, 4 cm wide? And how many in the height of the block if it is 3 cm high? How many atoms are there altogether in that block?

63.
a. Atoms are extremely small. They are so small that people can hardly imagine how small they are. But we can do experiments to find out how small atoms are. Then, knowing their size, we can work out how many atoms there are in some object of ordinary size that we can see. For example, a small aluminium saucepan is made up of about 10 000 000 000 000 000 000 000 000 atoms of aluminium. Write that in numbers in the quickest way you can.
b. In the question about the aluminium saucepan just above, the number you were given was only a very rough estimate. (It was not a wild guess, but was worked out roughly from real experiments.) Explain in your own words why you think it would be silly to give a value like 12 356 419 000 000 000 000 000 000, and claim that it was more 'accurate'.

64. Some astronomers who have collected a great deal of information about the stars think they can estimate how many atoms there are in the whole universe – all the stars and the planets put together.

Of course, that is only a very rough guess. They do not count just atoms; they also count electrons and the other small pieces which we think are inside atoms.

They say that they guess the total for the whole universe of all those little 'particles' is about 10^{80}.
a. Time yourself while you write out 10^{80} fully in ordinary figures. How many seconds did it take?
b. Time yourself while you write out 10^{80} in this short form, 10^{80}. How many seconds did it take?
c. Suppose your clock was only marked every five seconds, and did not show separate seconds or fractions of seconds. Describe a simple way in which you could find the time taken to write 10^{80} with such a rough clock.
d. How many times quicker is the short way of writing this big number than the long way, in actual time of writing? (Remember that 'how many times' asks you to *divide, not just to subtract,* and find how much quicker it is.)

65. In scientific 'standard form' we always write a number in the form of a power of 10 (like the 10^6 in the Earth's radius of 6.4×10^6 m) multiplied by another number which has one figure, *just one figure*, in front of the decimal point. So 25.4×10^3 mm expressed in standard form would be 2.54×10^4 mm. Then we carry on as many figures as we think our accuracy deserves after the decimal point. Try doing that yourself with the following examples. If you like, use your own measurements instead of those that are given you for the imaginary pupil called Tom.

a. Tom is 1 metre 39.7 cm tall. That is the same as 1397 millimetres. Write down his height in millimetres in standard form. (If you use your own height in inches you will have to turn it into millimetres by multiplying by 25.4, because that is the number of millimetres in one inch.)

b. Say, in standard form, how far you would advise Tom to carry his statement of his height. What figure should he stop at? Give a short, clear reason for your advice.

c. Suppose today is Tom's birthday and his age is just 12 years. Write that in standard form in months. Suppose his school writes to him now and says, 'Let us know how old you will be *next term*, in months.' Write down the most sensible answer for him to give in standard form in months.

d. Now turn his age into days. (Reckon $365\frac{1}{4}$ days in a year.) Express his age in days in standard form.

e. Suppose just after his birthday he writes to a friend in America and says, 'When you get this letter, I shall be just so many days old.' Put that number 'so many' in standard form and end it where you think is sensible. Give a short reason for your choice of how far to carry the numbers in this case.

Volume and weight: some simple arithmetic

You may have found that there were three sizes of aluminium block in the kit.

	Length	Breadth	Height
Block A	5 cm	4 cm	3 cm
Block B	8 cm	5 cm	5 cm
Block C	10 cm	2 cm	2 cm

Which block took up most space (had the largest number of centimetre cubes in it)? Which was the heaviest? Now arrange the blocks in order of volume, largest first. Then of weight. *Is the order the same?* Work out the weight of a cubic centimetre of the aluminium in each case. *Are they the same?* That number is called the density of aluminium – any aluminium.

Questions

66. The names of seven substances are written in the list.

a. Rewrite this list, putting the heaviest at the top, and arranging in order with the lightest at the bottom.

b. What do we mean by 'heaviest' if we make a fair comparison, and what would be a better word to use?

aluminium
candle wax
iron
glass
polystyrene
marble
lead

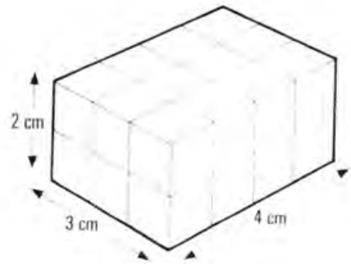
Note Three of these substances are so close they can be bracketed together in the list: which three?

67. 'Lead is heavier than feathers.'

a. Is this statement true? Which weighs more, 1000 kilograms of lead or 1000 kilograms of feathers?

b. If you were the manager of a storage firm which of the two would you rather store, and why?

68. A 60-gram block of marble measures 2 cm × 3 cm × 4 cm.



a. How many cubical blocks 1 cm × 1 cm × 1 cm are there in this block?

b. How many grams of marble are there in one of these 1 cm × 1 cm × 1 cm blocks?

69. *(Following from Question 68)*

a. A sculptor who wants to cut a statue out of marble orders a marble block 40 cm long by 30 cm wide by 20 cm thick. How many kilograms of marble are there in it?

b. After the sculptor has chopped away a lot of marble he has an irregular shape that has 40 kilograms in it. How many cubic centimetres has he got left?

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14 Experiment
Weighing liquids

Before trying a liquid, weigh some grain or some sand in a Perspex container. Fill the container so that the grain is just 5 centimetres deep. *What does the grain weigh? Does the grain fill the space completely?* Now try with 5 cm of water in the box instead of the grain. *What does the water weigh? Does the water fill the space completely? What are you going to do about the weight of the box itself?*

See 1000 cubic centimetres of water (1 litre) weighed in a large plastic box.

15 Demonstration
Testing a measuring cylinder *(Optional now)*

What volume of water does that Perspex container hold when it is filled to a depth of 5 cm with water? Now pour that water into the measuring cylinder you are going to test. And then another equal volume of water. And another. And another until it is full. *Are the graduation marks correctly placed?*

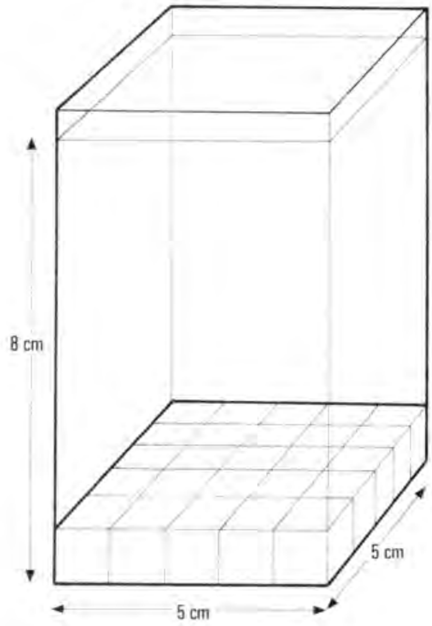
Progress questions

70. Jane is weighing liquids. She fills a Perspex box with water and puts it on a balance. It reads 275 grams. Jane says, 'Therefore the water weighs 275 grams.' She isn't quite right. What has she forgotten to do?

71. Water is put in a hollow box, and the water is 1 cm deep.

a. How many 'cubes of liquid' are there in this container in the layer shown? (Look back to Question 49 if you find this difficult.)

b. If it is filled up to the 8-centimetre height mark, how many layers of cubes will there be?



c. So how many cubic centimetres will there be in a box when filled up to the 8-centimetre mark?

72.

a. If the Perspex container in Question 71 was filled with water up to 4 centimetres in height, how many cubic centimetres would there be in it?

b. A potato is then dropped in and lies completely under the water. The water goes up to 5 centimetres in height. How many cubic centimetres of 'water and potato together' are there?

c. So how many cubic centimetres of potato are there?

73. Write out the following materials in two lists:

List A The ones which will sink if you put them in water.

List B The ones which will float in water.

(You can try them at home if you are not sure.)

steel (for example a knife or pair of scissors)
a raw potato
cork
glass (for example a glass marble)
ice
a coin
margarine
sugar
stone
rubber

Then add one more material to each list.

74. How could you use the Perspex container of Question 71 to help you find how many cubic centimetres of water a teapot will hold?

There are two ways of doing this – one starting with the teapot full of water and one with it empty. You will have to decide what 'full' is for a teapot.

Measure how much it will hold in two ways and say which you think is the best and why.

75. Suppose you have got a jug at home marked '400 cubic cm'. You can borrow from the lab a hollow box measuring inside 5 cm × 5 cm × 4 cm. How would you do a check to find out if the jug is correctly marked? Are you going to fill the jug or the box with water first? Explain why.

76. You may have used the Perspex container to weigh some sand.
a. Why is it a good idea to pack in the sand as tightly as possible?
b. Everyone in the class has a box and some sand. Suggest any reasons why they all get slightly different answers for the weight of a boxful of sand.

Questions

77. You are given 50 steel balls, all alike, and all very small. There is one balance available. It is not sensitive enough to weigh a single ball accurately.

How would you find how much one ball weighs? You are now given an egg-cup full of balls the same size. How would you find the number of balls in the egg-cup without counting them?

78. *(Advanced)* How would you find the volume and weight of an egg if the only measuring apparatus you have is a balance and a measuring cylinder which is too small for the egg to go into? (You may use the things you would find in a kitchen or in a laboratory, but no other *measuring* apparatus is to be used.)

79.
a. Suggest some possible way by which you might find your own volume. You may have a special kind of bath made for the purpose according to your instructions.
b. Suppose you breathe in and out again every few seconds. Does breathing change your volume?

80.
a. How much do you weigh? If you know your weight in stones convert to pounds; then to metric units, kilograms. (1 stone = 14 lbs; 1 kg = 2.2 lb)
b. Suppose you can just lift another boy or girl who weighs just as much as you do. Would you be able to lift a cube of cork if the length of one side of the cube is 60 centimetres (= 0.6 metre)? (1 cubic metre of cork weighs 250 kilograms.)

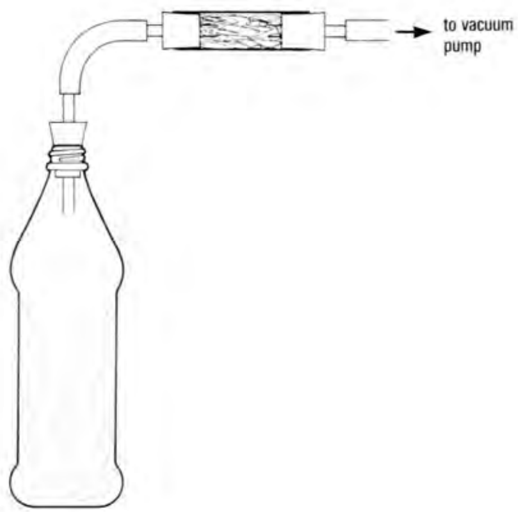
81.
a. Suppose you have a hollow rectangular plastic box and a ruler. How would you check the accuracy of a measuring cylinder marked in cubic centimetres?
b. Which is likely to be more accurate, your measurements of volume using the box or your readings of the height of the water in the cylinder?
c. Suppose you have a balance and can weigh the box. How can you find the volume of the box very accurately?
d. Suppose you need to know the volume of a hollow thing that has an uneven shape – a teapot for example. Suggest two quite different, easy, ways of measuring the volume it holds.

82. 100 cubic centimetres of water weigh 100 grams. 100 cubic centimetres of alcohol weigh 82 grams. Suppose 100 cubic centimetres of water and 100 cubic centimetres of alcohol are mixed.
a. How much does the mixture weigh?
b. If there is no change of volume on mixing the liquids so that the total volume is 200 cubic centimetres, what would 100 cubic centimetres of the mixture weigh?
c. In fact an experiment will show that the volume of the mixture is rather less than 200 cubic centimetres. What does this suggest about the particles of water and alcohol when they are put together?

Weighing air

16 Demonstration
Pumping air

In the materials exhibition you saw two similar bottles – one labelled AIR, the other VACUUM. Air had been pumped out of the second bottle. See that happening when the pump is attached to a bottle full of smoky air (see sketch).

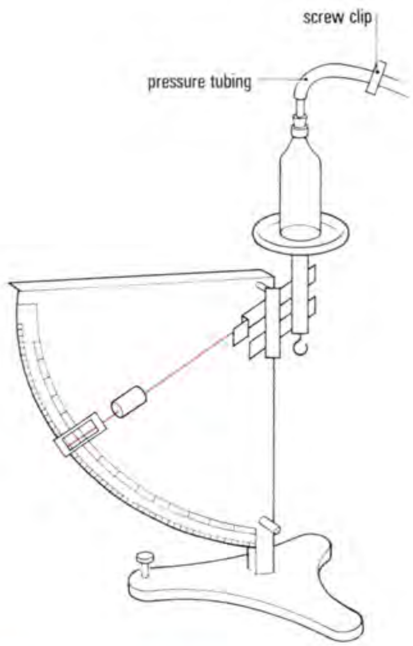


Question

83. See the demonstration sketched. Describe what happened in that test of the bottles labelled AIR and VACUUM.

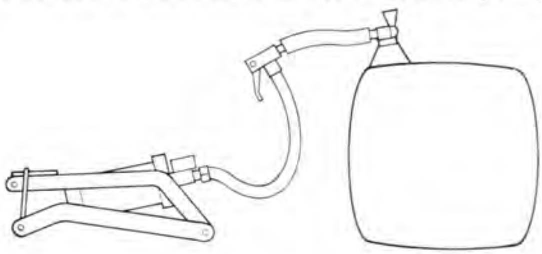
17 Demonstration
How can we weigh air?

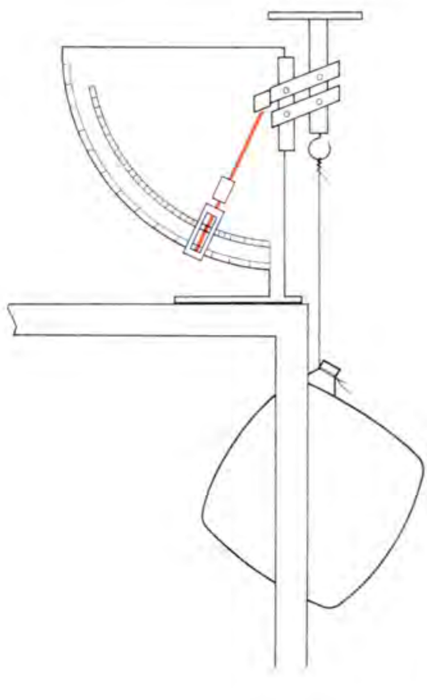
We might try to pump the air out of a weighed bottle. See the demonstration sketched (above right). That was rather a heavy bottle so the tiny weight of air within it is hard to measure. We might try a plastic bottle which weighs less than the glass one did. *What happens this time?*



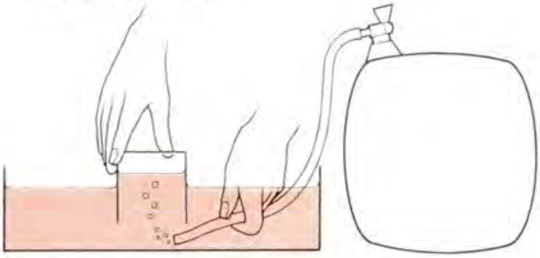
18 Demonstration

There is another way that will avoid the trouble you met in Demonstration 17. Instead of pump-





18 D. *continued*



ing air *out*, you can pump some air *in;* you add new air to the air that is already there. You do that with a foot-pump and it will be best to use a large plastic container. *How can you find the weight of the extra air? How can you find the volume of the extra air you pumped in?* You may want to use a plastic box which can hold 1000 cubic centimetres and a tank of water.

Now work out the weight of one plastic-boxful of air.

The weight of the air in the room Now you know the weight of a boxful (1 litre or 1000 cubic centimetres) of air. *How many boxfuls in a cubic metre? How many litres in a cubic metre?* (Remember – the box is a cube with a 10-centimetre side; that is a 0.1-metre side.)

How many cubic metres of space in the room? You will need to make estimates of the length of the room (in metres, remember), of its breadth, and of its height. Now you can find how many grams of air there are in the room. *How many kilograms is that?*

SOLIDS, LIQUIDS, AND GASES

When you did Experiment 13, weighing and measuring solid blocks, you found the weight of 1 cubic centimetre of aluminium.

What would a piece of aluminium which was the same size as the litre box weigh? How many kilograms is that?

In Experiment 14, weighing liquids, you found that a litre box of water weighed one kilogram. In Demonstration 18 you found that a litre-boxful of air weighs nearly 1.2 grams – that is, 1.2×10^{-3} kilograms.

Weights of a litre (or 1000 cubic centimetres)

aluminium	2.7 kg	or	2700 g
water	1.0 kg	or	1000 g
air	1.2×10^{-3} kg	or	1.2 g

Here are some more:

mercury	13.6 kg	or	13 600 g
salt crystals	2.2 kg	or	2200 g

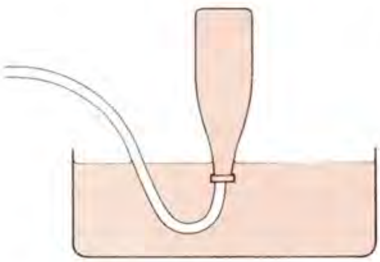
Questions

84. Roughly how many times denser is mercury than water? Salt crystals than water? Water than air? For water just say whether it is ten times, or one hundred times, or one thousand times denser than air.

85. You made a model salt crystal from closely packed balls. Scientists believe that real salt crystals are made up of closely packed molecules. Do you think the particles which make up the air are as tightly packed?

Progress questions

86. *(Try this at home)* Here is an experiment to find out how much air you breathe out in one breath. You need a sink full of water, several milk bottles under the water, and a piece of tubing.



Ask a friend to hold one bottle full of water as shown. You draw a deep breath and breathe out slowly into the tubing, so that the bottle fills with air. When you have filled one bottle, your friend replaces it with another, full of water. Carry on until the breath is finished. Each bottle holds about 600 cubic centimetres.

a. How much air did you breathe out?

b. Ask some of your family and friends to try too. Make a list of what you find. Is there any pattern in your list?

87. Air is difficult to weigh because it is so light, but you have seen or done an experiment on weighing and measuring air.

a. Explain how you got enough air to weigh easily, using a plastic box, a balance, and a foot-pump.

b. Then explain how the volume of the air you weighed was measured.

....

- -

Questions

88. If we open a box and see nothing inside it we immediately say that the box is empty, but, of course, it is not empty; it is full of air.

Write three sentences each giving a reason for supposing that air is really there.

89.

a. What volume of air do you think comes into and out of your lungs each time you breathe, when you are breathing normally? Is it near to 10 cubic centimetres? 100 cubic centimetres? 1 litre (1000 cubic centimetres)? 10 litres?

b. What would the volume be when you breathe in and out *as deeply as you can*? (Make a guess.)

90. *(Experiment which might be done at home)* You have guessed how much lungs can take. You can measure it by the following method.

Apparatus needed: large bottle, sink or bowl, water, measuring cylinder or plastic box, piece of plastic or rubber tubing.

Fill the bottle with water and have the sink or a large bowl half full too. Hold your hand over the mouth of the bottle. Turn the bottle upside-down and hold its mouth under water. Take your hand off the mouth. The bottle stays full of water.

Drop the tubing into the bowl and let it also get full of water.

Put one end of the tube into the bottle through the neck. Blow into the tube with one normal breath as nearly as you can.

Remove the tube, put your hand over the neck of the bottle, and turn it the right way up. Now use the measuring cylinder or plastic box to find how much water is needed to fill the bottle again. This is one normal breath. Do that again to find the volume of the deepest breath you can make. That is, roughly your full lung capacity.

This could be done at home if you can find a large enough bottle and piece of tubing and the kitchen measure your mother uses for liquids. A big tin can be used. The tubing could then be a short piece of garden hose. Or you can use several milk bottles. You may know their volume in pints. (1 pint = 570 cubic centimetres.)

91. Describe how you would do the experiment in Question 90 in reverse. That is, to find how much you breathe *in*, instead of out, at every breath. Try it.

Note Empty the water out of the tubing by blowing before you start, or else you will have a surprise!

92. *(A puzzle easily answered)* Imagine you are standing in shallow water on a gently sloping beach. The water is, let us say, 1 metre deep. There is a milk bottle full of water on the sand at the bottom. It has a cork and a tube, also a second hole in the cork. You are *not* allowed to bring the bottle up to the surface of the water. You have no other apparatus.

a. How could you get some of the water out of the bottle?

b. Why have *two* holes in the cork, when only *one* hole is needed for the tube?

93. *(Following from Question 92)* Suppose that, instead of a pint milk bottle you have, under the water (still 1 metre deep), a 5-litre (5000 cubic centimetres) 'petrol' can which is full of water. It has no cork. You have a piece of rubber tubing but nothing else. How could you get all the water out of the can without bringing it near the surface?

94. *(Difficult puzzle)* You cannot really answer this question, but you can think about it.

Suppose that, instead of being a girl or boy, you are a mermaid or merman, and you don't breathe air. You are deep down beneath the sea, and you have a bottle full of water. How would you get the water out, leaving *nothing* inside the bottle? Think about it; do not write anything.

But you are not a mermaid or merman.

Yet you do live at the bottom of an ocean, 'an ocean or air'. You have a bottle full of air. Your laboratory has a piece of apparatus for getting the air out, leaving nothing inside.

a. What do you call this piece of apparatus?

b. What do you call the 'nothing' which the apparatus leaves inside?

Q.94 *continued*

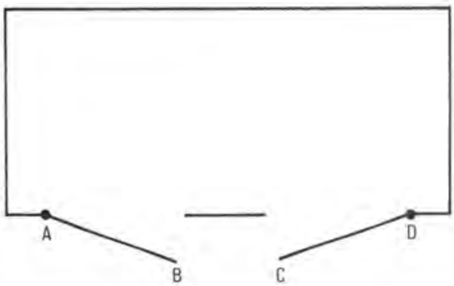
Note Is it still nothing, even if you do give it a special name?

c. How do you think this apparatus works?

95.

a. A thin plastic 'squeeze' bottle is joined to a vacuum pump and the pump is set working. What happens to the bottle?

b. The diagram is a top view (or 'plan') of a cupboard with two doors, AB hinged at A, and CD hinged at C. This cupboard is a bit of a nuisance.



(i) When AB is pushed shut, CD opens. Why?

(ii) When AB is pulled open, CD shuts with a bang. Why?

96. Did you succeed in showing that air has weight? How did you do it? Give a diagram and write a brief account, explaining to another pupil how it was done.

97. How would you measure the 'ordinary' volume of the extra air you weighed (Question 96)? How would you calculate the weight of 1 cubic metre of air?

98. One cubic centimetre of water weighs 1 g and 1 cubic centimetre of air weighs $\frac{12}{10\,000}$ g. What weight of: (a) water, (b) air, is enclosed in a box 10 cm × 20 cm × 5 cm?

99.

a. If air and water are made up of tiny particles of about the same size and weight, what can you say about the distance apart of the particles in air and water? Just make a rough estimate.

b. What other knowledge about air and water (apart from their weights) supports what you have said in answer to (a)?

100. A box measuring 10 cm × 20 cm × 5 cm has a strongly fastened lid fitted to it. Extra air is pumped in until the *air* inside weighs three times as much as what it was before.

The extra air is then released under water and measured at the same pressure as the air in the room. How many cubic centimetres of extra air will come out?

101. One cubic metre of water weighs 1000 kilograms, and 1 cubic metre of air weighs only $\frac{12}{10\,000}$ times as much.

a. How many kilograms of air are there in 1 cubic metre?

b. How much air (in kg) is there in a room 6 metres long, 5 metres wide, and 3 metres high? (That is about the size of a classroom.)

c. If, on a particular day, 1 per cent of this air is, in fact, water vapour, how much water is there in the air of the room? (1 per cent = one-hundredth part.)

102. *(Advanced)* As we go higher up in the Earth's atmosphere, the air gets thinner (less dense). However, if this did not happen, and instead the air remained the same at all heights, then the atmosphere would be 8 kilometres high. Also, for the same volume, air weighs $\frac{12}{10\,000}$ times (or 1.2×10^{-5} times) as much as water.

a. How many metres of water would make the same pressure as 8 kilometres of air (about 27 000 feet)? (We call that pressure '1 atmosphere'.)

b. How far down in a lake would you have to dive to find a pressure of: *(i)* 2 atmospheres? *(ii)* 3 atmospheres? (Remember *one* atmosphere is there to start with *above* the water.)

Changes solid - liquid - gas

19 Experiment
Melting and evaporating

Heat some substances in a flame and watch what happens. Try lead, solder, ice (in a beaker).

Put two or three drops of methylated spirit and two or three drops of water side by side on a glass. Watch what happens.

Dip one finger into water and another into methylated spirit and hold them up to dry. *What do you observe?*

20 Demonstration

See what happens when a little dry ice (solid carbon dioxide) is put into a balloon.

Suppose each of you was a molecule. Suppose the whole class are the molecules of a piece of some stuff. *If the stuff is solid, how do you think the class would look? (Remember, almost all solids are crystalline.) And how do you think it would look if it were a liquid? Would you really be further apart? What happens to a piece of wax or ice when it melts? Now what do you think the class would look like if it were a gas?*

Those ideas about molecules are important. We shall come back to them later.

Progress questions

103. Below is a list of things that you may have seen happening – if you have not seen any of them make sure that you do.

(a) Butter melting.
(b) Metal solder being heated.
(c) Ice-cube melting.
(d) Rubber being heated.
(e) Candle wax cooling down.
(f) Solid carbon dioxide being released into a balloon.
(g) Water being changed into steam.
(h) Copper sulphate being heated.

104. Can you list the things in Question 103 under the following pairs of headings:

I Those that change temporarily when heated/Those that change permanently when heated. (Are there any that don't change at all?)

II Those that take up more space when liquid than solid/Those that take up less space when liquid than solid.

III Those that take up more space when gas than liquid or solid/Those that take up less space as gas than liquid or solid.

If you can, add some more to each list.

From your experience complete the following two sentences:

Most substances take up . . . space when liquid than solid. Most substances take up . . . space as gas than as liquid or solid.

If a gas takes up more space than a liquid, do you think that the molecules of gas are further apart or nearer together than the molecules of liquid?

105. See if you can find out about the soda-water that you can make yourself with sparklet bulbs.

What is in the bulbs?
Why are they made of thick metal?
How does the soda-water come out and why?
What is left behind? Why is there a pop when the bulb comes away from the syphon?
Does the bulb feel hot or cold? Why?

106.

a. When wet clothes are hung out to dry, what happens to the water in them?

b. If you wet the back of your hand (for example by licking it) and then blow gently across it, what do you feel?

c. If you get wet in a swimming pool or a bath do you feel cooler if you can dry yourself with a towel or let the water dry by itself? Why? If you don't know, see if you can find out.

CHAPTER 2

Weighing small things

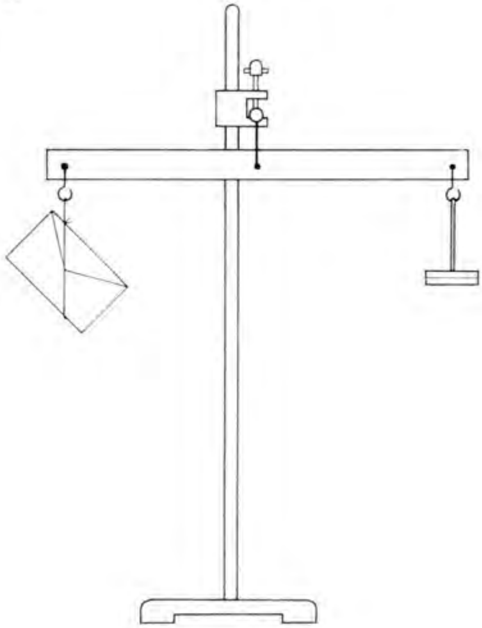
Or how to make your own microbalance

MAKING A MICROBALANCE

21 Demonstration

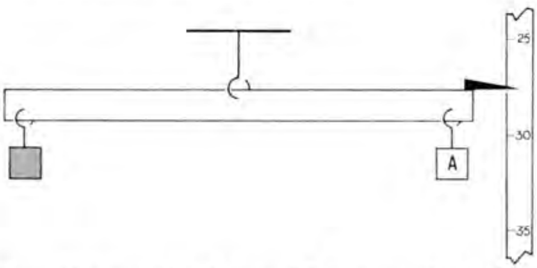
Simple weighing

See the experiments with a wooden bar used as a balance to weigh a small packet, a letter, and perhaps a pin. If that is disappointing for the pin, make your own microbalance, to weigh very tiny things.



Progress question

1. A balance is made like this.



When the weight A was 25 grams, the balance tipped up and the mark 25 was made where the pointer was. The marks 30 and 35 were made when the weight A was 30 grams and then 35 grams.

a. What weight is at A in the diagram? Give it as nearly as you can.

b. Would this balance show a difference if you added:

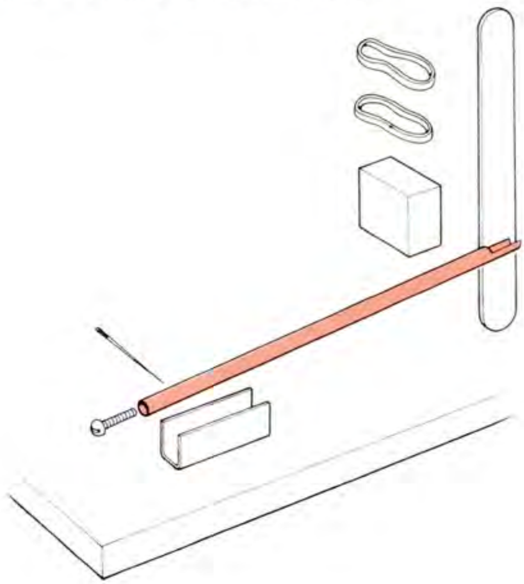
a small scrap of paper?

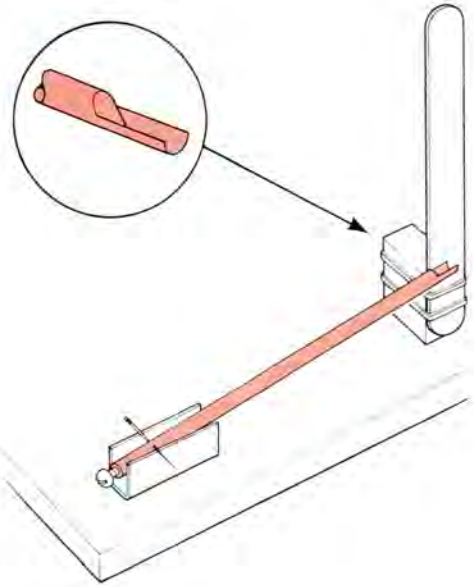
a hair?

22 Experiment

Making a microbalance

Use a drinking straw, a pin, a screw, a piece of metal channel, and a simple scale to make a very sensitive balance – a microbalance.





23 Experiment
Making weights for your microbalance

Your answer to Question 2 or 3 and the diagram below will tell you how to make weights for your own microbalance. Then use them to weigh a hair, a grain or two of sand, a dead fly, a postage stamp. What else can you think of to weigh?

Progress question

2. A piece of paper is marked out into 10 000 equal squares. The whole piece of paper weighs 5 grams. If you cut the paper into 5 equal parts each part would weigh 1 gram and have 2000 squares. So 2000 squares weigh 1 gram.

a. How many squares would weigh $\frac{1}{10}$ gram (0.1 gram)? (Imagine dividing the bit weighing 1 gram into 10 pieces)

b. How many squares would weigh $\frac{1}{100}$ gram (0.01 gram)?

c. How many squares would weigh $\frac{1}{1000}$ gram (0.001 gram)?

d. What is another name for $\frac{1}{1000}$ gram (0.001 gram)?

Question

3. Twenty sheets of thick writing paper, each 30 cm × 20 cm, together weigh 240 grams.

a. How much does 1 square centimetre of this paper weigh?

b. Suppose you cut a strip of this paper 0.5 cm wide. How long must the strip be to weigh 10 milligrams $\left(=\frac{10}{1000}\text{grams}\right)$?

Questions

4.

a. Suppose your straw balance swings across 5 spaces on your scale when 10 milligrams is added. How many milligrams does each division correspond to?

b. Balance makers tell their customers how delicate a balance is by stating its 'sensitivity'. This is a number that tells the customer how many spaces on the scale the pointer moves when an extra milligram is put on one pan.

Each space on the scale is called one 'division'.

What is the sensitivity of the balance in (a) in divisions per milligram?

5. What would be the effect on the sensitivity of your balance of:

a. using a shorter straw?

b. using a wooden skewer instead of a straw (with a larger counterweight if necessary)?

How could you be sure that your answers to (a) and (b) were right? Did you try some experiments that helped you to give those answers, or were you just guessing? (A scientist often makes sensible guesses, but then he always says very clearly that he *is* guessing.)

6. Suppose you wished to use your straw balance outside, in the open air; what troubles would you expect? How would you overcome the troubles?

7. Suppose you had a piece of paper of a suitable known weight.

a. How would you use your straw balance to find out how much a centimetre length of hair from your head weighs? (Be as clever as you can in thinking of any things that you can do to make this experiment as easy and reliable as possible.)

b. Have a look at your own head in a mirror and make a sensible guess as to the number of hairs on it. Say very roughly how much you think all the hair on your head would weigh.

c. From (b), make a very rough guess at the weight of hair a barber gets rid of every week.

d. Suppose you asked a barber to cut all your hair to *half its present length*. And you asked him to give you all the hair he cut off. How could you find out from that the total number of hairs on your head? (Say what measurements you would make).

8. If you wanted to weigh an 8-cm length of hair on the straw balance you might do this in several ways.

(i) Slip the hair down the straw until the end of the hair is level with the end of the straw.

(ii) Cut the hair into 8 lengths of 1 cm each and place all of these on the end of the straw.

(iii) Slip the hair into the straw so that 4 cm is inside the straw and 4 cm overhangs beyond the end of the straw.

a. Do you think all three ways would tilt the straw to the same mark and give the same deflection? If not, would any two of them give the same deflection? Which two? Or would all three give different deflections?

b. Can you say which one way gives the 'right' deflection.

c. *Experiment* Try this out for yourself and see how much difference (if any) there is.

d. Invent another way of placing the 8-cm hair that will give the 'right' deflection.

9.

a. *Experiment* You can find out something about the heavy gas carbon dioxide (CO_2) with your microbalance. Make a tiny cup or box of paper that will hold, say, 1 cubic centimetre. Hang it on microbalance and add something to counterpoise it. Then pour carbon dioxide gas into the cup.

b. *Puzzle* The weighing does not tell you the full weight of carbon dioxide you poured in. Why? (*Hint*: was there anything in the box which came out when you poured the carbon dioxide in?)

Progress questions

10. You have made a straw balance like one in the diagram for Experiment 22 for weighing tiny things. Copy the diagram and label the straw, screw, needle, balance stand, scoop or pan (for putting things on).

11. If you try to weigh a soapflake on your microbalance its weight is too light to move the straw. What could you do to find the weight of a soapflake using the balance?

CHAPTER 3

Rough measurement

Or how to guess sensibly

Question

1.

a. How many centimetres are there in 1 metre?
b. How many metres are there in 1 cm?
c. Is 1 cm longer or shorter than 1 inch? How many centimetres (roughly) in 1 inch?
d. What is 1 kilometre (1 km)? How many centimetres in 1 km?.
e. What is a millimetre (1 mm)? How many millimetres in a kilometre?
f. Name some common thing which has (roughly) each of the following sizes (the first is answered as an example).

1 cm	finger breadth
1 mm	
1 metre	

g. How many miles in 1 km (8 km = 5 miles)?

ROUGH MEASUREMENT

24 Experiment
How thick is a penny?

Use a ruler to measure the thickness of a single penny (in millimetres). *Is that a reliable measurement?* Think of a better way – and try that.

25 Experiment
How thick is a sheet of paper?

Can you use your ruler to measure the thickness of just one sheet? Think of a better way – and try that.

Progress questions

2. How could you measure the thickness of a penny if your ruler only had centimetres marked on it? (*Hint:* how many would you have in a pile measuring 1 cm high?)

3. Describe the best way you can think of to measure the thickness of a page in this book. Then measure it.

4.

a. A building is 13 storeys high and you want to guess its height. You guess the height of 1 storey, say 3 metres. Roughly how high is the building?
b. You go into the building and visit someone on the sixth floor. You notice that the topmost branches of a sycamore tree are level with the window. Roughly how tall is the tree?

5. A farmer found that his large cooking apples measured 10 cm across on average. The farmer had a box 80 cm long and 50 cm wide.
a. How many apples would go in *one row along the length* of the box?
b. How many rows would fill up the *width* of the box?
c. How many apples would there be in *one layer all over the bottom of the box?*
d. If there were 160 apples to pack, how many layers would be needed?
e. How deep should the box be?
You will find it easier if you draw a diagram or use blocks to represent apples.

6. Eggs do not all weigh the same as each other. How would you find the *average* weight of one egg if you had a number of eggs?
Do you know how they grade eggs into large, standard, and small? If not see if you can find out.
Also find out how apples are graded.

7.

a. Choose ten large objects and estimate roughly how long or high they are in metres and centimetres. Write down your estimates.
b. Now measure the objects in metres and centimetres and write down your measurements.
How good were your estimates?
c. Repeat (a) and (b) for ten tiny things but measure in millimetres.

8. You can count seconds of time by saying, 'I count one, I count two,' and so on at a steady

P.Q.8 *continued*

speed. Try this while watching the seconds hand of a clock or watch, to see how well you can do it. Then use this way to find out:

a. How long it takes your little brother or someone else to run up a flight of stairs; or to run 100 metres.

b. How long traffic lights stay green (they are not all the same, of course).

c. How long it takes your friend to read this question.

d. How long you take over each breath – first normally, and second after you have run upstairs. How much quicker is the second than the first?

Questions

9. About 3 cm from the left-hand side of a sheet of paper draw a long, thin, vertical 'ladder' with 22 rungs.

Count up to the sixth rung from the bottom, and label it '1 metre'.

Label the rungs above '1 metre' (going upwards): 10^1 metres (meaning 10 metres), 10^2 (meaning 100), 10^3, . . . , up to 10^{16} metres. Label the rungs below '1 metre' (going downwards): 10^{-1} metre (meaning 0.1 metre), 10^{-2} (meaning 0.01), 10^{-3}, . . . , down to 10^{-6} metre.

Each rung of this ladder represents a length 10 times the rung below and one-tenth of the rung above. Now write the following names by the side of your ladder, marking with arrows the correct places where they should come on the ladder:

Nearest star	10^{13} km	$= 10^{16}$ metres
Sun to farthest planet, Pluto	6×10^9 km	$= 6 \times 10^{12}$ metres
Sun to Earth	1.5×10^8 km	=
Earth to Moon	400 000 km	=
Earth's diameter	13 000 km	=
London to Edinburgh	640 km	=
1 kilometre	1 km	=
Height of Salisbury Cathedral	120 metres	=
Tall man	? *(Guess)*	=
Baby	50 cm	$= 5 \times 10^{-1}$ metres
Length of your little finger	? *(Measure it)*	=
Diameter of a pencil	? *(Measure it)*	=
Thickness of paper	10^{-2} cm	$= 10^{-5}$ metres
Red blood corpuscle	10^{-3} cm	=

10. The particles (molecules) of paper are about 1.5×10^{-8} cm across. Guess (with help from arithmetic) how many molecules there are in the thickness of the sheet of paper.

26 Experiment *(Optional)*
How thick (thin?) is aluminium leaf?

Aluminium is a metal which can be made in very, very thin sheets. Find out how thin these sheets are – they are too delicate to put one on top of the other.

GUESSING MEASUREMENTS

To be able to guess measurements is very useful. Very often, we don't need to know *exactly* how large a thing is – a good estimate is enough. How much does it cost? 'About £10'. What does it weigh? 'Under 5 kilograms'. How far is it to Birmingham? 'About 40 kilometres'. How many apples in a kilogram?

27 Experiment
Estimating lengths, time, and weights

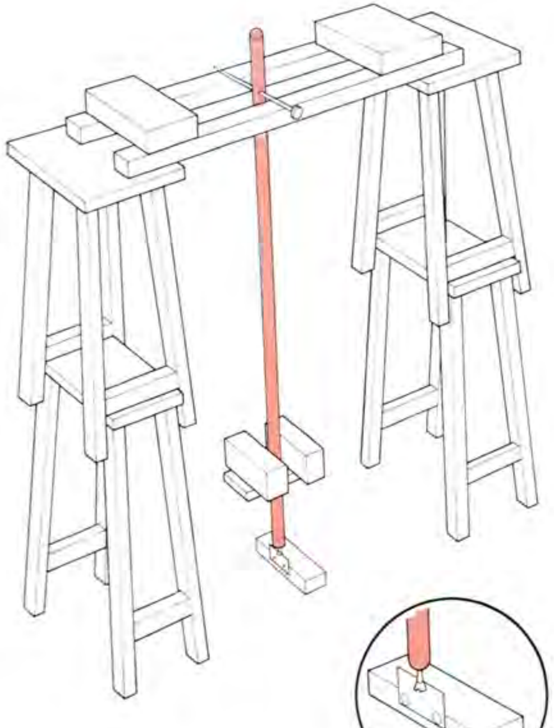
Guess some lengths, or times, or weights as suggested by your teacher.

28a Experiment
Using stop-clocks or watches

Use a stop-clock or stop-watch to measure some times in seconds. *How long for a boy to walk the length of the room? How long to run across the playground? How long for a ball to fall from the table to the floor? How long to run up the stairs?*

28b Experiment
Using a broom-stick to measure time

See the demonstration sketched (top next column).



Questions

11.

775 000 000 km	$= 7.75 \times 10^{11}$ metres
400 000 km	=
20 000 km	=
12 800 km	=
450 km	=
1 600 metres	=
91metres	$= 9.1 \times 10$ metres

The table above shows a number of distances, ranging downwards from 775 millions of kilometres to 91 metres. In the second column the first and last of these are measured in metres written in 'standard form'. Copy and complete the table. Then write the following *in their correct places* next to the first column of your table. (For example, London to Newcastle goes next to 450 km.)

Earth to Moon
One mile
London to Newcastle
Pole to Pole through the Earth's centre
Pole to Pole round the surface of the Earth
100-yards track.

12.

a. Write 10^{-4} metre as a decimal fraction of a metre.

b. Write 100 000 in a shorter way.

c. The diameter of a pin is about $\frac{1}{10\,000}$ metre. Write this as a power of ten.

d. The radius of a single atom of iron is about $\frac{1}{10\,000\,000\,000}$ metre. Write this as a power of 10.

e. Write the *diameter* of an iron atom in a short form (using (d) above).

13.

a. Use a metre rule or measuring tape to measure: your height; the length of your average pace as you walk; and the length of your foot (in a shoe) – all in centimetres.

b. Use your measurements to estimate:

(i) the height of the laboratory (or of a room at home) in *metres*;
(ii) the area of its floor in square metres;
(iii) its volume in cubic metres.

c. In the same way, estimate *roughly* the area of a playground or sports field.

14. Measure your hand-span in centimetres; that is, the distance across from tip of little finger to tip of thumb *as far apart as possible*. Use the span of your hand to estimate the length and width of the table or desk-top at which you are sitting. Measure them in 'spans' first. Convert them to centimetres. Then check with a ruler.

15. Guess the thickness of a playing-card (or postcard). (Hold its edge against a millimetre scale if you like.)

Then see how near your guess was by measuring the thickness of a counted number of cards (10, 20, 50, or 100).

16. Given 1 inch = 2.54 cm, find which is the longer race, 220 yards or 200 metres. How much longer? Give the answer to the nearest centimetre.

17. Seconds of time may be counted by saying 'Mississippi one, Mississippi two,' etc., each syllable being clearly said at normal speed. (If you prefer, say 'one little second, two little seconds'.) Test this by counting up to 'Mississippi ten' while watching a clock which has a seconds hand. Then try your skill at counting seconds up to half a minute in this way.

Q.17 *continued*

Suppose you were in a train one day, and you started counting like this just as your compartment passed a half-kilometre post. You find that you pass the next half-kilometre post as you count 'Mississippi fifteen'. How fast is the train travelling?

18. Make a simple balance as follows:

Find a hexagon-shaped (six-sided) pencil and balance a ruler on it. Collect a number of 2p coins. We will call the weight of a 2p coin one 'unit' of weight. Find, to the nearest whole number of 'units', the weight of a 10p coin and of other small objects (heavier than a 2p coin) that you can put on a ruler.

Can you suggest any way of using this balance to find the weight, in 'units', of a 5p piece? How?

Taking averages

19. Ten boys weighed the same piece of metal on the same balance (which weighs to the nearest gram). The ten results were:

173	**173**	**174**	**175**	**173 grams**
173	**171**	**172**	**174**	**174 grams**

One of the boys added up all these, and got 1732. He then divided by 10 and got 173.2 grams to one decimal place.

a. This is correct arithmetic, but how would you have got the same result much more quickly, without nearly as much arithmetic?

b. What is the 'best' value for the weight of the metal *to the nearest gram?*

20. *(Following from Question 19)* One boy wonders whether the balance is really correct, and to test this, he puts on to it the following weights taken from a set of weights that have been tested and are known to be accurate to much less than 1 g.

They are 100 g; 50 g; 20 g.

They are put on together, and the balance reads 168 g. Several people agree about this.

What do you now think is the 'best' value (to the nearest gram) for the piece of metal weighed in Question 19?

21.

a. Take any book and count the number of words in any three lines of print. Is there the same number in each line? What is the *average* number of words in a line?

Did any of the three lines you chose start or finish a paragraph? Did any of them have a part of a word on one line and part on the next? Would it be better, if you want to find the average number of words in a line, to avoid counting 'special' lines like those? Begin again if you think you ought to.

Did you count words with hyphens, such as 'test-tube' and 'co-operative', as one word or two words?

b. Now take two other sets of three lines each and find the average number of words in a line for each set. Do you get the same average for each of the three sets? Does your answer seem reasonable?

c. Without doing any more counting, what would you give as the best average for the number of words in a line?

d. Suppose you found 73 words in 10 lines. Is it sensible to say the average is 7.3 words in a line, or is 7 more sensible? (We do not use fractions of a word in talking or writing.) Which should a printer use for estimating the cost of setting type, 7.3 or 7? Explain why.

22. A tape measure, which is marked in centimetres up to 100 cm, is suspected to have stretched. Six boys use an accurate boxwood rule to measure the length marked as 80 cm on the tape. They obtain the following six readings:

80.4	**80.5**	**80.2**	**20.3**	**80.4**	**80.3**

a. What is the most likely value for the real length between the zero mark and the 80 cm mark on the tape?

b. Did you leave out the 20.3 value in finding the answer to (a)? If so, why do you think it right to leave it out?

c. What would you suggest the boy who took the 20.3 reading should do. (The tape was marked in centimetres on both sides, but from opposite ends. Can you suggest what happened?)

d. Some people think that by taking more and more measurements of the same thing with the same ruler or tape, and then taking the average of all readings, they will get a more and more accurate result. They think they can get as close as they like to the true value by taking the measurement enough times. Would this be true for measurements made with this tape? Why not?

23. *(Try this at home)* Take a pack of playing-cards and shuffle it well. Then make ten small cuts, exposing ten cards. How many of these belong to the suit of Hearts? Make a note of the number. Collect the cards, reshuffle and try again, making twelve tries in all.

a. Is there always the same number of Hearts exposed in each try?

b. What was the maximum number of Hearts exposed in a single try?

c. Your twelve tries will have exposed 120 cards. How many of these were Hearts? Does this seem reasonable?

d. What is the average number of Hearts exposed per try? (Work to one decimal place.)

e. What is the average number of Hearts exposed per cut? (Remember you make 10 cuts at each try.)

f. Does the answer to (e) mean anything? What would this answer have been if you had been given a 'conjuror's pack' in which all the cards were Hearts?

Guessing

Choose any *two* out of the following things, and in each case make the best quick rough guess you can – which is something a good scientist often has to do. Put your guess in standard form and carry the figures of the standard form as far as you think wise.

(i) The number of eggs a good hen lays in one year.

(ii) The number of litres* of milk an average cow gives in one year.

(iii) The number of half-litre* milk bottles a family of two parents and two children takes in one year.

(iv) The number of letters one postman delivers in one year.

(v) The number of chemist's shops in the nearest big city: Birmingham, Bristol, or whatever is near to you.

(vi) The number of grains of sand in a handful.

(vii) The number of hairs on your head.

(viii) The number of sewing-needles sold in England in one year.

(ix) The number of stars that you can see on a clear night outside your home with your eyes alone.

(x) The distance in metres between your bedroom and your physics classroom.

(xi) The amount of potatoes in kilograms that your family eats in a year.

(xii) The amount of potatoes in kilograms that you are likely to eat in the first twenty years of your life.

(xiii) The number of robins in England.

(xiv) The number of golden eagles in Britain.

(xv) The height in centimetres of the tallest tree or building within one kilometre of your school (say where it is, and what it is).

(xvi) The number of dogs in your county (not including puppies).

Note

*If your family takes milk in pints, you may guess in pints

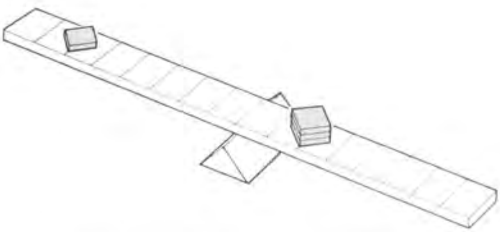
CHAPTER 4

Balancing a seesaw

Or how to look for a law

29a Experiment
Looking for a law

Take a seesaw and balance it on the wedge at the centre. Put some loads on each side. You should put the loads at the marks so that you know when a load is one step out or two steps out or four steps out from the centre. Don't put a load $2\frac{3}{4}$ steps out because that would make it harder to find out the scientific story of seesaws. First make the seesaw balance with two piles of loads (pennies), one each side.



When you have it balanced, the seesaw will tip over to one side and stay there, and it will tip over to the other side and stay there. You will not be able to make it stay exactly balanced in mid-air. That is because it is sitting on top of the support at the centre, ready to fall over either way. But this will be just like 'weighing sweets': when the scales are exactly balanced and you find ever so little more would tip the scale one way or the other.

You have balanced the seesaw with two piles of pennies. *How can you move the pennies and keep the balance?*

Find out what you can about a balancing seesaw, with different loads on it. Make notes in your notebook of what happens. See if you can find out some rule or story that you could tell other people about balancing loads.

29b Experiment
Using your law

Use a large seesaw made from a plank balanced on a brick, and your knowledge of the 'lever law' to weigh your partner.

30a Experiment
The game of Sym

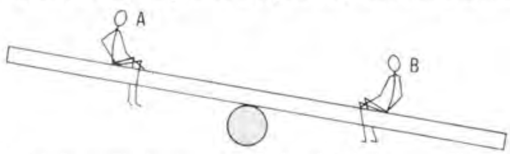
Start with the seesaw balanced with no pennies on it. Take several pennies and arrange them on the seesaw (at marks) so that the beam is again balanced. Make a note (by a sketch) of that pattern. The game is to find the smallest number of moves to arrive at that balanced pattern of pennies, starting with all those pennies in a pile at the centre point. A move consists of moving two pennies and no more; the move must be such that the seesaw is balanced before and after the move.

30b Experiment
Another game

(For two players.) One player puts pennies in some pattern on the marks on one side of the balance-point; his partner has to find where to put two pennies to balance.

Progress questions

1. A heavy boy and a light boy are on a seesaw.



a. Which is the heavy boy, A or B?
b. A wants to make his end go down. Which way along the plank must he move?
c. Draw the heavy boy and the light boy sitting on the seesaw in the right places for it to balance. (Make them *look* heavy and light.)

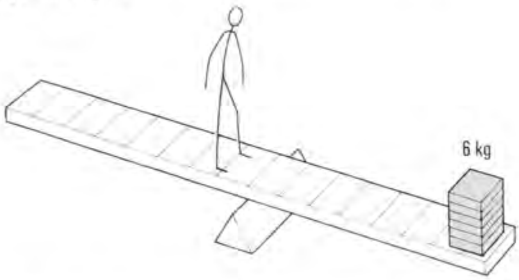
2. Two loads have been put on mark 2 on the left-hand side of this lever.

a. How many loads would you have to put on mark 1 on the other side to make the lever balance?

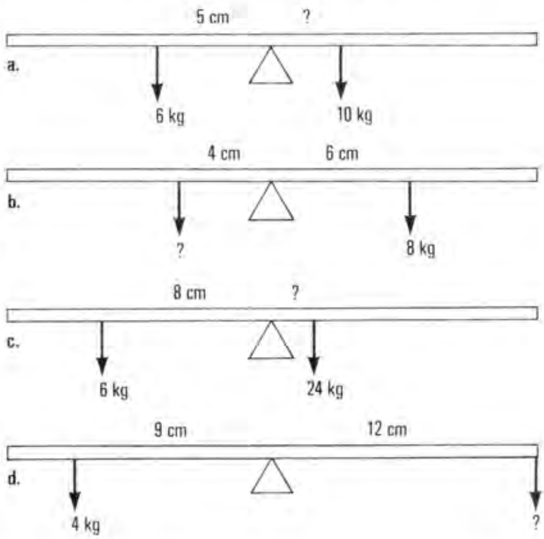
b. Where would you put one load to make the lever balance?

3. Four loads have been put on mark 3 on the right-hand side of the lever. Give all the ways you can think of to make this balance, saying in each case what loads must be put where on the left-hand side.

4. The pupil standing on this plank is balanced by a load of 6 kg. How much does the pupil weigh?



5. The following examples are all of *balanced* levers. Copy these out, and wherever there is a ? mark write in the correct load or distance.



Questions

6. *(Advanced)*
a. Tommy, weight 30 kg, sits at one end of a seesaw 4 metres long, supported at the mid-point. Where must Uncle John, weight 90 kg, sit to produce a balance?

Uncle John says: 'I don't like this. I want to sit out at one end too.' Tommy says: 'All right, it's perfectly possible to have you at one end and me at the other, and still balance the seesaw.' Tommy is right, but they will have to shift the balance-point (fulcrum) of the plank.

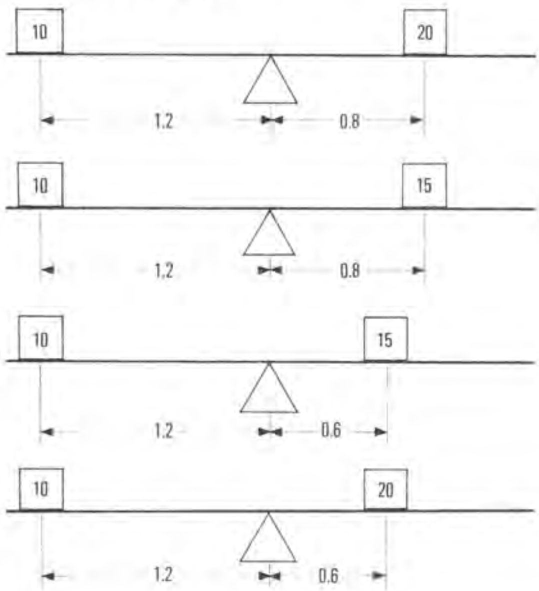
b. Draw a rough picture of the seesaw in the new position, marking in the fulcrum.

c. Draw arrows on your pictures of the seesaw to show Uncle John's weight pulling downwards and Tommy's weight pulling downwards.

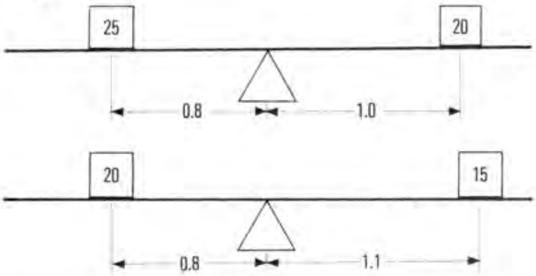
d. If you can, add one more arrow pointing downwards to show the weight of the seesaw itself. The seesaw is quite a light plank compared with Tommy or Uncle John. You can pretend that the whole pull of the Earth on the plank is a pull at the mid-point of the plank.

e. The plank does not fall down because the support (fulcrum) pushes it up. Draw an upward arrow for that push.

7. Here are six diagrams showing a plank resting across a support. The support is at the mid-point of the plank. Two loads rest on the plank, and their value in kilograms is shown on them. Their distance from the support (in metres) is shown beneath the plank.



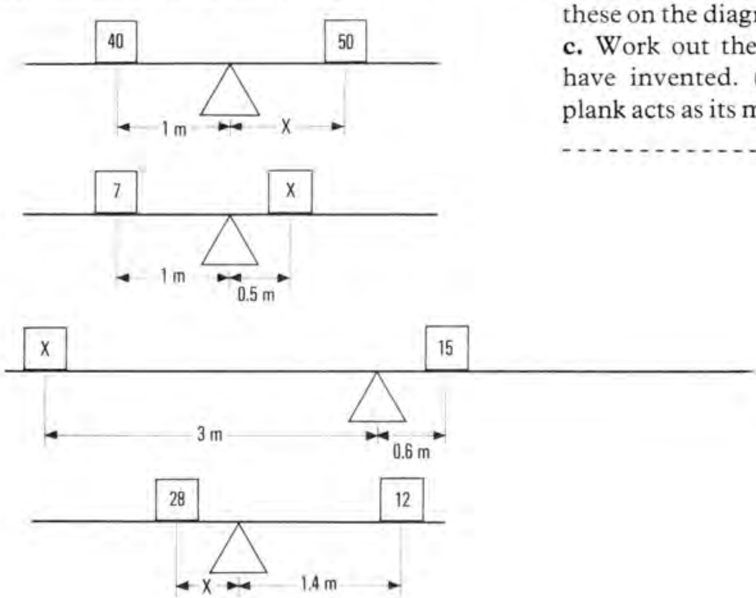
Q. 7 *continued*



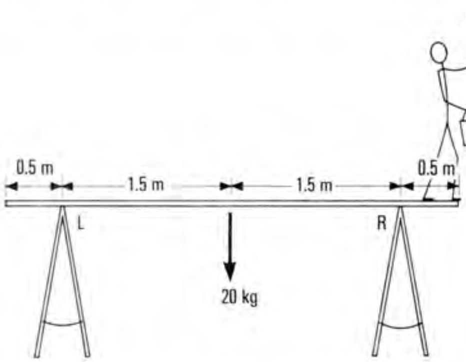
a. Copy the diagrams and draw arrows to represent the pull of the Earth on each load and the pull on the 10-kilogram plank. Add another arrow for the upward push of the supporting fulcrum.
b. Write at the side of each diagram either BALANCED or UNBALANCED.
c. Add in the 'unbalanced' cases a note such as 'left end tips downwards' to explain what you think will happen.

8. Below are four more diagrams similar to those in Question 7. The plank is always supported at its mid-point. This time the value of either *one of the loads* or *one of the distances* has been marked as X. *All the planks balance.*

Write a heading FOUR BALANCED PLANKS and beneath it copy the diagrams to scale, with arrows of suitable lengths, for the Earth's pull, as you did in the last question. One unknown load or one unknown distance is left as X in your diagram. At the side of each diagram write X = ? (put in the correct number). Don't forget to say whether the number stands for kilograms or metres.



9. A man who is painting a ceiling stands on a 20-kilogram plank 4 metres long stretched across two trestles L and R as shown. The plank is (foolishly) allowed to overlap the trestles by 0.5 m



at each end. The plank *just* begins to tip as the man gets to one end, the end near R in the drawing.
a. How many kilograms in the man? (We can pretend the weight of the plank acts at its mid-point.)
b. You could stop the plank tipping by tying it to the trestle at L, provided the trestles are heavy enough. But tying it to R would have little or no effect in stopping the plank tipping. Why not?

10. Tommy (who weighs 40 kg) wants to find how much a plank of wood weighs. He guesses the weight to be between 10 and 20 kg. He also has a 30-cm length of old broom handle and two trestles like those in the figure for Question 9.
a. Draw a sketch showing how Tommy could find the weight of the plank (in kilograms).
b. Invent some reasonable measurements and put these on the diagram.
c. Work out the answer from the numbers you have invented. (The pull of the Earth on the plank acts as its mid-point.)

CHAPTER 5

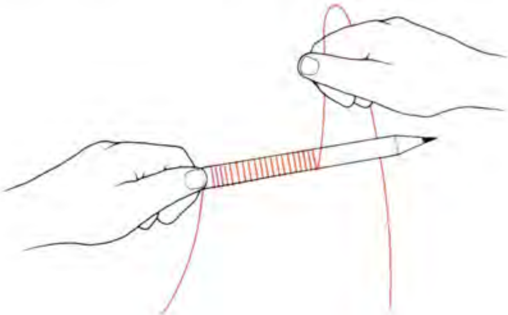
Investigating springs

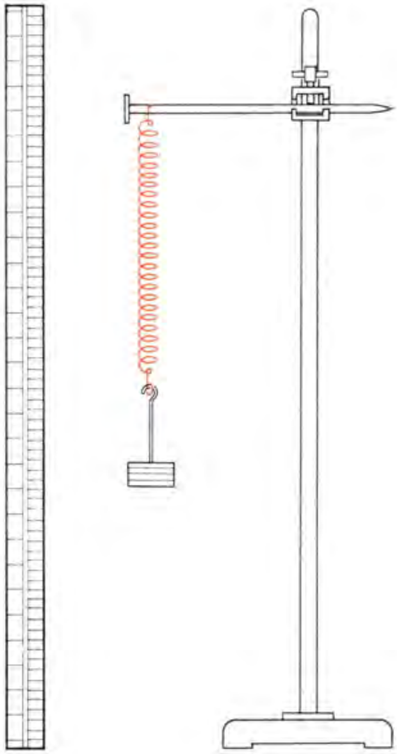
Finding a law for stretching and squeezing

31 Experiment

Making a spring

Make yourself a spring out of copper wire by winding it around a pencil. Now find out how your spring behaves. *Does it stretch regularly? What happens if you put too large a load on it? Can you put it back into the shape you started with?*





32 Experiment

Steel springs

Now find out all you can about the steel springs. *What do you look for? What do you measure?* Make a record. You will need two columns for that; one column for the load and the other for the stretch. You might like to plot a graph as you collect your results.

Suppose you are going to make springs for use in spring balances. *Have you found any simple rule for springs that would help you do that? What is that rule?*

Did this rule work for your spring of copper wire? You may wish to test a newly made spring before answering that question.

Does this rule work for a rubber band?

Does it work for your steel spring, on and on as you hang more and more and more on the spring?

The springs rule *What happened to the stretch when you doubled the load? And when you put on three times the load? And four times?*

When you double the load you double the stretch. When you treble the stretch you treble the load, and so on. The stretch goes up in the same proportion as the load.

Does the springs rule apply however much load you put on?

Progress questions

1. A copper spring is made by winding wire into this shape, and then loads can be hung on it to test how the spring behaves.

P.Q.1 *continued*

a. Did it keep its shape for small loads (say 20 grams)?

b. What happened to it with the larger loads?

2.

a. In your experiment to find out how a steel spring stretches, why didn't you hang all the loads on at once?

b. You put a 100-gram load on your spring. How did you find out how far it stretched? Draw a sketch to help explain your answer. Label the sketch.

c. Did you notice any kind of pattern as you went on adding 100-gram loads?

d. You can spoil a spring – that is, stretch it so much that it does not go back to its first length when you take the loads off. What load spoiled your spring?

e. If you went on adding 100-gram loads after your spring was spoilt what happened to the stretch?

f. Did you notice anything else that interested you in this experiment?

3.

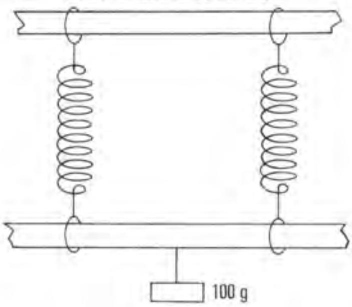
a. Here is part of a load/stretch table for a spring. Copy the table. Fill in the spaces. You may assume that the spring stretches regularly.

Load	**100 g**	**200 g**	**300 g**	**500 g**
Stretch	**4 cm**	**cm**	**cm**	**cm**

b. Copy the following sentences and fill in the blanks: 'When you double the load on a spring the stretch is . . . as big.'

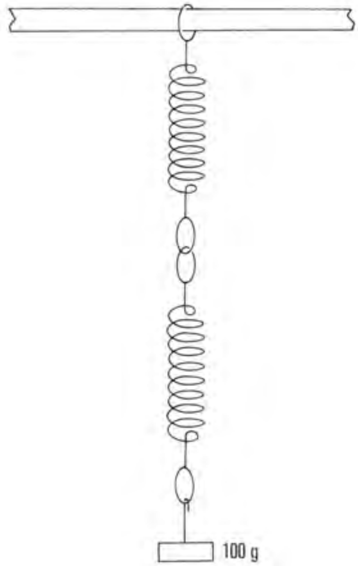
'When you treble the load, the stretch is . . . as big.'

4. If you hang two springs, exactly like the one in Question 3, so that they share a load of 100 g, how much would the stretch be?



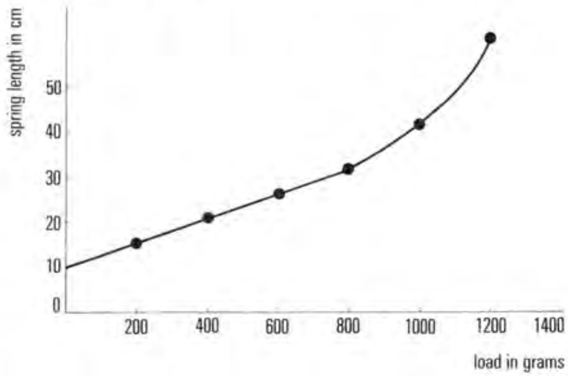
5.

a. The two springs (top right) are exactly like the one in Question 3. They *both* feel the pull of the 100-g load. So how much stretch is there altogether?



b. How many springs would you need to hang one beneath the other to produce a stretch of 12 cm with just a 100-g load?

6. Some pupils used a steel spring to make measurements of load and of spring length. They then plotted their measurements on a graph which is shown in the diagram.



Look at the shape of this graph and notice that its shape changes. Then answer the following questions:

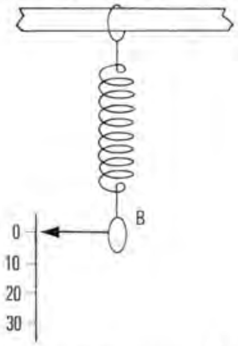
a. If 1200 grams was put on the spring and then taken off, would the spring go back to its starting length?

b. Up to what load would this have been a useful spring for measuring loads?

c. If this spring was stretched to a length of 25 cm, what load would be on it?

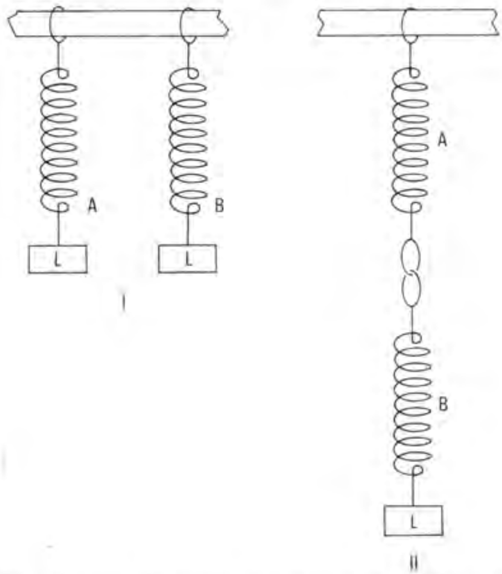
Questions

7. This spring has its free end B opposite the 0 mark on the scale when unloaded. When a 100-gram load is attached, B is opposite the 20 mark.



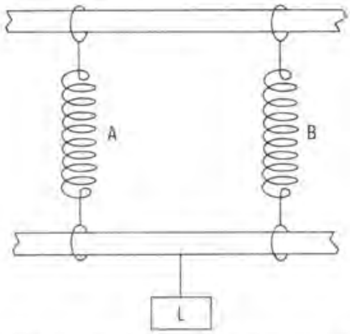
a. What reading do you expect for a load of 150 grams? For 25 grams?
b. If the reading is 10, what is the load? How did you get your answer?
c. What is the load when the reading is 22? Did you get your answer in the same way as for (b)? If not, how did you get it?

8. A and B are two exactly similar springs carrying equal loads. You may forget about the weight of the springs because it is so small compared with the weight of the loads. Each spring is extended by 6 centimetres by the load L (sketch I).



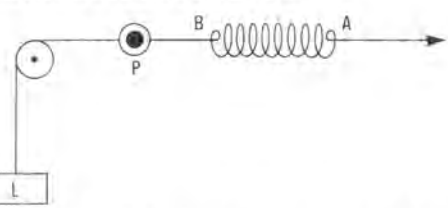
a. The load on A is removed and the spring B is attached to A, as in sketch II.
(i) How much does spring A now stretch when the load L is hung on B?
(ii) How much does spring B now stretch?
(iii) How far will the bottom end of spring B go up if the load L is removed?
b. *(Think about your answers to (a) when you answer the following question)*
Two springs P and Q are equal in every way except that P is twice as long and therefore has twice as many 'turns' as Q – it is made of twice as much wire. If a load of 1 kilogram stretches Q by 3 cm, how much will a load of 1 kilogram stretch P?

9. The same springs A and B, used in Question 8, are now joined side by side, a flat wooden stick at their bottom ends.



a. What is the stretch in A and B when a load L is attached to the centre of the stick?
b. What difference would it make to the stretch in each spring if the load L were attached at some point other than the centre? (This is not a question for calculations; just say in words what difference it makes if L is nearer A, and if L is nearer B.)

10. In the diagram one end, B, of a spring balance is fastened to a small ring. The ring is also attached to a string passing over a pulley and carrying a load L. P is a peg which fixes the ring in one place. But P can be removed.



The end A of the spring is now pulled to the right so that the reading on a scale is 3 kg.

The peg P is then removed. What happens to the ring, and what is the final scale reading of the spring:
a. if L is 2 kilograms?
b. if L is 3 kilograms?
c. if L is 4 kilograms?

Q.10 *continued*

Note There is no 'catch' in this question; it really is simple. The idea is to give you a little practice with 'pulls' or 'tensions' in springs. If L is 4 kilograms then the tension in the string is the pull of the Earth on 4 kilograms. (The pulley is supposed to turn freely without friction.)

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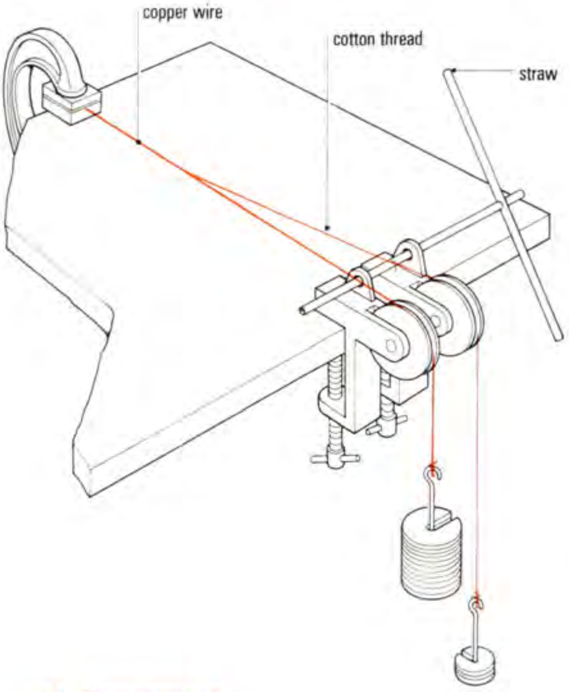
33 Demonstration

Does the springs rule apply to a straight wire?

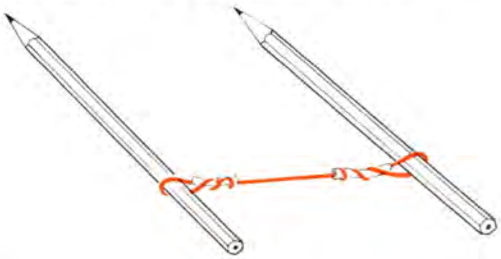
See the demonstration sketched.



34 Experiment

Stretching wire

Try stretching some thin copper wire yourself. Pull it gently so that you can feel what is happening. *What does it feel like as you pull harder and harder?* Have a look at the broken ends under a magnifying glass. *What do they look like?*



35 Experiment

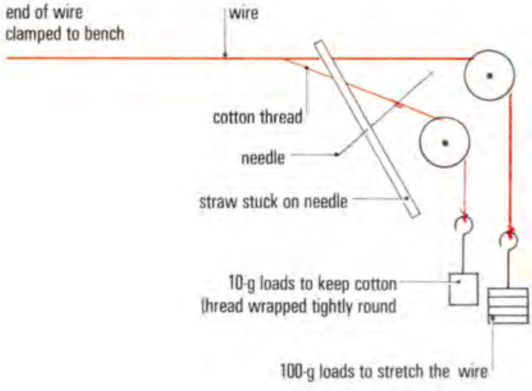
Feeling forces

You felt the forces in the last experiment. Try feeling the force between your left and right hands when you stretch an elastic band; two elastic bands; a string. Try twisting a piece of rubber foam. Now hold a lump of metal up on a string – or in your hand. It feels as though something else is pulling it downwards. That downward force is called the 'weight' of the lump.

Those forces were all 'attractions' – 'pulls'. Try two magnets – one in each hand. *Do they always pull together? Or are there pushes as well?*

Progress questions

11. Here is a sketch of the apparatus used to stretch copper wire.



a. Why did we use a straw and needle to show the stretch of the wire? Why couldn't we just measure the stretch on a ruler?
b. How did the straw move at first as we added 100-gram loads one after another?
c. How did the straw move as we took the loads off one by one?
d. What happened to the straw movements as we went on adding more and more 100-gram loads?
e. Does the way a copper wire stretches remind you of the stretching of a spring in any way?

12.
a. You have felt a copper wire stretching yourself. As you start pulling steadily how does it feel?
b. What does it feel like towards the end, just before the wire breaks?
c. Did the wire stretch more or less easily at the end than when it started stretching?
d. What shape was the wire where it broke? (Draw it.)

13. What happens to a rubber band if you give it a small pull, then a larger and larger pull?

14. In a trampoline a strong rubber sheet is fixed across a strong frame.

What do you see happening to the rubber sheet if a small child stands in the middle of it?

What happens if a heavier person stands on it?

What happens to the rubber sheet when someone jumps up and down on the trampoline?

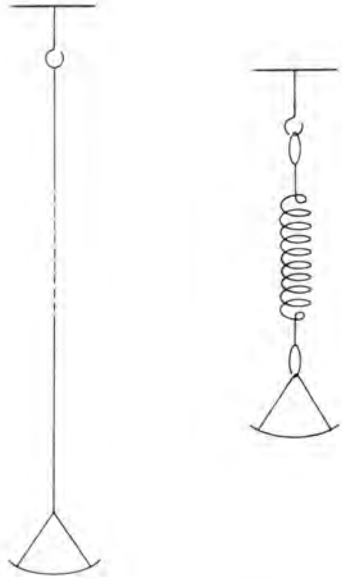
If you can, draw diagrams to show what happens.

Questions

15. A piece of thin copper wire 2 metres long is fixed to the ceiling so that it hangs vertically with a light dish at the lower end. An exactly similar piece of thin copper wire, also 2 metres long, is coiled into a tightly wound spring, and also has a light dish attached to it.

A load is then put on the dish attached to the *wire*, and the wire stretches by 1 cm. We will call this load P.

A different load, Q, when put on the dish attached to the *spring*, stretches the spring by 1 cm.
a. Which will be the larger, P or Q?
b. What is likely to happen when P is taken off again?
c. What is likely to happen when Q is taken off?



16.
a. When a load is put on a spring the distance between the coils of the spring is increased. What is it that will be increased when a load is put on a copper wire, as in Question 15? (We suppose that the wire is made up of atoms.)
b. A wire carries a load which is not quite big enough to break it. When the load is removed the wire shortens a little. But most of the stretch produced does not disappear; the wire is permanently stretched. Write one or two sentences explaining what has happened to the wire.

17. When you did an experiment with springs you plotted a graph, which looked like the one in the diagram.

a. What were you plotting upward?
b. When you put bigger loads on the spring, it began to stretch permanently. Then the points did not fit on your simple graph; where were they? Sketch the graph again and add more points to show what happened with bigger loads.

18. *(Advanced puzzle)* Suppose you have a spring of steel wire like the one in the figure.

A piece of strong thread is tied to one end and to the spring at its mid-point. The thread is loose, but when the spring is loaded up to about one-third of the load at which it stretches permanently, the thread is pulled taut. You continue loading beyond that up to the safe limit. What graph would you get? Sketch it and explain.

19. If we suppose that solid substances are made up of atoms, then some simple experiments tell us quite a lot about the forces atoms exert on each other.

a. You take a piece of metal or wood or almost anything, even india-rubber, and try to pull it into two pieces. It resists your pull. What does this suggest about forces between atoms?

b. You take a piece of metal, or india-rubber, between your fingers and thumb and try to squash it. It resists being squashed. What does this suggest about forces between atoms?

c. You take two pieces of metal, or india-rubber, and put them near each other. They do not fly together, and even if you touch them together they do not stick. What can you now add to your answers for (a) and (b) about forces between atoms?

d. *(Advanced)* Put together the observations and your conclusions in (a), (b), and (c) in order to make a general statement about how forces between atoms vary, in a solid, with the distance apart of the atoms.

20. *(Advanced)* A boy says that Question 19 proves that solids are made up of atoms because 'you can't explain what happens in any way except by talking about atoms'.

Is he right? What do you say?

CHAPTER 6

Air pressure and molecules

Squashing air; what air pressure can do Inventing a model for a gas

Forces and pressure

Some questions to start with.

Questions

1. This question describes four pairs of events. The items in each pair are similar, but with a difference. For example, in pair A, the shoes are different. Read the descriptions and then answer the question which follows:

A	A girl stands on soft sand in flat shoes. A girl stands on soft sand in high-heeled shoes.	How would the marks in the sand be different?
B	A boy presses his thumb on the flat top of a drawing pin. A boy presses his thumb on the point of a drawing pin.	What difference would his thumb feel?
C	The flat side of a knife is pressed against butter. The edge of a knife is pressed against butter.	What difference would you see?
D	A saucer is carefully placed flat on to water in a bowl. A saucer is lowered edge down into water.	What difference would you see?

Illustrate your answers with diagrams if it helps.

2. You stand with your bare feet on a smooth concrete floor. Then someone sprinkles gravel around you so that you have to walk away across the gravel. Why does the gravel hurt while the concrete does not? Answer, because the gravel sticks to your feet. Is that the whole answer?

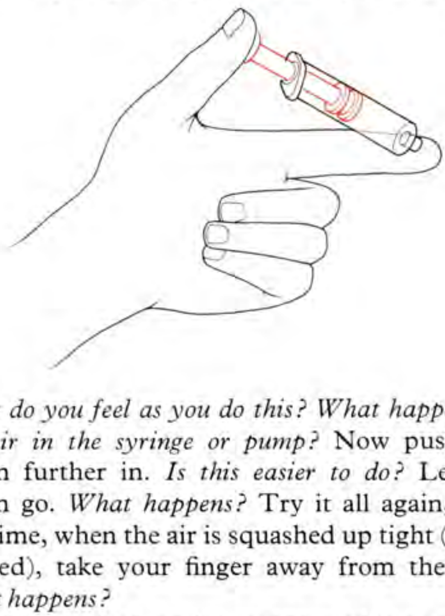
Let's think a little more about it.

a. Compare the load which the concrete floor has to support with the load which the gravel has to hold up. Is that load the same, or more, or less?
b. Compare the area of the gravel in contact with your feet, and the area of smooth concrete touching your feet. Is the area the same, or more, or less?
c. Compare the load per unit of area of gravel with the load per unit of area with the concrete. Is it the same, or more, or less?
d. Now answer the original question: 'Why does the gravel hurt while the concrete does not?'

A force, such as your own weight on the floor, produces a certain pressure. Stand on one leg. What happens to the force on the floor (your weight)? Yes, it must be the same. But what happens to the pressure on the floor? Yes, it is bigger – because the force is spread over only one of your feet and not divided between both of them.

36 Experiment
Squashing air

Put your finger firmly over the end of a syringe or a bicycle pump and push in the piston a little.



What do you feel as you do this? What happens to the air in the syringe or pump? Now push the piston further in. *Is this easier to do?* Let the piston go. *What happens?* Try it all again, but, this time, when the air is squashed up tight (compressed), take your finger away from the end. *What happens?*

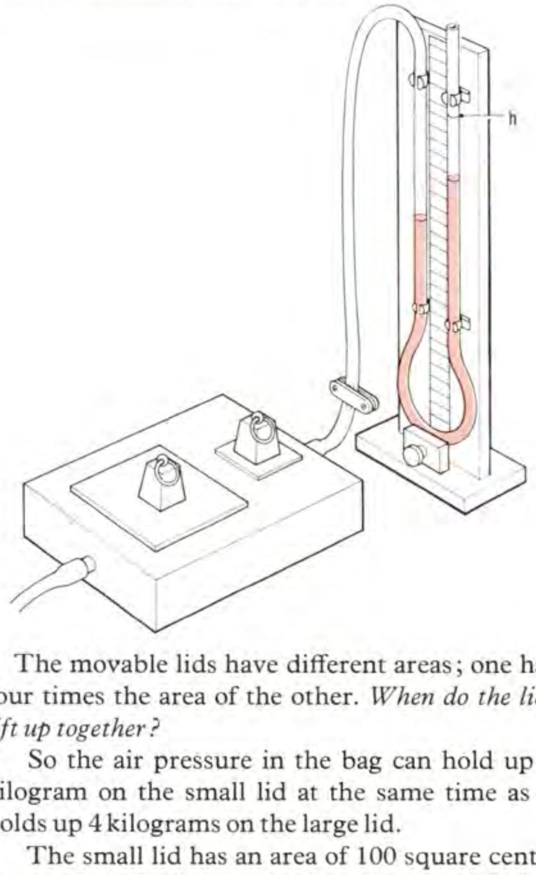
The squashed-up (or compressed) air pressed strongly on your finger, on the barrel of the

36 E. *continued*

syringe or pump, and on the piston. Then, when the pressure was released, that air moved quickly away. Trapped like that in the syringe, or pump, or in a tyre, air can hold up big loads. For example, an average motor car (about 1000 kg) is supported on air compressed in the four tyres.

37 Demonstration
Air pressure

See the demonstration sketched.



The movable lids have different areas; one has four times the area of the other. *When do the lids lift up together?*

So the air pressure in the bag can hold up 1 kilogram on the small lid at the same time as it holds up 4 kilograms on the large lid.

The small lid has an area of 100 square centimetres and the large one four times as much – that is, 400 square centimetres.

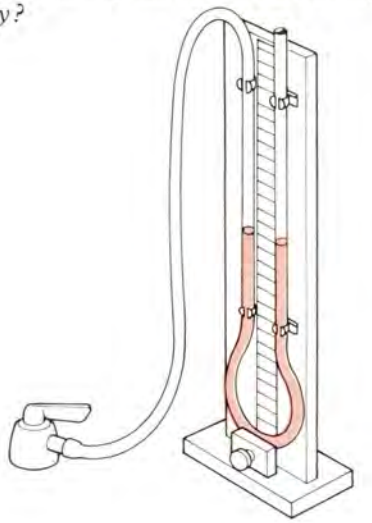
	Smaller	*Larger*
Area of lid:	100 sq cm	400 sq cm
Load supported:	1 kg	4 kg

The air pressure inside the box was able to hold up a load of 1 kg for every 100 square centimetres – that is, 100 kg for every square metre. (1 square metre = 10 000 square centimetres.)

The air pressure also holds up (supports) the load of the column of water marked 'h' in the U-tube. That U-tube gives a convenient way to compare gas pressures.

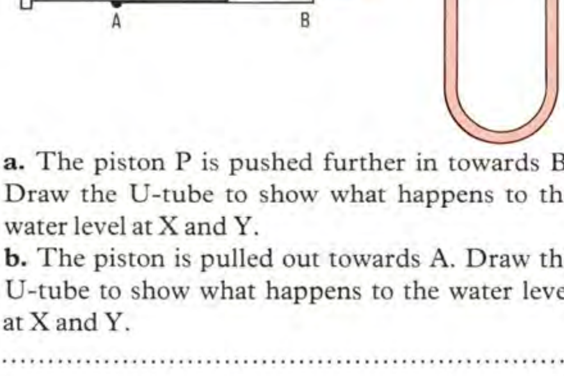
38 Experiment
Comparing pressures

Connect the gas supply to the U-tube which has coloured water in it. The technical word for this is 'manometer'. It is a pressure gauge which uses water. *What length of water column does the gas pressure support? Does your neighbour get the same length of water column? What does that tell you about the pressure of the gas at the gas taps in the laboratory?*



Progress questions

3. AB is a syringe with air inside. P is an air-tight piston that can be pushed in or out. The syringe is joined to a U-tube with some water in it. The water starts level at X and Y.

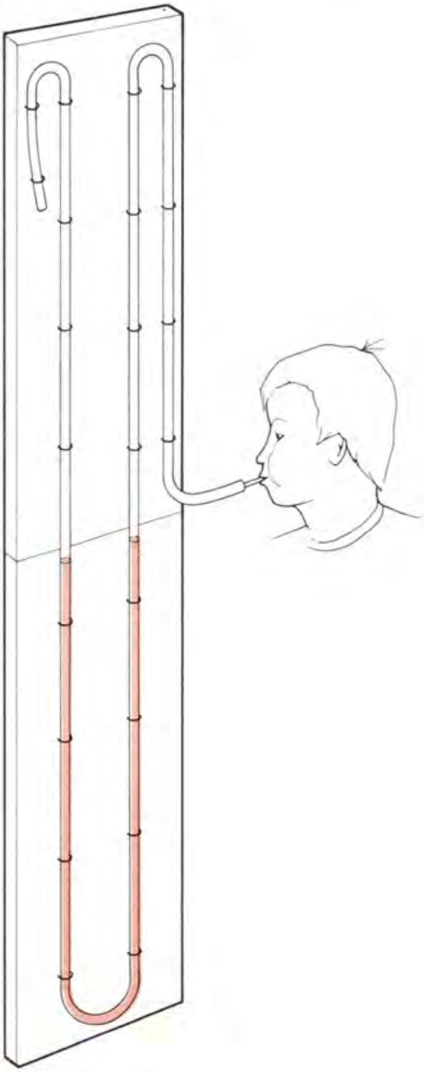


a. The piston P is pushed further in towards B. Draw the U-tube to show what happens to the water level at X and Y.

b. The piston is pulled out towards A. Draw the U-tube to show what happens to the water level at X and Y.

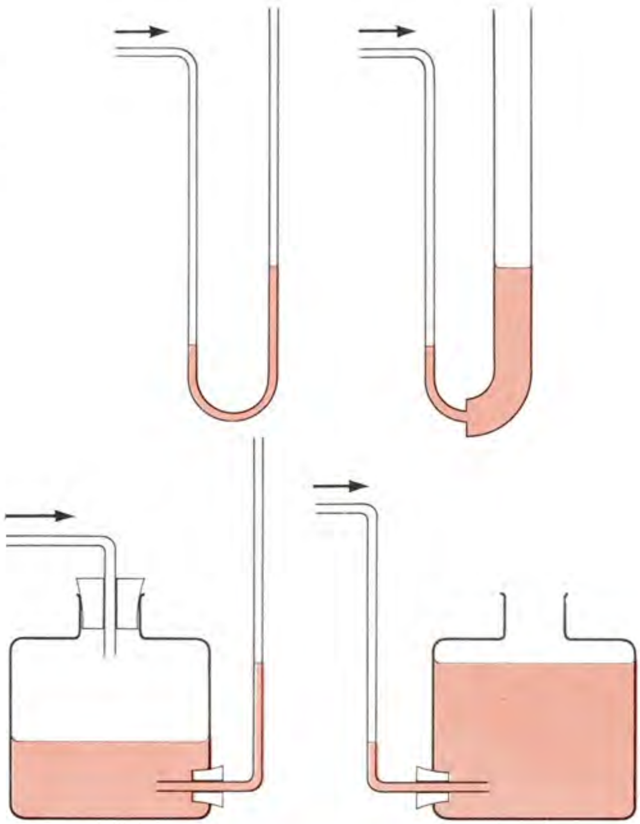
39 Experiment
Measuring your lung pressure

Use the very large water pressure gauge or manometer on the wall to measure your own lung pressure.



40 Demonstration
Using different manometers

Does a manometer have to have tubes with the same diameter on both sides? See the demonstration sketched.



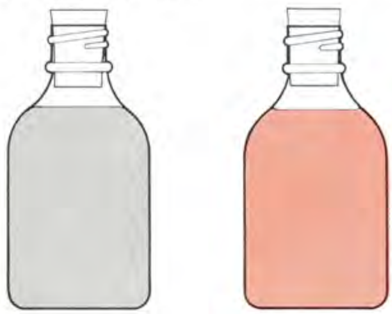
41 Demonstration
Using a different liquid in a manometer

What will happen if mercury is used instead of water in a manometer to measure the gas pressure?

Why does the mercury manometer show such a tiny difference in level compared with the water manometer?

42 Demonstration

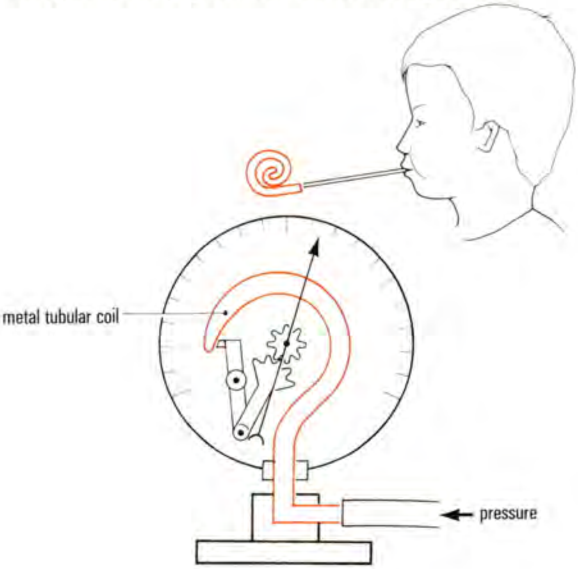
There are two small similar bottles. One is full of water; the other of mercury. *Which is the heavier? What does that tell you about the density of mercury? How does that fact explain the difference in level you saw in Demonstration 41?*



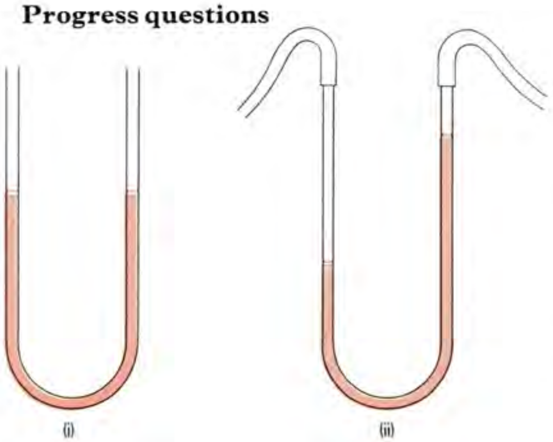
43 Demonstration
Another pressure gauge

A paper toy unrolls into a long paper tube (closed at one end) when someone blows into the mouthpiece at the other end. That is just what happens in a Bourdon gauge. A metal tubular coil unwinds a little when the pressure inside goes up (or winds up a little when the pressure goes down). This moves a pointer over a scale.

The Bourdon gauge works when there is a difference in pressure between the outside and the inside of the metal tube. The U-tube manometers work when there is a difference in pressure between one side and the other. So either of these pressure gauges must read zero when not connected to anything which causes a pressure difference. They are really 'pressure-difference gauges'.



Progress questions



4. In figure *(i)* a U-tube has water in it, and is open to the air on both sides.

In figure *(ii)* rubber tubes have been joined to the U-tube and someone blows to make the pressure greater.

a. Which side is he blowing?

b. What could you do instead to make the water go as shown in figure *(ii)*?

c. We can say, 'The difference in the pressure on the two sides is so many centimetres of water'. Copy figure *(ii)* and show on it where we have to measure these centimetres.

5.

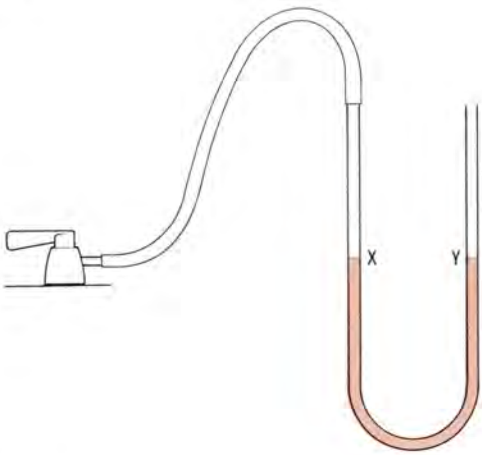
a. Describe how you measured your lung pressure using a long U-tube containing water. Draw a diagram.

b. What result did *you* get? Say where the measurement was made.

c. If you also tried this using a U-tube with mercury in it, what measurement did you get?

d. Why do you think the numbers in (b) and (c) are so different?

6. A U-tube containing water is joined to the gas tap.



a. The gas is turned on. What happens to the levels at X and Y? (Draw it if you like.)

b. Now, without removing the rubber tube, the gas tap is shut off. What happens to the water levels?

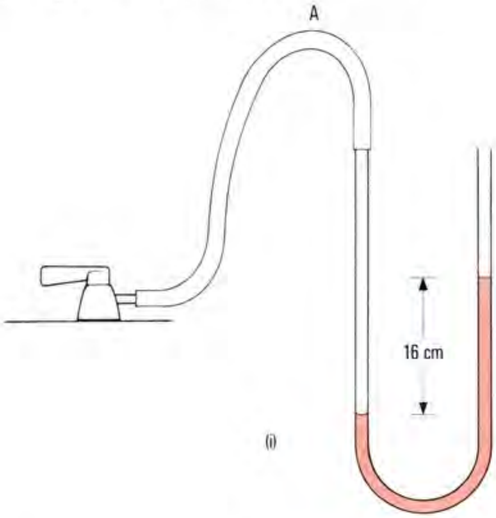
c. This experiment shows that the gas pressure in the pipes coming to the tap is greater than the pressure in the room.

(i) You actually knew this without doing this experiment. How?

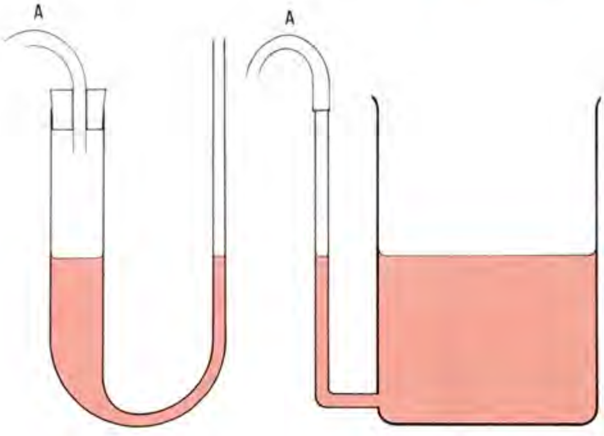
(ii) What do you measure to find out exactly *how*

much greater the gas pressure is than the pressure in the room? (Show it on a drawing if you like.)

7. The gas tap is connected to a U-tube and the water levels reach a steady position as shown in diagram *(i)*. Different shaped U-tubes are ready as in diagrams *(ii)* and *(iii)*.



(i)



(ii) (iii)

Copy these diagrams. In diagrams *(ii)* and *(iii)* show the water levels when the gas is connected to side A.

What measurement is the same for all the tubes?

Questions

8. You have a bicycle pump with a well-fitting piston. You put one finger over the nozzle and press the handle of the piston in.

a. What do you feel on your finger?

b. You use your whole arm and hand to push the handle and the piston which pushes the air; but you can hold the air back with just part of one finger. Why is this?

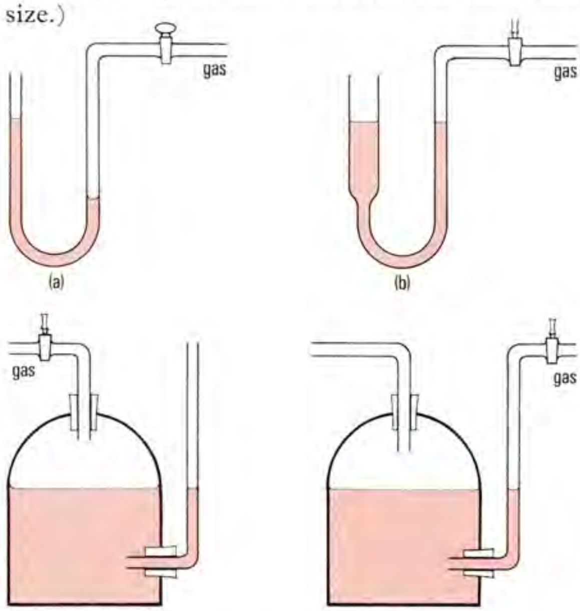
c. If you let go of the handle, what happens?

9. Why are skis so long? Why not have short ones, the size of one's boots?

10. When someone falls through thin ice on a pond, rescuers are always told to crawl across the unbroken ice and to lie flat when they get near the broken part. Why lie flat?

11. A 1000-kg car is supported on four tyres, each pumped up to what the makers say is the correct pressure. A few weeks later the pressure may have fallen as air leaked away. But the car still runs well and it is still a 1000-kg car. How is it that the same car can be supported by these two pressures?

12. The drawings are all one-tenth actual size. Figure (a) shows an ordinary U-tube water pressure gauge or manometer joined to the gas supply. What is the pressure of the gas? (Measure it on the diagram and remember the one-tenth size.)



(a) (b) (c) (d)

Figure (b) is a manometer with unequal arms. it is joined to the same gas supply, but the gas tap has not been turned on. Make a drawing showing what it will look like when the gas tap is turned on. Now do the same for figure (c) and figure (d), that is, make drawings showing what each end looks like when its tap is turned on.

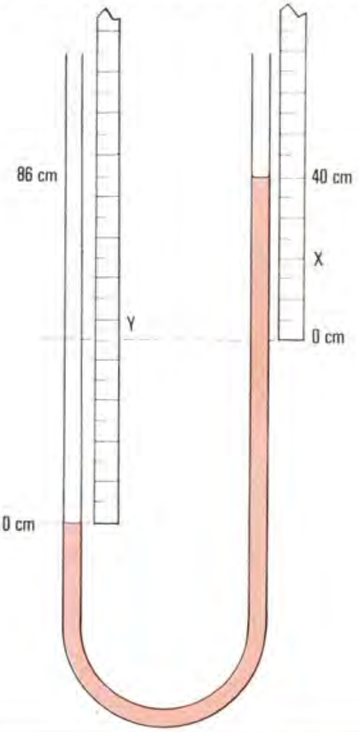
Q.12 *continued*

Remember to make the level difference right for the gas pressure you mentioned in (a). The same gas supply is used all the time. No water is lost from, or put into, the manometer.

13. How would you use a water pressure gauge (a U-tube manometer containing water) to find the pressure your lungs can exert? Draw a diagram. How would you make sure that you were finding the best or the highest possible pressure?

Do you think the result has anything to do with the capacity of your lungs, that is, the largest amount of air the lungs can hold? Explain the reason for your answer.

14. *(An unexpected result)* The diagram shows a pressure gauge made from a piece of plastic tubing. At first the levels of the water were the same on both sides, and a boy fixed a scale X with the 0 mark against the water level. Then he blew down the other side and sealed off the tubing on that side. The water level on the side with the scale was now at the 40 cm mark. 'The other side', he said, 'must have gone down 40 cm, so the difference in level is 80 cm.' But when he measured it, on another scale Y, the difference in level was not 80 cm but 86 cm.



Which of these two, 80 or 86 cm, is correct? Would it make any difference if the manometer was made of glass instead of plastic? Give reasons for your answers.

15. A manometer containing water, when joined to a gas supply, showed a difference of levels of 13.6 cm.

A manometer containing mercury, joined to the same gas supply, showed 1.0 cm.

A manometer containing oil, joined to the same gas supply, showed 17.0 cm.

1 cubic centimetre of water weighs 1 gram. What does 1 cubic centimetre of mercury weigh? Explain the reason for your answer.

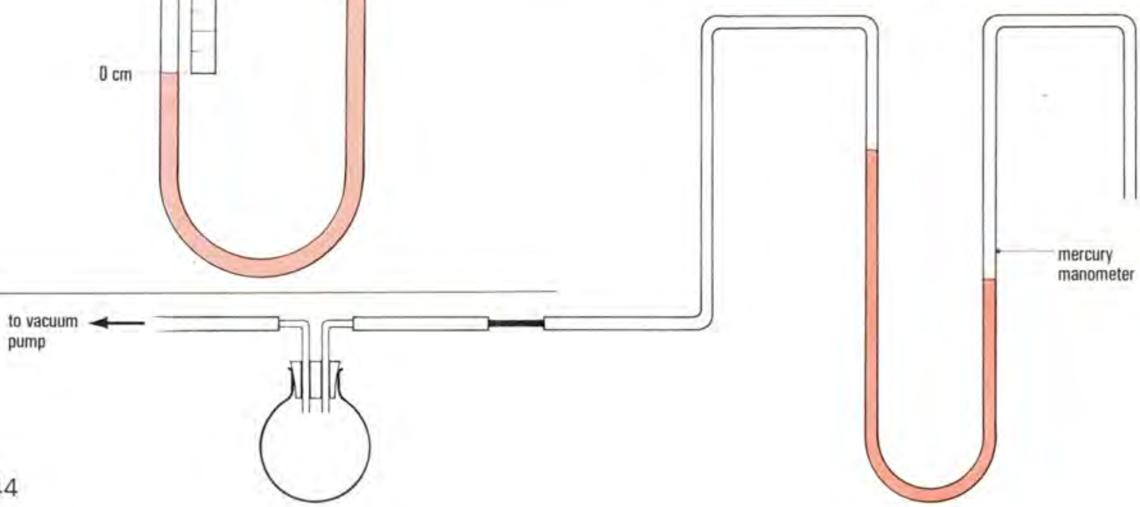
What does one cubic centimetre of oil weigh?

ATMOSPHERIC PRESSURE

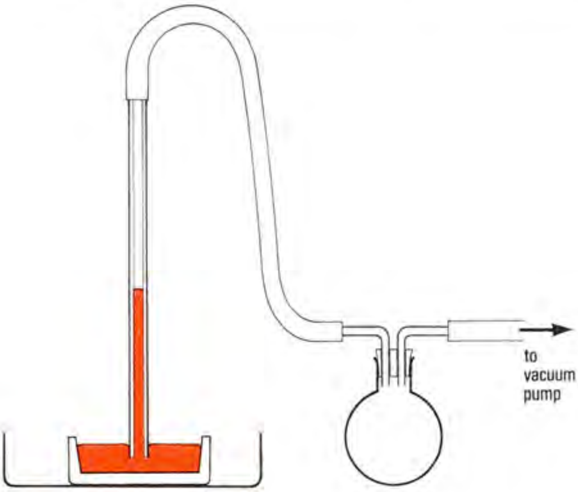
When the mercury manometer is connected to the gas tap, the pressure of gas in the pipe pushes the mercury round the tube a few millimetres. When disconnected, the mercury falls back so that the tops of the two columns are level again. *How can such a manometer be used to measure the pressure of the air in the room?* As we have arranged it, the air in the room presses down on the left-hand side and on the right-hand side – and there is no difference in level. *What can we do?*

44 Demonstration
The pressure of the atmosphere

See the demonstration sketched.



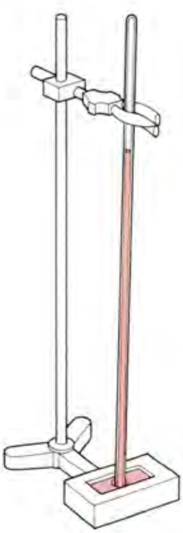
The barometer Imagine that the two sides of the U-tube were of different size, one being made of much wider tubing than the other. *Would you expect the same difference in level as you found in Demonstration 44? Would you expect the same difference in level if one tube were very, very much wider than the other?* A glass tube dipping into an open dish of mercury is a sort of U-tube with one very wide surface.

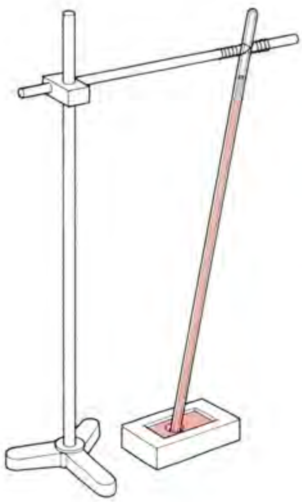


45 Demonstration
A barometer

See the demonstration sketched.

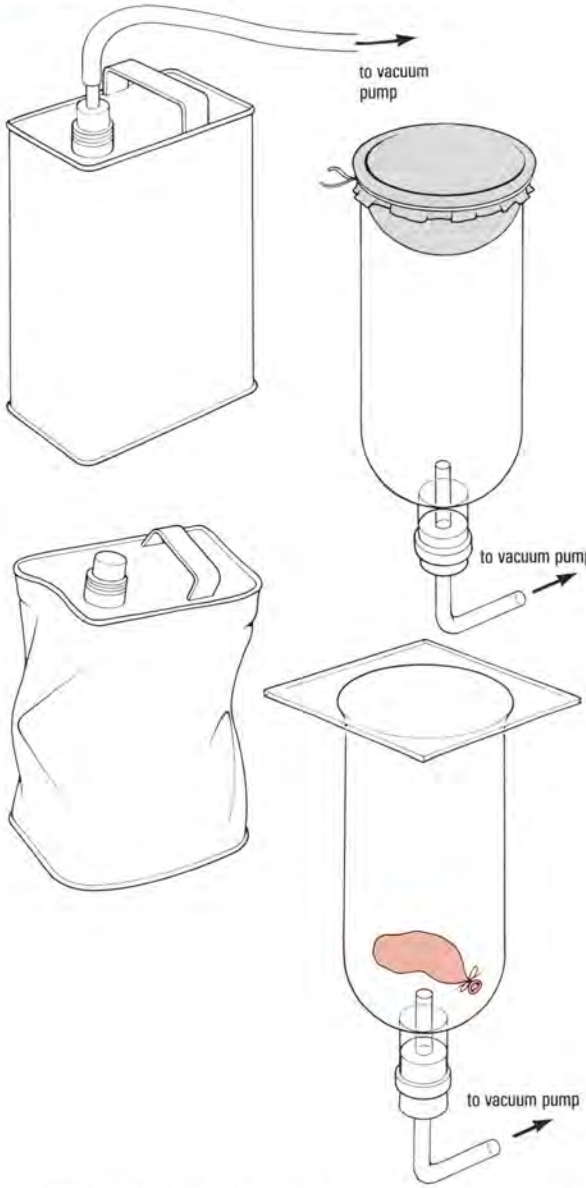
What is the height of the mercury column? What happens if the barometer tube is tilted a little to one side? A little more?





46 Demonstration
What air pressure can do

See some of the experiments sketched.



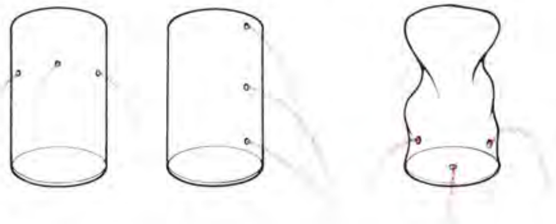
What happens if you pump the air out of a gallon can? Does the can squash down from the top?

47 Experiment
Which way does pressure act?

Water in an open can exerts a pressure – if there is a hole in the bottom, the water will run away. Now see what happens when holes are punched in different places. First try a can with equal holes punched with a round nail somewhere near the

47 E. *continued*

middle of the can and all at the same level. *Does the water spout out equally from all the holes? How would you make a test to answer that question?*



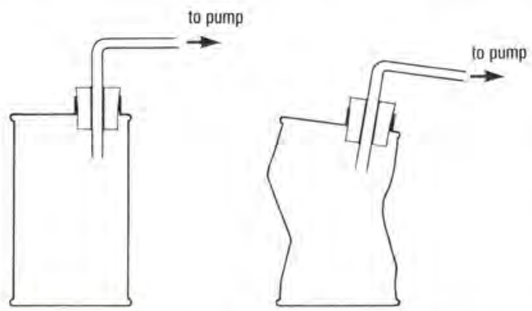
Next try another can – but this time with three holes. One of the holes should be near the top, one part way down, and one near the bottom of the can. *What happens when the can is filled with water?*

Finally, try a can which has been battered into an irregular shape. Drive the nail into the battered bottom at three different directions. *In which direction will the pressure make the water spout out of the can when the can is filled up? How fast will the water spout out? Now what can you deduce about the way the pressure pushes that water out of the can?*

Can you now say why the can which was squashed up by the air pressure collapsed in the way that it did?

Progress questions

16. A tin can was connected to a pump. The pump removed the air inside the can. The can caved in.



a. What presses on the sides of the can to make them move in?
b. Explain why the can caves in when the pump is switched on.

17. How does the experiment in Question 16 show that air pressure acts sideways and not just downwards?

18. What does a *barometer* measure?

Describe carefully how a mercury barometer can be made without using a pump, if we have a thick glass tube about a metre long, closed at one end, and a dish of mercury, and a metre rule.

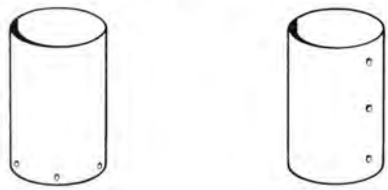
19. Someone takes a set of barometer readings for a week, and makes notes of the weather as well. Here are the readings:

Birmingham (1972):

13		73.8 cm	Trace of rain
14		74.5 cm	Dry
15		75.0 cm	Dry
16	November	74.5 cm	Dry
17		74.5 cm	Some rain
18		74.3 cm	Drizzle and some snow
19		72.0 cm	Heavy rain
20		72.0 cm	Rain

a. Was the atmospheric pressure higher on the dry days or on the damp ones?
b. Did a 'falling barometer' indicate a change towards better weather or worse?

20. A tin can has equal holes made in it by hammering nails in. Then it is held over the sink and filled with water.
a. Copy the two diagrams and on each one show how the water spurts out.

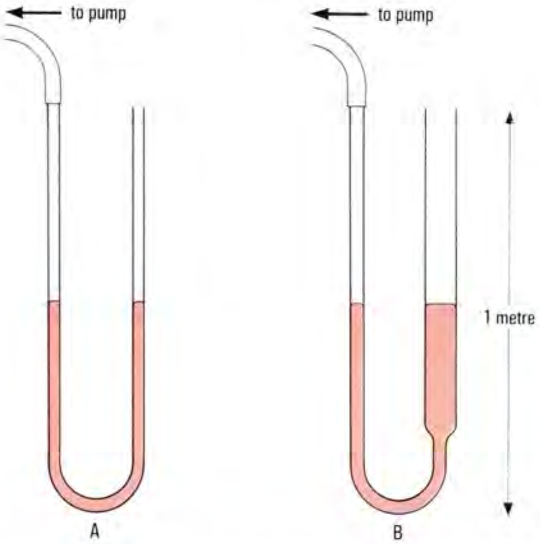


b. The deeper the water is, the more the pressure is. Which tin can shows this?
c. At the same depth the pressure is the same all round. Which tin can shows this?

Questions

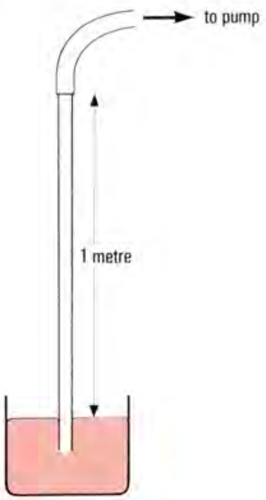
Measuring atmospheric pressure. How deep is the ocean of air in which we live?

21. A and B are two U-tubes, each of height 1 metre. They can be joined to a vacuum pump. Tube A has the same width both sides; tube B is narrow on the left, wide on the right. The tubes are half-filled with mercury, as shown in the diagrams.



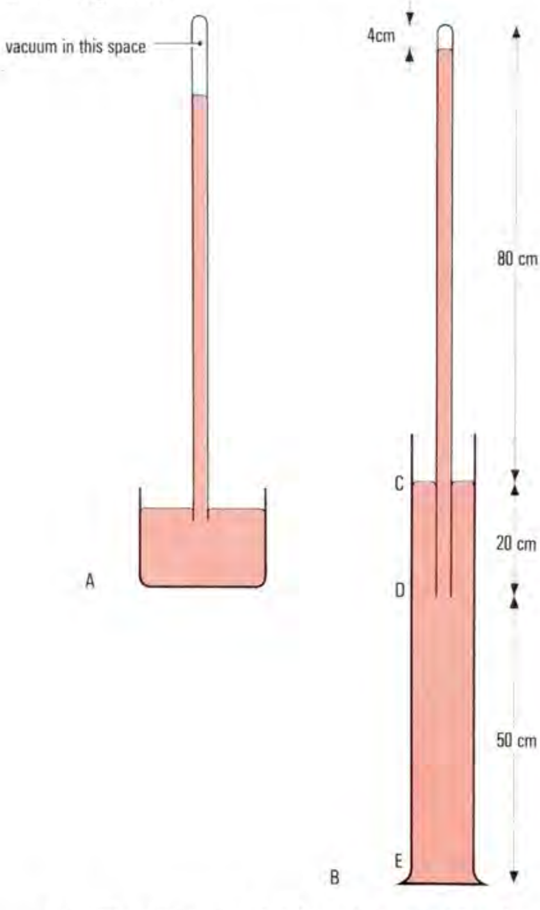
a. Draw a diagram of U-tube A, after the pump has been working, and mark in the height of the mercury column which just counterbalances the atmospheric pressure. What would you expect this height to be?
b. What happens to the mercury in B when the pump is set working? Why would the owner of the pump not be pleased?
c. What difference would it have made if A and B had been filled to the same level with water instead of mercury?

22. The figure shows a single open tube dipping into mercury. The pump is a vacuum pump.



a. Draw a diagram of this tube after the pump has been operating for some time, and mark in a distance, which if you measured it you would find to be about 76 cm.
b. What difference would it make if the tube were twice as wide?
c. What difference would it make if we had water in the apparatus instead of mercury?

23.
a. Copy the diagram A and mark in the height that represents the atmospheric pressure.
b. What is the name of this instument?
c. How is it made? Notice that the tube is closed at the top end.



24. The diagram B (above) is just like the one for Question 23 except that the shallow dish has been exchanged for a much deeper container which holds mercury.

The total length of the tube is 1 metre. Atmospheric pressure is 76 cm of mercury. There is 4 cm of vacuum above the mercury in the tube.
a. What happens if the tube is pulled 10 cm further out of the jar?

Q.24 *continued*

b. How much vacuum-space is there above the mercury then?

c. What happens if the tube is pushed 10 cm further down?

d. What is the pressure (in cm of mercury) at the level C?

e. What is the pressure (in cm of mercury) at the level D inside the tube?

f. What is the pressure (in cm of mercury) at E inside the cylinder.

g. Does the position of the tube make any difference to the pressures at C, at D, or at E? Give the reason for your answer. (Note that D marks the position of the lower end of the narrow tube.)

25. *(Three experiments)*

a. Hold your thumb on the spout of a tap and gently turn the tap on. What happens?

b. An old tennis ball has four or five holes punctured in it; then it is held under water and squeezed. What happens?

c. After being squeezed, the ball is released under water so that it fills up. It is then taken out of the water and again squeezed. What happens?

26. The experiments in Question 25 show the truth of *two* of the following true statements. Which two?

A. You can compress air, but you cannot compress water.

B. The greater the depth, the greater the pressure.

C. Pressure in water or air acts equally in all directions.

D. Experiments on water pressure are likely to be messy.

27. An old oil drum has three small holes made in one side, at one-quarter of its height from the top, half-way down, and one-quarter of its height from the bottom. It is filled with water and, of course, water comes out of the holes. Water is run into the drum from a tap to keep it full.

a. Draw a diagram showing what you think the water jets would look like. Try the experiment if you can. Does it show that 'the greater the depth, the greater the pressure'?

b. Now think of the sea with the atmosphere above it; an ocean of water with an ocean of air on top. How will the pressure change as we go: *(i)* deeper down in the sea; and *(ii)* higher up in the atmosphere?

28. There is an important difference between water and air. Think of a bicycle pump filled first with air and then with water.

a. What happens if you put your finger over the nozzle and try to push the handle when the pump is full of air?

b. What happens when it is full of water?

c. What can you say about the densities of water near the surface of the sea and at greater depths?

d. What can you say about the densities of air at sea-level and at greater heights?

Three DIFFICULT *questions for you to try your arithmetic*

29. To the nearest single figure, the pressure of the atmosphere is the same as the pressure of a height of mercury equal to 0.8 m. That is, an 'atmosphere' of mercury having the same pressure as the real atmosphere would only be about 0.8 m high. Mercury is 13.5 times denser than water.

a. How high would an atmosphere of water be?

b. Mercury is 10 000 times denser than air. How high does this make an atmosphere of air? Give your answer in kilometres.

30. The answer you should get in Question 29 (b) is less than 10 kilometres. This is a silly answer, because we know the atmosphere goes much higher than 10 kilometres.

a. If you know any reasons for supposing that there is air higher than 10 km up, say what these reasons are.

b. We asked you to use the same method for Question 29 (b) as for Question 29 (a). That was to help you to get a *rough idea*. Yet in some ways that gave you a mistaken idea. What was the mistake?

31. After answering Questions 29 and 30, give the best answer you can to the question at the head of this section: 'How deep is the ocean of air in which we live?'

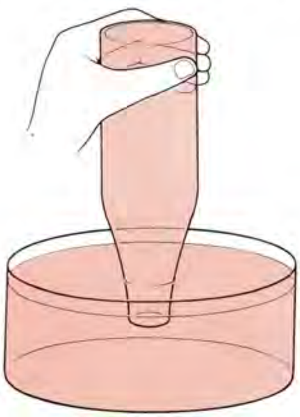
Living at the bottom of an ocean of air

32. *(Try this at home)* Take a glass tumbler or beaker and dip it under the water in a bowl so that it is completely full. Turn it upside-down and lift it very slowly. Describe what happens. Why does the water stay inside? And why does the water 'fall out' immediately the edge of the tumbler is lifted clear of the water in the bowl?

How tall would the tumbler have to be for some water to come out while the rim was still under water? Explain. (It would be very tall!)

33. *(Try this at home)* Take a piece of ordinary laboratory glass tubing or a milk straw and put it in the bowl of water so that it gets full of water. If necessary, you can suck water through it to make sure that all the air has gone. Hold it upright in the water; put your finger over the top end and slowly lift the tube up. What happens? Does the water come out this time when the lower end of the tube is lifted clear? Why not? What happens when you take your finger away from the top end? Why?

34. A wide-necked bottle is dipped under water in a deep bowl and then turned upside-down. The bottom end is then lifted up as shown.

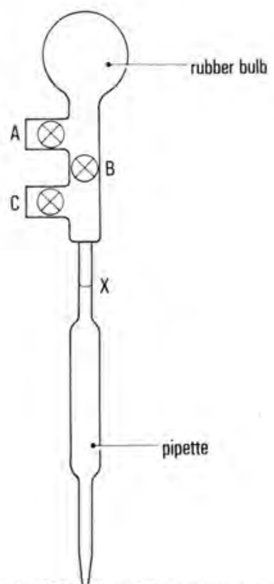


a. What stops the water coming out?
b. What would happen if the level of the water in the bowl were to fall just below the rim of the bottle? *(Hint:* this is sometimes called a 'glug' bottle; it is used to keep a water supply trough full for chickens to drink from, or in a greenhouse to supply water to plants.)
c. What difference would it make to this experiment if the bottle were 15 m tall?

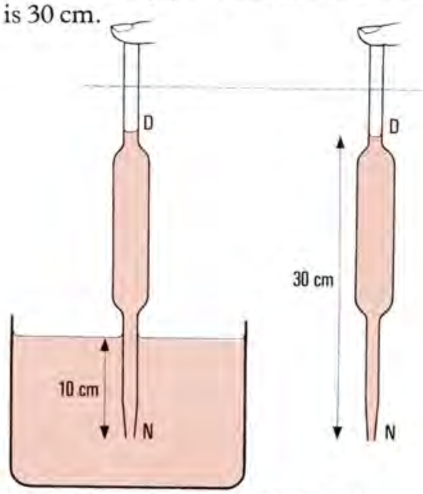
35. Explain what happens when you 'suck up' milk or fruit juice through a straw.

Chemists use pipette fillers to 'suck up' measured amounts of liquids into pipettes. The figure (top right) shows a pipette filler on top of a pipette. The bulb is made of rubber and air inside it can be squeezed out when the valve A is open. B and C are also valves.

Explain how you would use the pipette filler to draw some liquid into the pipette using valves A and B. How would you adjust the volume of the liquid in the pipette so that its surface was exactly level with the reference or 'full' mark X?



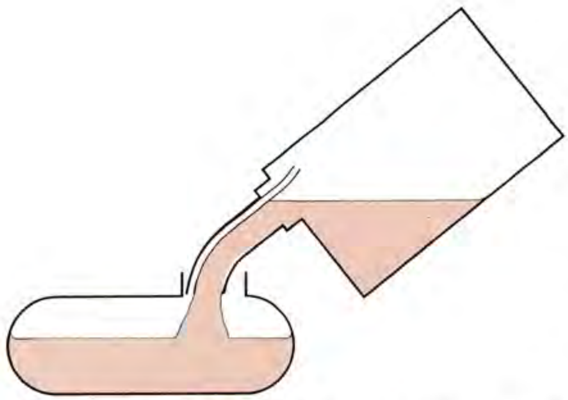
36. A pipette is filled with water up to the level D, which is a little below the 'full' mark. N is the nozzle of the pipette and the distance from D to N is 30 cm.



a. When the lower 10 cm of the pipette is in the water in the beaker, is the pressure at N above (+) or below (−) atmospheric pressure?
b. By how much (in cm of water) is the pressure at N above or below atmospheric pressure?
c. By how much is the pressure at D above or below atmospheric pressure?

The pipette is then removed from the water.
d. What is the pressure at N now?
e. By how much is the pressure at D above or below atmospheric pressure?

37. A glass bottle or a tumbler is held upside-down and pushed downwards in water in a bowl.
a. Why does the water not fill up the bottle?
b. A little water does enter the bottle. Why?



38. Cans used for filling petrol tanks of small engines often have spouts with a thin tube running through them as shown in the figure.

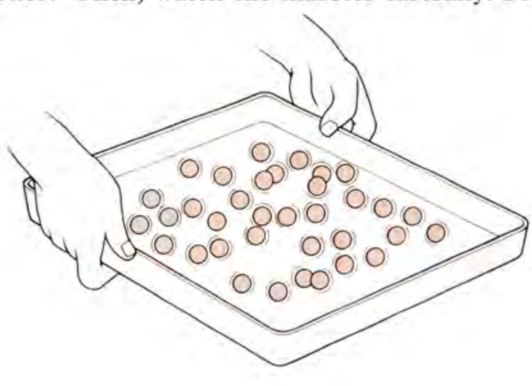
This tube is a safety device which stops the petrol tank from being overfilled. Why, when the spout is used, is it impossible to overfill the tank?

Model of a gas

You have now seen that a gas (like air) is squashy and that it exerts a pressure in all directions. Scientists think of the air as made up of tiny things (called molecules) which are very far apart and moving very fast, bouncing off everything they meet including the walls of the room, the furniture, you and I, and the other molecules themselves. *How would that make a pressure?*

48 Experiment
Model of gas molecules in motion

To see how that happens take a tray of marbles – about twenty will do – and, gently at first, push it around on the table first one way, then another. Listen to the collisions – marble against marble; marbles against the sides of the tray. *What do you notice?* Then, watch the marbles carefully. Pick



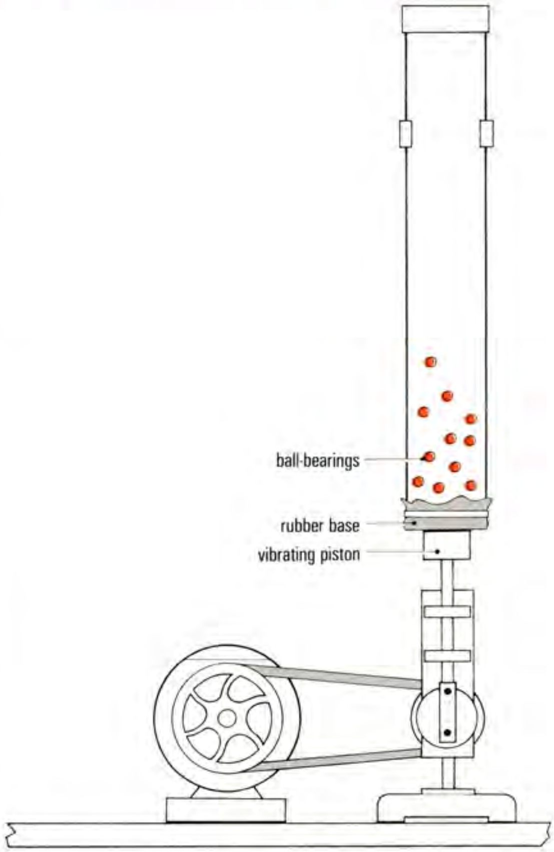
out one marble and watch it. *What does it do? How does the marble pressure on the wall occur? What happens to that pressure if you move the tray around more quickly? What happens to the pressure if you add another ten marbles?*

49 Experiment

Change the model by adding one larger marble to the other small ones. Watch that marble. *Does it move as far as the smaller ones do in, say, half a minute? Does it move as fast as the smaller ones?*

50 Demonstration
Another model of gas molecules – in 3-D

See the demonstration sketched.

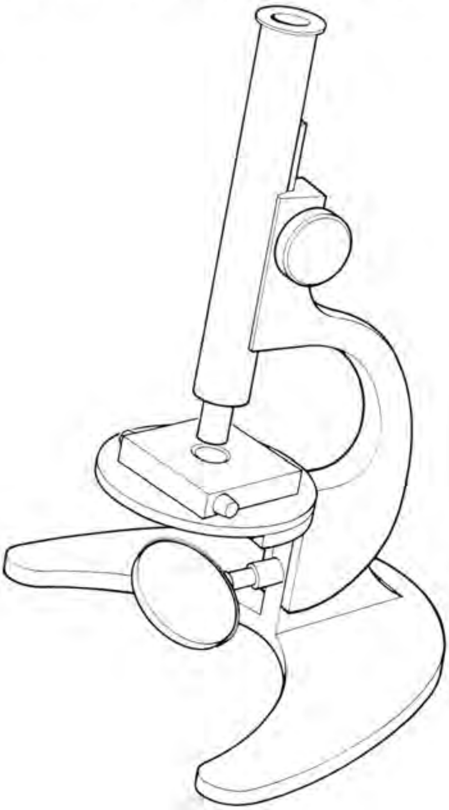


This is a three-dimensional model because the steel balls can move up and down as well as from side to side.

These models help us to think about gas molecules and how they cause a pressure. But the marbles aren't real molecules – only parts of a toy to help you think about a real gas.

51 Experiment
Looking at smoke particles

You cannot possibly see air molecules – they are far too small. But you can see the tiny particles of smoke which can float around in the air for a very long time before settling on the floor. You will need a microscope. And you will need to trap a little smoke in a small glass container or cell which fits under the microscope. Your teacher will explain just how to do this. The little lamp at the side will light the box up so that you see the smoke particles lit up by the beam. Start with



your microscope lens very close to the transparent lid of the cell and very slowly raise it until you can see many smoke particles floating in the air. *What are those smoke particles doing?* Make a sketch of what you see.

Why are the particles moving around like that? Are they alive? Are they all moving in the same direction?

How does the model in which you placed one heavy marble among lots of small ones help you to explain the movement which you see?

This movement of the tiny specks of white smoke ash is a result of a bombardment by the invisible air molecules. It is called the 'Brownian motion' after the man who first noticed it.

How small are molecules?

The Brownian motion tells us that the air molecules are smaller than the smallest specks of smoke we see. *How much smaller?*

You will need to know the size of the small smoke specks before you can answer that. *How big would you guess those to be? 1 mm across? 0.1 mm? 0.01 mm? Or even smaller? How many smoke particles could you park side by side along the edge of a postcard (15 cm long)?*

And now guess how many molecules you could park by the side of each smoke speck. How many is that along the edge of the card?

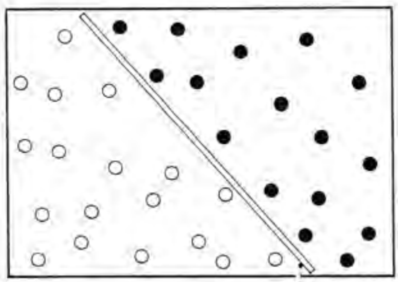
Molecules must be very, very small indeed – and atoms must be even smaller. Common sense tells us that.

52 Demonstration

Watch some dried peas being poured from one container to another. Then a handful of sand. Next a handful of very fine powder. And lastly some water. *From the point of view of a molecule, what is the difference between the water, the powder, the sand, and the dried peas?*

Progress questions

39. A tray is divided into two parts by wedging a ruler into it. There are some black marbles in one part and white marbles in the other part.



The marbles are all set moving by shaking the tray. While they are moving the ruler is taken out.

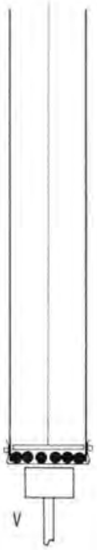
Q.39 *continued*

What do you notice about the marbles? Would they have done this if they were not moving?

40. A tube has some thin rubber stretched across its bottom end. Below the rubber there

is a vibrator V which is driven up and down so that it keeps on hitting the rubber. A number of small balls are put in the tube. What do you see happening when the vibrator is set working? Say it in words and also draw a diagram.

41. A cardboard disc is lowered into the tube and left sitting on top of the little balls.



a. What happens when the vibrator is set working? Say it in words, and also draw a diagram.
b. What happens when the vibrator goes faster?

42. A larger ball is put in among the balls in the tube, and the vibrator is then set working. What does the big ball do?

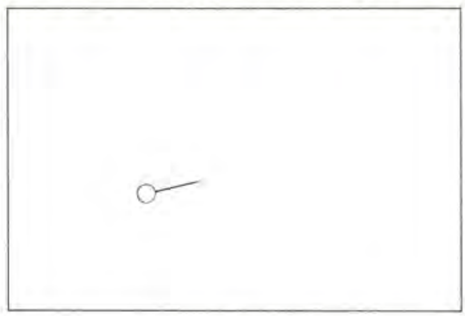
43. You have done an experiment putting particles that you could see among air molecules.
a. What small particles did you use?
b. What did they look like in the microscope?
c. Describe their movements.
d. What do you think made them move like that? (Remember they are surrounded by air molecules and we guess that air molecules are moving all the time.)
e. Why did you have to use particles so small that a microscope was needed?

Questions

Quickly moving particles

44.
a. How does the 'particles-in-motion' model for gases like air explain the fact that air can exert a pressure?
b. How does it explain the fact that air will exert a bigger pressure when squeezed into a smaller volume?

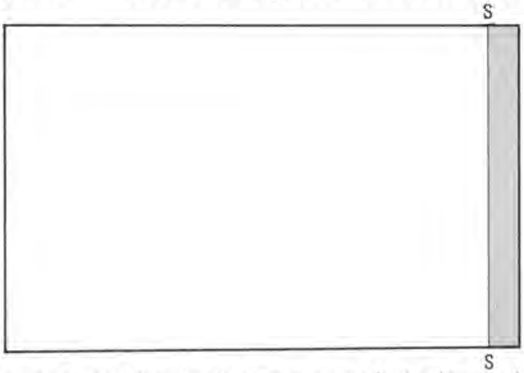
45.
a. A trayful of marbles can be a simple working model of a gas. Describe an 'experiment' you have done with such a model to illustrate one of the properties of a gas.
b. The rectangle shows a tray containing marbles drawn about one-quarter size. The marbles are similar to one another. But one is white whilst all



the others are coloured. Only the white marble is shown. The tray is being shaken. The white marble moves a little distance as shown by the short straight line before it hits another marble. Copy the diagram and draw ten or twelve more lines, showing how the white marble might move between the next collisions. Should all those lines be the same length? Does the colour of the marble make any difference? Or might we just as well be talking about any of the marbles?

46.

a. The figure shows a tray with one loose side, SS, which has been wedged in, but not tightly.



You put marbles in the tray and shake it gently; nothing much happens. You then shake it more violently; what is likely to happen now?

b. You have an empty can, like a treacle can, with a lid that wedges in. And you have a Bunsen burner. How could you do an experiment which is rather like (a), except that you are using air particles instead of marbles, and heating rather than shaking?

47. *(Difficult)* Someone doesn't fully understand the marble model because, he says, 'You have to keep shaking the tray of marbles or they will stop. But you don't have to keep shaking the air squashed up in a bicycle tyre to keep it exerting a pressure.' What do you say? (Remember that, if we think air particles are in motion, we also think that particles of solids are moving too – but they cannot move away from their positions.)

48. *(Difficult)* As you go higher up, the atmosphere of air gets thinner (less dense). How could you use the marbles and tray to show an 'atmosphere of marbles' that gets thinner higher up?

49.

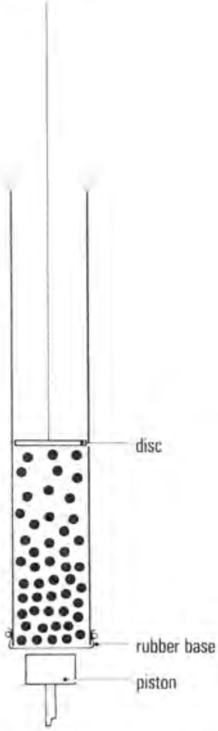
a. Among the twenty or so marbles in the tray, you put one larger marble weighing, say, three or four times as much. How will the movements of the large marble differ from the movements of one of the smaller ones?

b. Suppose you were looking at a tray being shaken which might contain marbles, but you were so far off that you couldn't see the small marbles, but could see a large marble, like that in (a). What would the movements of the large marble look like if:

(i) as well as the large marble there were small marbles in the tray?

(ii) if only the large marble was in the tray?

50. Look at the diagram.



a. When the apparatus is set working, what is the rubber base doing?

b. What, in actual fact, are the black blobs in the diagram?

c. Why does the cardboard disc stay where it is? What is supporting its weight?

d. What happens if a second cardboard disc is put on top of the first one?

e. Explain why we bother with this apparatus – that is, what is it meant to show us?

51.

a. How would you use the apparatus of Question 50 to show a 'model of the atmosphere'?

b. How would you use it to show the movements of a large particle among smaller particles?

52. The experiments with marbles and little balls show that a 'particles-in-motion' explanation of how gases behave *could* be true. But if someone says that playing with marbles and balls doesn't really prove anything about gas particles you have to agree.

Q.52 *continued*

Describe briefly one experiment you did (using a microscope) which really does give support to a 'particles-in-motion' theory of gases. Say what you did and what you saw.

53. *(Continuing Question 52)* Why does 'what you saw' lead you to suppose:

a. that air particles (we will now call them 'molecules') are very small?

b. that they are in constant rapid movement?

More about molecules in motion

54. Unless a gas is kept in a closed container it spreads out until it occupies (mixed perhaps with other gases) all the space available to it – this is a fact of common observation. There is no container round the Earth's atmosphere, and yet the atmosphere remains without losing pressure from one year to the next – fortunately for ourselves. How do you explain this?

55.

a. You probably have a very good vacuum in your house – inside a television picture tube. Air has been pumped from the tube until a very low pressure is reached. How does the distance between the molecules in the tube compare with the distance between the molecules in the air outside?

b. The picture is made by a stream of 'electrons' which shoot across the tube and fall on the coated screen, so making it glow brightly. What do you think would happen if a little air leaked into the tube? Give a reason for your answer.

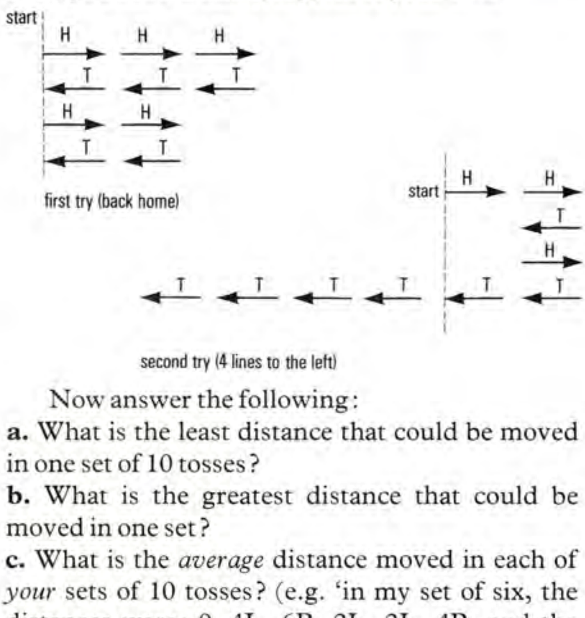
56. *(Just for amusement)* This is to find out what being a gas molecule feels like. Go out of your front door, taking a penny with you. Toss the penny: if it is heads, turn right, if tails, turn left. When you get to a place where there is a choice of paths, toss the coin again to decide which to take. If there are more than two alternative paths, at a crossroads, for example, you will have to toss the coin twice in order to make a decision. Notice how you get further from home, but not so far as you would if you walked in a straight line. You are behaving rather like a molecule; each street corner corresponds to a collision with another molecule which may change your direction. The varying distances between one street corner and the next correspond to varying distances travelled by one molecule between collisions with other molecules.

Note To make a better comparison you ought to include, at each road junction, the possibility of returning the way you came – but this makes it too boring! You will probably decide that being a molecule is not very interesting anyhow.

57. What is 'Brownian motion' a name for? What experiment have you done which shows real Brownian motion? (Just mention it – do not describe.)

Who was Brown? What was he doing when he discovered Brownian motion? How did he (wrongly) explain what he saw? (This is the sort of question you can answer from books or an encyclopaedia. Answer briefly, and don't spend much time on it.)

58. As a rough model of Brownian motion along one line only, toss a coin and draw a line on paper to the right if it comes down heads, and to the left if it comes down tails. Toss the coin ten times and draw equal lines each time. Go through this procedure several times, and write down how many lines you have moved to the right or to the left each time. (Two examples taken in this way are shown in the figure.) However, you should make, say, six of your own.



Now answer the following:

a. What is the least distance that could be moved in one set of 10 tosses?

b. What is the greatest distance that could be moved in one set?

c. What is the *average* distance moved in each of *your* sets of 10 tosses? (e.g. 'in my set of six, the distances were: 0, 4L, 6R, 2L, 2L, 4R, and the average of 0, 4, 6, 2, 2, and 4 is $\frac{18}{6}$ or 3'.)

d. Write down and complete the following sentence: 'In this comparison, tossing coins in order to decide which way to go represents chance bombardment by . . ., which are hitting a larger particle.'

Notice that a 'big jump', corresponding to 8 or 10 moves to the left or right, is very rare, but smaller moves of two or four are common. So it is with particles in Brownian motion.

(There are clearly some important differences between this kind of imitation 'Brownian motion' by coin-tossing, and real Brownian motion. The real motion is along any direction, but this is all along one line. Particles moving with real Brownian motion move all sorts of different distances between one change of direction and the next direction, but in this imitation each 'step' or distance equals every other step.)

59. A 1-kilogram brick is hung on a string in a glass box which is completely closed so that no draughts of air can reach it. The brick is a 'particle' which is being bombarded from all sides by air molecules. Explain in not more than three sentences why we do not observe the brick moving with Brownian motion.

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CHAPTER 7

Measurement of a molecule

How oil spreads out over a sheet of water

At the end of the last chapter you made a guess at the size of a molecule. Now we must try to measure that. We can't do it directly; molecules are too small. But we can do it in a roundabout way. We shall choose a molecule that is easy – a molecule of olive oil, which is a chain about a dozen atoms long. But first you must do some experiments on liquid surfaces, for you will be working with those when you make the actual measurement. You can do a lot of experiments on liquid surfaces and films at home, but try these first.

53 Experiment
Looking at drops

Watch some water dripping from a medicine dropper; watch the drops as they fall on a sheet of clean glass; look carefully from all sides at the pool of water which collects on the glass. Then let the drops fall on a sheet of glass which has been covered with paraffin wax. *Is there any difference in the shape of the pool?*

It looks as though drops and pools of water behave as if they had a skin. Of course, it is not a real skin that can be peeled away.

Progress question

1. Can you think of any examples that show liquid molecules 'pulling themselves together'? For example, water drops stand up on skin covered with sun-tan oil.

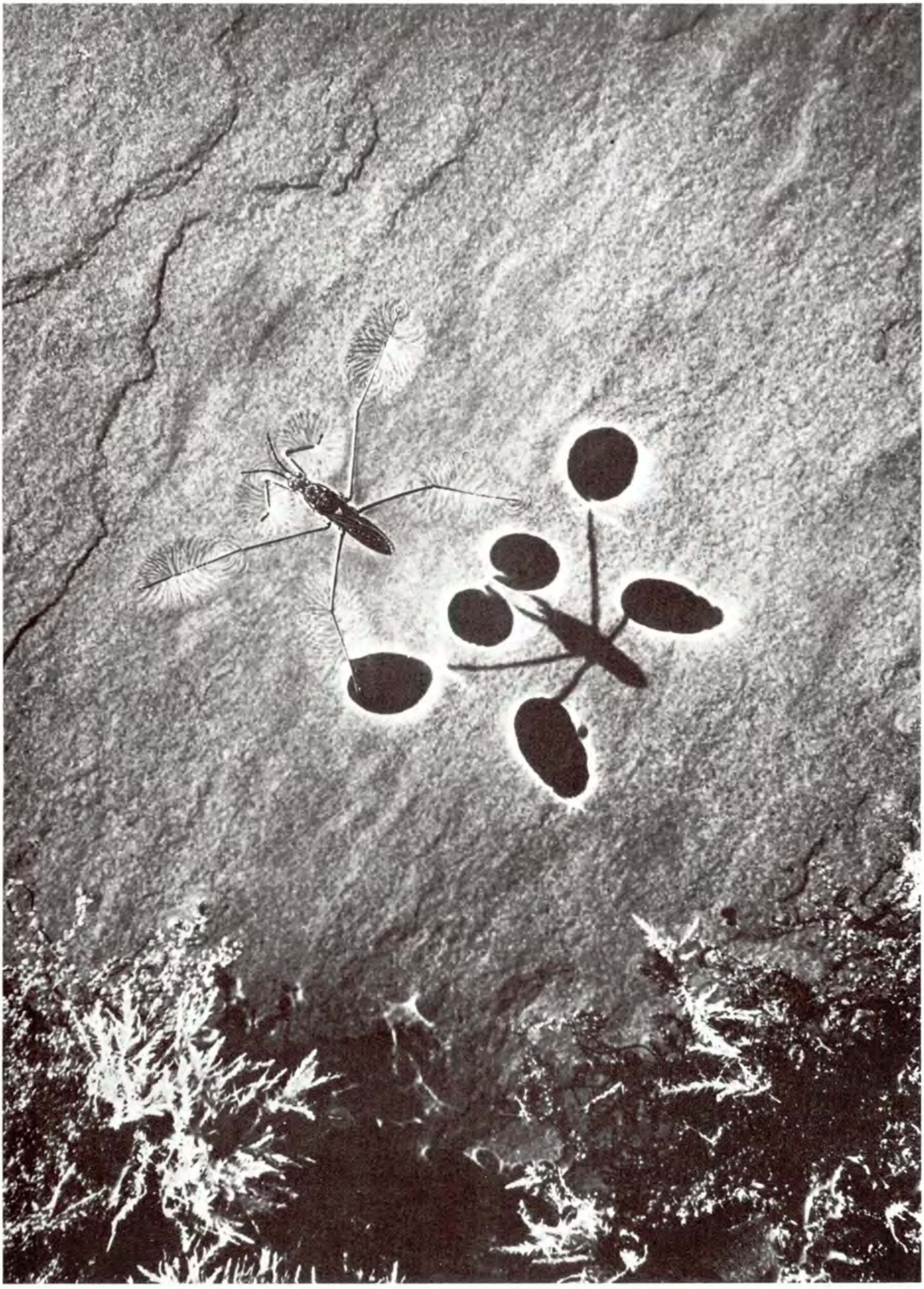
Question

2. What is meant by 'skin effect' or 'surface tension' in liquids? (Answer in one sentence.) Describe something you have seen which shows 'skin effect'.

Some insects (for example, pond skaters) are able to walk over the water without 'falling through'. Describe what is happening.

A droplet of water falling from a tap.
Photograph, Arthur Penniall, from Shaw, R. E. M. (1974) Study and revision scheme in physics, *Book 3. Dent.*

A Pond Skater (*Gerris* sp.) walking on the surface skin of the water. The skin is merely dented, not broken.
Photograph, Lou Gibson/Frank W. Lane.

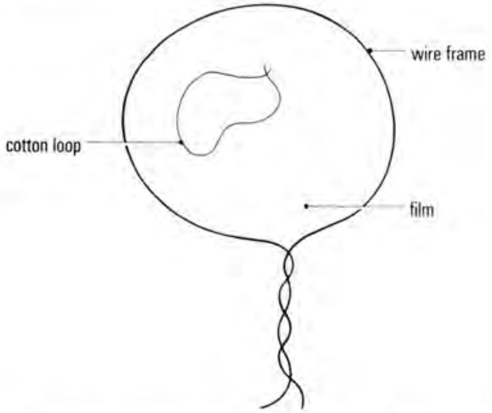


54 Experiment

Some experiments you could try at home

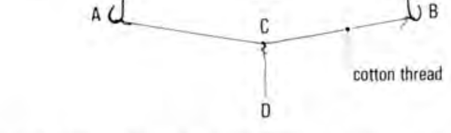
Everyone knows how to blow soap (or liquid detergent) bubbles. Here are some other things you can do with liquid detergent.

a. Bend a length (about 30 cm) of fairly stiff wire into a circle, leaving a short straight handle. Take a 10-cm length of cotton and tie this into a loop.



Dip the wire circle into a mixture of liquid detergent and water and lift it out carefully so that a film forms. Drop the loop of cotton on to the film and puncture the film within the loop. A pencil point will do this. *What happens?*

b. Bend another length of wire into the shape shown and tie a loose cotton thread between A and B. Tie another thread CD to the centre C of the

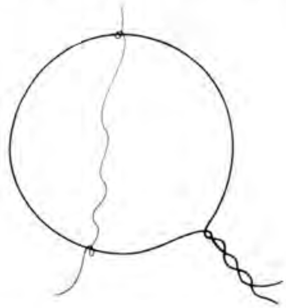


first thread. Dip the loop into the detergent. *What is the shape of the thread AB when the film is formed?* Gently pull on the thread CD and let it go again. *What happens?*

c. Place a drop of water on a waterproof surface. Now 'spoil' it with a touch of the detergent. *What happens? Is the surface still 'waterproof'? Why are detergents also known as 'wetting agents'?*

Progress question

3. Here is a wire frame with cotton tied loosely across it. Draw what happens when you dip it into soap liquid and 'pop' the film on one side of the cotton.



Questions

4. Draw diagrams to show:

a. A small pool of water on a clean glass (water wets glass).

b. A large drop of water and a small water drop standing on wax (water does not wet wax).

c. Why is the shape of the large drop different from that of the small drop?

d. Why are large raindrops round, although they are nearer in size to the 'large drop' than to the 'small drop' in (b)?

5.

a. A large drop of water standing on wax is given a small 'dose' of wetting agent. What happens? (Answer by a series of sketches.)

b. A girl brushes her hair with some oil to make it brighter, or lacquers it with stuff to make the hair waterproof.

(i) What happens if she holds her head in a shower of clear water?

(ii) What would happen if the water of the shower already had a little wetting agent added?

c. If you try to paint a picture on a toy balloon with water-colour paints, the paints will not 'go on' the balloon surface. What can you do to make it go on?

6. Why is detergent often added to washing-up water? And to sprays for plants? Find as many uses for detergents as you can. What happens to the detergent which is washed down the sink in the washing-up water? Why might this be a problem?

55 Experiment
Experiments with a water surface

These experiments will be successful if the dish you use and the water surface are really clean. Don't touch the water surfaces.

Start by powdering the water surface in the half-filled dish with a very light waterproof powder (e.g. talcum powder, lycopodium, or even face powder). Then you will be able to see what happens on the water surface.

a. Put a drop of alcohol on the powdered surface. *What happens?*

b. Take a clean dish with a fresh water surface; dust the surface and then touch it with a red-hot wire. *What happens?*

c. Take another clean water surface and touch it with a match-stick which has been dipped in oil and then wiped clean.

d. With another clean water surface, watch what happens when a speck of camphor is dropped on.

e. Finally take another clean dish and a freshly dusted water surface and touch it gently with a clean finger. *Was your finger quite so clean as you thought?*

Oil spreads out over a water surface and goes on spreading until it makes a very thin film which does not spread any more. It was Lord Rayleigh (a famous English physicist who lived from 1842 to 1919) who made a guess, one of the earliest good ones, at the size of a molecule by doing an experiment just like the one you have just done. He used a big tub, nearly a metre across, cleaned it carefully, filled it with water, and then put a tiny drop of oil on the water. He tried that again and again until he found the amount of oil that would just cover the whole surface of the water in the tub.

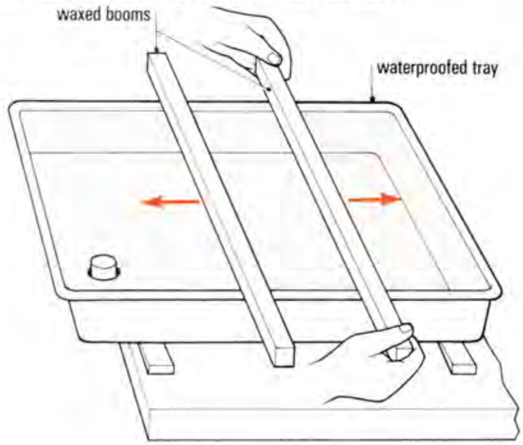
Lord Rayleigh knew that oil molecules are long molecules – a whole chain of atoms – and that they have one end that clings to water very strongly. The other end does not mind about water and so is left standing up from the water. Then the oil molecules will be upright like the pile on a good carpet.

He expected the oil to spread on the water until it would spread no more. *How thick do you think the oil patch will be then?*

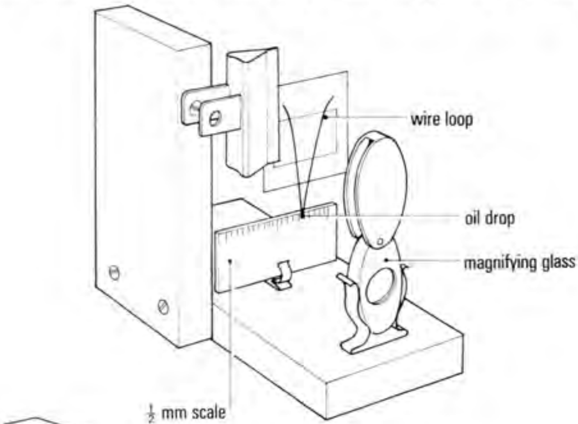
It's a risky guess, but worth making. Certainly the patch can't be thinner than one molecule.

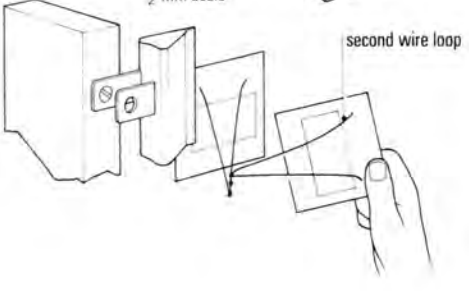
56 Experiment
Measurement of an oil molecule

The first thing to do is to prepare a clean water surface. Fill the waterproofed tray with water until it is 'over-brimming' – that takes care. Sweep the surface clean by moving two waterproofed waxed metal rods (or booms) out from the centre to the ends of the tray. Sprinkle a very little lycopodium powder on that clean surface.



Now you must make a very tiny oil drop – one which is just $\frac{1}{2}$ millimetre ($\frac{1}{2}$ mm) in diameter. Take a loop of very fine wire: dip it into the beaker of olive oil so that it picks up a single drop of oil. Slip the loop-holder into the special clamp so that you can see the drop and the $\frac{1}{2}$ mm scale in





56 E. *continued*

the magnifying glass. *Is your drop a little bigger than $\frac{1}{2}$ mm?* If so, try to tease away a little of the oil using a second wire loop. With care you can reduce it to the size you want.

Take the loop and its drop across to the clean water surface and gently touch the centre of the surface with the drop. *What happens?* Quickly use a ruler to measure the diameter of the oil patch.

If you don't succeed the first time, sweep the water surface clean again with your booms and try once more.

Now we have a problem – how shall we find the thickness of the film? The drop was $\frac{1}{2}$ millimetre across – so its volume was about $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$ cubic millimetre (that's 0.125 cubic millimetre). *Is that estimate of the volume too large or too small?*

The diameter of the patch of oil was measured as, let's say, w millimetres. Its area was about w^2 square millimetres. *Is that estimate too large, or too small?*

Now how will you find the thickness?

What is the thickness of your oil film?

This is a tremendously important estimate to have made. To estimate the size of the atoms which make up the oil molecule we have to ask the chemists how many atoms make up the chain which forms the oil molecule. There are about a dozen, they say. *So how large (or small) are the atoms of the olive oil molecule?*

Progress questions

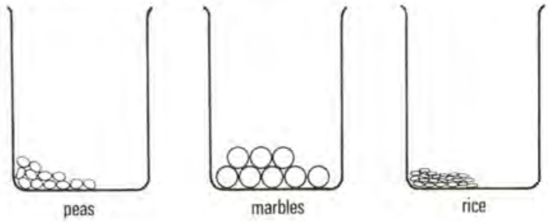
7. *(Try this at home)* Use a soup plate or cereals dish or something like that. Rinse it out and put clean water in it. Sprinkle a *thin* covering of powder on to the water. (Bath powder is useful. Pepper will do. It is just to show you whether the water surface moves.)

Touch your finger to some wet soap, then touch the water surface. What happens?

This experiment can be done again, but each time you must rinse the dish out thoroughly with clean water, and then use clean water and fresh powder. You can try rubbing your fingers on your hair, then touching the water; dip a match end, or handle of a teaspoon, in things like tomato sauce, cooking oil, shampoo, anything you can think of, and then touch the water surface.

Write an account saying what you used and what you noticed happening.

8. When you pour these things gently you get a layer on the bench.



This is a side view of the layer of peas:

a. Copy this, and draw side views of the layers you get for marbles and rice, to show the differences sensibly.

b. Copy and complete:

The grains of rice are *(bigger/smaller)* than the peas, and the layer of rice is *(thicker/thinner)* and spreads *(more/less)* than the layer of peas.

c. When olive oil spreads on water, a tiny drop of oil gives a big patch of oil. What does this suggest about the molecules of olive oil?

9. If you put a little oil on to some water, it spreads and spreads. Suppose you have a big pond of water, and could see that the oil had spread over about half of it and then stopped spreading, which of the following is the most reasonable guess?

A. The oil spread until the layer was exactly three molecules thick.

B. The oil spread until it was exactly one molecule thick.

C. The oil spread until it was less than a molecule thick.

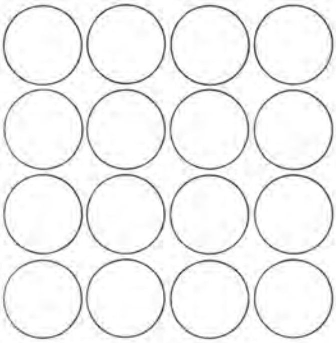
10. From the oil drop experiment we find that one molecule of oil is so small that about 50 million to 100 million of them could sit side by side along one centimetre length (about a finger's width!)

a. About how many grains of salt placed side by side would make 1 cm length? (Make a guess.)

b. About how many of your own hairs laid side by side would make 1 cm length?

Questions

11. A small room is 3 metres long × 3 metres wide × 3 metres high. A ping-pong ball is 3 centimetres diameter. The balls are packed as in the figure, but touching each other.



a. How many balls are needed to cover the whole floor of that room with one layer (= monolayer)?
b. How many are needed to fill the room?
c. A large room, which also has a square floor, requires a quarter of a million balls to form a 'monolayer' as in (a). How many balls could be laid along one side of the floor?

12.
a. Is the method of packing shown in the figure for Question 11 (but with the balls touching) the closest method of packing ping-pong balls? Try with coins such as pennies, on a flat surface. What do you find?
b. Look again at Question 11 (b): is your answer the *largest* number of balls you could get into the room?

13. One-tenth of a cubic centimetre of gold can be beaten into gold leaf so fine that it is a thin sheet 5 metres long by 1 metre wide.

$$1 \text{ cubic centimetre} = \frac{1}{1\,000\,000} \text{ cubic metre.}$$

a. What is the *thickness* of the leaf in metres?
b. What is its thickness in centimetres?
c. Is it safe to say that the length of a gold molecule equals our answers in (a) and (b)? If not, what statement about the gold molecule could we make safely?
(*Note* Ordinary commercial 'gold leaf' is about five times as thick as this.)

14.
a. How long is the side of the smallest square which still looks like a square when you see it with the naked eye? Make a sensible guess. About $\frac{1}{10}$ cm; or $\frac{1}{100}$ cm; or ....
b. With a good microscope you could see a square whose side is only $\frac{1}{1000}$ as long as that in (a). If 100 000 000 (10^8) atoms side by side stretch 1 cm, how many atoms are there along the side of the smallest square you can just see through the microscope?

15. Lord Rayleigh put a drop of olive oil of volume $\frac{16}{10\,000}$ cubic centimetres on a clean water surface. He found it spread out to a patch of area 10 000 square centimetres. He made use of that measurement to estimate the length of a molecule of olive oil but to do that he had to make one big assumption.
a. What was the assumption?
b. Make this assumption yourself, and calculate the length of the molecule.
c. Chemists tell us that the oil molecule is a chain about a dozen 'atoms' long. You might think of the 'atoms' as little balls.
Can you estimate the diameter of a single 'atom'?
What value do you find?
Note To calculate (b) remember:
volume of any slab = area of slab × height.
If you work in cubic centimetres and square centimetres your answers will be in centimetres.

16. Imagine a pupil in your class missed the oil drop experiment. He says: 'I never saw it. What was it for? What happened? What did you measure? What did you get out of the experiment.' Tell him, *in your own words*, first how you did the experiment. Then give your own measurements (or make up some possible ones) – and show him how to calculate the molecule size from them.

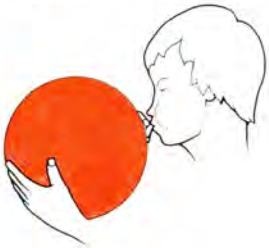
CHAPTER 8
Energy – a first look
Jobs that need fuel

What does your food enable you to do, besides breathing, keeping warm, growing and generally living?

57 Experiment
Jobs

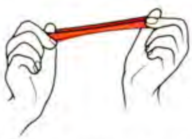
Here are some jobs for you to share out with other members of the class. Which of them make you use some of your food supply and which do not? Which of them could be done just as well with the help of a petrol engine or an electric motor?

a. Blow up a balloon.



b. Put the blown-up balloon down on the bench and sit and watch it.

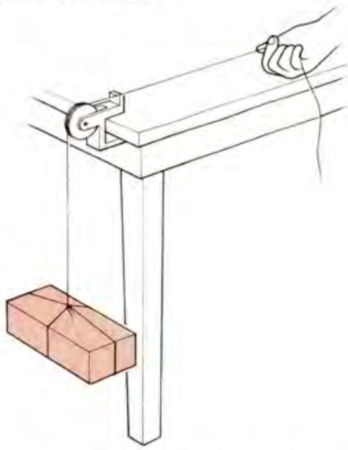
c. Hold a steel spring or rubber band between your fingers and stretch it. Let go.



d. Repeat this, but instead of letting go, slip the spring over two pegs to keep it stretched.

e. Tie a string to a brick and raise the brick from the floor to the bench by pulling on the string. Place the brick on the bench.

f. Attach a pulley wheel to the edge of the table; run the string from the brick on the floor up to the pulley, over it, and along the table horizontally. Raise the brick by pulling the string and just hold it 75 cm above the floor.



Here are some jobs to do in your imagination:

g. Bicycle uphill.

h. Turn the handle of a sewing-machine.

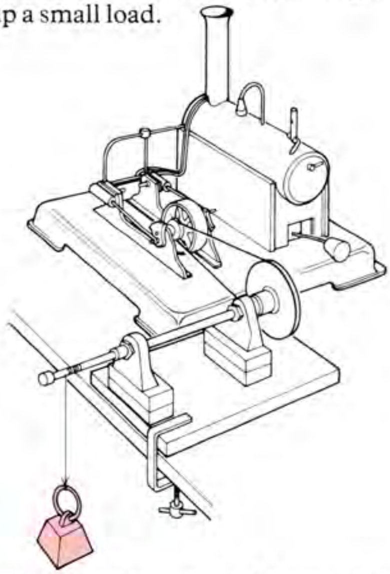
i. Climb a mountain.

j. Stir and go on stirring a large, thick pudding.

k. Switch on a torch lamp and leave it switched on.

l. Sweep the floor.

m. Light a burner under a model steam engine and let it haul up a small load.



You need fuel to do most of those jobs; the fuel is your food. Some of them could be done by engines using other fuels such as petrol or electricity. Some don't need any fuel at all. For example, you could just as well hold the brick 75 cm above the floor by putting a shelf there. When it is on the shelf it doesn't need you or an electric motor to keep it up there.

Progress questions

1. Who do you think needs the more food: a man lying in bed all day, or a man moving heavy loads all day?

2. Which do you think would cost more in electricity: a vacuum cleaner running for a minute, or a heavily loaded lift going up for a minute?

3. When you eat food, you are taking in 'fuel' to keep you warm and enable you to do things.
a. What fuel does a motor car use?
b. What fuel does a steam engine use?
c. What fuel does a gun use?
d. What fuel does an electric train use?

Questions

4. Here is a list of ten 'jobs' done by living and non-living things. Which of these is a job that needs fuel (a fuel-using job) and which require no

Q.4 *continued*

fuel? Answer for each F or O (fuel or no fuel).

a. A man hoisting a sack of potatoes off the ground.

b. Pillars holding up a heavy roof.

c. The molecules of the air in the room where you are sitting. They are in rapid motion.

d. The piston of your bicycle pump moving in and compressing air.

e. A man winding up a clock.

f. A carpenter's clamp tightly holding two pieces of wood together.

g. A refrigerator keeping things cold on a hot day.

h. Water keeping a boat afloat.

i. A bus moving along a level road against a strong wind.

j. A man or a computer doing sums. (Discuss this one in class.)

Food, fuel, and energy

Energy for jobs When you do a 'useful job' like lifting something from the floor to the table, your food provides something. That something is called 'energy'.

Do you have to have food for that? Could an engine that uses petrol do that instead? Or an electric motor, run by a battery?

Your food does more than provide energy which you need to do the jobs. It provides heat to keep you warm. It helps manufacture some chemicals for repair work and body building. And it helps make some chemicals which are fed to your muscles as 'fuel' to run those muscles as an engine.

When you haul up a load or climb a staircase or push something along, your muscles 'burn' some of those chemicals, producing some waste heat, but also something which is useful because the load gets hauled up or the cart gets shoved along. When energy comes from your muscles to some other useful form you are drawing upon fuel (chemicals in your muscles, provided by your food). In that way, your food is a fuel just as oats and hay are fuel for a horse, petrol is fuel for a car, and coal is fuel for a steam engine or a power station.

58 Experiment
Human energy chart

a. When you are at home, or in some other spare time, look through the chart that is printed here. *How much energy should* YOUR *food give you each day?* (Remember that the numbers in the chart are only rough guides; they are averages. Some people make better use of their food; and some make poorer use and need a little more food. Also, your needs depend on the exercise you take.)

b. If you had to live on sugar and water, and nothing else (a very bad idea), find out how much sugar you would have to eat each day. (Consult the chart and make a rough guess.)

c. As in (b) but only *bread* and water. (*Note:* a standard baker's loaf is about $\frac{1}{2}$ kilogram.)

d. As in (b) but only ice-cream and water.

HUMAN ENERGY CHART

Energy from food

Here is a table showing the energy which 100 grams of various foods can produce. The energy unit used is called the kilojoule.

Food			
Sugar	1660	Milk	280
White bread	1010	Butter	3350
Oatmeal	1700	Cheese	1800
Cornflakes	1550	Margarine	3350
Potato (chips)	1010	Egg (fried)	1010
Baked beans	390	Beef (roast)	1050
Cabbage	100	Fish cakes	920
Orange	150	Ice cream	840
Apple	190	Buns	1290
Rhubarb	20	Plain chocolate	2300

Human energy demands

How much energy do we need to take from food each 24 hours? The answer depends very much on the sort of people we are, particularly our age and job. Some average figures for overall use of energy per day are shown in the following lists.

Boys and Girls	
0–1 year	4 200 kilojoules
2–6 years	6 300 kilojoules
7–10 years	8 400 kilojoules

Teenagers	*Boys*	*Girls*
11–14 years	11 500 kilojoules	11 500 kilojoules
15–19 years	14 700 kilojoules	10 500 kilojoules

Adults (20 years and over)	*Men*	*Women*
Lying in bed	7 400 kilojoules	6 300 kilojoules
Light work	11 600 kilojoules	9 500 kilojoules
Heavy work	14 700 kilojoules	12 500 kilojoules
Very heavy work	21 000 kilojoules	

Pregnancy

Early months	10 000 kilojoules
Later months	11 500 kilojoules
Nursing the baby	12 500 kilojoules

Energy needed by a young man to perform some useful jobs per minute

Resting in bed	4 kilojoules
Standing still	8 kilojoules
Walking at 5 km per hour (3 m.p.h)	15 kilojoules
Digging a ditch	28 kilojoules
Running fast	42 kilojoules

Generally speaking, energy use by an adult man ranges from 53 kilojoules per minute for the heaviest work to 11 kilojoules per minute for the lightest. Such estimates are, of course, only averages. Just as our muscle strength varies from one person to another, so do our energy needs for the same rate of doing a mechanical job.

ENERGY SHIFTS

Names for forms of energy

Useful jobs need shifts or changes of energy from one form to another. Here are some names for different forms of energy. Later on, you will meet official scientific names, instead of these simple ones.

Chemical energy When you do a useful job, some of the chemical energy in your muscles is shifted across to some other form.

Springs energy For example, if you wind up the main spring of your watch, energy shifts from chemical energy in your muscles to springs energy in the watch.

Uphill energy If you lift a load of stores to the top of a warehouse, energy shifts to that load of stores – we shall say the stores gain uphill energy. And there it stays until it is shifted across to some other form.

Energy is never lost. We believe that energy is never lost, never manufactured in all the world. It is something which can be shifted around from one form to another. It's rather like money – that's always being shifted around. To get jobs done by a workman you have to transfer some money FROM yourself TO him. To get useful jobs of work done, you have to transfer energy FROM some store of energy in a fuel TO some other form such as the uphill energy of the raised-up loads.

Motion energy You can use the fuel to make something move faster and faster. You can't make a thing move faster without shoving it along and when you do that some energy is transferred FROM the fuel store energy TO energy of motion, or motion energy. Any moving thing has a store of motion energy. And motion energy can be used, because we can let the thing be brought to a stop, and in doing that it can haul up a load. Then energy would be transferred FROM motion energy TO uphill energy.

Mechanical energy You can use fuel to drive machinery faster and faster, and to keep the parts of the machine moving. This is a sort of motion energy, but we shall call it mechanical energy.

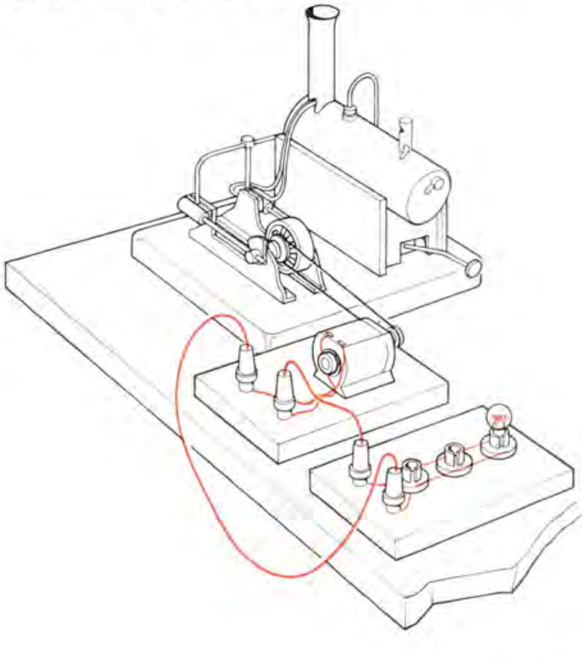
Light energy Energy travels very fast away from a flame, a bright electric lamp, the Sun, . . . , from anything that gives us light. We shall call this kind of energy 'light energy'. It is the energy of all colours of the rainbow. Also, some 'invisible colours' such as ultra-violet, and infra-red, and X-rays and wireless/radio waves all travel like light and produce heat when stopped, so we call their energy 'light energy' too.

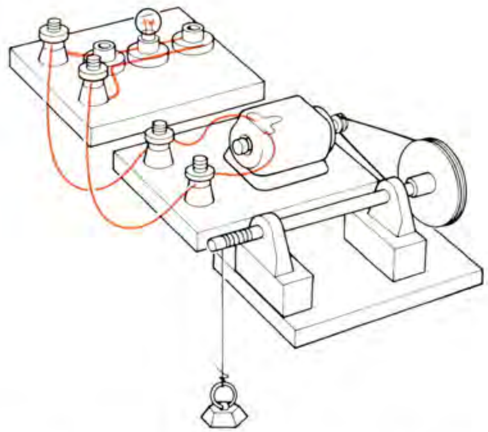
Some energy changes

59 Experiment
The energy circus

Many energy changes can be illustrated in the laboratory. You may see these experiments as a demonstration; but if possible you should share them out and act as circus-showmen yourselves.

(i) A battery lighting a lamp.





(ii) A heater runs a model steam engine and:
(iii) the model steam engine lifts a load; or
(iv) the model steam engine drives a dynamo to light a lamp.
(v) A load falls down and spins a dynamo to light a lamp.
(vi) Two moving carts collide.

Progress questions

5. You want to get a sack of potatoes to the top floor of a block of flats. You can carry this up the stairs yourself, using food energy. Energy is something that is got from 'fuel' (coal, petrol, food, etc.).
a. Suggest another method of doing this job, and say what 'fuel' is then being used.
b. If you carry the potatoes up the stairs, you also have to take *yourself* up, using 'fuel' for this. In the method you suggest in (a) is there also extra 'fuel' needed?

6. You could lift a heavy bag of sand from the ground to a shelf high up. When the bag is up there you might make it do some useful job when you let it fall off the shelf. Describe some useful jobs that you could make the bag of sand do.

Find out how builders get sand, cement, etc., up to the top of a house.

7.
a. A van runs into a wall and knocks it down. Does it go on moving as fast afterwards?
b. This is an example of motion energy (something moving) which makes something happen. Give some other examples.

8.
a. An electric motor turns when electricity is put into it. There is a motor in a hair dryer. Name a few more things which have electric motors in them.
b. A dynamo produces electricity when it is turned. Can you think of any example of a dynamo being used?

9. Look at the following types of energy changes, and write down an illustration of each.
Example: Food energy → motion energy.
Answer: A boy throws a rubber across the room.
a. Food energy → uphill energy.
b. Uphill energy → motion energy.
c. Food energy → springs energy.
d. Burning coal energy (chemical energy) → motion energy.

10.
a. When a boy stretches a rubber band, the energy change is FROM . . . energy to . . . energy.
b. The stretched rubber band then shoots a pellet across the room: the energy change is FROM . . . energy TO . . . energy.
c. When an electric train moves, the energy change is FROM . . . energy TO . . . energy.
d. When a motor car moves, the change is FROM . . . energy TO . . . energy.
e. When a stretched spring pulls a weight up, the energy change is FROM . . . energy TO . . . energy.
f. When a man lifts a child up, the energy change is FROM . . . energy TO . . . energy.

11. You can warm your hands by rubbing them together. Or you can warm the desk by rubbing hard with a rubber. The energy transfers are like this:
Food energy → motion energy → heat.

Give some other examples of energy changes ending in *heat*. Draw the energy chains if you can.

12. Suppose you take a bean bag up to the roof of the school and then drop it over the edge, the energy story goes like this:
Food energy → uphill energy of bean bag → motion energy of bean bag.

What do you think happens to all this energy when the bean bag hits the ground?

13. Some clocks work by a wound-up spring, which then drives the hands. We can write for the energy changes:
Food energy → springs energy → motion energy.
a. Some clocks work by a weight which has to be raised. Then, as it slowly falls, it drives the clock. Write out the energy changes for this kind of clock.

b. Some clocks are electrical. Write out the energy changes for this kind. (*Hint for starting point:* fuel energy in power station.)
c. If you know of any clock or watch that is driven in a different way from those given, write out its energy changes.

Questions

14. When 'useful jobs' are done, energy is transferred from one form to another. Often there are several changes, one after the other. For example, when an electric bell is run by a battery:

> Energy is transferred FROM chemical energy in the battery TO electric energy; FROM electric energy TO mechanical energy in the vibrator; then FROM mechanical energy TO sound energy and some heat.

Copy out the following jobs and write out the energy changes for each one (as in the example).
a. A match is burnt in air.
b. A falling load spins a dynamo, which lights a lamp.
c. A tennis player serves a ball into the net.
d. A fast-moving car is brought to rest on a level road by its brakes.
e. You wind up a clockwork train and then let it run round and round the track until it stops.
f. A cricketer in the outfield throws in the ball, which is caught by the wicket-keeper without it bouncing.
g. An archer shoots an arrow into a target far away.
h. Light falls on a photographer's exposure meter and the needle swings across the scale.
i. Methylated spirit burns in a model steam engine, which drives a dynamo, which lights a lamp.

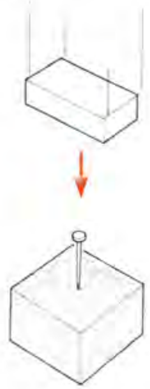
15. 'You wind up a clockwork train and then let it run round and round the track until it stops.' Think about that more carefully. The train moves in three stages:
(i) starting from rest, it goes faster and faster until it reaches top speed;
(ii) it does several laps at that steady speed;
(iii) its speed gradually falls to zero.
Write a sentence or two about the energy changes which take place during each of those stages.

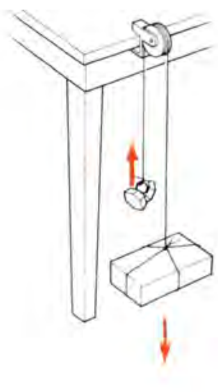
16. Coal, petrol, and other fuels are stores of energy. Sometimes we wish to store energy in a form which is easy for us to carry and use. For example, the spring of the clockwork train of Question 15 or the bow-string of Question 14(g). Think of two other ways in which we store energy conveniently, and write a sentence or two about each example. (There are at least two very common examples, and other less well known ones which are becoming very important.)

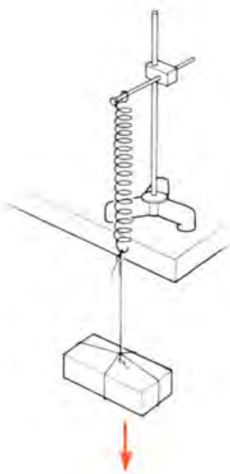
More about uphill energy

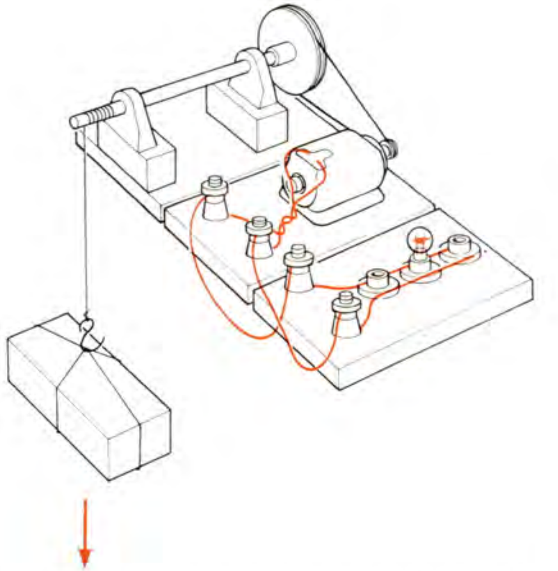
60 Demonstration
Jobs a brick can do – if it is high up

A brick that is high up can do a job for us as it falls. It can move downwards going faster and faster, getting ready to drive in a nail; it can lift another, smaller brick, if there is a suitable pulley arrangement; it can stretch a spring; it can pull a string that can spin a dynamo and light a lamp. See the experiments sketched, and perhaps some other things a brick can do.









Question

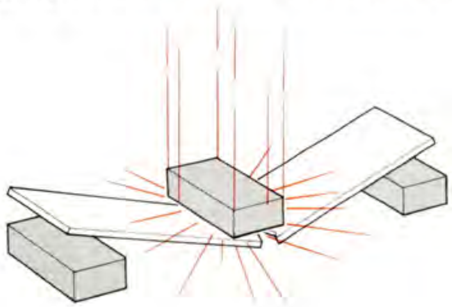
17. A 2-kilogram brick rests on the edge of a shelf 2 metres above floor level. Because it is above the floor it can do a job as it falls to the floor: we say it possesses uphill energy.

Could the brick do a bigger job if it were resting on the top of a 3 metre-high bookcase? How much bigger? What about its uphill energy?

---

61 Demonstration
Motion energy does a job

Suppose that we were to push a brick off the table so that it falls 1 metre to the floor. It might land on a 'bridge' of hardboard (see sketch). *What happens to the hardboard?* That job was done because the brick's uphill energy had shifted into motion energy by the time it had reached the hardboard.



Questions

18. If you are cycling along quite fast and come to a hill you can stop pedalling and coast some way up the hill. Where do you get the energy from for that?

19. A carpenter lifts his hammer and then drives a nail into some wood. What kind of energy does the hammer have? What energy changes take place before the hammer strikes the nail?

20. You drop a cup on the floor and it smashes into pieces. Where does the energy to break the china into pieces come from?

More uphill energy

Suppose now that we lifted the brick back to the table and then put another brick by its side. *How much uphill energy would the two bricks have?* We had to shift twice as much chemical energy from food energy to get two bricks up there from the floor as to get one brick up there. *How much uphill energy would three bricks have if placed side by side on that table top?*

Question

21. A village on top of a hill has to have its water pumped up from a lake below. The water is stored at the village in a large tank 10 m × 6 m × 4 m deep.

a. How many cubic metres of water does the tank hold?

b. One day the pump that sends the water up to the tank failed. The water level fell by 1 metre in an hour. How much water was the pump able to drive up in an hour?

c. The pump, which was petrol driven, could raise 60 cubic metres of water through a height of 15 metres in an hour. During this time it used one litre (1000 cubic centimetres) of petrol.

How many litres of petrol would be needed to pump 120 cubic metres of water?

---

62 Demonstration
Energy and the swinging pendulum

Watch a pendulum swinging. Think about the energy of the bob. At the lowest point of the swing the bob is moving quite fast; so it must

have a lot of motion energy. As it swings to its highest point that energy decreases; it disappears. But the bob gets it all back by the time it reaches the lowest point again. You may imagine some storage system – the energy of the moving bob is not really lost as the bob climbs uphill but goes into some invisible, stored-up form. This is the form we called uphill energy.

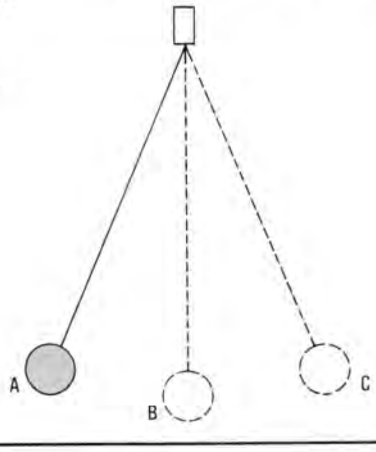
So, as the bob swings the energy is transferred FROM uphill energy TO motion energy then back TO uphill energy, then TO motion energy, and so on.

What happens to the energy as the pendulum swing gets smaller and smaller?

Progress question

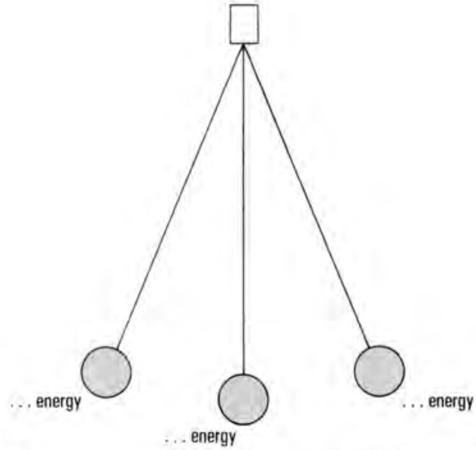
22. The diagram shows a pendulum hanging near the floor, swinging from A to C and back again. What kind of energy does it have most of when it is:

a. at A?
b. at B?
c. at C?

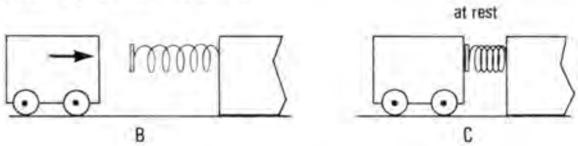


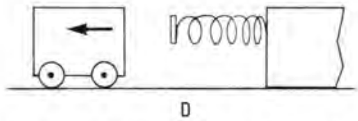
Questions

23. The diagram shows three positions of a swinging pendulum bob. The two farthest positions are on either side. The place where the bob is moving fastest is in the middle. Copy the sketch and write in the missing word for each position.



The second diagram shows a truck hitting a springy buffer at a wall.

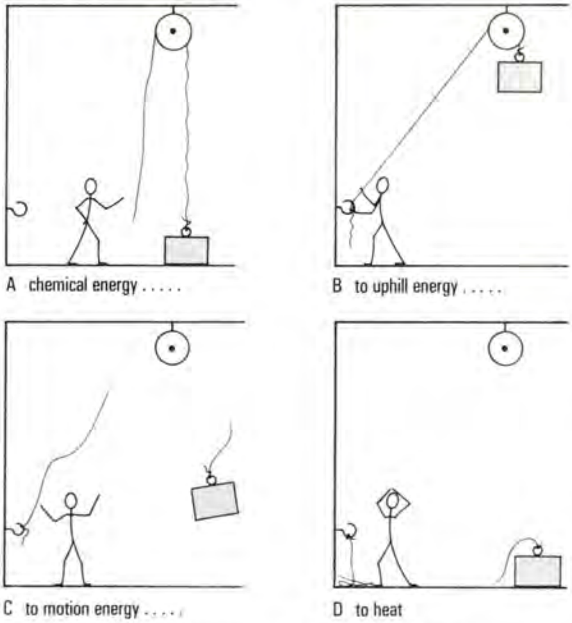




a. In the same way, copy each of the three sketches B, C, and D and label each either 'motion energy' or 'springs energy'.

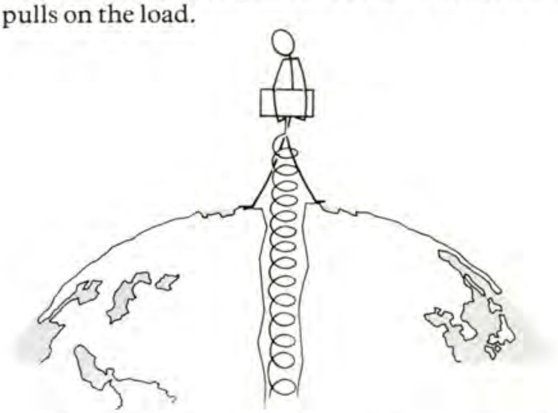
b. Write two or three sentences telling what energy changes take place when the truck meets the buffer.

24. You can see what has happened to the man and the rope and the load. Write four sentences explaining the *energy changes* that have taken place, from A to D.



The imaginary spring

Gravitational (uphill) energy When you stretch a spring, energy is stored in the spring. Later, when you release the spring, that energy appears again. Maybe uphill energy is something like that. Imagine a spring connected between the load you lift up and the centre of the Earth. There is no real spring there, but the imaginary spring's pull will help you to think about the way the Earth pulls on the load.



If the spring is *very long*, as it is in this case, all the way from the centre of the Earth to you, you will not stretch it much when you pull the load up a few centimetres. You will not change its length much; only from 6400 kilometres to 6400 kilometres plus a few centimetres. So you will not change its pull very much, however tightly stretched it is already. Even if there were a real spring you would not expect its pull to grow stronger when you raised the load higher. And in the case of the pull of the Earth ('gravity'), we do not notice any increase when we raise something higher up. Actually there is a very tiny decrease, but far too small for us to notice.

So, as we pull on the load against the imaginary spring, energy is stored up. If we let go, that energy is transferred to motion energy of the load and the load goes crashing back to the floor again.

Nuclear (= 'atomic') energy Everyone knows now that atoms have energy stored deep inside them and that it is difficult to get at that store of energy and to release it for use. However, a few kinds of atom – the *radioactive* ones – do not stay the same for ever like atoms of copper or sulphur. They suddenly unlatch a small part of that store of energy and shoot out tiny 'bullets' from their innermost core.

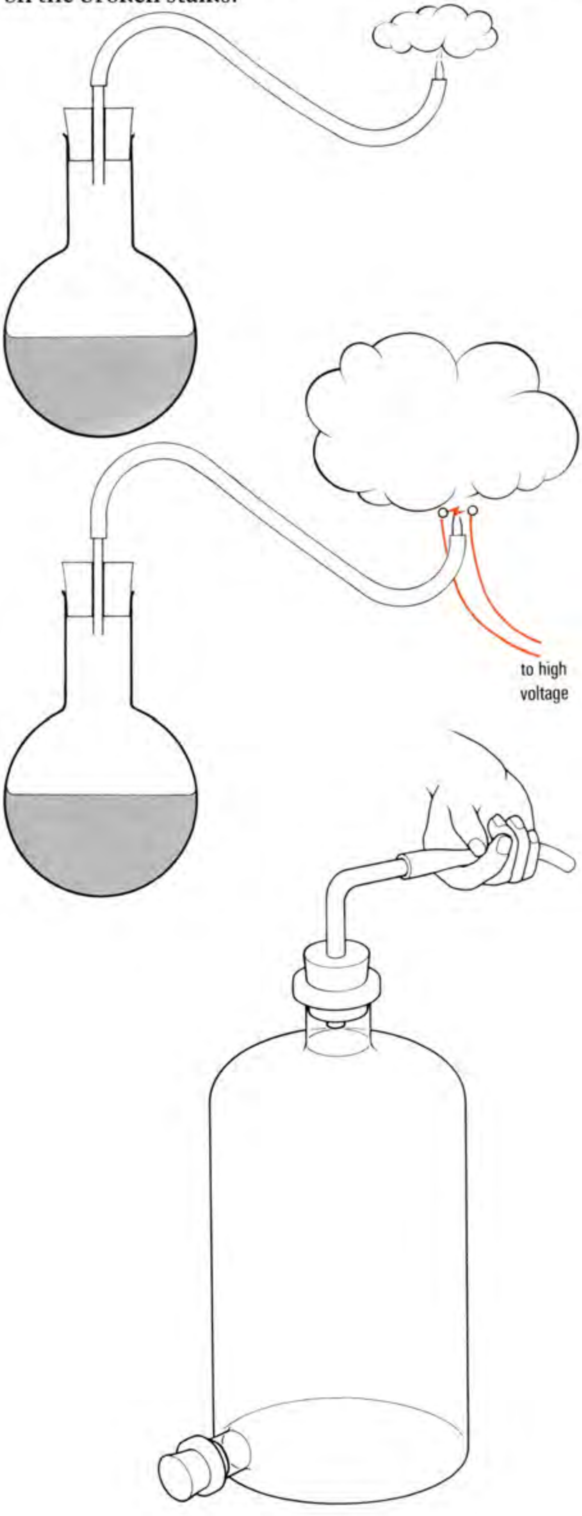
A cloud chamber is an apparatus that enables us to see the paths of those atomic 'bullets'. Then we see the effect of radioactive atoms blowing up. Before you see a cloud chamber working, you need to know some things about fog and clouds.

Clouds are formed when damp air cools. It is easy to make air cool by letting it expand. A flame or an electric spark makes it easier for a cloud to form in wet air.

63 Demonstration
Making a fog

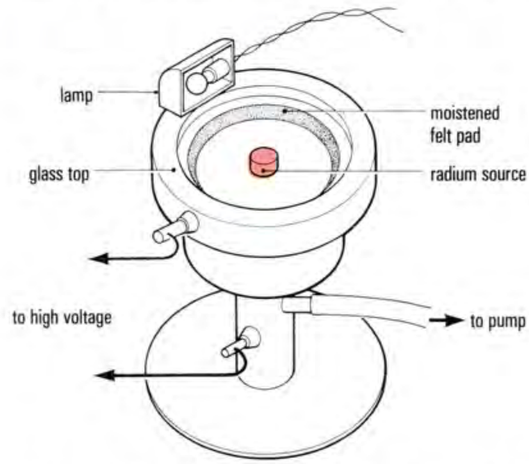
a. Steam from boiling water condenses into a cloud of tiny drops when it meets cold air.
b. An electric spark helps.
c. Expanding wet air. Take a large bottle containing air and a little water. Pump some extra air in. Wait for it to cool back to room temperature. Then open the stopper suddenly. The wet air expands and cools and then a fog forms.

When the 'bullets' from radioactive material pass through damp air they leave a trail of damaged air molecules, and tiny drops of water form easily on those. So they mark the trail. As someone said: 'Suppose a cannon ball is fired through a field of ripe wheat. If you were watching from a helicopter above, the ball would move too fast for you to see it, and you would hardly notice the trail of broken stalks. But wait a few minutes and the track will be marked by a line of dark birds settled on the broken stalks.'



64 Demonstration
Cloud chamber

See the tracks for yourself. Each is made by a single atomic bullet hurled out by a radioactive atom with huge motion energy. We say the atom



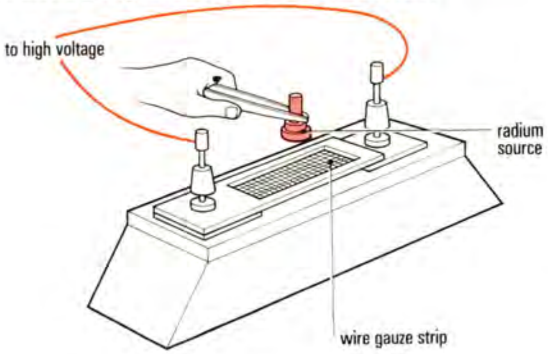
has released some nuclear energy. The track is a line of water drops, formed just after the bullet has whizzed through the wet air. See the photos of such tracks.

Disintegration of a nitrogen nucleus by an alpha particle.
Photograph, Lord Blackett.

If apparatus is available, you may be able to operate a simpler form of cloud chamber yourself (diffusion chamber).

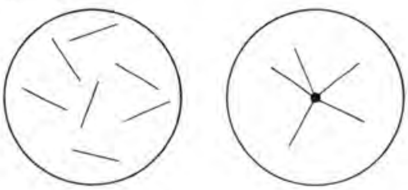
65 Demonstration
Spark counter

Another detector of these radioactive events is the spark counter. It responds with a spark to the bullets which make the tracks in a cloud chamber. By counting these sparks you can count how many radioactive atoms blow up and shoot one bullet each into the spark counter. Then you are counting explosions from single atoms.



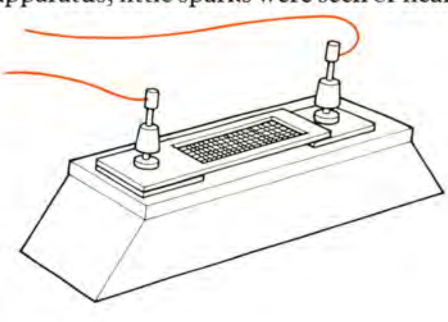
Progress questions

25. You have looked at things happening in a *cloud chamber*. You may have seen something like A or B below.



The marks stand for the white lines you saw, which are rows of tiny water drops. The water drops were showing the track of something moving – what was this something? What kind of energy was being shown by this experiment?

26. When the teacher held something above this apparatus, little sparks were seen or heard.



a. What was the something that the teacher held near it?
b. If you wanted to, you could count the sparks. What was really being counted?
c. Are the counts regular (like a watch ticking) or irregular?

Questions

27. Here are some examples of energy storage:
Winding up the main spring of a watch.
Raising the weight of a grandfather clock.
Using energy from a car battery to turn the starter-motor of a car.
Operating a pile-driver, i.e., using a diesel engine to raise the weight used to drive in the 'pile'.

Write a sentence or two about each of these examples and the energy changes which are used in each of them.

28. *(Difficult)* Imagine a hole has been made right down through the centre of the Earth and out to the other side. What do you think would happen if you dropped a brick into the hole? Give two answers, saying what would happen:
a. if the Earth were like the Moon and had no atmosphere (air) at all;
b. if the hole is full of atmospheric air. (You can assume that the brick does not touch the sides of the hole.)

Say also what energy changes take place:
c. if the brick falls into an empty hole as in (a);
d. if the brick falls into a hole of air as in (b).

YEAR 2

CHAPTER 9
About forces

Pulling and pushing; turning and twisting

Elastic forces

66 Experiment
Stretching things

Here are some ways in which *you* exert forces. *What do you notice about these forces? How do forces alter as you go on pushing, pulling or twisting? What happens when you let go?*

Use the collection of rubber bands, steel springs, rubber tubing, rubber and plastic foam, etc., to find out.

a. Stretch a piece of elastic (sewing elastic or a rubber band). Someone says, 'The pull increases the more you stretch.' *Do you agree?*

b. Carefully stretch the steel wire spring to twice its length. *What do you observe? Let go. What does the spring do?*

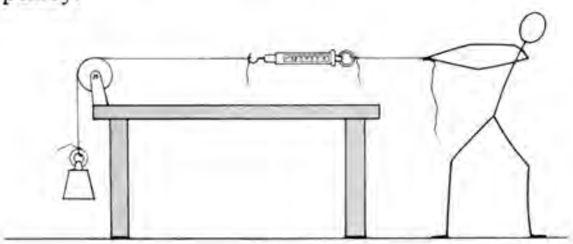
c. Hold the spring straight. Carefully twist it through one turn. Let go. *What do you observe?*

d. Now stretch it again – to twice, three times, four times its length. *What happens?*

e. Find out all you can about the other materials.

67 Experiment
A special case

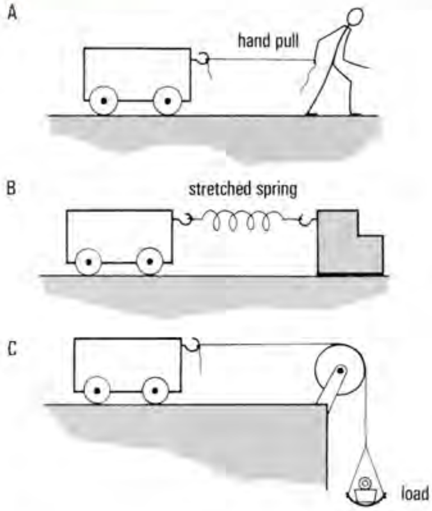
With some things the force gets bigger the further you go. *Is this always true?* Try to find out by lifting a load by means of a cord which passes over a pulley.



Progress questions

About forces

1. Diagrams A, B, and C show three ways of making a toy cart move faster. We call the force moving the cart in diagram A 'muscle force'.



a. What do we call the force moving the cart in B?
b. What force is moving the cart in C?

2. In List 1 there are some kinds of *forces*. In List 2 there are some *jobs* forces can do.

List 1 : Forces	*List 2 : Jobs*
A Force made by your muscles	P Start something moving or make it go faster
B Pull of the Earth	Q Stop or slow down a moving thing
C Pull of stretched rubber	R Set something spinning
D Push of squashed air or gas	S Twist something
E Force made by a magnet	T Lengthen something
F Force made by friction	U Shorten something
G Push of a compressed spring	

a. Give an everyday example of each of the *jobs* in List 2 happening. Then say which sort of *force* in List 1 makes it happen.

For example: job (T), 'I stretch a rubber band', can be done by force (A), 'Pull made by my muscles'.

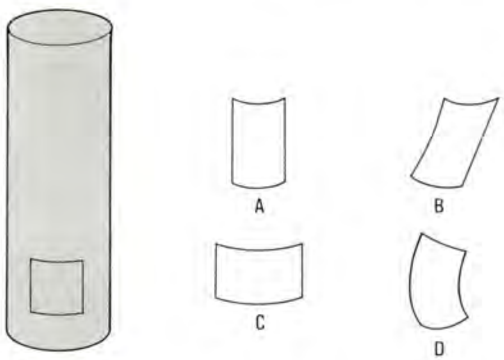
b. If you can, add another kind of force to List 1. Also add another job, that some kind of force can do, to List 2.

Questions

3. In Experiment 66a you found that the pull did increase as you stretched the rubber band more and more. Here are some more ways in which you exert forces. Try some of these at home and make a note of your observations.

a. Turn on the tap.
b. Turn off the tap.
c. Pull out a drawer and push it in again.
d. Pull up a tough, deep-rooted weed.
e. Dangle a cord over the edge of the stairs and attach it to a chair, stool, or other convenient heavy object. Then pull up slowly.
f. Push the top of the backrest of a chair so that it tilts on its back legs, more and more. The chair should be on a carpet, or you should make sure in some other way that it does not slide.
g. Find an empty bottle, cork it and slowly sink it deeper and deeper under water in a pail, or a sink, or a water butt.
h. Try pushing an uncorked bottle under water, neck upwards.
i. Now hold the uncorked bottle under water, tilted so that it fills. Then slowly lift it out, neck upwards.
j. Hold the uncorked bottle under water so that it fills, then slowly lift it out, *neck downwards*.
k. Wind up a clock – very gently!

4. The diagram shows a square drawn in ink on a short piece of thick rubber tubing. The tubing is upright and its lower end is fixed to the table.



An experimenter applied some kind of force, a pull, or a push or a twist, to the upper end. The square was forced out of shape into the rectangle (A). (Remember that the tubing is upright and held fast at the bottom.)

Did he apply a pull, a push, or a twist?

Then he removed the force and started again. He applied another kind of force to produce shape (B). Then (C); then (D).

For each case (B, C, D) say whether he applied a push or a pull or a twist. If a twist, say whether the direction of the twist on the upper end is clockwise or counter-clockwise.

5. A man steps off a moving bus and falls badly. In what direction does he fall? What force or forces cause him to fall?

(He is a rather silly man, but you can assume that he was sensible enough not to hold on to the bus as he stepped off!)

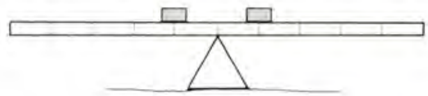
FORCES AND TURNING EFFECTS

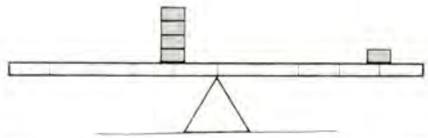
68a Experiment
Turning forces on a seesaw

Try this experiment with a seesaw or a balanced bar. First make sure that the bar is balanced.

Then place a load (1 piece) just one space out on the left: balance this roughly with a load of 1 piece on the other side.

Then build up a bigger and bigger load one space out on the left by changing to loads 2, 3, 4 and so on. Each time roughly balance that load with a single load placed somewhere on the right.



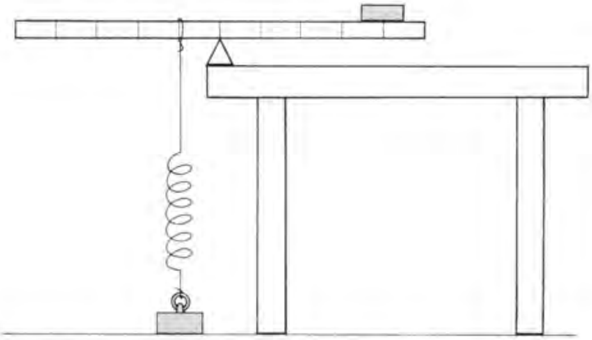


Here you have a weighing machine for weighing the force with which the Earth pulls down on the left-hand load.

68b Experiment
A machine to measure the force of a spring

This machine can be used to measure the force exerted by a spring.

Replace the big load on the left by a spring. Tie a loop in one end of the piece of thread and fasten the other end to the spring. Slip the loop over the bar, one space out from the centre. Tie the spring down to a heavy weight on the floor so that the spring is just stretched.



Now you can measure the pull of the spring by moving a single load along the right-hand side of the bar until it balances again.

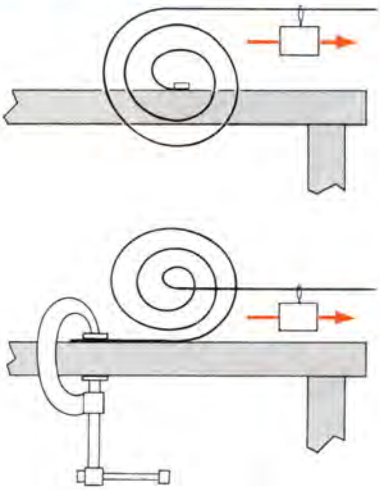
Which way does the force of the spring try to turn the bar, clockwise or counter-clockwise? And which way does the pull of the Earth on the load turn the bar? Are these turning effects equal or not when the bar balances?

69 Experiment
Turning effect on a door

Try the turning effect of a force on a door by pushing it at the handle, then half way across, and lastly near the hinge. *What do you observe?* You may see other examples of forces producing a turning effect. For example:

70 Demonstration
The screw jack *(Optional)*

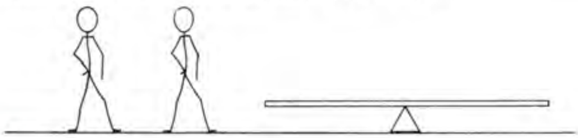
71 Demonstration
The giant clock spring



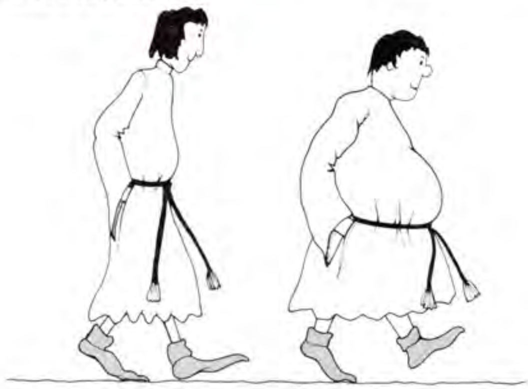
Progress questions

6.

a. These are *twins*. Draw a diagram to show them sitting on the seesaw to make it balance.

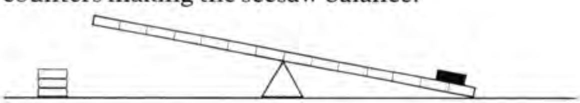


b. Now draw Fatty and Skinny sitting on a seesaw, to make it balance.

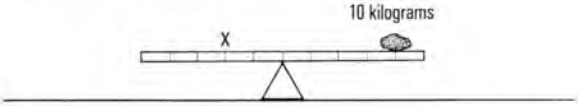


c. Now write two sentences, explaining what you did in answering (b).

7. Copy the diagram. Show the pile of three counters making the seesaw balance.

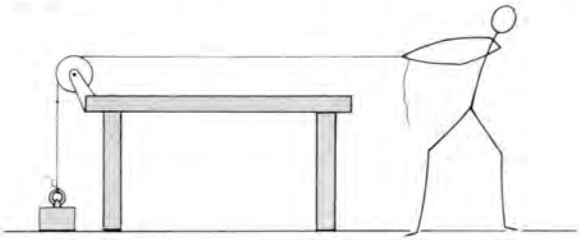


8. In the diagram, someone pulls on a string at X to make the seesaw balance.



a. Must he pull *up* or *down*?
b. How much must he pull to balance the seesaw?
c. You could also make the seesaw balance by hanging a load at X (instead of pulling). How many kilograms, hanging at X, will make it balance?

9. When you do the following jobs, does the force you use get *bigger* or *smaller* or stay the *same*?
a. You climb up a rope.
b. You haul a weight up by the method shown below.



c. You stretch an elastic band.
d. You push a broken-down car along a level road.
e. You wind up the spring of a clock.
f. You squash a rubber.
g. You turn off a tap.
h. You blow up a balloon.

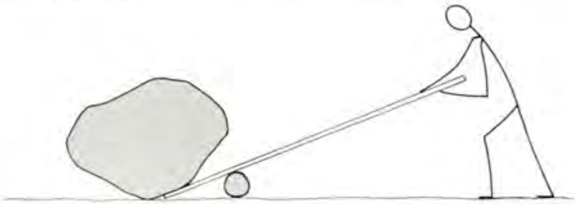
10.
a. You want to open a heavy door. Think where you would give it a push. Now copy the following sentence, choosing the correct words in brackets.

I would push a heavy door *(near the hinge/in the middle/near the opening edge)* because then I would be pushing *(near to/a long way from)* the hinge, so I would need to push with a *(big/small)* force.

b. Suppose you want to lever up a tight-fitting lid on a paint (or coffee) tin. Would you use a 1p piece or a 2p piece? Now copy and complete:

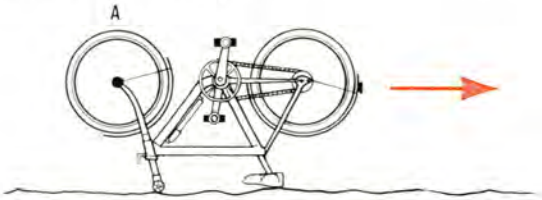
To open a tin, I would use a *(1p piece/2p piece)* because then I could push *(near to/further from)* the turning point so I would be pushing with a smaller force.

11. A man is using an iron bar to lift up a heavy rock.
a. Should he push down or push up on the bar?
b. Would it be helpful to have a longer bar, or a shorter one?



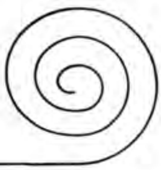
Questions

12. The sketch shows a bicycle standing upside-down on the saddle and handle-bars. The wheels can turn easily.



a. What would happen if you gave the front wheel a straight push at A?
b. Suppose you wanted to slide the whole bicycle along the floor in the direction shown by the arrow. Where would be the best place to push?

13. Most watches have two springs like the one below, and some clocks have them too. One is called the main spring; it is the spring you wind up.



a. What does the main spring do? What use is it in the watch or clock?
b. Some clocks (for example, grandfather clocks) do not have a main spring. What do they have instead to do the same job? The other spring is a small open weak one attached to a wheel that spins forward and back. These are called the hairspring and balance wheel.
c. What do the hairspring and balance wheel do for the watch or clock?
d. Some clocks (for example, grandfather clocks) do not have a hairspring. What do they have instead to do the same job?

14. A boy says there is no advantage in using two engines to pull a train, because you can't get two engines that are equally strong. If used separately, one engine must pull the train faster than the other. The addition of the slower engine could then only slow down the train. What do you say?

MAGNETS AND FORCES

Most of the forces you have looked at so far come from your muscles or other springy things. Other forces come from the pull of the Earth (gravity, as it is called) – the weight of things. But there are still other kinds of forces.

72a Experiment
Magnetic forces

Find out all you can about the forces between magnets. *Do the ends always attract one another?*

Are the forces between two magnets large, small, or none, when the magnets are:
(i) a long way apart; (ii) a few centimetres apart; (iii) a few millimetres apart?

72b Experiment
Suspended magnet

Hang up a bar magnet with two loops of thread.

What happens to the magnet? Why is one end (pole) called the North-seeking pole? What is the other end called?

What does this experiment tell you about the Earth, the magnet and forces? Mark your magnet's North-seeking pole with chalk.

72c Experiment
Magnet vs magnet

Hang up a second bar magnet and put a chalk mark on its North-seeking pole. Slowly bring the North-seeking pole of your first magnet near to the North-seeking pole of the hanging magnet. *What happens?*

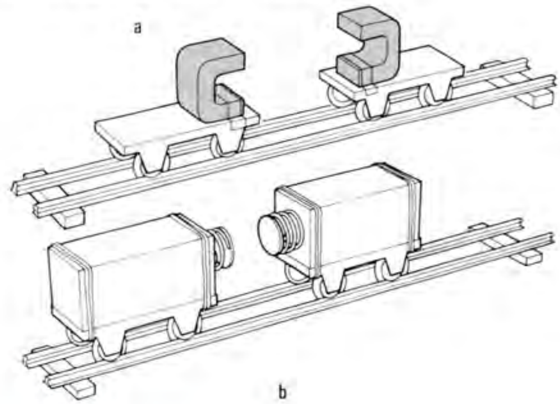
Try the two South-seeking poles.

Then a North-seeking pole near a South-seeking pole.

Name the pairs of poles which repel one another; and which attract one another. Now make up a *rule* to remind you what happens when two like poles are brought together. And another for two unlike poles.

73 Demonstration
Forces in collisions

See the experiments sketched:
a. with two magnets as buffers on trucks.
b. with springy buffers on the trucks.



74 Experiment
Invisible collisions

You can feel collision forces of air molecules if you put a finger over the outlet of a bicycle pump or syringe and then drive the piston in.

Progress questions

15.

a. Can a magnet pull an iron nail towards it?
b. Can a magnet pull another magnet towards it?
c. Can a magnet push another magnet away from it?
d. Can a magnet push an iron nail away from it?
e. Can a magnet make another magnet turn round?

16.

a. Copy and complete:

When you hang up a magnet all on its own, one end will point . . . and the other end will point . . . .

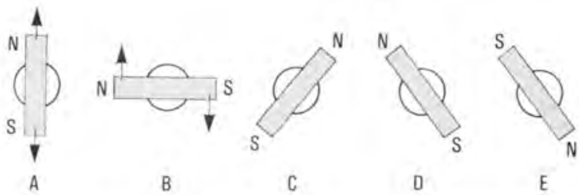
b. Why do we call one end of the bar magnet the 'North-seeking' pole?

17. A magnet will pick up an iron nail.
a. Will each end pick up the iron nail?
b. Will a magnet pick up a gold ring? a brass coin? a steel sewing needle?

Questions

18. You saw an experiment with two powerful horseshoe magnets. Each was on a small truck. The open ends of the magnets faced each other.
a. Describe what happened when the trucks were given a push and ran towards each other.
b. Suppose one magnet is then turned upside-down and refixed on its truck. What difference will that make, when the trucks run towards each other?
c. Describe how you could use pieces of sponge rubber and a length of elastic instead of the magnets to show a similar collision of the trucks.
d. So both a pair of magnets and pieces of sponge rubber with an elastic thread can be used to show forces of attraction and repulsion. Say what differences there are:
(i) between the attraction due to two magnets and the 'attraction' due to the pieces of stretched elastic; and *(ii)* between the repulsion due to two magnets and the 'repulsion' due to two pieces of sponge rubber.

19. How would you find which is the North-seeking pole of a magnet and which the South, without making use of a compass or any other man-made magnet?



20. The five diagrams show five positions of a short bar magnet which is placed on a flat piece of cork and then floated on water. The arrows in (A) and (B) show the forces due to the Earth's magnetism which act on the magnet when it is placed in these positions.
a. Copy all the sketches and add suitable arrows to (C), (D), and (E).
b. The magnet in (A) stays in this position and does not move in any way. What does this tell you about the poles of the magnet?
c. Give a reason for your answer to (b).
d. Write against your diagrams (B), (C), (D), and (E) the words 'clockwise' or 'counter-clockwise', according to whether you think the magnet will turn in the same direction as the hands of a clock or in the opposite direction.

CHAPTER 10

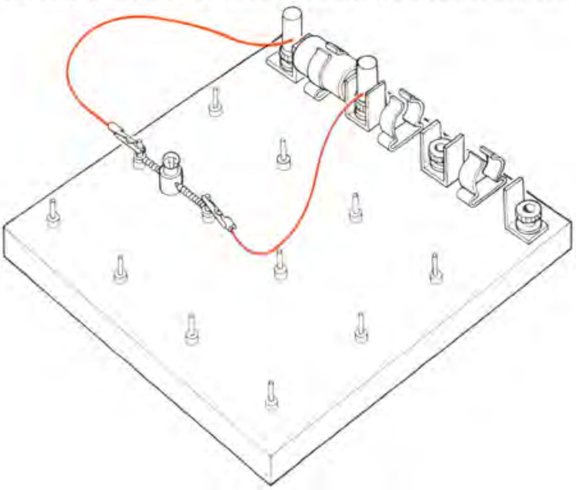
Electric circuits

Exploring and using electric currents; making an ammeter and finding a law

Experiments with lamps, batteries, and circuits

Do some experiments to find out what electric currents do. You will find that you cannot make anything happen until you join up your lamp and other things in a complete circuit* of metal wires starting from the battery and leading all the way round back to the battery again. This is a long series of experiments. Try them one after the other.

Circuit board Use a board with pegs so that you can connect up circuits quickly. As you can see, it can take up to three cells. (When there are several cells, connected together, we call that a battery.) The only other things you need for the



first experiment are a lamp holder and two metal connecting wires. Later on you may find it useful to draw electric circuits in your notebook and write a note in your own words, saying what happened. But in these first experiments with electric currents you won't need to do that.

**Circuit*. 'The policeman ran out of the front door and made a circuit of the house.' The word 'circuit' tells you about the path the policeman took. Where did he go? Where did he finish?

Engineers and scientists use the word 'circuit' for electricity in the same way.

If you want to light a lamp from a battery of cells, you must have a metal wire all the way round, from the battery to the lamp and on back to the battery. The circuit must be complete: if there is a gap, the lamp does not light.

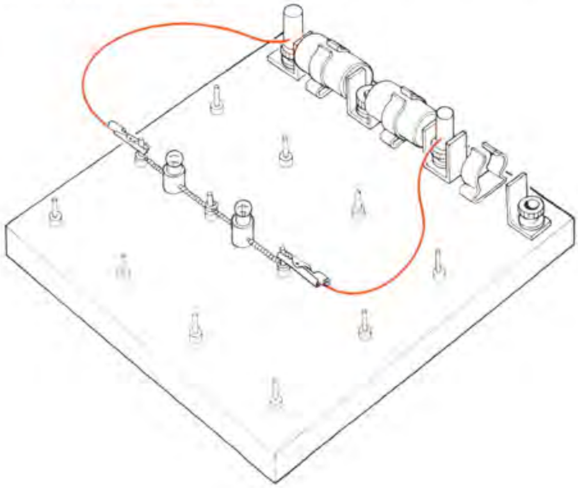
75 Experiment
Lamps, batteries, and circuits

a. Make the lamp light.
b. Try turning the lamp round. That will reverse the connections to it.
c. Find out if it makes any difference if you turn the cell round end for end.
d. Switch the lamp on and off. Use your fingers and common sense first.

Then you may ask for a proper switch.

Sometimes accidental breaks occur in a circuit because the pegs on the board work loose. If this happens, tighten the nuts which hold the pegs to the board.

e. Try changing the pattern of the connecting wires so that the shape of the circuit is no longer square. *Does that make any difference?*
f. Add a second lamp. Arrange things so that both of them light. (If you can't see whether a lamp is glowing or not, shield it with your hand.)
g. Take your second lamp and its holder out of the circuit (you will need it again). Take a second cell. Connect up the circuit with two cells and only one lamp. *How does that lamp look now?*
h. Turn *one* of your cells round end for end. *What does the lamp do now?*
i. Arrange a circuit so that you can light *two* lamps from two cells. *Are the lamps as bright as when you connected one lamp and one cell?*



75 E. *continued*

j. Turn *one* of the cells round. *Does it matter which one?*

There are some other experiments you might try. (These are optional.)

k. Two lamps with three cells.

l. Three lamps and two cells.

m. Three lamps and three cells.

A name for a definite current

A lamp's worth In your first circuit, one lamp was lit by the current from one cell. That lamp ran at normal brightness – you might say you had a 'lamp's worth of current'.

When one *lamp was lit by* two *cells, was the current 'one lamp's worth', or more, or less?*

When three *lamps were lit by* three *cells, what was the current like?*

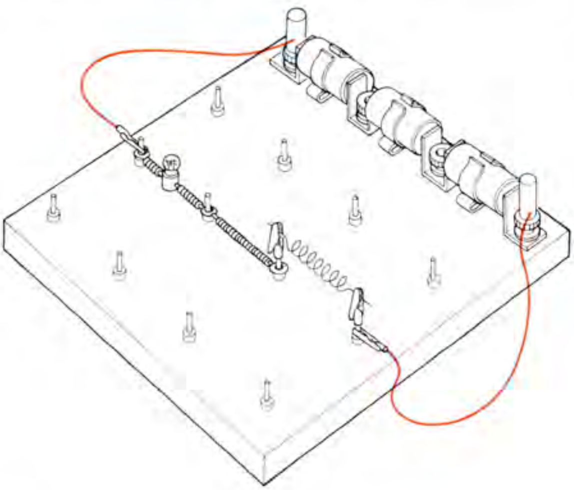
Heating

Is the very thin wire (filament) inside a fully lit lamp warm, or hot, or very hot?

Heating is one of the things that an electric current does.

76 Experiment
Electric heating

Try a short length of very thin bare wire in a circuit with *one* lamp and *three* cells. The sketch shows a neat way to arrange this. The 'crocodile clips' slip over the metal pegs so that wires or other things can be held firmly in the circuit.

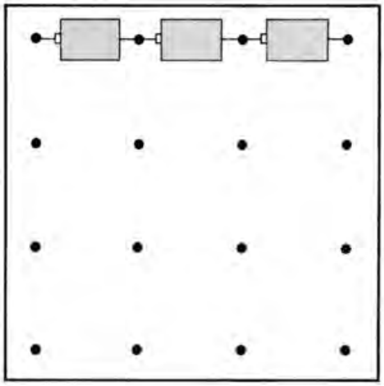


Progress questions

Electric circuits

1. Make a list of all the things that change electrical energy to some other form of energy. (They could be things at home or elsewhere.)

2. Here is a circuit board and three cells, connected in series.



a. Copy the diagram. Draw connecting wires and a lamp showing how you used *one* cell to light a lamp. We call this 'normal brightness' or 'one lamp's worth' of current.

b. Label the positive end of the battery with a + sign.

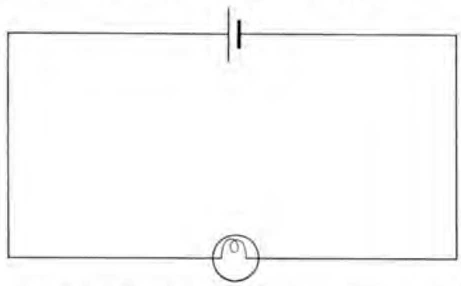
c. Does it make any difference to the lamp if you turn the battery round?

d. Make a similar sketch showing how you used one cell to light two lamps which are in the same line (in series).

e. How many cells do you need to light these two lamps to normal brightness?

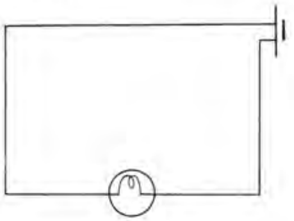
f. Does it make any difference to (e) if you turn one of the cells round?

3. This is an electrician's diagram which shows one cell connected to make one lamp light.



a. Copy this diagram and add labels 'cell' and 'lamp'. Mark the positive end of the cell +.

b. What do the joining lines between cell and lamp stand for? Are they pieces of string or what?
c. Will the circuit work (to light the lamp) if it is joined up like this?



4. 'An electric current can produce heat.' How do you know for yourself that this statement is true?

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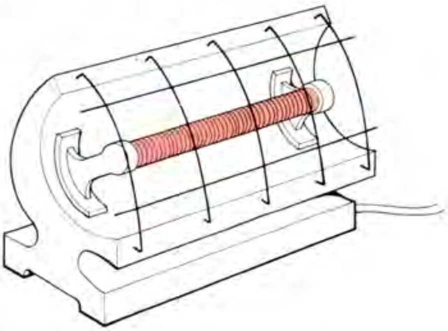
Question

5.
a. Many household appliances use electric heating. Your mother may use an electric iron. Name four other appliances you might find at home which use heating by electric currents.
b. Electric filament lamps also make a lot of heat – in fact a dozen ordinary filament lamps produce as much heat as a 'one-bar electric fire'.



Is 'fire' a good word to use in that description? Explain your answer.

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Magnetizing

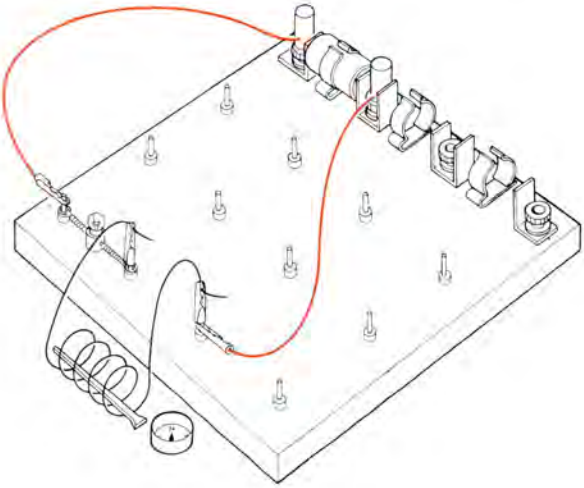
77 Experiment
Making an electromagnet

Try to use an electric current to make an iron nail become a magnet. Take a long piece of wire and wind it in a coil round the nail. Use wire that is easy to bend (flexible). The wire must be covered with some protecting stuff (insulation) so that when you wind it into a coil the electric current has to go round and round the coil. The current must not pass through a 'short-circuit' of copper made by metal coils touching each other.

You will find it best to wind a tight coil round a pencil first. Make the whole coil about 5 cm long. Then slip it off the pencil and slide it over the nail.

Connect that coiled wire in a circuit with a cell and a lamp.

Now see if the coil with the nail inside it is a magnet (see diagram).



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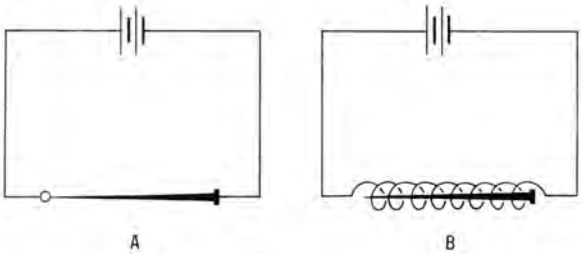
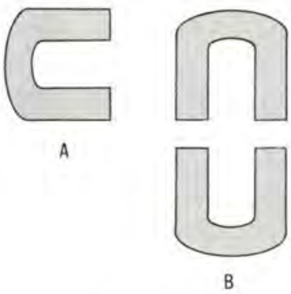
Progress questions

6. 'An electric current can produce magnetism.'



a. If you wanted to use electric current to magnetize an iron nail, would you use circuit A or circuit B?
b. How would you test whether the nail was magnetized or not?

7. Diagram A shows a C-shaped piece of iron.



If you put two of these pieces of iron together, as in diagram B, and then lift the top one, it just comes up and leaves the other behind.

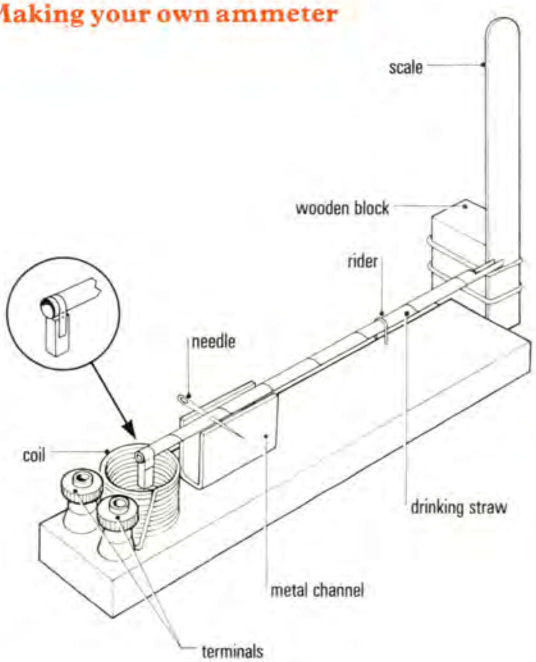
How could you use electric current to make the top piece of iron lift the other? (Not by tying them together or using glue!)

....

Current and magnetism So electric currents can make magnets as well as heat wires and lamp filaments. You have already used that heating effect to tell you when you have a current of a definite size, 'one lamp's worth'. Now you are going to use the magnetic effect for the same job.

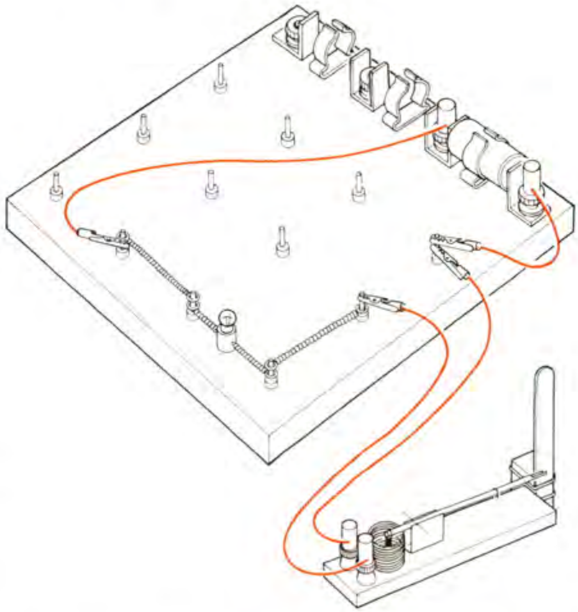
78 Experiment
The current balance

78a
Making your own ammeter



Set up a current balance, as in the diagram. When it is finished, make sure the straw balances horizontally and that it is able to swing freely.

Then test the instrument by connecting it in a circuit with one lamp and one cell. *What does it do?*



Ask your teacher to see whether your balance is ready for use.

You can see that 'one lamp's worth' of current is flowing in the coil of the balance.

Slide the wire rider along the straw to counterbalance the force this current exerts on the magnet. Move the rider until the straw is horizontal again. Then you know that your balance is set to measure 'one lamp's worth of current'.

78b
Using your current balance

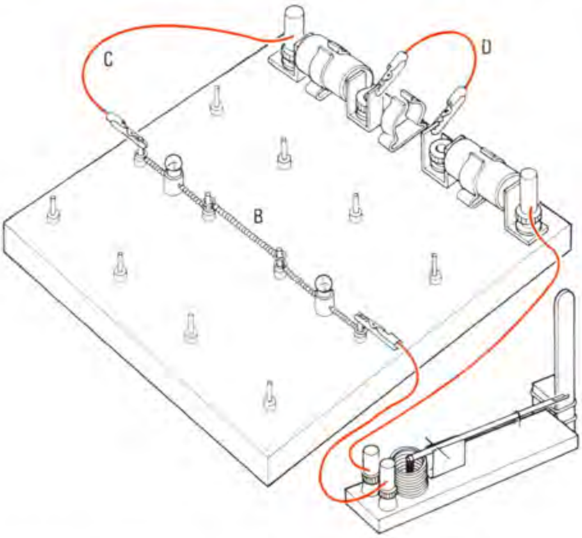
DON'T MOVE THE RIDER OR THE BALANCE, but put a second lamp into the circuit in line with the first one. Does the balance now tell you that the current is 'one lamp's worth', or more, or less?

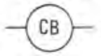
78c
Stronger battery

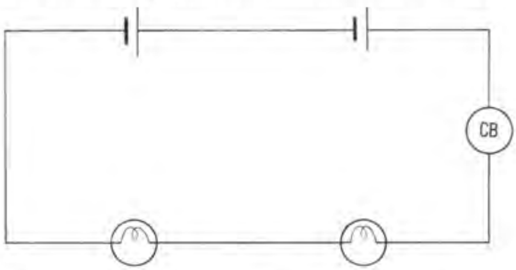
Take that second lamp out of the circuit and put a second cell in. *What does the balance tell you about the current this time?*

79a Experiment
Current at different places in the circuit (a specially important experiment)

Connect up the circuit shown below. This is a series circuit. We have redrawn it in the form



which electrical engineers use. The sign  means a cell, the sign  means a lamp, and the sign  means a current balance.



See opposite for a collection of these signs.

First make sure that the rider is in just the right position to counterbalance the magnetic force with 'one lamp's worth of current'. Then, *without touching the rider again*, connect your current balance at point B in the circuit, between the two lamps.

Then try it at C, and finally at D, between the two cells.

What do you notice about the readings of your current balance?

What does this tell you about the current in a series circuit?

If this surprises you, do the experiment again to make absolutely sure.

79b Experiment
The same important experiment with an ammeter

Your current balance is a very effective instrument – but it is not designed to be carried around. Instruments for measuring currents are called ammeters and they do just the same job. Such instruments are made by the thousand. They are marked in the units for current which all electrical engineers use – amperes (or amps, for short).

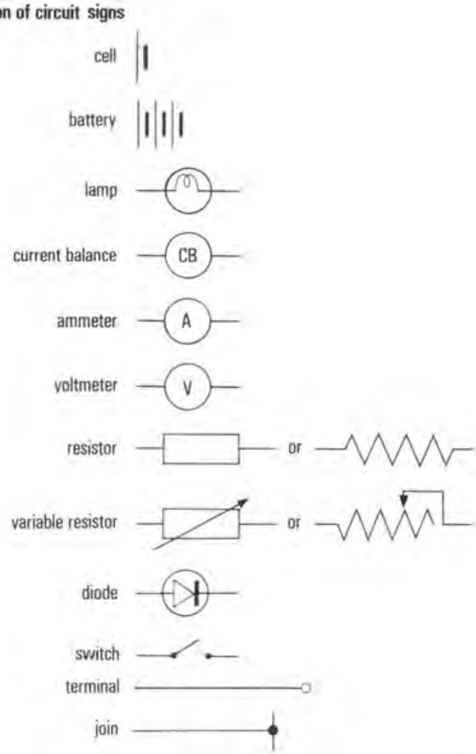
Try an ammeter (scaled from 0 to 1 ampere or A) instead of your current balance in the series circuit which you have just used. *Is the current still the same wherever you measure it in that series circuit?*

Drawing diagrams for circuits

Now is the time to start drawing diagrams for circuits in your notebook.

Use the professional electrical symbols or signs. Do not draw the connecting wires curved or tangled as they often are in a real circuit. Draw them as straight lines up and down or left and right on your paper. You should draw neatly with a pencil; but you need not use a ruler. Ruling lines would take too much time away from the real experiment.

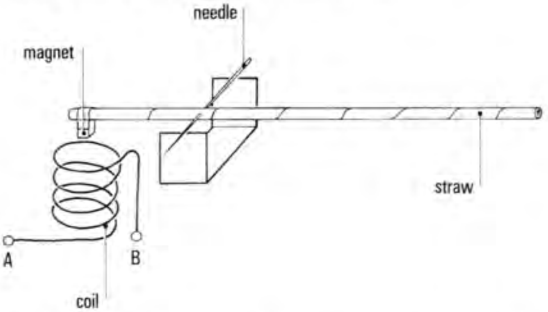
A collection of circuit signs



If you like, draw the circuit properly for each of your earlier experiments. Then you can quickly follow your sketches and set up any of them that you are not sure about.

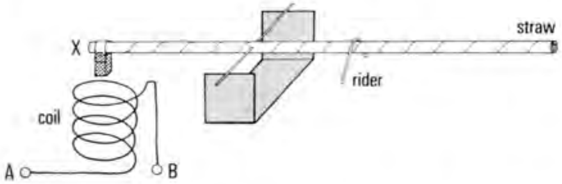
Progress questions

8. Here is a current balance. Points A and B can be joined into an electric circuit.

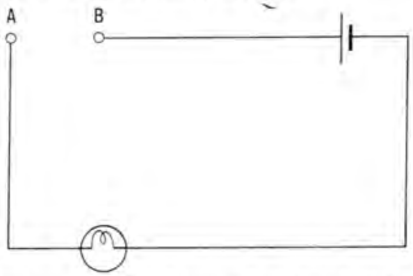


a. What happens if you pass a current through the coil?
b. What happens if you turn the battery round to make the current go the other way?

9. Try this question if you have done experiments with a wire 'rider' on your current balance.



A and B are the points you join into your circuit, so that there is electric current in the coil.
a. What is X?
b. You join AB into a circuit like this one. You move the rider to balance the straw.



Then you keep AB joined to the circuit but you turn the cell round.
(i) Does your lamp still light?
(ii) Does your straw still balance?

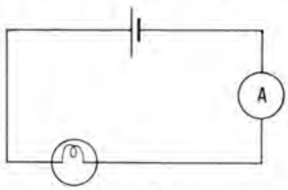
c. You turn the cell back again and add another cell, the same way round.
(i) Have you made the current bigger or smaller?
(ii) Have you made the force on X bigger or smaller?
(iii) Which way do you have to move the rider to balance the straw again? (*Towards* the needle or *away from* the needle?)
d. Instead of having one lamp and one cell, you have two lamps in series and one cell.
(i) Have you made the current bigger or smaller?
(ii) Have you made the force on X bigger or smaller?
(iii) Which way do you have to move the rider to make the straw balance?

10. A pupil did three experiments with his current balance, with:
A Normal current (one battery, one lamp)
B Less than normal current (one battery, two lamps)
C More than normal current (two batteries, one lamp)

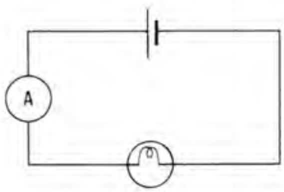
Each time the straw was balanced, he marked the position of the rider. Here is his straw with his marks.

a. Which mark (P or Q or R) goes with Experiment A?
b. Which mark (P or Q or R) goes with Experiment B?
c. Which mark (P or Q or R) goes with Experiment C?

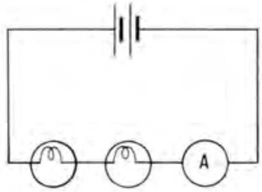
11. The lamp in diagram (a) is normally bright.



a



b



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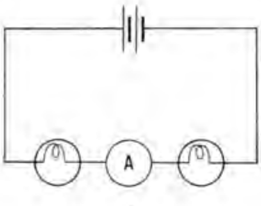

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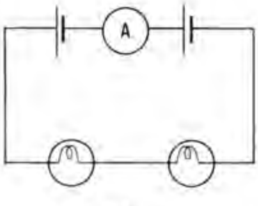
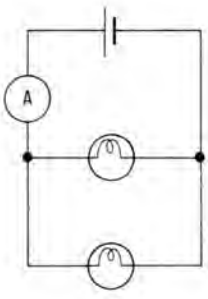


e



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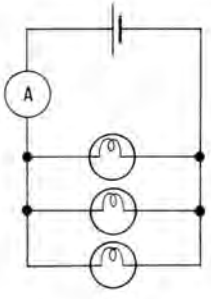
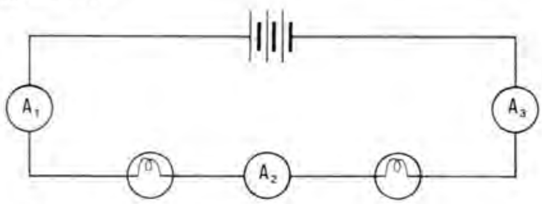


g

The current through it, shown by the ammeter, is 0.1 ampere. Say whether the current shown by the ammeter is 0.1 ampere or more, or less, in each of circuits (b) to (g). All the lamps are the same and all the batteries are equally strong.

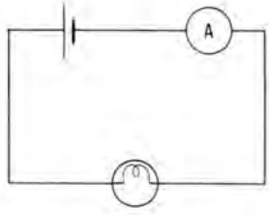
12. This circuit has three ammeters in it, A_1, A_2, and A_3.



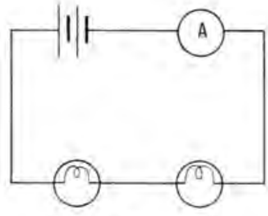
a. If you know the reading on ammeter A_1, can you tell what the readings on A_2 and A_3 would be?
b. If I have only one ammeter, does it matter *where* I connect it to find the current in a series circuit? Explain your answer.
c. Ammeter A_1 reads 2.0 amperes. What will A_2 and A_3 read?

Questions

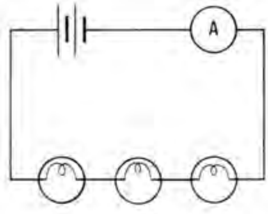
13. Each of the five drawings (*(i)*, *(ii)*, *(iii)*, *(iv)*, *(v)*) (top right) shows a circuit containing ammeters, cells, and lamps.
a. Which symbol means an ammeter, which a lamp, and which a cell? Answer by copying circuit *(i)* and writing labels on it.



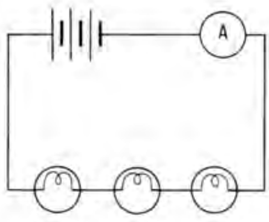
(i)



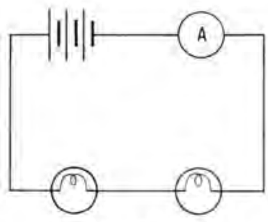
(ii)



(iii)



(iv)



(v)

b. The positive (red) end of the cell can be shown by a + sign. How is it shown in the symbol? Answer by drawing the symbol and adding the + sign.

14. If the lamp in *(i)* is at normal brightness, what can you say about the lamps in *(ii)*, *(iii)*, *(iv)*, and *(v)*? Say whether each is normal, or less bright, or brighter.

15. Copy circuit *(iv)* and include a switch (symbol —/ •—) that would turn off the lamps without any of the wires having to be disconnected.

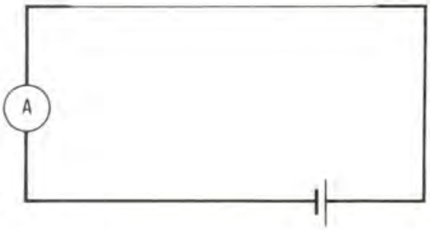
16.
a. In which of the circuits (*(i)*, *(ii)*, *(iii)*, *(iv)*, *(v)*) (above) would you expect the cells to run down most quickly?
b. Give a reason for your answer to (a).

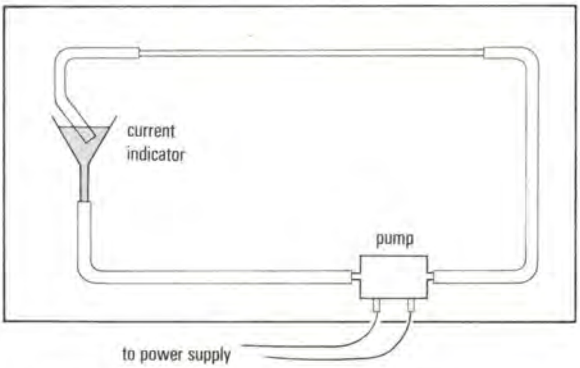
A CURRENT OF ELECTRICITY: THEORETICAL KNOWLEDGE

There *is* something which is the same all the way round the series circuit: the brightness of the lamps is the same; and the reading of the ammeter is the same. This behaviour reminds scientists of water being pumped round a closed ring of pipes. So they say, 'There is a current; there is something running round the circuit which stays the same all round.'

80 Demonstration
A water circuit

The sketch shows a 'water circuit' (and the corresponding electric circuit for comparison).





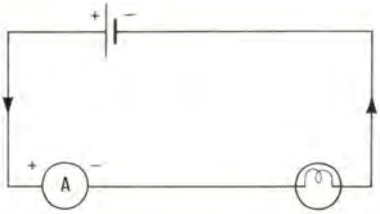
See an actual model if possible. If you cannot, look at the sketch and think about what must happen (this is called 'doing a thought experiment').

Current? Is there *really* something that moves round through the copper wires and through the lamps, something which makes those lamps light, something which pulls in the magnet of the current balance? As far as you or I can tell, we can only say:

> This behaviour of the electric current is *rather like* the behaviour of a current of water flowing. We do not know whether anything is really flowing, and we certainly do not know what it is. If it flows, it might be some kind of 'juice' flowing one way or the other way round the circuit.
>
> Instead of some smooth 'juice' flowing like water in a pipe, the current might be a procession of tiny particles, little bits of electricity moving along like a line of rabbits in a burrow. We must wait for more experiments before we can say which is right.

Nowadays we believe that there *are* tiny things which move when there is an 'electric current'. In some cases there are several kinds of moving thing, but we cannot show you that yet.

For the moment we shall stick to the standard agreement, used by all electrical engineers, that bits of positive 'electricity' come out of the positive (red) terminal of a cell or battery and go round the circuit to the negative terminal of the cell or battery.

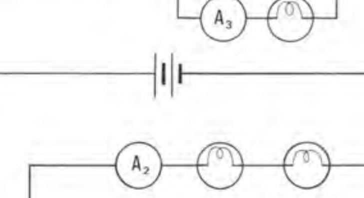


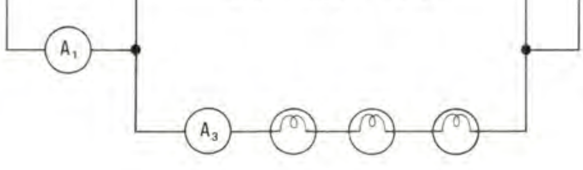
Arrows on circuit diagrams That standard agreement was settled long before anybody knew about 'electrons'; and we still use that agreement.

If there *are* electrons – negative electrons – travelling along the wires, they move the opposite way from the arrows on the circuit diagram.

Some more circuits: things in parallel

81a Experiment
A branching circuit

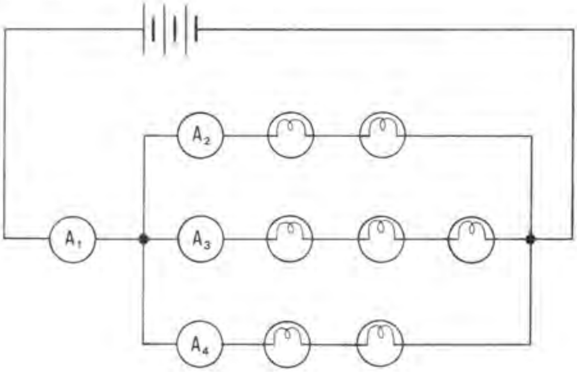




So far, all the circuits you have explored have been 'series circuits'. Try some parallel circuits. *Are the ammeter readings what you expected?* Make up a rule to describe these readings.

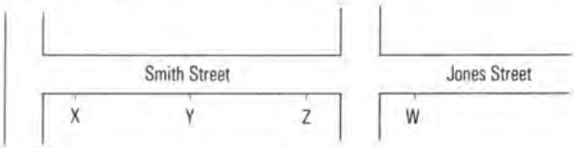
81b Experiment

Try the circuit shown below. *Does your rule apply to that?*



Progress questions

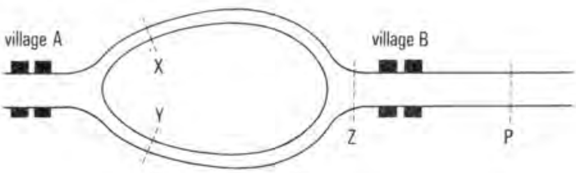
17. *(If you are not sure about this, try Question 18 instead)*
A traffic manager wanted to get a count of the number of cars passing along Smith Street, where there are no turnings and there is nowhere to park. After one hour, the counter at X said, '60 cars passed here'.



a. Did counters at Y and Z say the same, or not?
b. Would a counter at W, in Jones Street, *always* get the same result as X did?

Explain your answer.

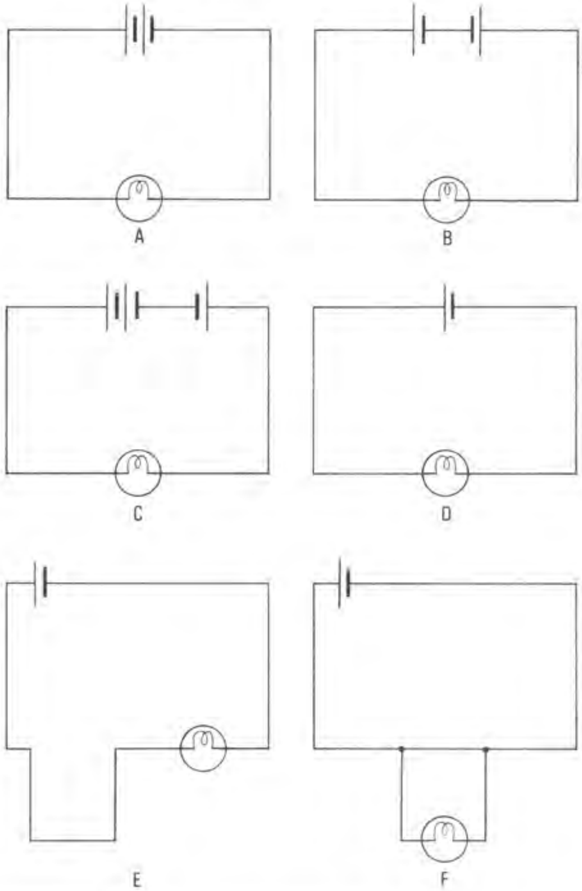
18. There are two roads from one village to another, as in the diagram below.



One morning a boy at X counted 50 cars going along his road from A to B in two hours, and a boy at Y counted 30 cars going along his road in the same two hours.
a. How many do you think a boy at Z would have counted in the same time?
b. Do you think the simple answer you gave in (a) is likely to be true in real life? Can you say how many cars the boy at P counted? Or can't you be sure? Explain your answer.

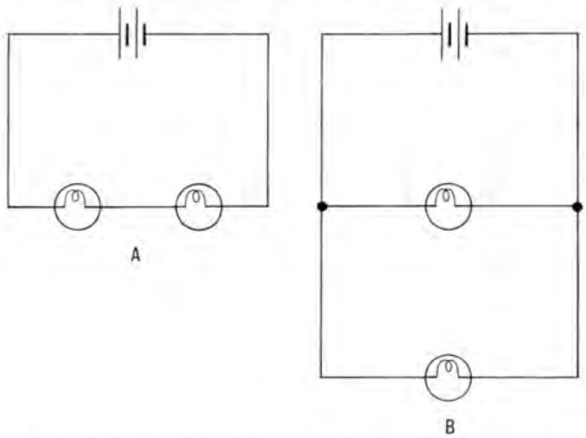
19. When we use one cell to light one lamp, we call the brightness of the lamp 'normal'.

Copy the circuits below, and write by each circuit whether the lamp is normal, or brighter than normal, or dimmer.



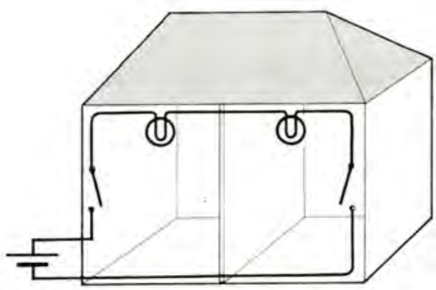
Explain what is happening in circuit F.

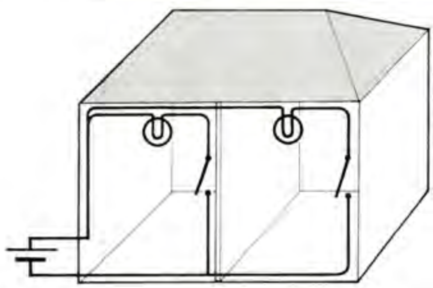
20. Look at these two circuits, A and B.



a. Which of them will give the most light?
b. Which will run the batteries down the fastest?
c. Which do we call a *series* circuit?
d. Which do we call a *parallel* circuit?
e. Suppose in circuit A one lamp has a broken wire in it. Will the other lamp stay alight, or not?
f. Suppose in circuit B one lamp has a broken wire in it. Will the other lamp stay alight, or not?

21. Suppose you are trying to wire up a dolls' house with two lamps in it. Each lamp has a switch to put it on and off*. Here are two ways of trying it.

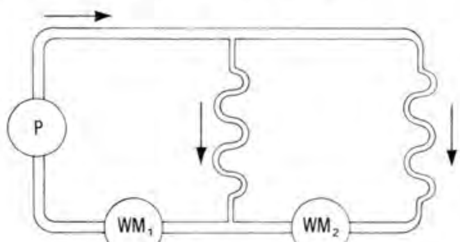




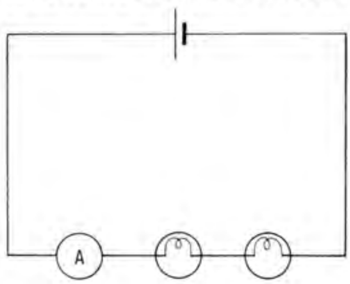
a. Which of these circuits is most like circuit A in Question 20?
b. Which of them is most like circuit B in Question 20?
c. Which of these will be the correct one for what you want in the dolls' house?
d. Copy the correct diagram, and put into it an extra switch (main switch) for putting both lamps off at once.
e. If you thought the lamps were not bright enough, what could you do to make them brighter?

Questions

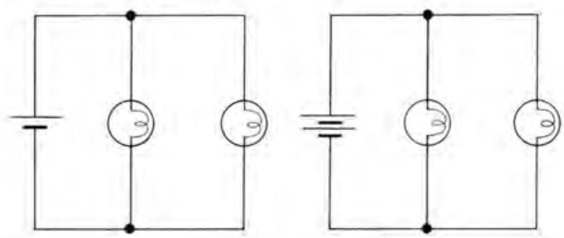
22.
a. The figure shows a water pump, P, driving water through two narrow pipes, A and B, and two 'water meters' WM. Draw an electric circuit, containing a battery, two lamps and two ammeters, which is similar to the water circuit.



b. Draw a water circuit, containing a water pump, a water meter and two narrow pipes, which is similar to the electric circuit shown below.



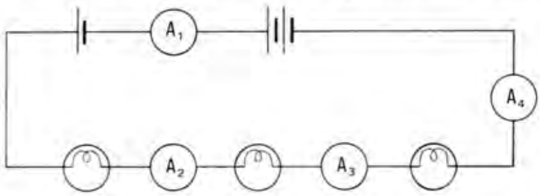
23.
a. Are the lamps in circuit A and circuit B in series or in parallel?



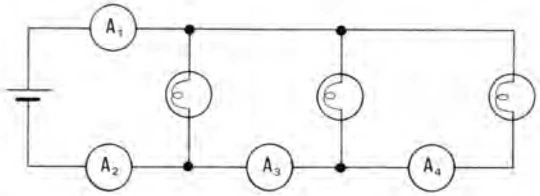
**Note* A switch is a way of closing or opening a gap in a circuit, and is often drawn as a little metal gate which can be shut or opened.

b. Are the lamps A at normal brightness, or less bright, or brighter than normal?
c. Do you expect the lamps in B to be at normal brightness, or less bright, or brighter than normal?
d. Copy circuit A above and include three switches, so that you could turn off both lamps together, or only one lamp, or only the other lamp.

24.
a. In the circuit, ammeter A_2 reads 1.5 units.



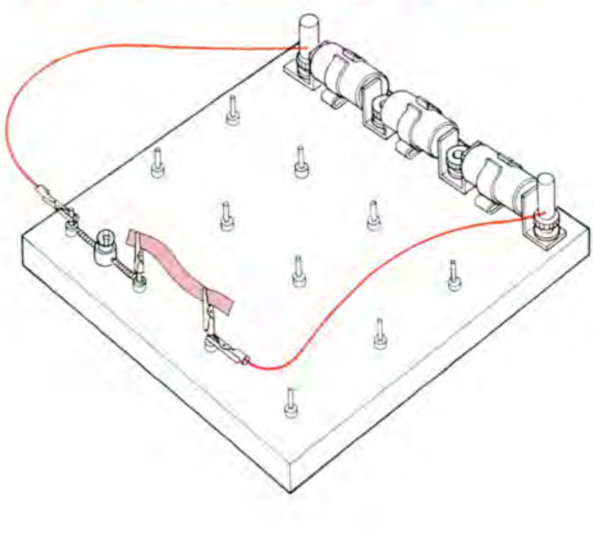
What do the ammeters A_1, A_3, and A_4 read?
b. In the circuit, ammeter A_1 reads 1.5 units.



What do the ammeters A_2, A_3, and A_4 read? Assume that all the lamps are alike and that the ammeters read correctly.

CURRENTS AND CONDUCTORS: RESISTANCE

82 Experiment
Trying various materials in circuits



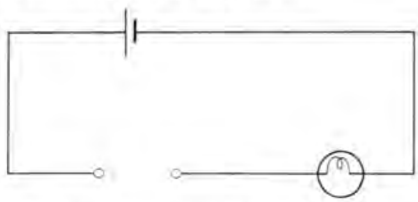
All the circuits used so far have been made with wires of metal to carry the current. Try some other materials to see whether they also carry electric currents. You could use the arrangement shown below and clip each sample between the two crocodile clips.

Try a piece of wood, a strip of paper, a length of nylon thread, a pencil lead, a strip of aluminium foil – ask for some others if you have time. *Which of your samples could be called 'good conductors of electric current'?*

The piece of thin wire you used in Experiment 76 reduced the current through the lamp so that it just glowed – we say that thin wire has a higher resistance than a thick wire.

Progress questions

25. This circuit has a gap in it.



a. Which of the following materials can you use to fill the gap and make the lamp light? Write a list of them.

Wood, copper, brass, marble, Perspex, paper, iron, lead, carbon, slate, aluminium, hair.

b. Copy the following sentences and fill in the blanks with the words 'conduct' or 'not conduct':

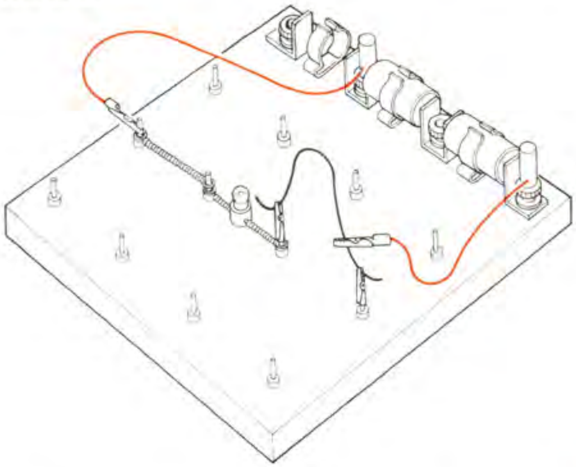
Metals will . . . electricity.
Plastics will . . . electricity.

26. The following sentences refer to wires of the same material but of different thicknesses. Copy the sentences, putting 'thin' and 'thick' in the right places.

Electric current goes through a . . . wire more easily than . . . wire of the same material and length. To get a larger current, it is better to use . . . wire than . . . wire.

83 Experiment
Making a variable resistor

Try a length of about 25 cm of the thin wire in the circuit and make connection to the cell with a 'flying' lead which has a crocodile clip on the end. This will allow you to have all the thin wire in the circuit, or only three-quarters, or a half, or even less of it.



Slide the crocodile clip along to use none, some, and then all of the thin wire.

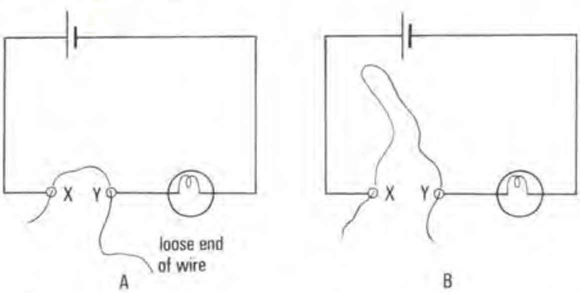
What do you notice as the length of the wire in the circuit is increased?

What can you say about the 'resistance' of the wire and the length of it in use?

....

Progress questions

27. You are given a long piece of thin wire which is *not* copper. (Copper is a very good conductor.) You connect this in your circuit with clips at X and Y, but a long loose end is left. Diagram A shows that. Then you move the clip at Y so that you have more wire between X and Y, as in diagram B.



a. What does that move do to the brightness of the lamp?

b. What does it do to the size of the current?

c. (This is a question for a guess. Then consult your teacher.) Do you think it likely that any electric current keeps going along the loose end of wire?

d. Copy this paragraph, choosing the correct words:

A long piece of thin wire lets (*a lot of/only a little*) current through. It is (*easy/hard*) for current to get through a long piece of wire. The longer the wire, the (*easier/harder*) it is.

Note A neat way of showing such a long wire which makes it harder for the current to travel in a circuit is to draw it like this:

We say this sort of wire has a big resistance.

....

84 Experiment
Using a variable resistor or rheostat

This behaviour of current changing with the length of wire enables people to control the currents flowing in circuits. Special components called 'variable resistors' or 'rheostats' do the job much more neatly than your long wire with the flying lead.

a. Try a variable resistor instead of the long wire.

b. Try the variable resistor with an ammeter as well, in series with the lamp.

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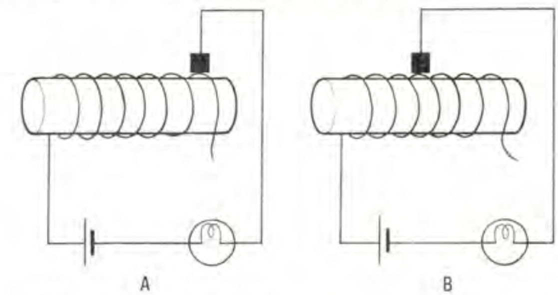
Progress questions

28. Instead of using an untidy length of wire, you can roll it on a frame, into a tight spiral. An arrangement for touching the wire anywhere along the frame can be made like this.

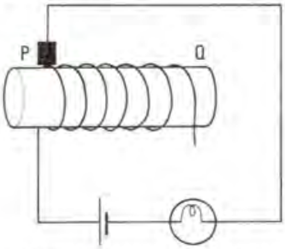


a. Which circuit has the brighter lamp, A or B?

b. Copy and complete this remark by choosing the right words in brackets.

The lamp is dim in circuit (*A/B*) because the current has to go through a (*long piece/short piece*) of thin wire. The lamp is bright in circuit (*A*/*B*) because the current has to go through a (*long piece*/*short piece*) of thin wire.

29. Copy and complete:
When the slider moves from P to Q, the current gets (*bigger*/*smaller*) and the lamp gets (*brighter*/*dimmer*).



85 Experiment
Radio resistor

In a radio or TV set you will find 'fixed resistors' as well as variable ones. Try a fixed radio resistor in your circuit. *What happens if you turn the fixed resistor end for end?*

Other experiments

86 Experiment
Another important radio component: the diode

Also try a 'diode' in the circuit with lamp and ammeter.

What happens if you turn it round end for end?

Components that do this used to be called 'valves'. *Why? What can you say about the resistance of this diode?*

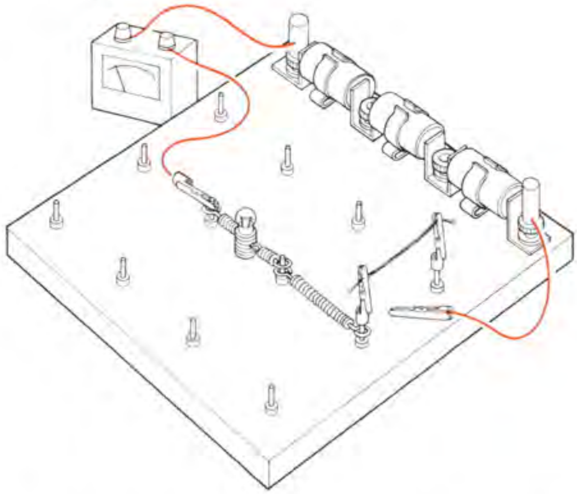
87 Experiment
Investigate and think

Take some very thin wire (for example, a few strands of steel wool) and clip this into the circuit. *Does a current flow?* Now blow gently on this thin wire. *What happens to the resistance of the wire when it gets hot?*

SHORT CIRCUITS AND FUSES

88a Experiment
A fuse

Set up the circuit shown (top right). The flying lead will allow you to shorten the length of the steel wool strands in the circuit. Do this very carefully.

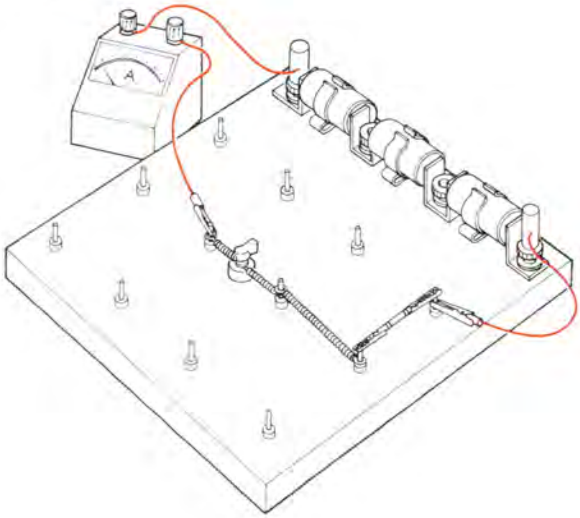


What happens? What happens to the current?

This is the way a fuse works. A fuse is a safety device. If the current is too great, the fuse melts and breaks the circuit. So the current is cut off. That is what people mean when they say that a fuse has blown – it has melted and so cut off the current.

88b Experiment
Testing a fuse *(Optional)*

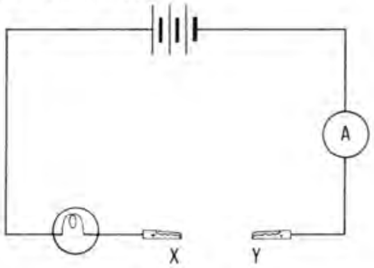
You might test a cartridge fuse like the one in a mains plug. One which is marked 0.25A is suitable. Set up the circuit shown below. Carefully increase the current through the fuse. *Does it blow at 0.25A?*



Progress questions

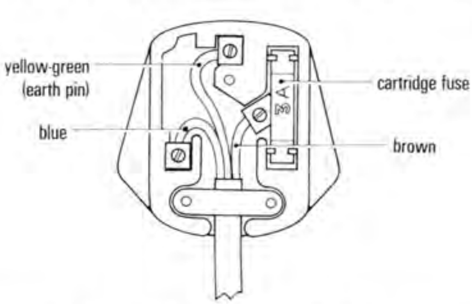
30. A short piece of thin wire is included in a circuit, and it gets so hot that it melts.
a. Will the electric current keep running after the wire has melted?
b. In many household circuits there *is* such a piece of wire. What is it called?

31. Here is a circuit you could use to show a friend how a fuse works.



a. What special wire do you put between X and Y?
b. When you do the experiment, you move the clips X and Y to shorten the wire between them. As the wire gets shorter, what happens to the reading on ammeter A?
c. What happens to the size of the current?
d. What do you expect to happen to the special wire?

Fused plugs The diagram shows a mains plug which is open, allowing you to see the fuse.



Because this plug is connected to a reading lamp taking a small current (about 0.5 A), the fuse is marked 3 A. That means that if the current in the circuit between the plug and the lamp rises to just above 3 A, the fuse will 'blow' and the current will be cut off.

What might cause that to happen? Perhaps a breakdown in the insulation of the wires leading into the lamp so that there is a short-circuit. When this happens, you must put the fault right before you put a new fuse in the plug. *Why?*

If the mains plug is to be used with something like an electric fire, which might take as much as 10 A, a fuse which 'blows' at a higher current than that is used. This is normally 13 A, and that is the highest you may use with an ordinary mains plug.

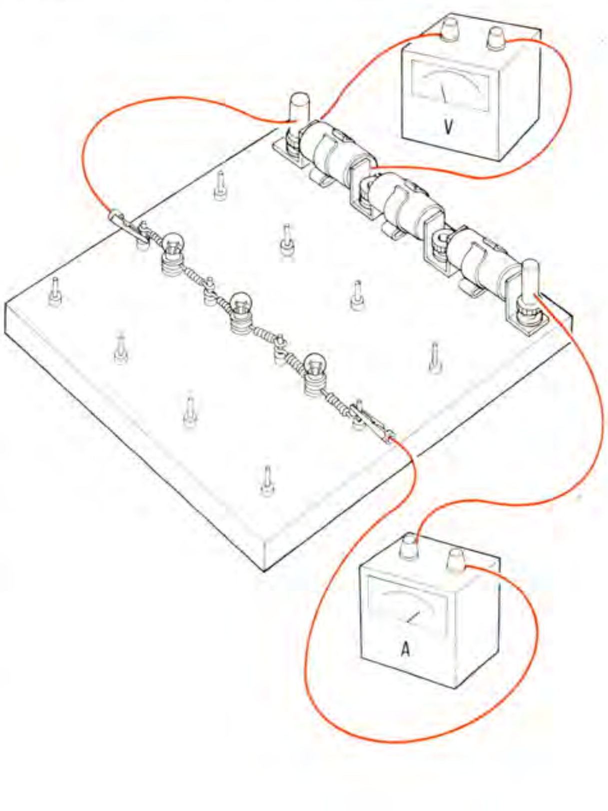
Plugs, wires, and earthing

The mains plug shown in the last section has another very important safety device in addition to its fuse. There are three wires and three prongs to it. That third 'prong' is 'earthed'. That means that there is a connection back to the power station through the deep wet earth itself. This prong is attached to the metal casing of the fire or whatever appliance it is. And that means that, whatever goes wrong inside the metal casing, you can never get a shock from it. The fuse will blow as the current travels through the earth back to the power station.

COUNTING THE CELLS: VOLTMETERS

89 Experiment
Using a voltmeter *(Optional now)*

Set up a circuit with three lamps and three cells in



series. Attach two leads to a 'voltmeter'. Now connect these two leads across (that is, *in parallel with*) first, one cell; then two cells; then three cells. *What are the three readings of the 'voltmeter'?*

How many cells are needed to light one lamp fully? Two lamps in series fully? Three lamps in series fully? What does the voltmeter tell you?

Is the voltmeter connected in series or in parallel? Is the ammeter connected in series or in parallel? What does the ammeter count?

COUNTING IN SCIENCE

In Experiment 89 you used an ammeter to count amperes and a voltmeter to count cells.

We often have to count when we make a measurement in science. Suppose I measure the length of a piece of paper with a centimetre scale. I just put the edge of the scale against the paper, move the scale till the top of the paper is at zero and then I see the bottom of the paper is at, say, 20.6 centimetres; so I say the length is 20.6 cm.

But I could do it like this: I could get something just 1 centimetre long and use it to make a mark 1 centimetre from the top of the paper. Then 1 centimetre again from that mark; and then 1 centimetre again, and so on, like a man pacing off a distance in paces. Then all I have to do is to *count* the number of times I mark off another centimetre on my way down the sheet. Of course, when I come to the end there is a bit left over and then I must mark 1 millimetre, and then one more, and so on, and count how many millimetres.

What does a clock really do when it keeps track of the time for you?

Your current balance, and the ammeter as well, seemed just to measure a steady force when there was a steady current; but if it were a current of water, you could certainly measure by counting how many cubic metres go past any point that you watch, in every second, in every hour.

Maybe there is something corresponding to that with ammeters.

IMPORTANT WORDS FOR ELECTRIC CIRCUITS

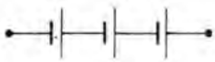
Circuit A complete ring of metal wire that runs from a cell or battery or a dynamo to a lamp or other apparatus and on back to the cell or battery. The ring may be square or round or any shape.

Cell Uses chemical changes to drive a current. The positive terminal is the button in the middle of one end of a flashlight cell; and the negative terminal is the metal base at the other end.

Symbol: 

Terminal The place on a lamp, cell, battery, dynamo, motor, . . . where you attach wires to form a complete circuit.

Battery Several cells in series, the positive terminal of one joined to the negative of the next.

Symbol: . (This is a quick way of writing  A car battery is usually six large cells in series. These cells use acid and lead and lead oxide as the chemicals; and they can be recharged by driving a current backwards through them. The positive terminal is marked in red.

Series When things are joined up in series, they are connected head to tail like several railway locomotives pulling one train. The current has to go through each in turn.

Parallel When things are joined in parallel, they are side by side (your feet, when you bicycle, work in parallel). The current divides and part goes through one branch, the rest through the other.

Connectors Wires, metal strips and suchlike that we use to join things together to make a circuit. When wires lead out to one side of a circuit, to connect some special thing, we sometimes call them 'leads'. Some leads have plugs at the ends to plug into special terminals. Or they may have 'crocodile clips' to fasten to other leads or terminals.

Electric current The name for something that happens in a circuit that contains a battery or a cell or a dynamo. We see heating in places, and perhaps some magnetic effects or some chemical effects, but we cannot see or hear anything moving.

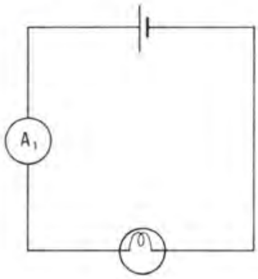
Conductor Any material that will carry current.

Insulator A non-conductor. Current will not go through it.

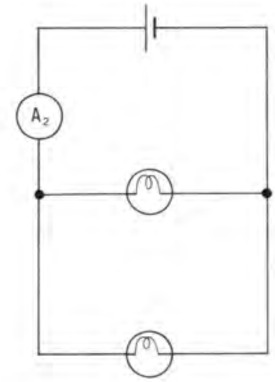
Insulation A covering of insulator to protect wires.

Progress questions

32. The lamps in circuits *(i)* and *(ii)* are all the same kind of lamp.



(i)

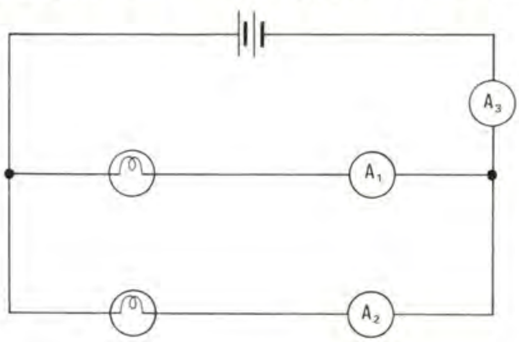


(ii)

a. In circuit *(ii)*, there are two 'paths' for the electric current to go through. We say the two lamps are in parallel. Does this make it easier or harder for current to flow compared with circuit *(i)*?

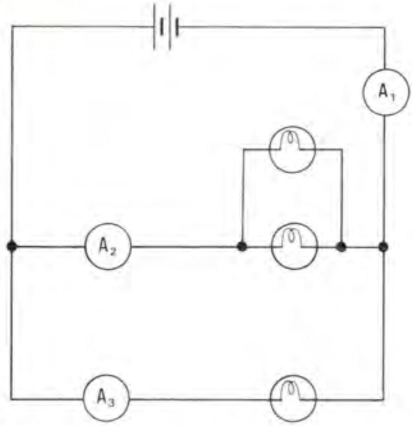
b. So which ammeter should have the higher reading, A_1 or A_2?

33. In the circuit shown, ammeter A_1 reads 0.2 ampere, and ammeter A_2 reads 0.2 ampere.



What do you think ammeter A_3 reads?

34. Ammeter A_2 reads 0.4 ampere. Ammeter A_3 reads 0.2 ampere. What do you think ammeter A_1 reads?



35. In a house the following things are all switched on at once:

Two lamps, each taking 0.5 ampere.
An electric fire, taking 5 amperes.
An electric cooker, using 20 amperes.

a. If there is an ammeter in the cable coming from the power station, what is its reading?

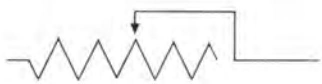
b. Suppose all the appliances are left switched on for the same length of time. Which is likely to cost the most?

Questions

36. Here are some electrical symbols:

(i)

(ii)



(iii)

What do you think they represent? Describe (in one sentence for each) something that you have used that could be represented by the symbols *(i)* and *(ii)*.

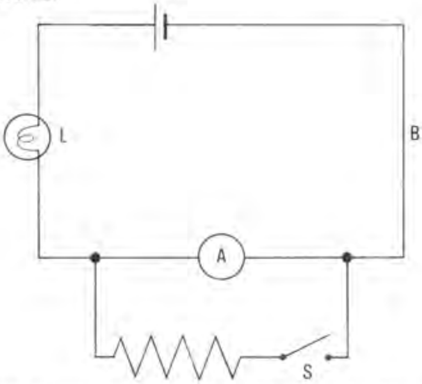
Note Sometimes you will see the symbols below instead of *(i)* and *(ii)*:

(i)

(ii)

37.

a. In the circuit shown below, the ammeter reads 1 A with the switch off and 0.9 A with the switch on (closed). Suggest what has happened to the other 0.1 A.



b. When a second ammeter is joined in the circuit at B, it does not noticeably change its reading whether the switch is off or on. Why not?

38. A boy connects a lamp to a cell and the lamp lights. He takes a similar lamp and connects that to the cell 'in series' with the first lamp.

a. What is meant by 'in series'?

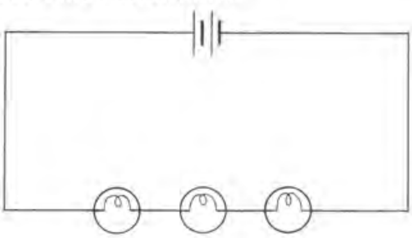
b. Is the first lamp brighter, as bright, or less bright now?

c. Which is the brighter – the first or the second lamp?

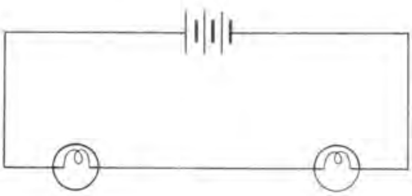
39. There are two ways in which you can light two lamps as brightly as one lamp. One way uses a single cell; the other way uses two cells.

Make two sketches showing how you could connect up the two circuits.

40. Here are two circuits.



(i)



(ii)

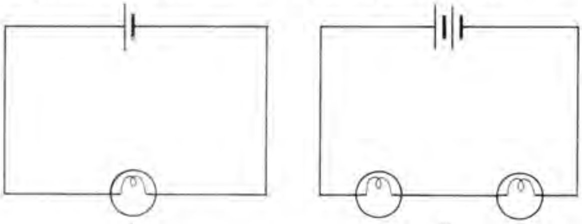
a. In each case, how does the brightness of the lamps compare with normal brightness?

b. It is possible to rearrange these lamps and cells so that all the lamps are lit normally. Can you think of two or three ways of doing this? Make sketches of the circuits you would use.

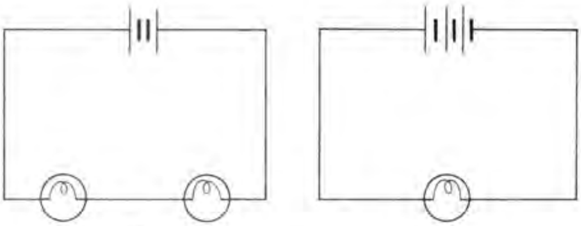
41.

a. The lamp in circuit *(i)* (below) is normally bright. What can you say about the brightness of the lamps in *(ii)*? In *(iii)*?

b. What is almost certain to happen if circuit *(iv)* is joined up? Would an ordinary wire fuse be able to prevent the disaster? Explain your answer.



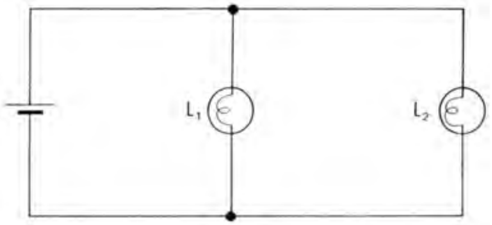
(i) (ii)



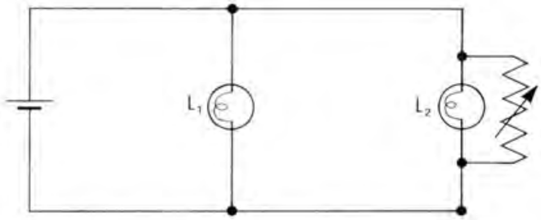
(iii) (iv)

42.

a. Draw the circuit *(i)* (next page), and include a 'dimmer' that would dim lamp L_2 without affecting lamp L_1.



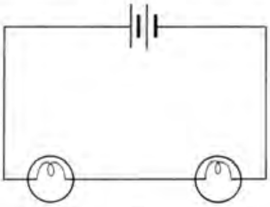
(i)



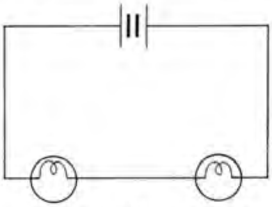
(ii)

b. In answer to part (a) of this question, Freddie Jones drew the circuit *(ii)*. Why is this a 'fool's circuit'? What are the bad results of using it?

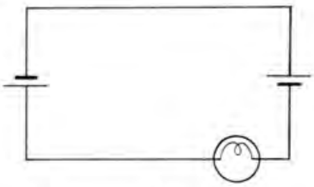
43. The figures show circuits containing similar lamps and similar cells. Say for each circuit whether the lamps are less than normally bright, normally bright, or more than normally bright, or if they are not lit up.



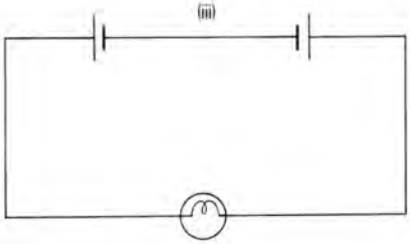
(i)



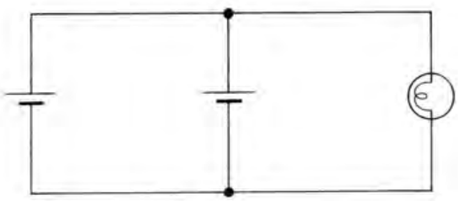
(ii)



(iii)

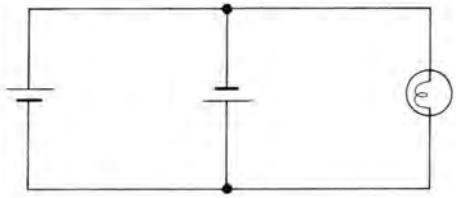


(iv)



(v)

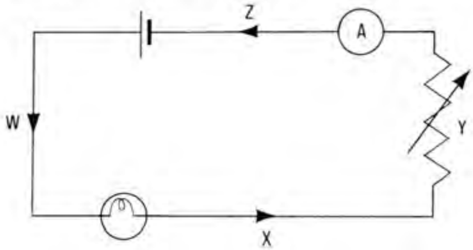
44. This sketch shows another 'fool's circuit' connected up by Freddie Jones. Why is this one a 'fool's circuit'? What would happen if you used it?



45. In the circuit diagram there are *four* arrow heads. Three of them are there to show the 'official' direction of the current. The fourth is there for quite a different purpose.

a. Which is the fourth arrow head, W, X, Y, or Z?

b. What is that fourth arrow head for?



CHAPTER 11

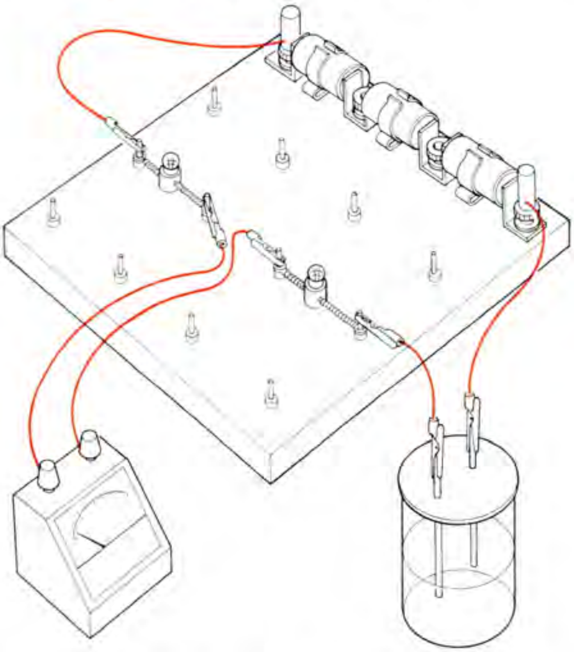
Electric currents

Currents in liquids, gases, and in a vacuum Streams of electrons

CURRENTS IN LIQUIDS

90 Experiment
Trying liquids

a. Send an electric current through some distilled water. Use the apparatus shown below.



b. Then add a little salt to the water. *What happens now?* You must look carefully at the two electrodes.
c. Wash out the beaker and try distilled water with a little diluted sulphuric acid added. *What happens?*
d. Wash out the beaker again and try tap water. Then try distilled water with some added sugar. Finally, try some paraffin in the beaker. *What happens in each case?*

What can you say about these liquids as conductors of electricity? Why is it important that the 'electrodes' in the beaker should not touch each other?
e. Now draw a circuit diagram for the experiments (a), (b), (c) and (d), marking the two connections to the electrodes X and Y.

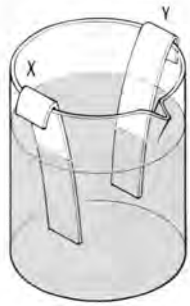
Add arrows to your diagram to show the 'official' direction in which 'positive' current flows. *Which way does it flow, according to our agreement,* IN THE LIQUID *(from X to Y or Y to X)?*

Does the fact that we use this agreement mean that it MUST *be true? (That is, does it mean that there must be real, positive bits of electricity (or perhaps not bits but a smooth stream of positive 'juice') flowing round the circuit?)*

91 Experiment
Copper plating

a. Wash out your beaker and put some blue solution of copper sulphate in it.

Replace your carbon electrodes (pencil leads) by two strips of thin copper sheet which you can clip to opposite sides of the beaker. They must not touch one another because that would make a short circuit.



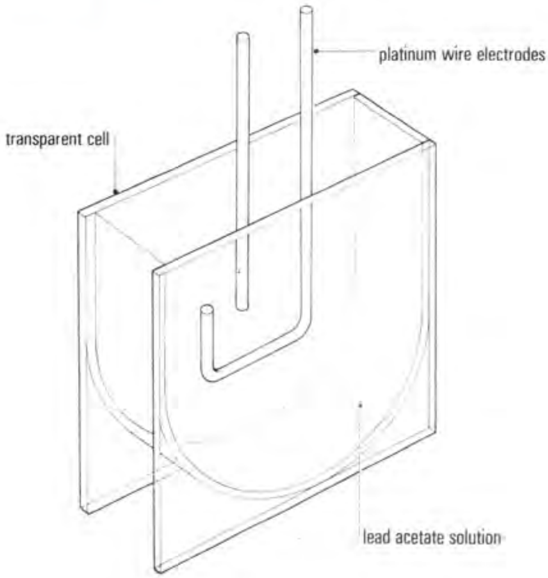
Run the current for three or four minutes. *What do the copper strips look like after that?*
b. Now replace the copper strips by the pencil leads and try the experiment again. *What happens this time? Can you now explain what you saw when you used the copper strip electrodes?*
c. Try copper-plating some other things. Your teacher will have some things for you to try.
d. Set up the experiment with the pencil leads and the copper sulphate solution again and run the current for a minute or two.

Look at the electrodes and note down which one has gained some copper.

Then interchange the ingoing and the outgoing wires. *What happens now?*

92 Demonstration
The lead tree

See the crystalline lead tree grow in the apparatus sketched below.



Electric carriers: ions

Let us forget about the 'official current direction' (+ coming out from the battery) and wonder what happens in the copper sulphate solution.

Maybe there are some things made of copper which carry the electric current across. Scientists believe that there are such 'charge carriers', and they give them an old Greek name for travellers, *ions*.

Here are some questions to help you to think about ions.

Progress questions

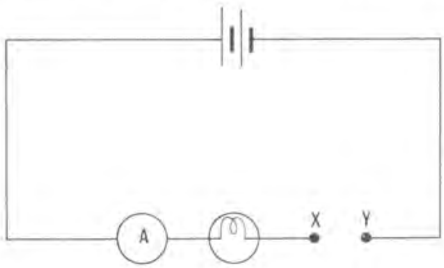
Electric currents

1. You may have tested whether electric current will go through different liquids.
a. Some liquids conduct electricity and some do not. Write down some which do carry current.
b. Did any changes happen in the liquids which conducted current? (Did they change colour, or fizz, or anything else?) Write down some of the things you noticed.
c. Does it make any difference:
(i) If you move the wires close together in the liquid?
(ii) If you make the liquid deeper?

2.
a. If you wanted to copper-plate a brass drawing-pin what liquid would you use?
b. Does it matter whether you connect the brass drawing-pin to the + side or the − side of the battery?
c. When the electricity moves, copper moves too. Perhaps the copper in the solution carries the electricity across? Does the copper go from + to − or from − to + ? What sort of charge must the copper have?

Question

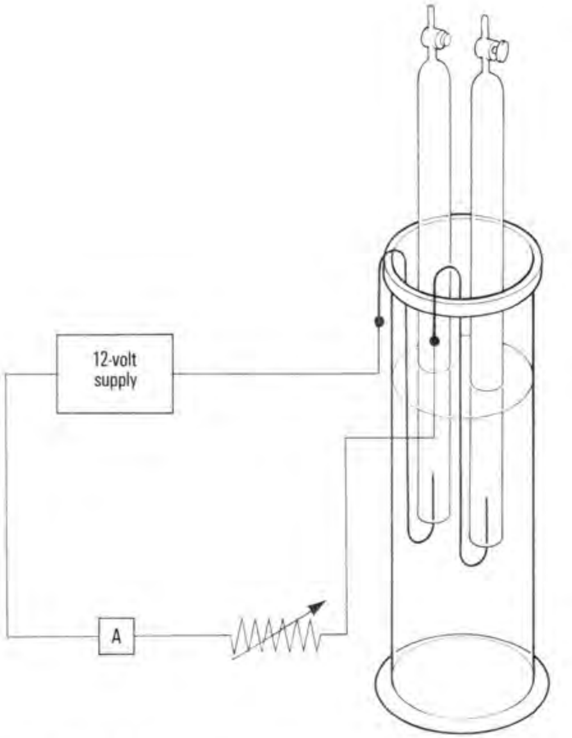
3.
a. What did you observe when you used the copper electrodes in copper sulphate solution? Was the copper deposited on the copper strip joined to X or to that joined to Y? Which way did the copper go through the solution? (X to Y, or Y to X?)



b. Suppose each copper atom carries electricity with it. Which way is that electricity going? In the official direction or the other direction? Then which sort of electricity (+ or −) is carried by the copper?

93 Demonstration
Ions in water

See the demonstration sketched (top right). The current is passed through water with a little sulphuric acid in it (acidulated water). *What happens? What gas comes off at the positive electrode? What gas comes off at the negative electrode?*



What does the result suggest about the way in which electricity is carried through the acidulated water? Which sort of electricity (positive or negative) is carried by the hydrogen? Which sort goes with the carriers that release the oxygen?

Travelling ions Maybe there are ions travelling both ways in these solutions at the same time – one lot carrying positive charges and the other carrying negative charges. This is an imaginative guess about the way electricity is carried through these solutions, and there is a lot of other evidence from chemistry to support it.

Notice that this tells us nothing at all about the way in which electricity is carried in copper wires and other metals.

So we shall go on using our 'official' direction for the current in a wire.

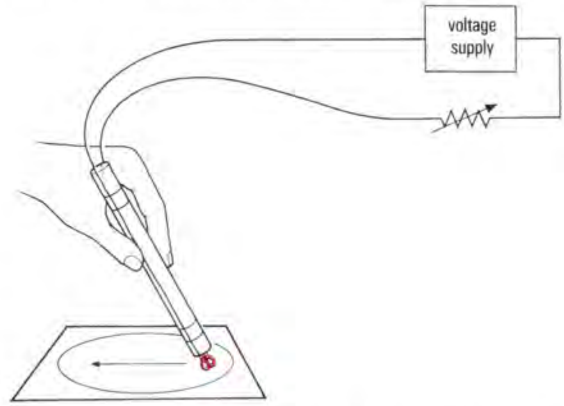
An investigation of electrolysis

94 Experiment
The magic pen

Chemists use 'indicators' which can show the motion of ions by changes in colour.

Here is a simple way of doing this.

a. Soak a filter-paper in the indicator. Place the wet paper on a sheet of metal (to act as a conducting back) and 'write' on the paper with a 'pen' made of two electrodes which are connected to a battery.



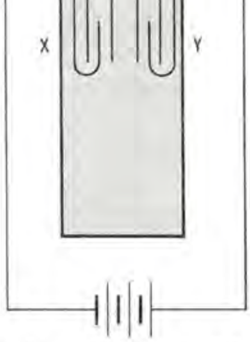
b. What happens if you reverse the connections to the battery?

c. Suppose now that you were to connect the pen to an 'alternating supply'. *Guess what this means. Guess what will happen.* Now connect the pen to an 'alternating supply'. *Were you right?*

....

Progress question

4. You have seen a demonstration in which electric current in slightly acid water produces *gases*. We caught gas bubbles given off at X and Y in the long tubes.



a. What were the two gases? Where have they come from?

b. Which one was there most of?

....

Question

5.

a. What name is given to the particles which we suppose carry the current in some solutions (for example, the copper in copper sulphate solution)?
b. What did the name mean in the original Greek?
c. Why do you think this new name was chosen, instead of just 'copper atoms' or 'copper molecules'?

Conductors and insulators Electric currents will flow through metals, some non-metals (for example, carbon) and some solutions (for example, salt water). These substances are good *conductors* of electricity.

Electric currents do not flow in rubber, glass, or paper, and do not seem to flow in such liquids as sugar solution or oil. *These are insulators.*

CURRENTS IN GASES

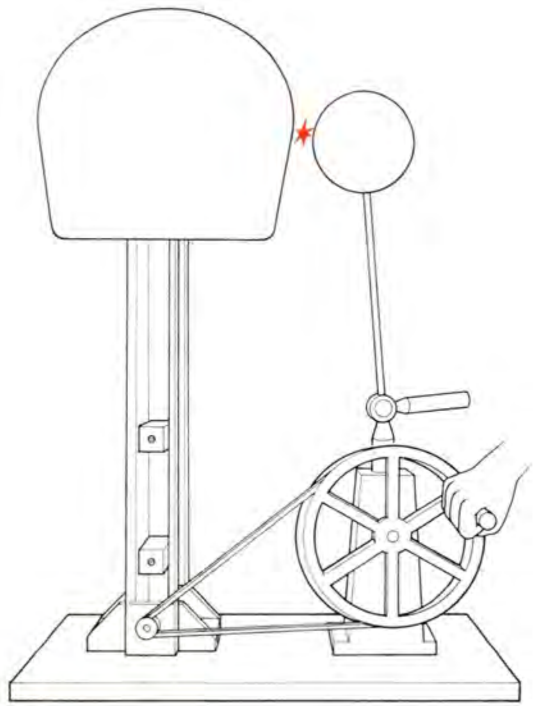
Can gases carry currents? Does the air carry currents? Suppose the air carried electric currents as easily as copper does. *What would happen to the electric currents you have been working with?* Air cannot carry current at all easily or it would spoil your experiments. *And what would happen to the batteries?* It looks as if air must be a non-conductor, a very good insulator.

Air and other gases are good insulators under ordinary conditions (e.g. room temperature) and with batteries or the electric mains as a source of electricity. But it is possible to make them conduct. For example, when a spark jumps from some supply of electricity to an object which is connected to the earth. When this happens a tiny current can be measured.

95 Demonstration
Making sparks *(Optional now)*

See a Van de Graaff generator making sparks through the air.

Under certain conditions, gases can become quite good conductors. For example, in neon lamps and fluorescent lamps or tubes.

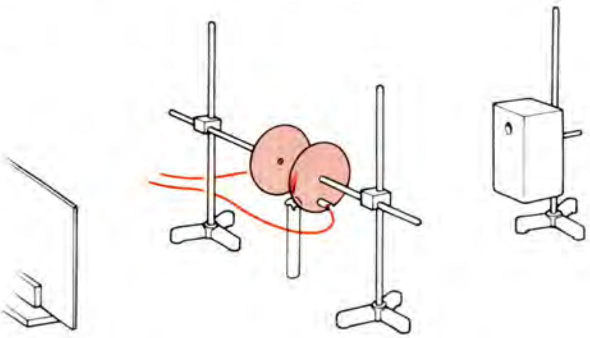


96 Demonstration
Luminous gases

See a neon or fluorescent lamp glowing near the Van de Graaff generator. (Or you may see sparks made by some charges stored up from a high-voltage d.c. supply.)

97 Demonstration
Ions in air: candle flame

See the demonstration with a candle flame. When the plates are charged, how many streams of particles can be seen in the shadow?



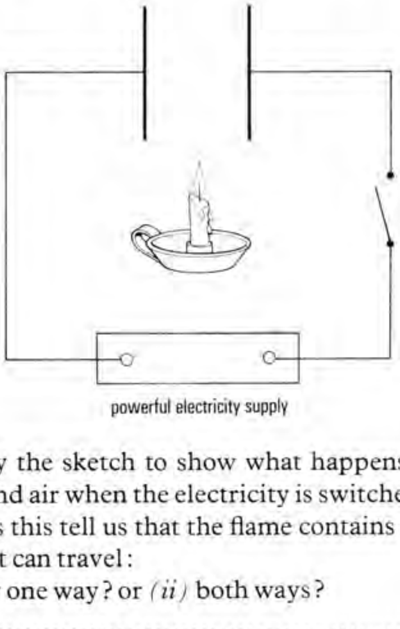
Make a sketch showing these streams in the shadow.

Progress questions

6. If you set up a circuit and leave just a tiny air gap – perhaps just a loose connection – the circuit will not work. Why is this?

7. We have found that electric currents can travel through metals and some liquids. Electricity can sometimes travel through air and other gases, but it is hard to make it do so.
a. What is lightning?
b. What is neon lighting?

8. Here is a sketch of an experiment with a candle flame. The streaks show the path of hot air rising above the flame. The electricity supply is switched off.



powerful electricity supply

a. Copy the sketch to show what happens to the flame and air when the electricity is switched on.
b. Does this tell us that the flame contains electricity that can travel:
(i) only one way? or *(ii)* both ways?

Questions

9.
a. How do you know, without doing any further experiments, that air must be a very good insulator? Mention two or three of the curious things that might happen if, by waving a wand, you could suddenly make the air around us become conducting.
b. 'Yes,' said one boy, 'that's all very well for air, but it doesn't prove that other gases are insulators.' How would you discover whether carbon dioxide is an insulator, given a cylinder of compressed carbon dioxide?

10. Describe experiments which show air (or some other gas) carrying electricity. (Sketch the apparatus. Then write a sentence or two saying what happened.)

11. Two types of electric lamp are in common use in houses and schools; the 'tungsten-filament' lamp, and the 'fluorescent' lamp. Find out what you can about these lamps by looking at some.

Also look at diagrams in books. (Do not trouble with any of the more advanced information given in the books.)

Now write six sentences comparing the two types of lamp, answering such questions as: Where does the light come from? Does the current go through solid, liquid, or gas? How do the colours of the light from a tungsten lamp compare with those of light from a fluorescent lamp? What about the temperature of the outside surface of each lamp when you feel it with your hand?

CURRENTS IN A VACUUM

Can electric current go through a vacuum? A TV picture tube has a vacuum inside it; yet electricity goes all the way along the tube to make a picture at the front. So it must be possible for an electric current to go through the vacuum. Something must carry the current. *Could it be ions?*

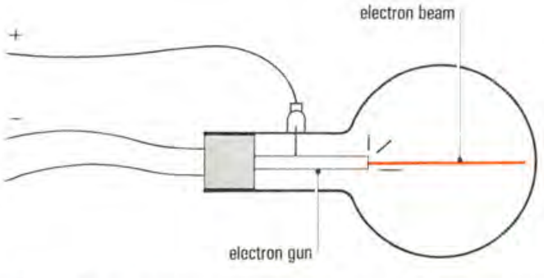
At the back of the TV tube there is an 'electron gun' which releases very small ions, called 'electrons'. We arrange to drive those electrons down the tube so fast that they go slam into the face of the tube inside, making it glow.

If there is a little gas left in the tube, the electrons go slam into one gas molecule after another and make them glow. Then the tube does not make a good picture.

98a Demonstration
Observations on an electron stream

You may see this glow appearing in a special tube. This tube has an 'electron gun' in it like the gun in a TV tube that releases electrons. The electrons come out from the gun at tremendous speed.

You can see the path the electrons take in the tube because there is a little gas left in it. This gas glows when the electrons hit it. If you look for a blue or greenish glow in the gas, you can see the



path of the electrons as they come shooting out from the gun.

98b Demonstration
Swinging the electron stream

The tube also has two small plates, just outside the gun muzzle, one on either side of the stream of electrons.

We can make the electrons in the stream swing over to one side by connecting the plates to a battery. The battery gives one plate a positive electric charge and the other a negative charge. Those charges pull and push the electrons sideways as they fly past.

What would happen if the battery were reversed? What do you think would happen if the two plates were connected to an alternating current supply?

98c Demonstration
Cathode ray oscilloscope *(Optional now)*

In a TV tube, we make a stream of electrons paint a picture for us on the inside of the face. In another kind of tube, much like a TV picture tube, we make a stream of electrons plot graphs for us, or show us the shape of sound waves or radio waves.

That tube is called a 'cathode ray tube', and it is used in 'cathode ray oscilloscopes'. In a cathode ray tube, electrons rush out in a horizontal stream from an 'electron gun' at the rear end. They travel to the front, where they make a bright, glowing spot. There is a pair of plates just outside the muzzle of the gun (like the little plates outside the gun in the demonstration tube). These plates are given large or small electric charges, depending on the thing we want to plot on the graph. There is also another pair of plates, just beyond the gun, arranged to swing the stream to and fro sideways.

The electrons obey orders instantly. They move the glowing spot to a new position far quicker than you can move a pencil in plotting a graph.

We can use a clever arrangement to swing the spot smoothly and regularly across from left to right again and again. This is called a time base. The spot moves steadily across. After this, the spot is switched off for the return journey.

At the same time, any electrical signal we may be interested in is fed to the other pair of plates so that the spot is moved up and down. The spot plots a graph of our signal (up) against time (along).

Progress questions

12. You may have seen a cathode ray oscilloscope (a laboratory TV) working.

a. What makes the bright spot on the cathode ray oscilloscope tube?

b. Describe what we made the spot do.

13. A water current can move a boat down a river or run a water mill. An air current can move a balloon or run a windmill. What can an electric current do? Give as many answers as you can.

Questions

14. You may have seen in the laboratory a clear glass apparatus with a very good vacuum inside. By means of a special device called an 'electron gun', electricity can be shot through the tube. Imagine a similar 'thought experiment' (that is, one you can do in your head) that might be done with: *(i)* a rifle firing bullets; and *(ii)* a powerful hose 'firing' water. Describe your experiment and say what you think you would see.

Note A 'thought experiment' is one which you do in your head, though it might be very difficult to make the apparatus. But you do not think it necessary to do it, because just thinking about it helps you to sort out your ideas.

15. After that 'thought experiment', a pupil said that the electricity from the gun could not consist of particles; it must be a stream of something like water, 'Because', he says, 'if there were particles we should see a flickering effect, a series of 'blips', where the electrons hit the glass. But we don't. We see a continuous light. Therefore the beam must be continuous'. What do you say to this?

Electric charges

Charges pull and push each other *What is it that moves the electron stream sideways? What does the battery provide?*

We have said that connecting the pair of plates just outside the gun to the battery puts electric charges on them. These push and pull the electron stream and move it.

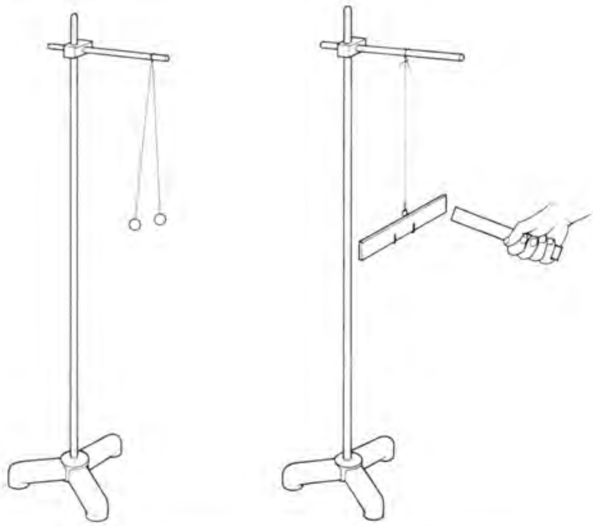
99 Demonstration
Charges pushing and pulling

See the demonstration sketched. The balloons have had charges put on them by rubbing.

100 Experiment
Electric charges

We can get electric charges by rubbing strips of insulating material. Take a pair of plastic strips – one is made of polythene, the other of cellulose acetate – and 'charge' them by rubbing them with a quick stroke on your coat sleeve.

Try the effect of bringing these strips near to small, light, conducting balls hung from fine nylon threads.



We think there is some electricity at rest on each strip. It is not moving as a current is. So we call it a charge. Find out as much as you can with the apparatus sketched above.

What can you say about the forces between the charged strips? How many sorts of charge are there? Can you keep a charge on a conductor? On an insulator?

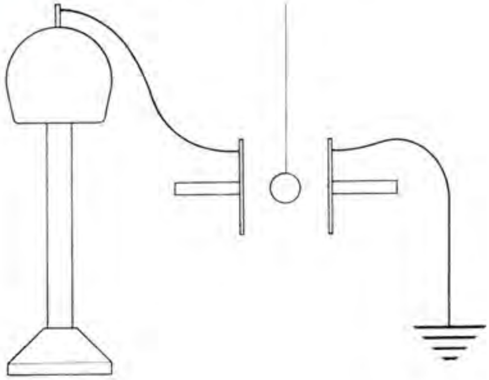
An object that is charged picks up little bits of paper. It pushes away things that are charged in the same way and attracts things that are charged oppositely. That is all we can tell you at present about these charges.

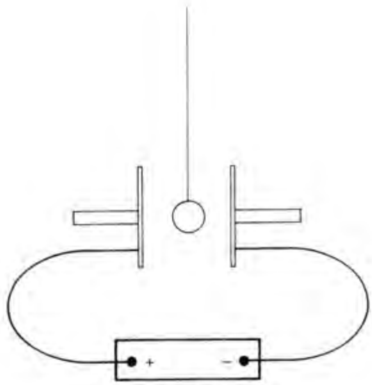
101 Demonstration
Charging machines *(Optional)*

If your school has a Van de Graaff generator, or other electrical machine, you will be able to see these charges exerting quite strong forces.

102 Demonstration
Comparing the motion of charges with currents

See the demonstration sketched.





powerful electricity supply

Charges and magnets You have earlier done some experiments with magnets which are similar to Experiment 100. *Do the magnets and the charged strips give the same or different results? In what way are they different? Can you get a magnet to repel a charged strip?*

Progress questions

16. When you rub certain things, they pull light objects, like scraps of paper, towards them. We say a thing that can do this is 'electrically charged'.
a. Make a list of the things you tried which became electrically charged.
b. *(Try this at home)* Warm some paper to make it very dry. Tear it up into tiny scraps. Then rub a plastic pen or comb on your jersey, and hold it near the scraps of paper. What happens?
c. Try rubbing other things on cloth or on your hair, or rubbing them together, and try them again near the scraps of paper. You can also try them near scraps of aluminium foil. Make notes of any interesting things you notice.

17. You are sure to have noticed a crackling or a sparking when you take off nylon clothes. When you comb your hair vigorously, on a dry day, have you noticed it 'standing on end'? What do you think is happening? Describe anything else of the same kind.

18. A boy rubs two balloons on his jersey and then hangs them up near one another. Do they move towards one another (attract) or do they push away from one another (repel)?

19. You have a polythene rod which has been rubbed, so it is electrically charged.
a. How could you show the rod is charged? (You have scraps of paper, or fine hair, or cotton.)
b. You also have a very light ball, hanging on a long, fine thread. You hold the charged polythene rod so that it touches the light ball. What happens?
c. The ball gets some of the 'polythene charge'. When you have two things, both charged with 'polythene charge', do they attract or repel?

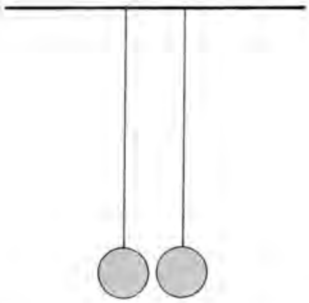
20. You are given two light balls, each hung on a thread. One is charged with 'polythene charge', and the other with 'acetate charge'.
a. What happens when you hold a charged acetate strip near the ball with the polythene charge?
b. What happens when you hold a charged polythene rod near the ball with the acetate charge?
c. Now copy this chart and fill it in. (Say whether they *repel* or *attract* or have *no effect*.)

	Ball with polythene charge	*Ball with acetate charge*
Charged polythene rod		
Charged acetate strip		
Charged plastic ruler		
Charged glass rod		

d. Did you find any charged material which *repels* both balls?

Note We believe that the charges we get from acetate and polythene are just like charges from a battery.

21. Two little balls are hung by thin threads as shown.



a. They are each touched with a wire from the + side of a high-voltage supply. What happens to them?
b. They are each touched to the − side of a high-voltage supply. What happens to them then?
c. One is touched to the + side and one to the − side. What happens now?

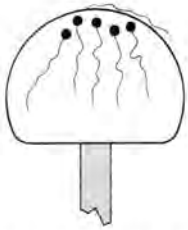
22. Copy the following and fill in the words 'attract' (pull together) or 'repel' (push apart).
a. Two + charges will . . . one another.
b. Two − charges will . . . one another.
c. A + charge will . . . a − charge.
d. Two charges of the same kind always . . . one another.
e. Two charges of opposite kinds always . . . one another.

23. Metals are conductors of electricity or charge. Even your hand is a conductor of electricity, although not a very good one.
a. So why can't you charge a metal rod in the same way as you charge a plastic comb?
b. How can we keep charge on a piece of metal?

24. When a Van de Graaff machine runs, its metal sphere becomes much more charged than if we just rubbed it.
a. What do you see when another conductor, such as a metal ball, is held on a stand and moved near to the charged sphere?
b. What is happening to the charge on the Van de Graaff sphere?
c. Where have you seen sparks produced by electricity from a battery or the mains?
d. Describe how we used the Van de Graaff machine to light up a lamp.

25. The big sphere on a Van de Graaff machine is charged. A small ball hangs on a silk or nylon thread so that it touches the sphere.
a. What do you see the little ball do?
b. Is it being repelled, or attracted, by the Van de Graaff sphere?
c. Suppose the sphere has a positive charge. What sort of charge has the little ball?

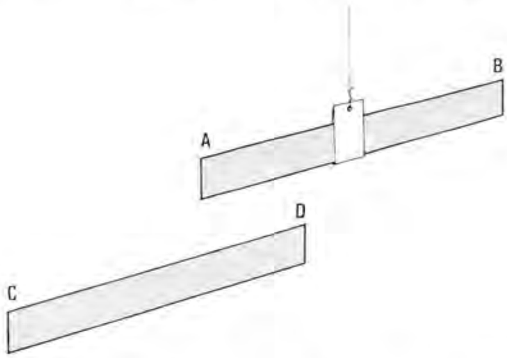
26. Some pieces of cotton thread are stuck to the Van de Graaff sphere with Plasticine. The sphere gets charged and the cotton threads get charged as well.



a. Will the sphere now attract or repel the threads?
b. What do you see the threads do?

Questions

27.
a. A strip of 'cellulose acetate', AB, is hung up (suspended) in a paper stirrup from a cotton or nylon thread. This acetate strip is then charged at



both ends by rubbing them with tissue-paper. A similar acetate strip, CD, is also charged at both ends. The end D is then brought close to the end B. Then C is brought close to A and then to B. Say what will happen in each case.
b. All the charges on AB and CD were produced on the same material in the same way. Are they like or unlike? What is the general rule about these charges which applies to these experiments?

Q.27 *continued*

c. A similar experiment is done with polythene strips EF and GH. Are the observations different from, or the same as before, when the acetate strips were used?

28.

a. Still using this apparatus, the experimenter brought up the charged polythene strip GH to the suspended and charged acetate strip AB. What did he observe this time? Would it make any difference if he brought the acetate strip near to the suspended charged polythene strip?

b. What is the rule about charges in this case?

c. What happens when a metal ruler, or a piece of wood, or your hand, is brought up to *(i)* the suspended charged acetate strip; *(ii)* the suspended polythene strip?

29.

a. You have done some experiments with small, very light plastic balls. What happens when one of the balls is hung up on a nylon thread and a charged acetate strip is brought near?

b. The ball, untouched by fingers, is rubbed with that acetate strip. The strip is then taken away and then brought back near to the ball again. What happens?

c. A charged polythene strip is brought near to that ball, which is still charged with the acetate kind of charge. What happens?

d. State the simple rule which covers all the cases.

30.

a. In the experiments with the very light plastic balls, it is important for the balls to be supported on an *insulating* thread, and to be coated with a *conducting* layer. Why is this?

b. You have investigated conductors and insulators using an electrical circuit which included a battery. What differences are there between what you found then and what you found when using the light plastic balls?

CHAPTER 12
More about forces

The pull of the Earth; the force of friction Force and pressure

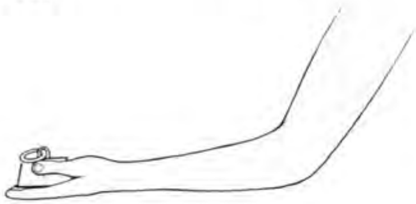
PULLS, PUSHES, AND MUSCLES

In earlier experiments, you experimented with forces. You stretched a spring, a rubber band, etc. You pulled a string taut in lifting a load with the help of a pulley. *How do you know that there is a pulling or pushing force in a stretched spring, a squashed spring, a taut string?*

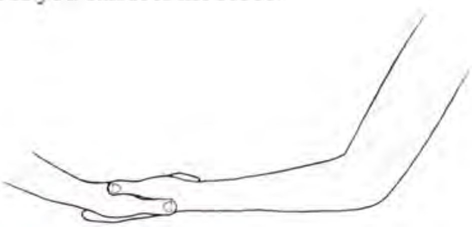
Your muscles, which enable you to exert the force, also tell you something about the size of the force – whether it is large or small. But your muscles do not tell you exactly how large or small.

103a Experiment
Your muscle force

Take an object – for example, a kilogram load – and hold it with your forearm outstretched horizontally. With your other hand you can feel what is happening to your arm's biceps muscle and tendons.

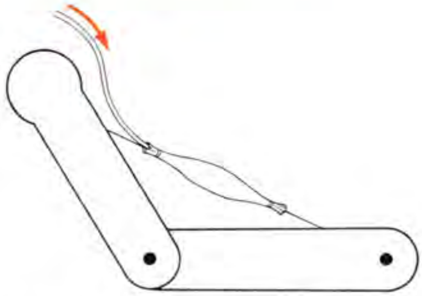


Let your partner take the object from you. Then ask him to press down on your hand with the same force as that exerted by the object. Now both of you can feel the force.



103b Demonstration
Model of arm and muscle

You may see a model of the human arm and its muscles. That shows *what is happening whilst you are holding the object up.*



In which direction did you exert the force on that object?

What would happen to that object if you were suddenly to stop exerting that force? The object would fall to the ground, going faster and faster until it hits the floor.

An object in Australia would do the same. *Describe the direction in which that object will fall.*

The Earth's pull

We guess from the way things fall that the Earth is pulling on our object and all other objects around us. We call that attractive force, the pull of the Earth on any object, the weight of that object. In physics that is all '*weight*' means, *the pull of the Earth on the object in question.*

We believe the Earth pulls every object towards it. *Do ordinary small objects pull each other? Does one cricket ball attract another ball placed on a level table? Have you ever seen them roll towards each other, pulled by attraction?*

You will never see that – and the reason is the Earth is so huge, compared with a cricket ball. The Earth has so much stuff in it that it pulls things towards it with very large forces which we can easily feel.

We believe that all objects, even small things like cricket balls, attract each other, and some advanced experiments show this is true. But the pull between the two cricket balls is so very small that we cannot detect it.

Question

1. There are two kinds of force that act on the kilogram load which you were holding at arm's length.
a. Name these forces and give the direction in which each kind pulls.
b. How do you know they are the same size?
c. What happens when you take your hand away?

Measuring force

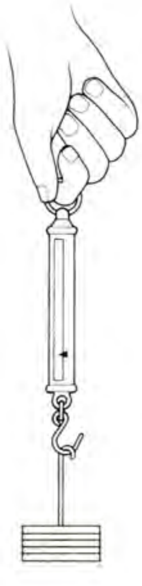
The kilogram you have been experimenting with could just as well be hung on a spring. The spring would stretch until it was pulling *upwards* just as strongly as the Earth was pulling *down* on the kilogram.

When you hang a larger load on a spring, the spring stretches more. This gives a tool for measuring forces. This force-measurer is called a spring balance. Spring balances used for measuring forces usually give the force in 'newtons'.

A newton is almost exactly one-tenth of the pull of the Earth on 1 kilogram.

104 Experiment
Making a spring balance marked in newtons

Take a spring balance which has a blank scale and several loads, each of 100 grams (= 0.1 kg). Each of these is pulled to the Earth with a force of almost 1 newton.



Hang one of these from the hook of the balance and make a mark at the point where the pointer is. That is the mark for a force of 1 newton.

Then hang two loads on the balance and make another mark labelled 2.

Then make marks for 3; then for 4; and so on as far as you can go.

When you have done this, find out how much the Earth pulls on a stone or some other object. Your result will be in newtons.

105 Demonstration
Weighing a brick

If, for example, a brick is hung from a spring balance, the force will be shown as 16 newtons.

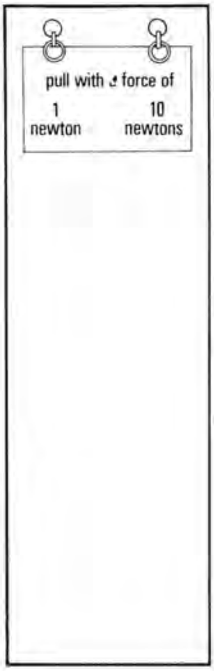
How many kilogram loads in that brick?

106 Experiment
Feeling for weight: forces box

The forces box allows you to feel the weight of (= pull of the Earth on) a kilogram and perhaps a pound.

One of its strings will be labelled '1 newton'. *What do you think there might be inside on the other end of that string?*

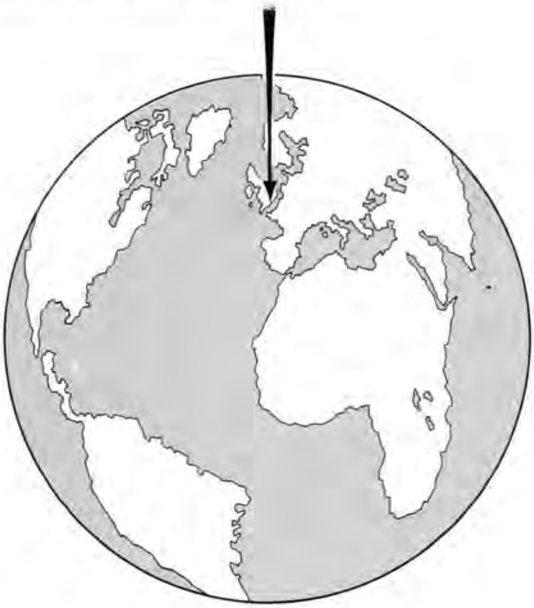
Use your spring balance and the forces box to find the pull of the Earth on 1 pound.



Progress questions

More about forces

2. The Earth is pulling downwards on you.
a. What would happen to you if the floor under you were suddenly removed?
b. When you are standing still, is the floor pushing you up with a force which is more, or less, or the same as the Earth's pull down?



3. When something falls down, we can say the Earth is pulling it. Below left is a drawing of our round Earth seen from one side. One arrow is drawn showing what we mean by 'down' in Britain. Copy or trace the drawing and put in some arrows showing what is meant by 'down' in several other parts of the world.

4. The Apollo crews who went to the Moon found that their *weight* on the Moon was less than on the Earth. Which of the following statements is the best reason for this?
a. The men were thinner by the time they reached the Moon.
b. There is no air on the Moon.
c. The Moon's gravity force is less than the Earth's gravity force.

5. If a lump of iron is marked *1 kilogram*, we know that the Earth's pull on it is about 10 newtons of force.
a. What is the Earth's pull in newtons on a 2-kilogram lump of iron? On a 100-kilogram lump of iron?
b. About how many kilograms are there in you? (A rough answer will do.)
(If you do not know how much in kilograms, it is useful to know that 8 stone is roughly 50 kg.)
c. Then what is the Earth's pull on you in newtons?

Questions

6.
a. What is another, shorter name for 'pull of the Earth'?
b. An object is hung from a spring balance which shows that its weight is 6.2 newtons. If the object and the spring balance are taken to the Moon, will the balance show the same reading, or more, or less?
c. Give a reason for your answer to (b).
d. *(A catch question)* The same object is used in a laboratory on Earth. It is placed on one pan of a beam balance (like the lever used earlier) and is balanced by loads in the other pan with a total weight of 6.2 newtons. The beam balance is taken to the Moon and the same object balanced again. What do you expect now? The same result as in (b), or what?
e. Give your reason for your answer to (d).

7. You are given a spring balance (with a pan attached) and a scale which is completely blank (unmarked). You are also given a single load whose weight is exactly one newton, and a large jar of small lead balls. Suppose you want to mark the scale in newtons at 0, 1, 2, 3, 4, and 5 newtons.
a. How would you do that? (Assume that the spring balance follows Hooke's Law, that is, the stretch of the spring increases in direction proportion to the load on the pan.)
b. Suppose the spring balance does not follow Hooke's Law. What would you do?

8. If you can find a copy, read H. G. Wells's short story, 'The Strange Case of Mr Pyecroft'. Then say why a better knowledge of physics would have made Mr Pyecroft more cautious in using the Indian formula.

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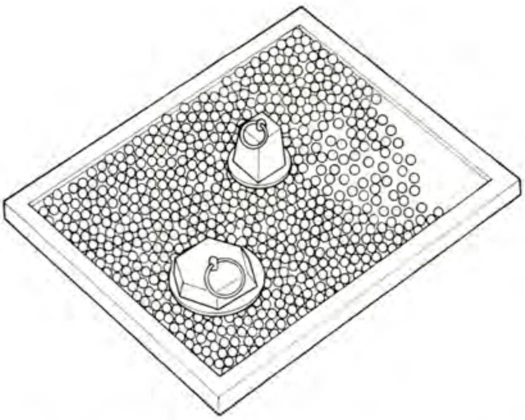
107 Experiment
Feeling for mass

If you would like to feel what a kilogram of stuff feels like without bothering to feel the pull of the Earth on it by lifting it up, you can push a kilogram along on a flat 'coasting table'. The tiny balls act as rollers and make the friction almost nothing.



Then you can feel how easily you can get that kilogram of stuff moving without your having to make an extra push against friction.

Mass

Even when there is no friction, you still have to push hard if you want to get a thing moving fast; or else you have to go on pushing for a long time.

That is really an important thing about all kinds of matter: to get it moving, or to make it move faster, you have to push it.

The more matter or stuff you have, the more difficult it is to get it moving. A scientist would say that the more mass you have, the more difficult it is to get it moving.

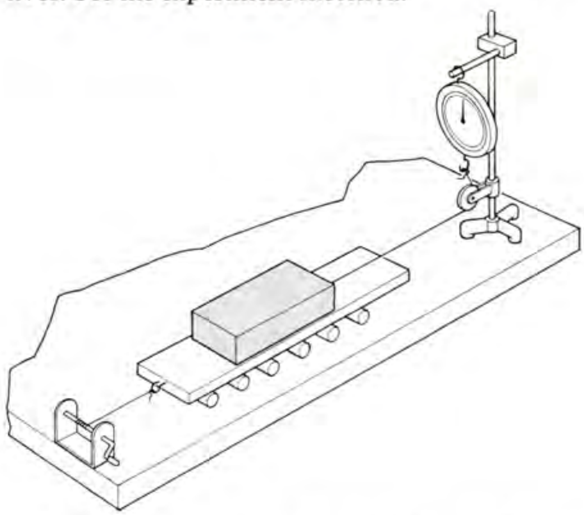
A kilogram has more mass than a gram. So you have to push harder to get the kilogram moving across the coasting table than to get a gram moving in the same way. The kilogram is more massive. And that is true wherever you are – on Earth, in a space-ship, or on the Moon.

You have used loads of 1 kilogram and also of 100 grams. Those loads had masses of those amounts. Grams and kilograms, pounds and tons, are names for units of mass.

FRICTION

108a Demonstration
Investigating friction*

Friction is a very important force in our everyday lives. See the experiment sketched.



A plank is towed along under a block of wood which rubs on it. The frictional (= dragging) force between them is measured with a spring balance. The plank is pulled steadily to the left, while the block is held at rest by the spring balance.

*If you watch several experiments with this apparatus, you will learn how the force of friction behaves. The full story is a very complicated one and microscopes and other instruments are needed to find out what happens when one surface rubs on another.

Progress questions

More about forces

9.
(Try this at home) Find a heavy book, or put something heavy on a tray, or in a box with a flat bottom. Stand it on a carpet, or a piece of cloth.

Push it with one finger, gently at first, then harder – and feel how there is a force pushing back. Now push harder. This force pushing back is called 'friction'.

a. Now try again, with your heavy thing, on many different surfaces – you could try a smooth floor, a table top, your bed.

Which surface made the biggest friction force?

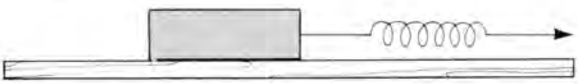
Which surface made the smallest?

Make a list of the surfaces you tried, with the one with the biggest friction force at the top, then the next biggest – and so on.

b. Look up the word 'friction' in a dictionary. Write down what it says.

c. Try putting your book or tray on two *round* pencils which will roll on a table. Does this make the friction force less or not?

10. A block of wood is resting on a table (or on a plank clamped to a table). The block is pulled by a spring. The spring has to give quite a lot of force to make the block move.



a. What do we call the force that *stops* the block moving?

b. Another block of wood is put on top of the first one. Does the bottom block need *the same*, *more*, or *less*, spring-force to move it?

Questions

11. *(This is a question to be answered when you have seen a friction demonstration)*

a. Explain why the frictional force between the block and the plank is equal to the reading of the spring balance.

b. Suppose the block is rectangular, 15 cm × 10 cm × 5 cm. Its weight is 5 newtons and it has a mass of 500 grams. When the plank is pulled at a small steady speed, the spring balance reads 3 newtons.

The plank is then pulled at twice that speed. Do you expect (from experiments you have seen) the spring balance to be reading 3 newtons? Or 6 newtons? Or 1.5 newtons? Or what?

The plank is pulled at the small, steady speed (as in (b)) and, this time, an extra load of 500 grams has been placed on the block, so that there are two blocks pressing down. What do you expect the spring balance to read now?

During these experiments the block had one of its largest faces on the plank. The block is turned so that a smaller face 15 cm × 5 cm is on the plank. What do you expect the balance to read?

c. The plank and block are at rest and the balance pointer is at zero. Then the pull on the plank is slowly increased until slipping occurs. Is the balance reading *just before* the block starts to slip 3 newtons, or more, or less?

108b Demonstration
Friction without motion

Friction force is an adjustable force, up to a point. Leave the plank at rest and place the block loosely on it. The spring balance reads 0. Now wind the plank very gently along.

The block is carried a little way along the plank, and that stretches the spring balance – a small force; then more force; and then still more, until the block starts slipping.

If friction were not adjustable like that, we should find it difficult to walk. And it would be difficult to speed up a car or bicycle.

Question

12. As you saw in the experiment described in Question 11c, there is a difference between the frictional force when two surfaces are not quite slipping and when they are already slipping. What does this fact explain about:

a. the skidding of tyres on a smooth road;

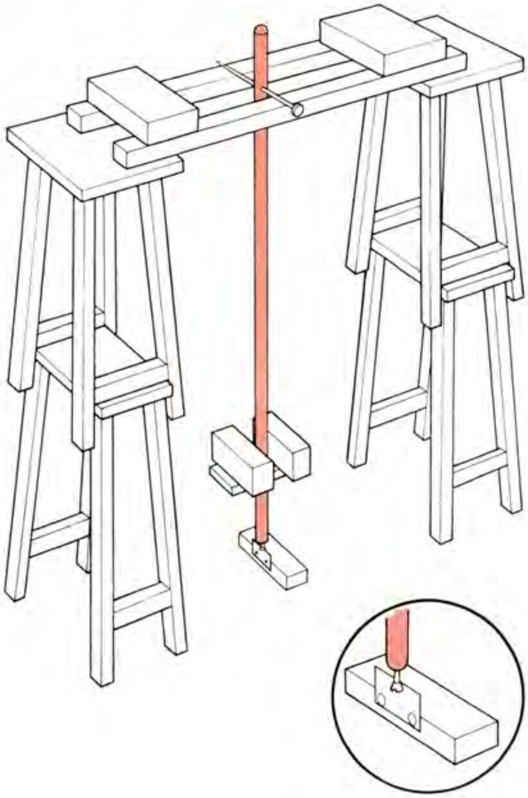
b. some instruments in an orchestra? (What scrapes across what?)

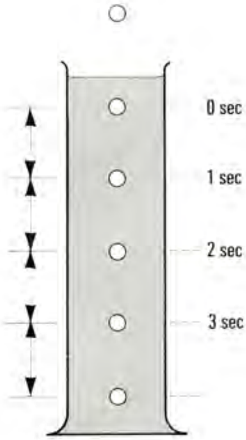
FLUID FRICTION

109a Experiment
Falling in water

Things which move through liquids are also dragged by frictional forces. Find out what you can about friction by letting some small beads fall through water in a tall glass jar.

You may wish to time the beads as they fall. The large broomstick pendulum is good for that. You can mark the jar with a felt-tipped pen.





Progress question

13. You have watched small plastic beads dropped into water.
a. They fall slower in water than in air. What do we call the force that makes them go slower?
b. Do the small beads fall faster or slower than the big ones? Which beads have the biggest force slowing them down?
c. The picture shows some marks put on a jar to show where one bead was after 1 second, 2 seconds, and 3 seconds. Was it getting faster, or slower, or going at a steady speed? How did you tell?

Question

Falling in water

14. A small object, like the beads you used, which is 'heavier' (denser) than water, is held just under the water in a deep pool and released.
a. From your experiment, imagine its motion and describe it in one or two sentences.

(If you can, sketch a rough graph of downward speed against distance fallen.)
b. Say what you think 'terminal velocity' means.
c. When a falling object reaches its terminal velocity, what is the *total* of all the upward and downward forces acting on it?

Air resistance

Objects falling through the air experience friction. The air opposes the motion with a dragging force.

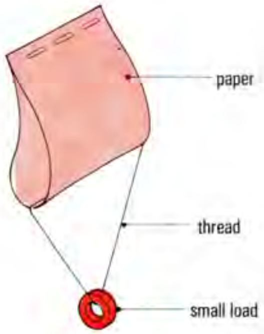
109b Experiment
Slow-motion raindrops

If you have some plastic beads which have been swelled by boiling water, try letting them fall in air. Their motion is slow enough for you to watch it carefully.

110 Home Experiment
Parachute and wing model

Make a toy parachute with a handkerchief or piece of tissue paper. Hang a table-tennis ball or a small stone on it and watch its motion as it falls.

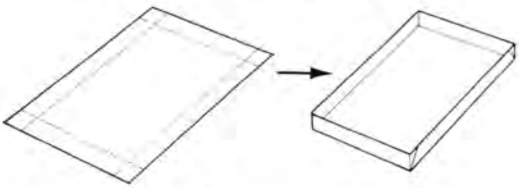
You can make a model of an aeroplane wing out of a sheet of paper and staples or Sellotape. Hang a tiny load below and watch as it falls.



111 Experiment

Air resistance

To find out more about air resistance, make a rectangular tray from a sheet of paper (about 20 cm × 15 cm) with sides bent up about 2 cm.



A plain sheet of paper flutters when allowed to fall, but these trays will fall more steadily. Find out all you can about the way such trays fall. You can have more paper and there are all sorts of things you can try.

Progress questions

15. When you drop a leaf and a stone at the same time, they do not reach the ground together. Which falls faster? What makes the other go slower?

16. You have done some experiments with paper trays. Write a sentence or two about what you saw:

a. when you dropped an empty tray;

b. when you put a coin (or some more paper) on it and then dropped it;

c. when you dropped it upside-down.

17. A parachutist is falling at a steady speed. Is the friction force of the air more than the Earth's pull on him, or is it less? Or is it the same?

Questions

Falling in air

(Answer these questions when you have done some experiments with paper trays falling in air)

18.

a. Describe *two* experiments you did which led to useful or interesting knowledge; and say what this was. (Write two or three sentences for each experiment and one for each conclusion.)

b. What sensible scientific experiments might be done with the paper trays, using each of the following pieces of apparatus?

(i) A smoke generator.

(ii) Several pennies.

(iii) A punch that makes holes in paper.

(iv) An electric fan.

19. Try the following experiment. Get a 2p coin. Cut a small disc of stiff paper the same size as the coin.

Hold the coin flat between the thumb and the fingers of one hand. Hold the paper disc in the same way with the *other* hand. Let both drop at the same time.

a. Which reaches the floor first? What makes the difference?

b. Now put the paper disc on top of the penny and drop both together. What happens?

c. A friend who has done the same experiment says it shows that, if air resistance is removed, paper falls as fast as pennies. The experiment certainly does not disagree with this conclusion. But would you go all the way with him in saying that 'it shows that . . .'?

If not, write a sentence or two saying why not.

What would be a better experiment to show the same thing? You may have seen the film of this experiment being carried out on the Moon!

20.

a. A man with a parachute is heavier than a man without one. Yet he falls more slowly with his parachute open. Explain why.

b. An aircraft dives vertically with its engines off. It reaches a constant speed of 600 kilometres per hour. What two forces are acting on it when it

Q.20 *continued*

reaches that terminal velocity? What can you say about these two forces?

c. The aircraft is still diving when the pilot switches on the engines (a 'power dive'). What happens now? Assume the plane does not hit the ground or break in pieces.

21. *(For class discussion)* 'An earwig, a cat, a man, and an elephant all fall over a high cliff. The earwig walks away unharmed, the cat breaks a leg, the man is killed, and the elephant is smashed.' Why is there this difference?

A newton

22. A pupil says that it is easy to remember how big a newton is—it's the pull of the Earth on an apple. Is this a sensible estimate?

Force and pressure

You have already seen that the atmosphere exerts a pressure. That pressure can collapse an empty can (that is a can from which most of the air has been pumped) and it can support a column of mercury just over $\frac{3}{4}$ metre high (76 cm). That illustrates one way in which pressures are quoted – in metres (or centimetres) of mercury.

The atmosphere presses in all directions on everything on the surface of the Earth. To find out how large these forces are we could weigh a column of mercury which was 76 cm long. But how wide a column should we take? Take a square centimetre – and then we shall know the force exerted by the atmosphere on each square centimetre of the Earth's surface.

You already know that a cubic centimetre of mercury weighs 13.6 gram. A mercury column 76 cm long and 1 square centimetre in area would have a volume of 76 cubic centimetres. That is a load of 76×13.6 gram (1034 g) or about 1 kg.

The pull of the Earth on that load will be 1×10 newtons, or 10 N.

So the force exerted by the atmosphere on each square centimetre of the Earth's surface is about 10 newtons. *What is the force on a square metre?*

Some pressures:

	cm of mercury	newton per sq m	newton per sq cm	p.s.i.*
The atmosphere	76		10	15
A car tyre (above zero)	200	2.7×10^5	27	40
(above atmospheric pressure)	124	1.7×10^5	17	25
Blood pressure maximum	120	1.6×10^5	16	24
minimum	80	1.05×10^5	10.5	16

*The p.s.i. (pounds per square inch) is an old unit often still used in quoting tyre pressures.

Questions

23.

a. Take a drawing pin between your fingers by the pointed end and press the head of the pin against the palm of your other hand with, say, a force of 2 newtons. Suppose now you reverse the pin and push the sharp end against your palm with the same force, 2 newtons. Not the same thing at all! Why not?

b. Take a magnifying glass and look at the pin. You decide that the area of the point is 1 square millimetre (rather blunt!), while the area of the head is 1 square centimetre.

Then, when the head is pressed against your palm, $\text{pressure} = \frac{\text{force}}{\text{area}} = \frac{2 \text{ newtons}}{1 \text{ sq cm}} = 2$ newtons per square centimetre. What is the pressure on your palm if you press the pointed end of the pin against it? (Remember that 1 square millimetre is $\frac{1}{100}$ square centimetre.)

24. It is said that a girl wearing shoes with very small heels (that is heels having a small area of contact with the ground) makes a bigger dent in a polished wooden floor than an elephant would. Why is this? After all, it would take very many girls to make the load of an elephant.

25. *A home experiment*

a. Weigh yourself, or make a good guess at your weight in newtons, and write it down.

b. Take your shoes off and stand on a sheet of paper. Draw round your feet. Make the best estimate you can of the area of each foot in square centimetres.

c. Now work out the pressure of your feet on the floor in newtons per square centimetre and in newtons per square metre.

d. What is the pressure when you stand on one leg?

26. All of us have to withstand the pressure of the atmosphere, which is about 10^5 (= 100 000) newtons per square metre. Measure the area of your chest and calculate the force on it. How is it that you not only bear this force, but do not even feel it?

CHAPTER 13

Using energy

More about jobs and energy shifts: work Machines which multiply forces

Useful jobs

Man has to use very big forces for some jobs; for example, in hammering rivets to hold bridges together, in launching an astronaut's rocket, in supporting the roof of a tunnel under a river, in pulling a heavy train.

Sometimes these forces can be made quite easily. Think of the force you can make with nutcrackers, or when you put something into a vice and tighten it up. The nutcrackers and the vice are force multipliers. You *can* 'multiply' forces, get a large force from a small one, without having to use fuel.

Could you make a machine that would multiply energy without needing fuel? Such a machine would put out more energy than you put in. *Is that possible?* Suppose you had such a machine, how could you make millions of pounds in building electric power stations?

Some of these forces are useful to us just because they stay where they are. When you clamp up some pieces of wood in a vice while the glue is setting, you don't have to go on paying money or burning fuel to keep the forces going.

But there are other jobs which forces do for which it is necessary to pay, and go on paying, because they go on using fuel. To haul a big load up to the top of a high building, we must provide fuel for an engine, or we must provide food for a man to do the job.

There are many such jobs which need fuel. In each case whatever applies the force has *to move along*. *It always costs fuel when a force moves something along*. And fuel costs money. When we use fuel we draw on a store of energy that will do useful jobs for us.

....

Progress question

Using energy

1. If you were on a desert island, you might want to take a plank or slab of rock that you found on the beach to a higher place (to start building a hut for yourself). You would have to do that job by using your own muscle forces.

But in your own country there are many machines which could do this job for you.

a. Make a list of the different ways in which the job of getting a load up a hill could be done.

b. When your load is at the top of the hill, it has extra uphill energy. If you lifted it yourself, this uphill energy came from your own food energy. Say where the energy must come from in each of the machines on your list.

....

NAMES FOR FORMS OF ENERGY

In Chapter 8 we talked about useful jobs that cannot be done without fuel or food. When those jobs are done, something we call *energy* shifts from one form to another. Fuel and food are stores of chemical energy. We invented simple names for other forms. Here is a list:

		Scientific name (to be used later)
UPHILL ENERGY	The energy an object gains when it is lifted higher up against gravity	Gravitational potential energy (P.E.)
MOTION ENERGY	The energy an object has because it is moving	Kinetic energy (K.E.)
SPIN ENERGY	The motion energy of spinning things	Rotational kinetic energy
SPRINGS ENERGY	Energy stored in a wound-up spring, or in a stretched spring or wire	Strain energy or potential energy (P.E.)
CHEMICAL ENERGY	Energy stored in explosives or stored in fuels and foods, together with the oxygen needed for their burning	Chemical energy or molecular energy
ELECTRICAL ENERGY	Stored in the space around electric charges, or carried with electric current	Electromagnetic energy

NUCLEAR ('ATOMIC') ENERGY	Stored deep inside every atom, released when the unstable radioactive atoms 'explode'	Nuclear energy
LIGHT ENERGY	Of light, infra-red and ultra-violet; also X-rays and radio waves	Radiation energy
HEAT	The form of energy that makes things warmer, melts solids, and boils liquids	Heat

We believe these are all different shapes or forms of the same thing.

Shifting energy

We don't manufacture energy and we don't believe that it ever disappears completely. But we do shift energy from one form to another form. In that way, energy is rather like money.

A wise country doesn't manufacture money – more coins every day – but there are very important shifts of money from one person to another, or from a person to a shop and so on. To get jobs done you have to transfer some cash FROM yourself TO someone else.

Similarly, to get these useful jobs done you have to transfer some energy FROM some energy store in a fuel TO some other form. Fuel can also be used to drive something and make it go faster.

You can't make a thing move faster without pushing or pulling it along; and when you have pushed it some distance, some energy has been transferred FROM the fuel TO motion energy.

WORK
Work is energy transfer

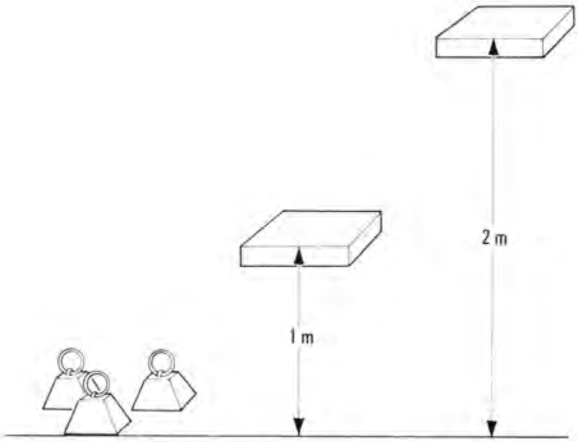
112 Demonstration
Adding up the bill for energy

Suppose we want to lift 3 kilograms from the floor to a bookshelf 2 metres up. We can't make that happen by wishing.

We have to draw on some chemical energy in our muscles. And that energy is transferred to uphill energy gained by the raised 3 kilograms.

We can do that in one move. Or we can do it in stages like this:

Stage 1 Raise 1 kilogram 1 metre high.
Stage 2 Raise that 1 kilogram to the shelf 2 metres high.



Stages 3 & 4 Raise the next 1 kilogram in two stages like that.
Stages 5 & 6 Raise the last 1 kilogram in two stages like that.

In that way we have to do six jobs, each one raising 1 kilogram through 1 metre. You know that the Earth pulls with 1 newton on each 100 grams. So each of those six jobs is done by a force of 10 newtons pulling up 1 metre. We call each of these energy-transferring jobs: 10 newtons multiplied by 1 metre, or 10 newton · metres.

Doing the job in six stages like that costs just the same in food or fuel as doing the whole job in one move. (Experiments have been made to test that and it is true.)

The total transfer of energy is 6 lots of 10 newton · metres, or 60 newton · metres.

You can get the same answer for the job done in one move: 30 newtons hauled up 2 metres = 60 newton · metres.

That experiment gave you the shift of energy FROM the chemical store in your muscles TO uphill energy of the 3-kilogram load. It was 60 newton · metres.

You have already seen that it takes a force of 10 newtons to lift 1 kilogram against the pull of the Earth. *If you lift 1 kilogram through a vertical height of 1 metre against the pull of the Earth on it, how many newton · metres of energy do you transfer FROM your chemical store TO 'uphill energy'?*

You calculated that shift of energy from one form to another by multiplying the force you exerted by the *distance moved.* That is what we shall call 'work'.

Work measures the energy transferred (= shifted) FROM one form TO another as a useful job is done. Since we measure forces in newtons and distance in metres, it is sensible to measure the work in newton · metres.

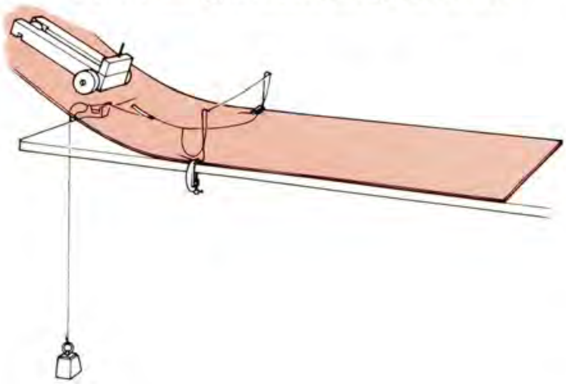
Examples of calculating work When you raise two kilograms, using a force of 20 newtons through a distance of three metres, the transfer of energy from chemical energy in your muscles to uphill energy is (20 newtons) × (3 metres), or 60 newton · metres.

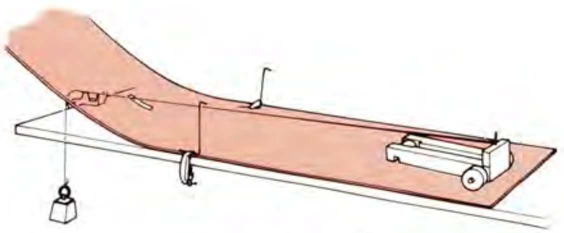
What happens if you now let the 2 kilograms fall back to the floor? The pull of the Earth on them is 20 newtons, the distance they can fall is 3 metres, and so we say that the transfer of energy FROM uphill energy TO motion energy is (20 newtons) × (3 metres), or 60 newton · metres.

Energy changes

113 Demonstration
Uphill energy and motion energy

You can see or imagine this happening if you let a trolley run down a smooth, curved slope, so that instead of crashing, it rushes along the table.



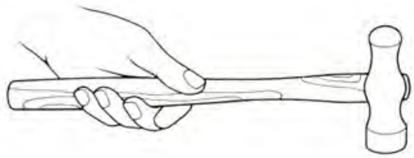


If, at that moment, the trolley snatches up a string which runs over a pulley to a load, the motion energy of the trolley will be transferred to uphill energy of the load as the trolley stops.

114 Experiment
Energy change in a crash

What happens to the energy if the moving trolley does crash into an obstacle at the bottom of the slope?

To find out, try hammering a small piece of lead. Feel the lead first to test its temperature. Feel it again after several strong hammer blows in quick succession.



The chain of energy transfer here must be FROM chemical energy in your muscles TO uphill energy of the hammer; then TO motion energy of the falling hammer; finally TO heat.

Progress questions

Energy changes

2. Below is a list of energy transfers, with spaces for examples of them. Copy this out and fill in as many spaces as you can.

Energy transfer		*Example*
Uphill energy	→ motion energy	A stone falls off the top of a cliff
Springs energy	→ motion energy	
Food energy (chemical)	→ motion energy	
Coal energy (chemical)	→ motion energy	
Electrical energy	→ motion energy	
Motion energy	→ uphill energy	
Motion energy	→ heat	
Electrical energy	→ heat	
Uphill energy	→ springs energy	
Gunpowder energy (chemical)	→ motion energy	

3. You have seen some experiments which showed one kind of energy transferring to another kind. Choose one experiment that you found interesting, and describe how it was done and what you observed.

(Here are some headings to remind you, but you can choose a different one if you like.)

Motion energy transferring to uphill energy.
Motion energy → heat energy
Electrical energy → uphill energy
Height energy → springs energy
Heat energy → electrical energy

4. Here is a list of things happening in which there are energy transfers. Copy the list and fill in as many blanks as you can.

Example	*Energy transfer*
You kick a ball	Food energy → motion energy
A candle burns	.... → ....
A bicycle dynamo lights a bicycle lamp	.... → ....
A vacuum-cleaner motor turns	.... → ....
An archer pulls out the string of his bow	.... → ....
A petrol engine makes a car go	.... → ....
A brake slows down a bicycle (or a car)	.... → ....

5. Here are some jobs, and the energy changes are partly written for you. Copy the statements about the energy changes and fill in the blanks.

a. Methylated spirits burn in a steam engine which raises a load.

FROM . . . energy in the methylated spirits
TO . . . energy in the tank and water
TO . . . energy in the steam
TO . . . energy in the pistons and wheels
TO . . . energy of the load.

b. Water falls down a hillside and drives a turbine, which drives a generator, which provides electricity for an electric fire in your room.

FROM . . . energy in the water
TO . . . energy in the water
TO . . . energy in the turbine and generator
TO . . . energy in the power transmission lines and wires
TO . . . energy in the electric fire and air.

6. Copy out the following jobs, and underneath write the energy changes, using a pattern like this:

'FROM . . . energy in the . . . TO . . . energy in the . . . , etc.

Read this example which tells you the energy changes in Job A.

Job A A boy blows up a balloon, then lets it go. The energy changes are:

FROM chemical energy ('breakfast energy') in the boy
TO springs energy in the balloon
TO motion energy of the balloon and air jet

Then TO heat energy in the air and balloon.

Now write a story of the changes, like the story for Job A, for each of the Jobs B, C, D, and E.

Job B A battery lights a lamp.

Job C A brick drops on a balloon and the balloon escapes and bounces up into the air.

Job D A pendulum swings to and fro.

Job E A falling load pulls a cord, which spins a dynamo, which lights a lamp.

7. Here are some more jobs. For each job, give the chain of energy transfers. Here is one example.

Job: A boy throws a stone into the air, which then falls to the ground.

Chain: Food energy → motion energy → height energy → motion energy → heat.

Write out energy chains like that for the following jobs. Copy each one, then below it write the energy chain.

a. A person winds up a watch; the watch keeps time for a few days, then slows to a stop.

b. An oil-fired power station makes an electric train run, the brakes are put on, and the train stops.

c. A father gives a child on a swing one hard push, then leaves it to swing and slow down and stop.

d. On Guy Fawkes' Day a rocket goes up, explodes, and fragments come down.

Work

***8.** How much energy transfer (work) is there when:

a. 1 kg is lifted through a height of 5 metres?

b. 3 kg is lifted to a height of 5 metres?

c. 3 kg is lifted to a height of 10 metres?

**Notes*

a. Reminder: in lifting a 1-kilogram block, we use a force of 10 newtons.

b. We measure energy transfer in newton · metres. For example, if a force of 5 newtons rises 3 metres, the energy transfer is $5 \times 3 = 15$ newton · metres.

9. The pull of the Earth on a small bag of cement is 20 newtons. The bag is lifted up through 5 metres.
a. What sort of energy transfer (work) is there?
b. How much energy transfer (in newton · metres) is there when the bag is lifted through 1 metre?
c. How much energy transfer is there when the bag is lifted through all 5 metres?
d. The bag is dropped (by accident!) What *sort* of energy transfer is there? *How much* energy transfer is there?

Questions

Energy changes

10. You lift a $\frac{1}{2}$-kilogram book from the floor on to a shelf 2 metres above. By accident, the book falls to the floor again.

Copy the following statement describing the energy changes that take place. Fill in each blank by choosing one of the following names: chemical energy, heat, newtons, newton · metres, motion energy, uphill energy. (Some of these names are used twice.)

> When I lift the book on to the shelf I exert a force of 5 . . . and I transfer 10 . . . of . . . into . . . . When the book falls down again, the energy is changed FROM . . . TO. . . . After the book has hit the ground, the . . . has been changed TO . . . .

11. A boy drags a 20-kilogram sack of potatoes across the kitchen floor. To do this, he pulls with a horizontal force of 80 newtons. He moves the sack 3 metres.
a. How much energy does he transfer into heat?
b. Where does he get the energy from?
c. A man then lifts this same sack on to a shelf 1.5 metres above the floor. How much energy does he transfer when he lifts the sack? (Remember that it takes an upward force of 10 newtons to lift 1 kg.)
d. How is it that the man needs to transfer more energy in moving the sack 1.5 metres than the boy does in moving it 3 metres?

12. It is quicker to answer Question 11 by asking 'How much *work* when the man lifts the 20-kg sack through a height of 1.5 metres?'
a. Suppose the man lifts 25 of these 20-kg sacks up a staircase 3 metres high, how much is the work altogether?
b. A strong horse is supposed to be able to transfer about 750 newton · metres each second from food energy to useful mechanical energy. That is the fastest rate it can keep up for a short time. In fact, this is the rate of transferring energy that we call '1 horse-power' (1 H. P.).

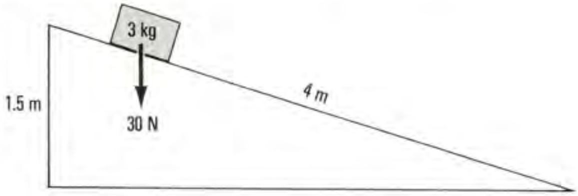
Suppose such a horse is used to lift the sacks.
(i) How long will it take to lift 20 sacks?
(ii) Give the reason for your answer.

(You may assume that the horse operates some suitable piece of 'sack-lifting' machinery, such as a set of pulleys, and that no energy is wasted in the machinery. In fact, energy would certainly be wasted in using it.)
c. Nowadays the man would use a 'fork-lift truck' to do the job. He does not get so tired, and he might save something on food, but he has to pay for something else – what else? (That is, as well as buying the truck itself.)

Work

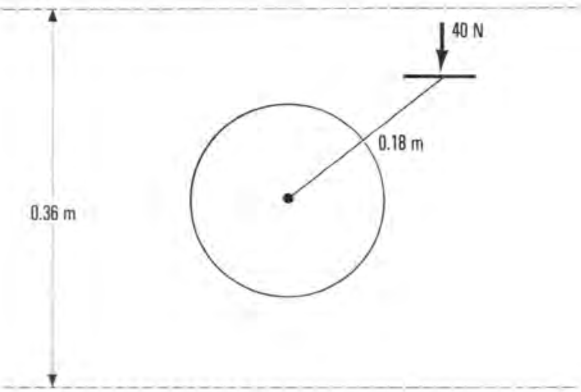
13. Energy transfer, or work, is calculated from (force) × (distance moved). But you must be careful about 'distance moved'.

Here are two problems, each with two answers, one right and one wrong. Show that you know which 'distance moved' to choose by writing down the *right* answer to (a) below. Is it 120 newton · metres or 45 newton · metres? Say why it is right and the other answer wrong. Then do the same for (b).
a. A boy pushes a 3-kg block to the top of a very smooth slope 1.5 metres high and 4 metres up the incline. He then lets it slide down the full 4 metres.



Uphill energy transferred to motion energy
= *work*
= *(force)* × *(distance moved)*
That is, = *either (i)* (30 newtons) × (4 metres)
= 120 newton · metres
or (ii) (30 newtons) × 1.5 metres)
= 45 newton · metres

b. A girl riding a bicycle pushes the pedal from 'top dead centre' to 'bottom dead centre' with a steady push of 40 newtons straight down all the time. The length of the pedal crank is 18 cm.



Transfer FROM chemical energy in muscles of cyclist TO machine

= *work*

= *(force)* × *(distance moved)*

That is, *either (i)* (40 newtons) × (0.36 metres)

= 14.4 newton · metres

or (ii) (40 newtons) × *(the semi-circular distance through which the pedal moves)*

= (40 newtons) × ($\frac{1}{2} \times 2 \times \frac{22}{7} \times 0.18$ metres)

= 22.6 newton · metres

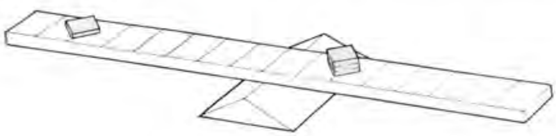
Now copy the following sentence and add a few words at the end to show clearly what is meant by:

'Work (energy transfer) is equal to (force) multiplied by (the distance moved . . .).'

Energy and machines

115a Experiment
Can machines create extra energy?

The first *machine* you met was the simple lever, or seesaw. This is a 'force multiplier'. It will give a big force for a small one, if you choose unequal distances.



The lever can give you more *force*. It can *multiply* force. *But can you get more energy out of it than you put in it?*

To find out, balance a seesaw with a big load one space out from the centre and a smaller load ten spaces out from the centre.

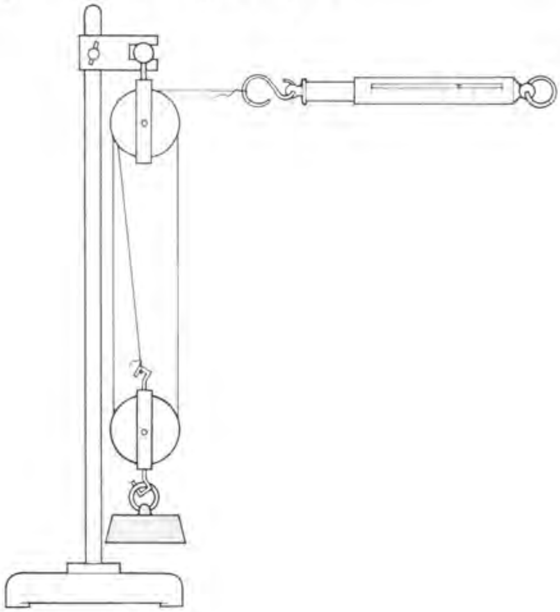
How big must the small load be to balance? One-tenth of the big load. Now suppose the lever swings, the little load going down 10 centimetres and the big load going up. *How far will it go up?* 1 cm up. *Why?*

How much energy transfer is there from the lever to the big load? The *work* is *(force)* × *(distance)*, that is, (the pull of the Earth on the big load) × (1 cm).

How much energy does the little load lose and give to the lever? (The pull of the Earth on the little load) × (10 centimetres). But the little load is only one-tenth as big. So the two lots of work are exactly equal. Just as much energy is transferred from the little load to the lever as from the lever to the large load. The lever does not multiply energy.

115b Experiment
What can pulleys do?

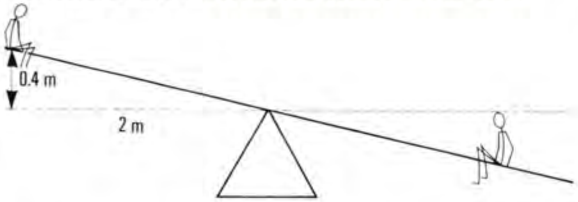
Do an experiment to find out if the same thing is true for pulleys. *Is a pulley system a force multiplier? Is it an energy multiplier?*



Questions

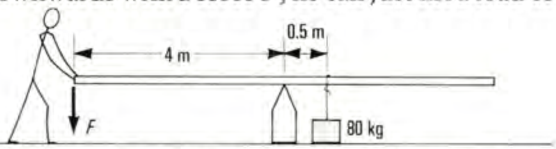
Machines

14. An 80-kilogram man and his 40-kilogram daughter are on a seesaw, so they must be at different distances from the centre to balance.



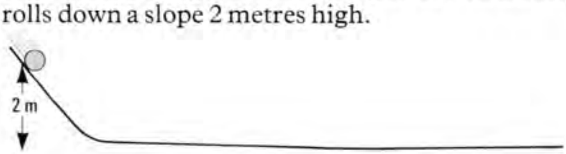
a. If the child is 2 metres from the centre, how far out must the man be to balance?
b. Suppose in swinging the seesaw, the child rises 40 cm (0.4 metre). How much uphill energy is given to her?
c. How far does the man go down when the child goes up 40 cm? (This is the important step in this question. Think about it. Draw a *large* diagram and measure it.)
d. How much uphill energy does the man lose?

15. A man uses a long plank to lift a heavy load. He arranges the plank across a pivot. By pushing downwards with a force F, he can just lift a load of



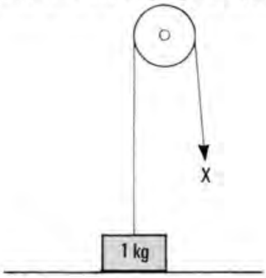
80 kilograms (which the Earth pulls with a force of 800 newtons).
a. How big must the effort force F be?
b. Then the load is . . . times as big as the effort force. How many times?
c. If the plank swings on the pivot so that the effort moves down 25 centimetres (0.25 m) how much energy is transferred from the man to the plank?
d. How far is the load raised?
e. How much energy is transferred from the plank to the load?
f. A gain in force is found in (b). Is there any gain or loss in energy?

16. A $\frac{1}{4}$-kilogram ball (weight 2.5 newtons) rolls down a slope 2 metres high.



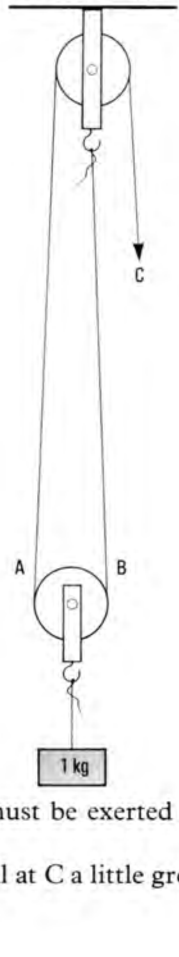
a. What kind of energy did it start with?
b. What kind of energy did it end with at the bottom of the slope?
c. How much of the first kind of energy (in newton · metres) changed into the second kind?

17. What size pull (in newtons) must be exerted at X on the rope to pull up the 1-kilogram load at a steady speed (or just to lift the load)?



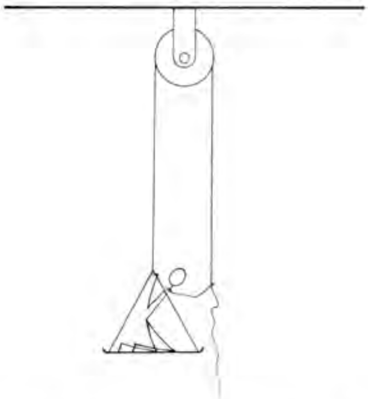
a. Two ropes are pulling up on the kilogram load. How much upward pull (in newtons) must *each* rope exert at A and B to lift the kilogram load?

Assume that the bottom pulley itself is too light to make any difference. (Remember that the Earth pulls about 10 newtons on each kilogram.)



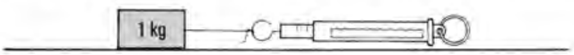
b. What pull (in newtons) must be exerted at C to lift the load?
c. Why, in real life, is the pull at C a little greater than your answer to (b)?

18. *(A question for discussion)* A 70-kg man stands on a 30-kg platform. The platform hangs from a rope which passes over a pulley and the man holds the end of the rope.



a. What force does the man have to exert on the rope to hold both himself and the platform up?
b. One boy answering this question said that the answer to (a) is 100 kg. Why is this obviously wrong?
c. *(A hard puzzle)* Suppose the man weighs 49 kg and the platform 51 kg. What happens?

19.
a. If you lift a kilogram up 2 metres, how much work is transferred to uphill form? (Answer must be in newton · metres.)
b. You drag a kilogram of iron along the bench.



Suppose the force of friction pulling against you is 1 newton. How much energy do you transfer if you drag the kilogram of iron 2 metres along the bench? (*Hint:* Which matters for this work transfer, the pull of the Earth or the drag of friction?)

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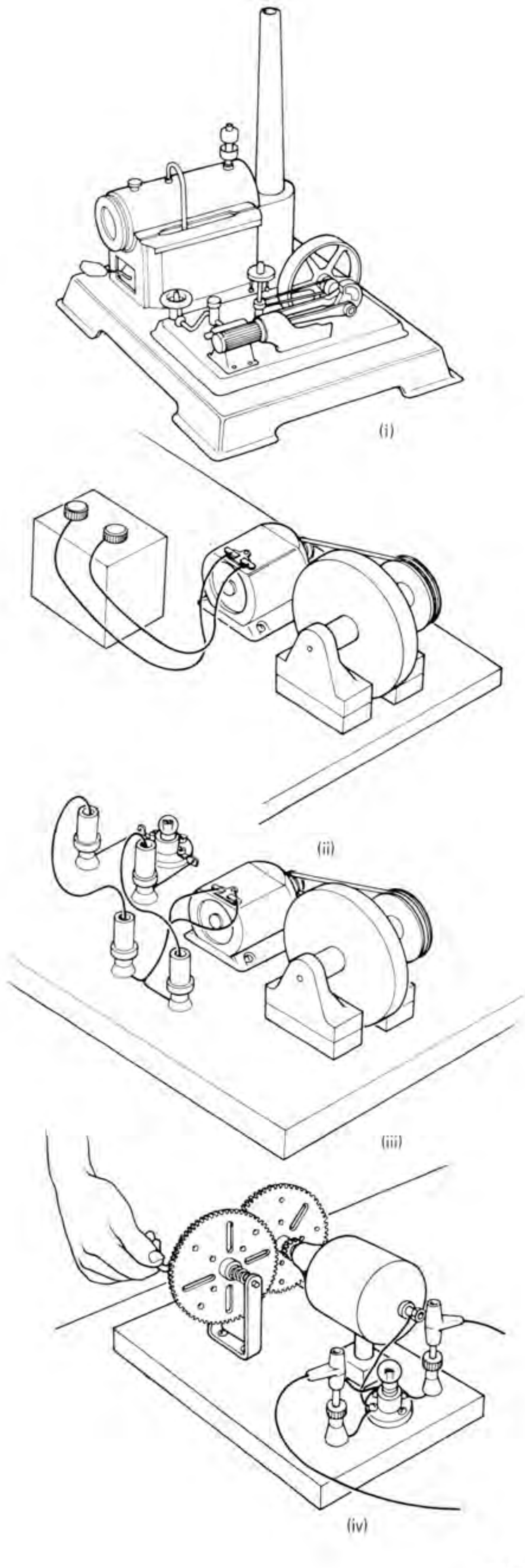
MORE ENERGY CHANGES

116 Experiment
Energy circus

You have already investigated several energy changes in the laboratory. Here are some others for you to try and demonstrate in your class.
(i) A model steam engine makes a heavy flywheel go faster and faster.



(ii) A battery drives an electric motor which makes a heavy flywheel go faster and faster.
(iii) The spinning flywheel drives an electric generator and so lights a lamp.
(iv) Grind a handle round against a friction brake which gets very hot.
(v) Drive a dynamo by hand and light 1, 2, and then 3 lamps.

Question

Energy changes

20. Write out the energy changes for each of the changes given in Experiment 116. Use the form, 'Energy is transferred FROM chemical energy in the methylated spirit TO heat which boils off the steam. The springs energy of the steam is transferred TO mechanical energy of the engine . . . . '

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117 Experiment
Other simple energy changes *(Optional now)*

Watch some of the following demonstrations; or, if you like, try them yourself. In each case think about the changes from one kind of energy to another kind. Describe the changes by giving the name of each kind of energy.

117a Pendulum

Hang a brick or block of wood on a long string. Watch the changes of energy as it swings between uphill energy and motion energy.

117b Vertical spring

Hang a load on a spring. Raise it gently with your hand until the spring is not stretched. Let go. Catch the load and stop it when it reaches the lowest point in its motion.

What are the forms of energy in the change from LET GO *to* CATCH?

117c Horizontal spring

(i) Lay a spring on the table. Anchor one end. Pull it and hold it stretched. *What are the forms of energy changes?*

(ii) Tie a thread to the other end of the anchored spring and run it over pulleys to a load far above. Stretch the spring by hand (as before), then let go. Watch what happens to the load. *What are the forms of energy that change?*

(iii) Undo the thread and load. Attach a small cart instead. Pull it by hand and stretch the spring. Then let go and watch what the springs energy does to the cart. *What are the forms of energy that change here?*

117d Cart on a rough surface

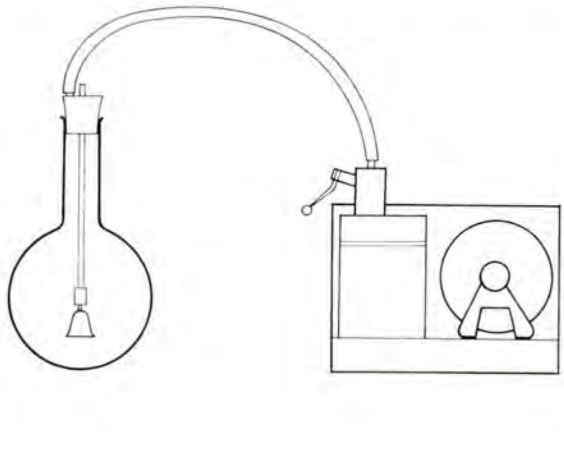
Give a small cart a quick push so that it has motion energy. Let it run along the table. But put a piece of rough cloth on the table. *What are the forms of energy that change when the cart runs on to the cloth?*

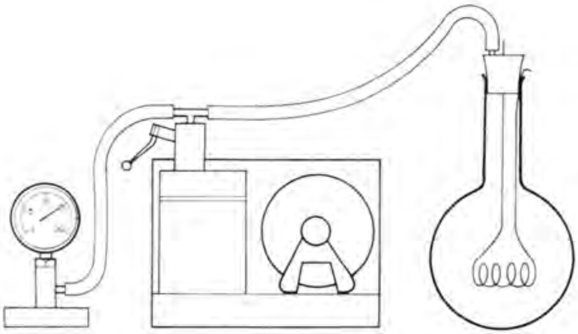
Light energy The lamp filaments you connected in the electric circuits all got hot. In the lamp, electrical energy was transferred TO heat and light energy. *Can light energy travel through a vacuum?*

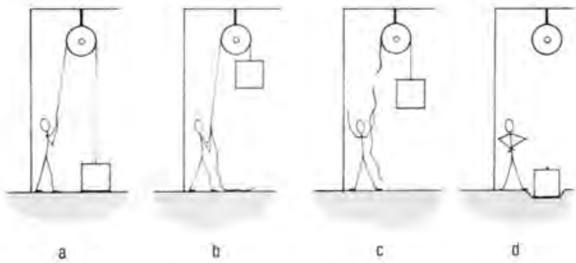
Light energy (along with some other sorts of energy) reaches us from the Sun: that energy must reach us through empty space. This is strange, for the energy is moving but no actual stuff is rushing along. What moves is a wave. But not all waves can travel through a vacuum. Water waves don't. *What about sound waves?*

118 Demonstration
Energy through a vacuum?

See the experiments sketched below, which will answer this question.







Heat

Now you have examined many energy changes, you will have noticed how often the name 'heat' appears – and usually at the end of the chain. In most cases we do not mind this because it is the shifting of energy which is important and which enables us to get useful jobs done.

But there are times when we are especially interested in the final heat; for example, when we heat the water for the washing-up, or a bath, by burning a fuel such as gas (with oxygen from the air).

Progress question

Cost of energy

21.

a. When you eat sugar it provides energy. 100 grams of sugar can give you 1 600 000 newton · metres of chemical energy. If sugar costs 32p per 1000 grams, how much does this energy cost you?

b. When an electricity bill is paid, you are paying for the electrical energy converted to other forms. A fairly usual price is about 1p for a million newton · metres. Is electrical energy more or less expensive than sugar energy?

c. A small electric fire takes about 15 minutes to give out a million newton · metres of heat energy. So it costs about 1p for 15 minutes. How much will it cost for an hour?

Questions

Energy changes

22. You can see what has happened to the man and the rope and the load. Write four sentences describing the energy changes that have taken place.

23. Here are some more examples of energy changes. Write sentences for each of these, describing the chain of energy transfer.

a. Child spins a top; the top hums and finally stops.

b. Car generator charges accumulator which, later on, lights the car's parking lights.

c. Wind turns the 'windmill' sails of a windpump. Windpump raises water out of a drainage channel into a river at a higher level.

d. Water in a high reservoir runs down large pipes and turns the blades of a turbine wheel. Turbine drives electric generator. Generator supplies current to electric fire in your room.

e. Radium atom's nucleus emits fast 'bullet' (= alpha-particle) which hits a screen and makes a faint 'splash' of light.

f. Gas warms oven in which dough turns to bread.

g. Bullet placed in rifle, trigger pulled, hot gases formed in gun-barrel, bullet shot out, hits wall.

h. Nuclear reactor makes high-pressure steam, which turns a steam turbine, which drives a generator, which makes electricity.

Motion energy

24. A brick whose weight is 25 newtons is lying on the ground. A man picks it up and raises it 1.6 metres above the ground. He then allows it to fall back to the ground.

a. How much energy does the man transfer in lifting the brick?

b. How much uphill energy has the brick gained when it is 1.6 m above the ground?

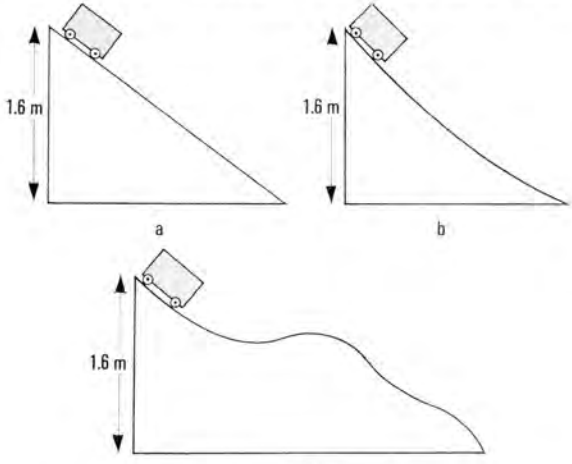
c. What is the falling brick's motion energy just before it hits the ground?

d. What then happens to this energy when the brick hits the ground?

25. Suppose that in the last question the brick had fallen into a hole in the ground 0.4 m deep.

a. What is its motion energy just before it hits the bottom of the hole?
b. The brick seems to have acquired some more motion energy than the man gave it in the first place. Think of an explanation for this.

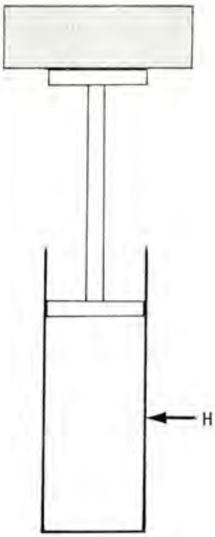
26. A small cart, whose weight is 60 newtons, runs down a straight, sloping hill (a), or a curved hill (b), or a 'switchback' (c). In each case, what is



its motion energy when it reaches the bottom? You may neglect friction in each case. What can we say about the speed of the cart at the bottom of each hill?

Compressing air

27. The sketch below shows a brick put on top of a piston that encloses air in a cylinder (like a bicycle pump – with the end closed). The piston moves down, bounces up and down several times,



and then settles at a place 8 cm below where it was before. The air is compressed when the piston moves down. The brick and the piston together weigh 30 newtons.
a. How much uphill energy was lost when the piston had fallen 8 cm?
b. In its first move downwards, the piston fell more that 8 cm. Why?
c. Why did it bounce a short way up again?
d. Why did it finally come to rest?
e. What would have happened if there had been a very small hole in the piston?
f. Suppose the piston was air-tight, but there was a very small hole at the point H in the sketch. Which of the following statements is correct? Give the reason for your answer.
(i) In the end the piston stops at H.
(ii) The piston falls to the bottom of the cylinder.
(iii) The piston stops above H.
(iv) The piston stops below H.

28. Remember that we have 'explained' gas pressure by saying that it may be caused by the bombardment of the molecules of the gas. Hold a bicycle pump with the handle at the top. *Keep the lower end open.* Push the handle (and piston) down.
a. What change in the motion of the air molecules in the pump occurs as the piston moves down?
b. How does this change take place?
c. What happens to the air?

Now try the pump *with the lower end tightly closed.* Again push the piston down – about half-way down the pump barrel.
d. Does the change you mentioned in (a) still take place? If you say *it does not*, give the reason for your answer. If you say *it does*, then answer (e).
e. The air cannot now get out of the pump. Yet you have agreed that the piston pushed the molecules downwards. What has happened to this downward motion of the molecules? And what about the temperature of the air in the pump?

Measuring your own energy

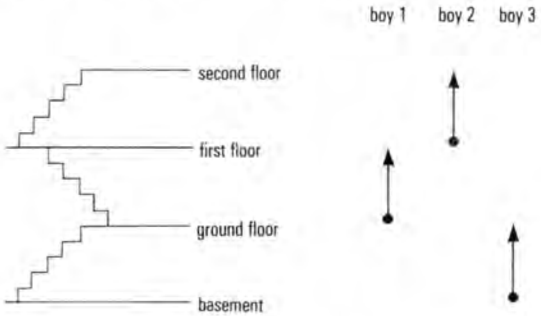
119 Experiment
Climbing stairs

Measure the height of a flight of stairs. Find your own weight in newtons.* Find out the work in newton · metres when you climb from the bottom to the top of the stairs.

*10 pounds ≈ $4\frac{1}{2}$ kilograms. Remember the Earth pulls 10 newtons on each kilogram of you.

This work tells you the energy you have transferred from food energy or chemical energy in your muscles to uphill energy.

Climbing stairs To climb those stairs you will also have to convert some energy to waste heat,



and that is not included in your calculation. In fact, the useful form is only about one-quarter of all the energy you draw from your food energy.

Maybe your school has several floors and several flights of stairs. Imagine a boy (weight 500 newtons) who started Experiment 119 at ground level. In climbing to the first floor, 3 metres higher up, he transferred:

(500 newtons) × (3 metres)

or 1500 newton · metres of energy TO uphill energy.

So did another boy (who also weighed 500 newtons) who climbed up from the first floor to the second floor. And so did a third boy of the same weight who climbed from the basement to the ground floor. Each boy transferred the same amount of energy to uphill energy, even though each started at a different level.

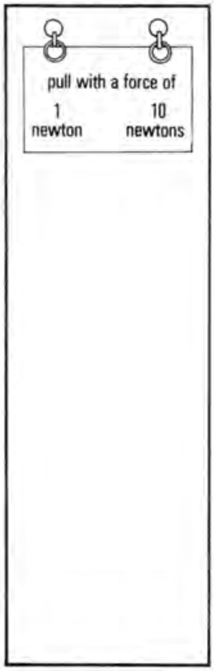
There is no 'sea-level' for uphill energy – we can only use *differences* of uphill energy. Each of the three boys has transferred 1500 newton · metres to uphill energy in climbing from one level to the next.

Joule: a new name for the newton · metre

You calculated the work in your climb in the units we have called newton · metres. These units are so useful that they have been given a shorter name, *joules* (pronounced 'jools').

120 Experiment
Giving 1 joule to the forces box

If you pull the string labelled 1 newton on the forces box to its fullest extent, which is 1 metre,

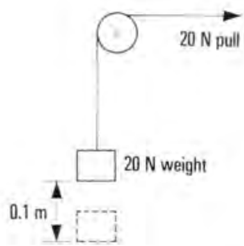


you will transfer just 1 joule of energy FROM chemical energy in your muscles TO uphill energy.

Questions

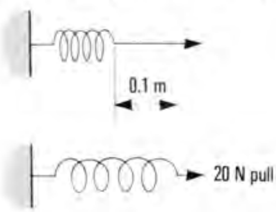
Springs energy

29.



a. A man lifts a stone whose weight is 20 newtons through a height of 10 cm (= 0.1 m). How much uphill energy does he give to the stone?

b. A man pulls a spring out through a distance of 10 cm (= 0.1 m). The force he uses to hold the spring in the stretched position is 20 newtons.



Q.29 *continued*

While he is pulling it out he uses no more force than is necessary to stretch it. So the first bit of the stretching is done with a force that is practically zero; then he uses more force for the later stages, and only for the last bit does he have to exert to the full 20 newtons.

Why, in doing this, does he store less springs energy than he stored when he lifted the stone 10 cm?

c. Make a guess at the actual amount of energy stored in the spring in (b). The obvious guess is the correct one, if the spring behaves properly.

30. In Question 29(a), suppose the man lets the stone fall back to the floor. In (b), suppose he releases the spring. It will snap back, bounce about, and come to rest.

a. What is the final form of the energy in each case?

b. Give two other examples of energy changes in which the same final form is reached.

Heat

Your answers to the last question show that energy very often gets transferred to heat. All the same, it is possible to convert heat into forms of energy; or, rather, to convert some of it. In any machine that converts heat into some other form, there must be a difference of temperature that the machine can use. One part must be hot; another machine part must be much colder.

On the other hand, if we have a number of things all at the same temperature (room temperature, for example), we cannot get a difference of temperature without supplying energy from outside.

31.

a. Can you think of a machine which converts heat into mechanical energy? Give its name.

b. Where does that machine get the high temperature from?

c. What is the low temperature (cooling) part?

d. It is very likely that you have in your home, or have seen somewhere, a different machine which makes some things colder (and other things hotter). What is it called? And, in the particular machine you are thinking about, in what form does it get its supply of outside energy?

CHAPTER 14

Warming things up

What happens to temperature, to length, to state?

121a Experiment
Warming water

Use an electric heater to heat some water for exactly 5 minutes. Take one kilogram of cold water. Find out what happens to its temperature.

First measure the temperature of the cold water. Switch on the heater. Stir the water. Switch off at the end of 5 minutes *and go on stirring*. Make a note of the highest temperature the water reaches after switching off.

(If your balance will not weigh more than 1 kilogram, weigh a beaker and add 0.5 kg of water to it. Put this water – and then a second 0.5 kg – into your saucepan.)

121b Experiment

Start again with just 0.5 kg of cold water. Note its temperature and then run the heater for 5 minutes as before.

What can you say about the energy which is supplied by that electric heater running, in each case, for just 5 minutes?

What warming-up effect does this energy have on (i) *1 kg of water and* (ii) *0.5 kg of water?*

Measuring heat

For a very long time scientists and engineers have measured whatever it is that warms things up (something which they have called 'heat') by what it would do to the temperature of 1 kilogram of water.

If the temperature of 1 kilogram of water rises by 1 °C, then one unit of heat has been supplied.

We will call that unit a 'thermal unit', although you may hear it called a kilocalorie by some people, or even a Calorie by slimmers.

What would happen if you started your experiment with water from the hot tap? Would that be a reliable way to work?

Was your own experiment a reliable one, or was there something which played a part and which you ignored?

How many thermal units did your heater deliver to 1 kg of water in 5 minutes?

How many to 0.5 kg?

Were there any other jobs which the energy transferred from the electricity supply had to do in addition to warming up the water?

121c Experiment

Find out how many *thermal units* are supplied to 1 kg of water by a Bunsen burner in 1 minute.

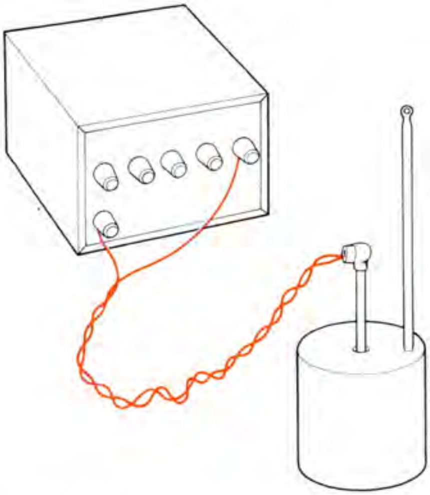
121d Experiment

How many thermal units are supplied to 1 kg of water when 1 cubic centimetre of methylated spirit is burned?

122 Experiment
Warming up aluminium

When you warmed up the water in the saucepan, you couldn't avoid warming up the aluminium saucepan as well. Now warm a kilogram block of aluminium with your electic heater for 5 minutes, just as you did with the water.

Take the temperature before you start and when it reaches its highest value.



Is the temperature rise the same, or more, or less than in the case of the kilogram of water? Was the energy output of the heater any different? Was the warming-up effect of that energy on the aluminium the same, or more, or less than the effect of water?

So 1 kilogram of water has a greater 'appetite for heat' than 1 kilogram of aluminium. That is to say, the heat capacity of 1 kilogram of water is greater – nearly five times greater – than the heat capacity of 1 kilogram of aluminium.

Now look back at Experiment 121. You were asked if your results were reliable. Remembering that the electrical energy had to warm up the aluminium saucepan as well as the kilogram of water in the saucepan, you can see that they were not reliable.

Did you weigh your saucepan? If so, you can answer the following question:

How many thermal units would the aluminium saucepan have taken up in the 5 minutes of heating:
(i) if it behaved just like water?
(ii) if, being aluminium, it took only one-fifth as much heat?

Progress questions

1. Make a list of things at home which can convert electrical energy into heat.

Warming things up

2. I put a kettle containing 1 kilogram of cold water on the gas ring, and it takes 5 minutes to get up to boiling point.

My friend puts on a small electric kettle, containing $\frac{1}{2}$ kilogram of cold water, and it takes 5 minutes to get up to boiling point.

Which gives more heat in the 5 minutes:
a. the gas supply; or
b. the electricity supply?

Can you say *how many* times as much?

3. A heater is used to warm up 2 kilograms of water. The heater runs for 5 minutes. The water warms up from 10 °C to 20 °C.

Then the *same heater* is run in the *same* way for the *same* length of time, 5 minutes, to warm up a 2-kilogram block of aluminium. The aluminium warms up from 10 °C to 60 °C.
a. Which (water or aluminium) shows the larger rise in temperature?
b. How many times larger is it?
c. If you wanted the aluminium to have the same rise of temperature as the water, how long should the heater be run to warm up the aluminium?

4. An electric heater is used to warm up 2 kilograms of water in an aluminium saucepan. Not all the heat from the electric heater goes to the water. Suggest some places where some of it has gone.

5. Which cools more quickly, a cup of hot tea or a teapotful of hot tea? Why?

6. 1 kilogram of aluminium needs *less* heat to raise its temperature through 1 °C than 1 kilogram of water does. Suppose you wish to do an experiment to show that to some other pupils. Describe your experiment.

Questions

7. How many thermal units will be required to warm up 2 kg of water from 15 °C to 25 °C?

8. Pretend that the energy required to warm up 1 kg of water through 1 °C is only one-tenth of

its actual value; (that is, imagine that the heat capacity of water is one-tenth of its actual value).
a. What difference do you think this would make to the climate of the British Isles, which are surrounded by water?
b. What difference would it make to the pleasure of a long and lingering hot bath?

9. You are given a thermometer, a balance, a candle, a tripod, and an empty tin of suitable size:
a. How would you measure the heat (in thermal units) given out by the candle per minute?
b. Why is this experiment likely to give a value which is too low?

10. When you measured the warming-up effect of energy supplied to solids and liquids, you used a balance and a thermometer.
a. A thermometer does not by itself measure the warming-up energy we call heat. What name is given to the thing which a thermometer *does* measure?
b. *(i)* Invent an experiment in which different amounts of energy produce the same change of reading in a thermometer.
(ii) Invent another experiment in which the same quantity of energy produces different changes of reading in a thermometer.
c. How do you calculate the warming-up energy from the readings of the balance and thermometer:
(i) if the substance being warmed is water;
(ii) if the substance is not water?

Other ways of warming things up You have used an electric heater to raise the temperature of some water and of some aluminium. But temperatures can be raised in other ways – for example, by friction. (Brake drums and discs get hot when the brakes are applied to a car which possesses motion energy.) Or even by hammering, as you found when you did Experiment 114.

Warming up gases

In a diesel engine, the oil and air mixture in the cylinder is fired by a sudden high compression, which raises the temperature, almost like the sudden hammer blow on the lead.

Instead of compressing the gas, we might have warmed it up in some other way – perhaps with an electric heater or a flame. *What will happen to the rapidly moving molecules of the gas then?*

Each molecule will push the wall of the container harder when it hits it, and so the pressure will be greater. *How can gas molecules bouncing about in a closed box bounce harder? What must have happened to them when we warmed them up?*

123 Experiment
The marbles model of a gas

Take the tray of marbles which is our model for a gas. Pretend to 'warm it up'. *What kind of energy do the marbles have more of now?*

Do they bounce harder when they hit one another and the walls of the tray? Where did the energy for all this come from? Where does it come from when a real gas is warmed up? And what do the real molecules do as a result of that?

Progress question

11.
a. Write a sentence or two about the scientist's picture of how the molecules of a gas (at room temperature) move.
b. When the gas is heated, what difference does it make to the way the molecules move?
c. So, when a gas is heated, what kind of energy do the molecules get more of?
d. What is the scientist's picture of how the molecules in a solid move? What difference do you think heating the solid will make?

Temperature and thermometers

In all warming-up experiments, you have used a thermometer to measure the temperature. That's what temperature is – the thing that a thermometer measures.

You probably used a thermometer which uses the expansion of mercury to show how high the temperature is.

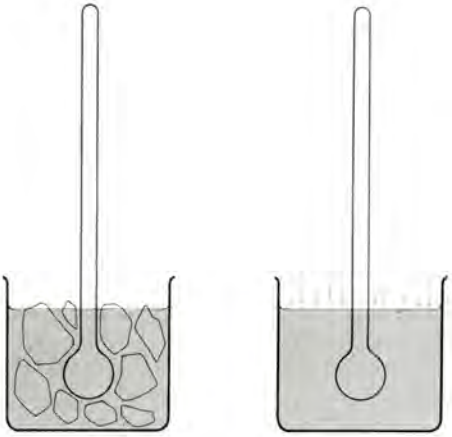
There are many types of thermometer in use and we can't expect that they will all agree with one another at all temperatures. So scientists select one particular type as standard and compare the other sorts with that. Fortunately, mercury thermometers do agree with that standard quite well.

Progress question

12. When you put a laboratory thermometer into warm water, you see the thread of mercury rising.

a. Why does the mercury rise?

b. Copy the drawings and colour in the mercury in each diagram.



c. Write the correct number by the top of the mercury in each case.

d. Once these two numbers are marked, how do you decide where to put the 50 °C mark?

e. Match this list of temperatures:

−3 °C, 20 °C, 37 °C, 103 °C

to the list given below:

A comfortably warm room is about . . .

The blood of a healthy person is about . . .

(On the Fahrenheit scale it is 98.4 °F and that is . . . °C.)

Boiling jam is about . . .

The ice-making compartment in a refrigerator could be at . . . .

OTHER EFFECTS OF WARMING THINGS UP

You have been experimenting with a very important effect of warming – raising the temperature of things. There are other effects as well.

Expansion

124 Experiment
Expansion of a solid

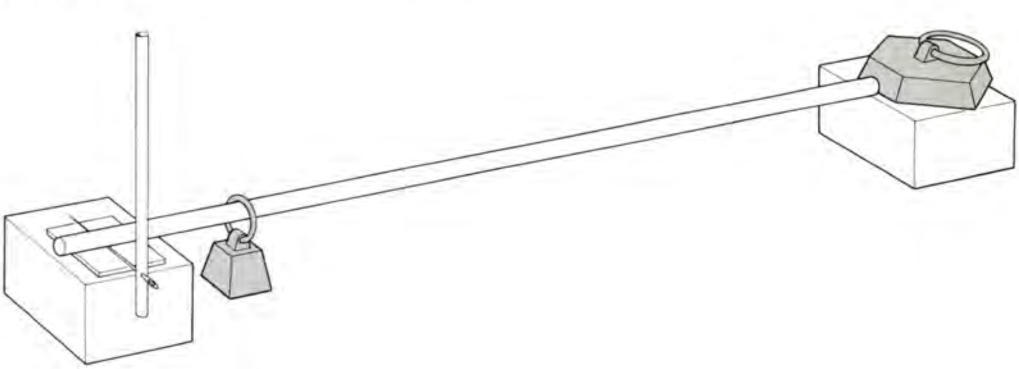
Take a long rod of iron or brass. Support it on a brick near each end and place one end against a firm stop (for example, a kilogram sitting on the brick). See below.

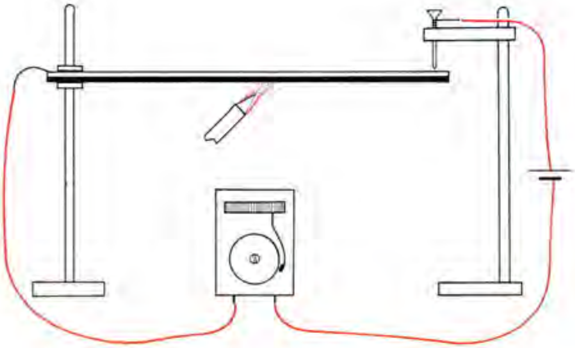
Put a needle under the other end of the rod to act as a roller, and then fix a straw to that needle so that it acts as a pointer. Then heat the rod strongly with a Bunsen burner flame. *What happens?*

Metals expand Experiments show that different metals expand by different amounts. For example, a copper bar expands more than the same length of iron. Certainly, neither expands very much, but the copper does expand about 1.5 times as much as the iron does.

What will happen when you heat a bar made up of a strip of copper welded firmly to a strip of iron of the same length?

This device is called a 'bimetallic strip' and it is used as a heat-operated switch in fire alarms, as a temperature controller in electric irons, and as a switch to operate the flashing direction indicators in motor cars.





The sketch shows a bimetallic strip in use as a simple fire alarm. *Can you make a sketch which shows how the other two devices might work?*

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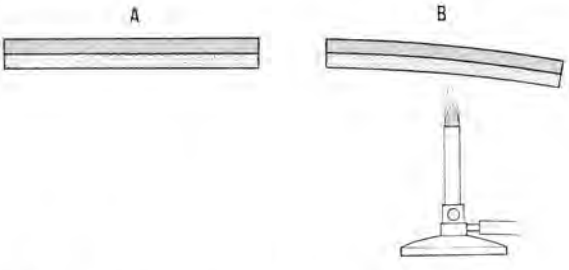
Progress questions

13.
a. Draw a large diagram of the experiment you did which showed what happens to the length of a metal rod when it is heated.
b. In your experiment:
(i) was it easy to see whether the rod was getting longer?
(ii) was it enough to make it lukewarm, or did you have to make it very hot?
(iii) did the rod get shorter again when it cooled down? How do you know?
c. How long did you have to heat the rod? If you can't remember, do you think the time was nearer half a minute or 10 minutes? Why was time needed?

14. A bar is made of two strips of metal welded together like A.

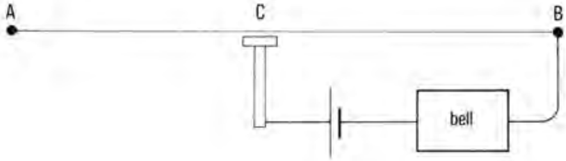
When it is held and one end is heated, it begins to look like B.



a. Why does the bar bend?
b. What happens to it when it is left to cool?

15. Think of expansion and contraction as you answer this question.
a. The ends of a long metal bridge are put on rollers, instead of being fixed in the ground. Why?
b. In a road which is made of huge concrete slabs, there are gaps left between slabs. Why? Why isn't this necessary for a road made of tarmac?

16. You can make a fire alarm like this. A long wire, AB, is supported so that it nearly touches a contact, C; then B and C are connected to a battery



and bell, as shown. If a fire breaks out near the long wire AB, what happens? Explain why this can make the bell ring.

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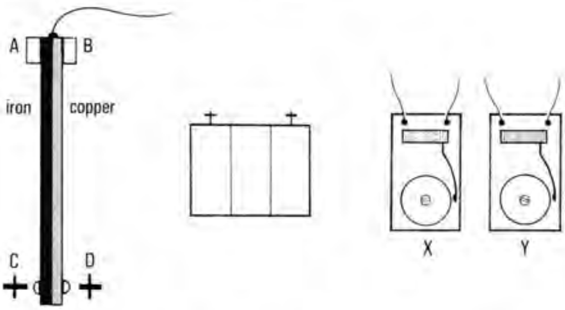
Questions

17. Look at the left-hand sketch below, which shows a 'bimetallic strip' of iron and copper firmly fastened together. For the same temperature rise, copper expands $1\frac{1}{2}$ times as much as iron.



a. What happens when this strip gets warmer; does it touch C or D? Give a reason for your answer.
b. What happens when the strip is cooled?

18. You are given two electric bells, X and Y, and a battery that will work them, one at a time.

Also you have connecting wires and the apparatus shown in the left-hand sketch above. This apparatus consists of a 'bimetallic strip' which is fixed at AB with the other end left free. Connecting wires can be fastened to the fixed end AB and to the two contacts at C and D.

Q. 18 *continued*

The idea is to put the bimetallic apparatus in a box which is to be kept at a steady temperature. If the box gets too cold, then bell X is to ring; if the box gets too hot, then bell Y rings.

Draw a circuit showing how you would complete the circuit, and explain how the whole thing works.

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125 Experiment
Cracking glass

When a piece of window glass is heated it cracks. *Why is this?* When you have seen that demonstrated you may try it for yourself. Heat small pieces of soft glass and of hard (heat-resistant) glass in a flame and then plunge them into cold water. *What happens? Is there any difference in what happens to the two pieces of glass? Why?*

Expansion of liquids

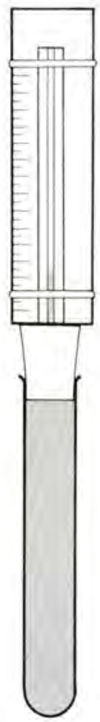
126 Experiment
Mercury expanding

Dip a mercury thermometer into some warm water. Watch it very carefully. *What does the mercury column do? What do you think is happening to the mercury in the bulb of the thermometer?* Now take it out of the water. *What does the mercury do now? When does mercury in a thermometer contract?*

127 Experiment
Giant model of a thermometer

Make a giant model of a thermometer from a glass tube and a length of glass tubing. Fill it with water. Plunge the 'bulb' into hot water. Watch very carefully and write down exactly what you see.

Ask for a second model made from a hard or heat-resistant glass tube and try the experiment again. *What happens this time?*



Progress questions

19. Some oil is put into a small bottle so that the bottle is full to the brim. The bottle is weighed, then put into boiling water with its top just above the surface.
a. What would you expect to see happen when the bottle is put into the boiling water?
b. After 15 minutes the bottle is lifted out and put on the bench. What would you expect to see then?
c. When it is cold, the bottle is weighed again. Would you expect it to weigh more than before, or less, or the same? Give a reason for your answer.

20. Boiling water is poured quickly into a thick drinking glass.
a. Which part gets hot first?
b. What happens to the part which gets hot?
c. What may happen to the glass?
d. The same thing does not happen if the glass is made of Pyrex (heat-resistant glass). Why not?

21. You put water in the test-tube, as shown in the diagram, and then heat it gently.
a. At first only the glass gets warmer, while the water is still cold.

(i) Does the test-tube get larger?

(ii) What happens to the water in the narrow tube? Does it go up? Down? Or stay in the same place?

b. If you use a Pyrex test-tube, is there any difference in your answer to (a)?

c. When both the glass *and* the water in it get warm, you will see the water level in the tube rising. Which of the following statements could be true?

A Water expands when it is heated.

B When water and glass are both heated to the same temperature, they expand equally.

C Water expands more than glass does for the same temperature rise.

D Glass expands more than water does for the same temperature rise.

....

Melting and boiling

128 Experiment
Melting

Put a little naphthalene in a test-tube and heat the tube in hot water until it just melts.

Then let it cool. Watch it carefully. *What happens?*

Then try warming other things in a Bunsen flame. Try a small piece of lead, a few centimetres of solder, a piece of iron wire, a piece of copper wire. *What happens in each case?*

If there is snow about, try heating a tin can of tightly packed snow *very gently*, stirring it as you go, and watch the temperature change.

Watch a little 'dry ice' (carbon dioxide 'snow') warm up. It is best placed in a polythene bag or a balloon, squashed flat, and then sealed up.

129 Experiment
Boiling

Half-fill a small beaker with water and bring this to the boil over a Bunsen burner.

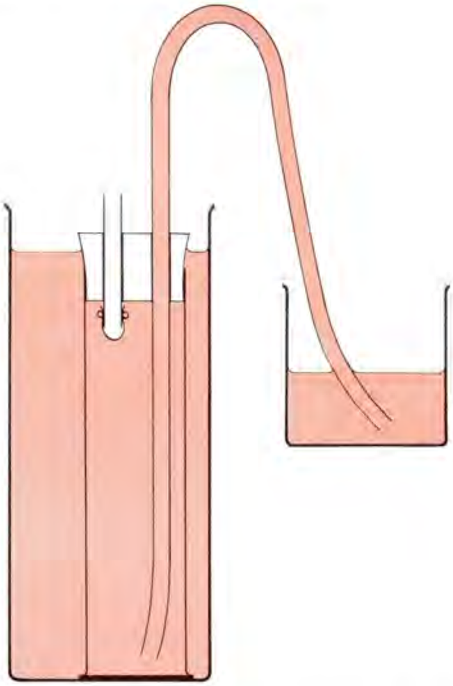
Watch the water very carefully. *What do you see? And, perhaps, hear?*

Changes in volume

When a little carbon dioxide snow turned to gas in the balloon (Experiment 128), a tiny volume of the solid became a large volume of gas.

130 Demonstration
Petrol changing to petrol vapour

The sketch shows a measuring cylinder which is full of hot water. So too is the flexible tube leading through the bung to the reservoir (R).



The bung also has a short glass tube through it which has a rubber cap over the end inside the cylinder.

And the whole cylinder is in a tall beaker of hot water – at around 90 °C.

Then a tiny drop (0.1 cubic centimetres) of petrol is injected through the rubber cap into the hot water in the cylinder.

What happens to that droplet of liquid petrol? How much is the expansion? How many times larger is that than the volume of the original drop?

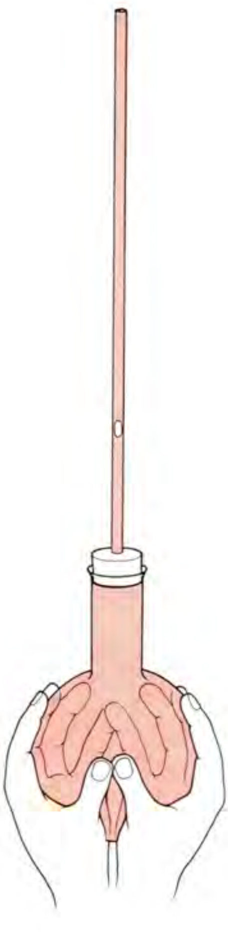
When *water* turns to steam, the expansion is even greater than that. It is about 1600 times.

When water freezes to ice, another volume change (also an expansion) occurs. The ice takes up more space (about 10 per cent more) than the water from which it came. So, as it freezes, ice can exert strong forces. No wonder that water pipes sometimes burst when the water inside them freezes. *When is the burst pipe first noticed?*

Expansion of gases

131 Experiment
Warming up a gas

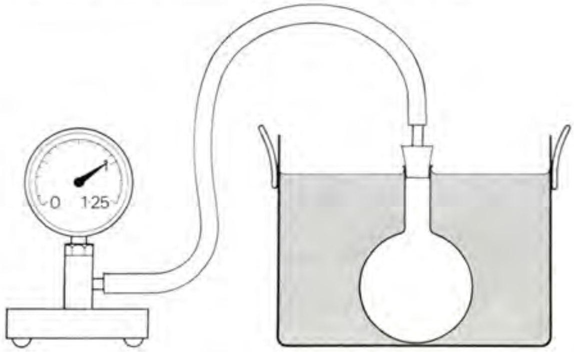
Take a small flask fitted with a cork and a long, narrow glass tube which has a bead of oil in it. Cool the flask in some cold water; and then warm it in your hands.



What does the bead of oil do? What happens if you plunge the flask into a saucepan of warm water? What has that done to the air in the flask?

132 Experiment
The effect of warming up a gas on its pressure

This time, fit the flask with a short glass tube. Attach a rubber tube to connect the flask to a pressure gauge. Now the air in the flask cannot expand, but it can change in another way.

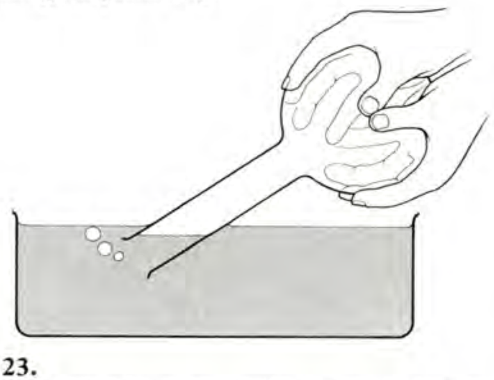


What is the pressure in the flask when you have connected it all up?

Now hold the flask down in a saucepan full of cold water. *What happens?* Try it in hot water. *What happens?*

Progress questions

22. You have a bottle or flask with nothing but air inside it. You hold it so its opening is under water, as the diagram shows. If your hands are warm, you will see air bubbles come out of the opening. Explain why.



23.

a. Air expands very easily when it is heated. Describe how you can show this with apparatus A.

b. How easy is it to make oil expand? Suppose you

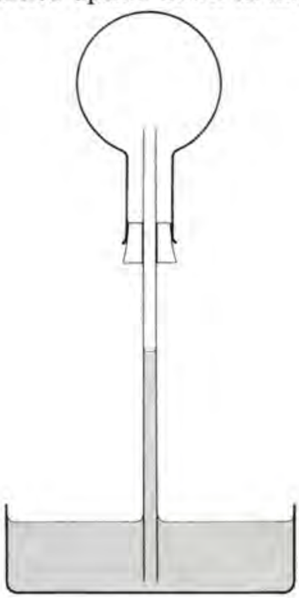
did exactly the same experiment with apparatus B. What would you expect to see?

24. If you trap some air inside a flask and heat it, what happens to the pressure in the flask? Describe an experiment you have done which shows this.

....

Question

25. Galileo made a thermometer like the one in the sketch below. A flask is fitted with a long tube and turned upside-down so that the end of



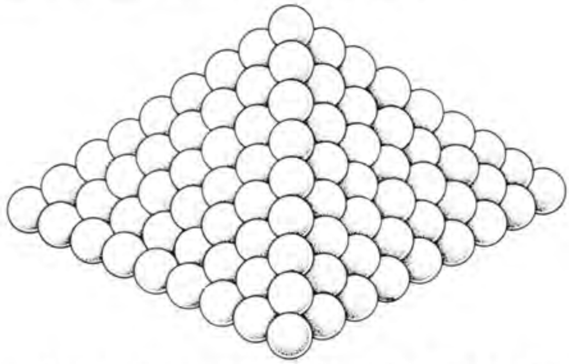
the tube is under water. The level of the water is shown in the sketch.

a. How does this arrangement act as a thermometer? That is, why does it give different readings for different temperatures?

b. This is not a good form of thermometer. It might give different readings at the same temperature on different days. Explain why.

ATOMIC AND MOLECULAR PICTURE OF MATTER

In Chapter 1, you imagined that solid objects were made up of tiny atoms piled up like oranges on a fruit stall, and that there were different patterns of piling for different types of crystal.



Now you certainly couldn't pick up a pile of oranges by taking hold of the top layer and lifting, but you can pick up a crystal that way.

What does that tell you about atoms in a solid?

So, in solids, you must imagine that the atoms are held together by quite strong forces.

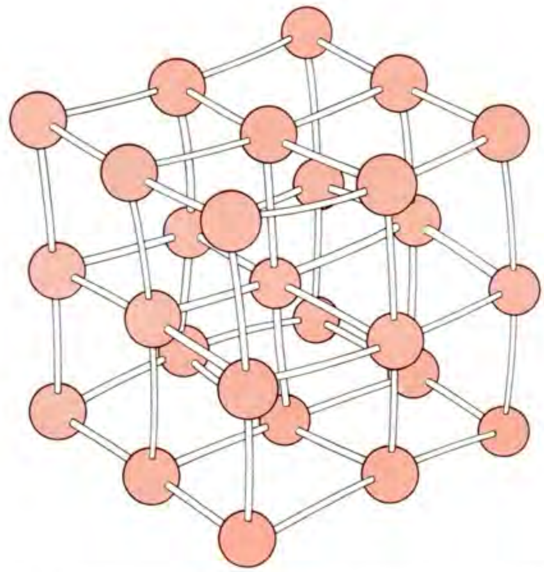
If you tried some springs earlier, you found that copper wire is quite springy. If you stretch it and let go, it will return to its original length.

So the forces holding the atoms together must be springy ones which resist pulling apart. They must also resist pushing together.

133 Demonstration
Model of a solid

Imagine a piece of a solid magnified by a super microscope, something like the model shown in the sketch on the next page, with a basic shape which doesn't change very much whatever happens but in which individual atoms can vibrate a bit.

Now suppose you warmed this model up a little. Maybe then the atoms would vibrate a little more violently. And if you warm up the model more and more, the moving atoms might stretch the springy forces between them so much that they begin to break apart.



As more and more energy is given to the solid, more and more atoms break free until the solid loses its basic shape and has melted to a liquid. That must need quite a lot of energy, which must go into storage. We should be able to get this energy back again when the liquid freezes to a solid once more.

134 Experiment
Model for evaporation of a liquid

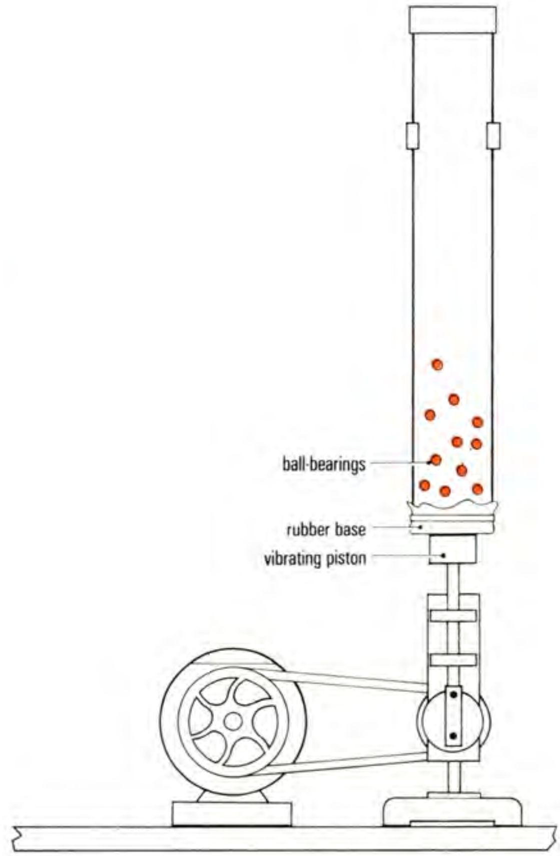
Tilt the tray of marbles so that they just run down to one end and form a layer there. Then shake the tray gently, keeping it tilted. *What happens to the marbles?*

Shake the tray harder. *Now what do those marbles do?*

This is a very simple model of a liquid turning into a gas. The model is a flat one (in two dimensions).

135 Demonstration
Model of a gas

You should also see a model of this in three dimensions. See the diagram in the next column.



Progress questions

26.

a. When an ice-cream melts, does it take up a lot more space, or a lot less than when it was solid, or about the same?

b. When butter melts, does it take up a lot more space than when it was solid, or a lot less, or about the same?

c. When solder melts, does it take up a lot more space than when it was solid, or a lot less, or about the same?

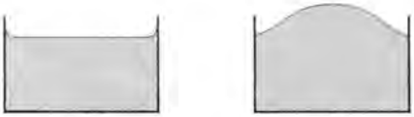
d. Copy and complete:

When a solid melts, it turns into a . . . .

e. Do you think the molecules in a liquid are a lot farther apart than in a solid, or a lot closer together or about the same distance from each other?

27.

a. When you make ice-cubes, they often stick up in the middle, although the water started off flat. What can you say about the volume of the ice, compared with the water it came from?



b. If you put an ice-cube in water, does it float, or sink? Which has more molecules in it, a cubic centimetre of ice, or a cubic centimetre of water?
c. The molecules in ice and water are about the same distance apart. When water turns to steam, what can you say about the spacing of the molecules then?

28. You have a tray with several marbles in it.
a. How would you arrange the marbles and what would you do to make a model of:
(i) Molecules in a solid?
(ii) Molecules in a liquid?
(iii) Molecules in a liquid with a few evaporating occasionally?
(iv) Molecules in a gas?
b. Explain why a liquid evaporates, that is, how a molecule in it suddenly gets energy to leave the rest.

Questions

29. Describe an experiment you have done with a tray of marbles, a simple model of particles of liquid turning to a gas.
b. Describe the difference between the movement of the particles representing the liquid and the movement of those representing the gas.
c. What happens to this movement if you 'warm up' the model?
d. How does your model explain the way in which gases expand when they are warmed up?
e. How does the model explain the increased pressure which a warmer gas exerts?

30. Why are the melting point of ice and the boiling point of water (0 °C, 100 °C) good temperatures to choose as 'fixed points' of a thermometer scale? What would happen if we used a centimetre scale on the stem instead?

31. A boy gets two results from two experiments to measure the warming-up effect produced by an electric heater running for one minute.

In the first experiment the temperature of about 2 kg of water rose by about 10 °C.

In the second experiment, the heater ran for the same time with about half the quantity of water, and produced about twice the temperature rise.

The boy uses a thermometer marked in whole degrees, and he believes he can estimate temperatures with it to the nearest 0.1 °C.
a. Why is the first experiment, with a larger amount of water given a smaller temperature rise, likely to give a more accurate result than the second experiment?
b. The boy then says: 'I shall get a still more accurate result by heating 10 kg of water through about 2 °C – or even 20 kg through 1 °C.' Why is this *not* a good idea?

CHAPTER 15
Heat transfer

Transferring heat through solids, liquids, gases, and across space

Men and women spend a lot of time and money moving heat around, transferring it from place to place.

They may have a grate at home in which coal or coke is burned. Or they may have a central heating system with a boiler in which coke or gas or oil is burned. Or they may use an electric heater with a polished reflector behind it. They may use an electric iron to press their clothes. They may have a refrigerator to cool their food, and a gas or an electric cooker to warm their food.

All these things transfer heat from one place to another. The space heaters take heat from a source and transfer it to the rooms in the house and the people in those rooms. The refrigerator takes heat from the foods, cools them down, and slows up some other changes. The cooker transfers heat to the foods, warming them up and making other changes.

You must look at the ways in which heat is transferred to see how they are used in these appliances. There are three ways in which heat can be transferred from a hot place to a cold place.

Conduction In this type of transfer, heat is handed on from one bit of stuff to the next, like a message being handed along a line of people from neighbour to neighbour.

Convection In this type of heat transfer, the hot material itself moves, carrying its heat with it, like a skilled footballer dribbling the ball through his opponents from one end of the field to the other.

Radiation This is a very difficult thing. This is not a matter of something hot carrying heat itself, or of atoms handing heat on from one to the next. Radiation seems to act in quite a different way.

Hot things do give out radiation – they produce something at the expense of heat. So they cool down unless we keep on supplying heat.

But the heat that disappears does not travel out as heat; it seems to change and travel out in an entirely different way. You will find that it travels extremely fast, and usually in straight lines.

That is why people call it radiation. Radiation means something that travels out like the spokes of a wheel (*radii* in Latin). When radiation *hits something and stops*, it usually turns its energy back into heat.

The ways of transfer

I write a message on a piece of paper. I want to get it to someone over on the other side of the school. That message can be *conducted* from pupil to pupil, or *conveyed* by a gang of pupils running with it.

But if we want to think about the message being 'radiated', we must take it to a radio station where it can be changed to a radio message which radiates out. On the other side of the Channel, or somewhere else far away, it can be turned back into another message on a piece of paper.

Conduction

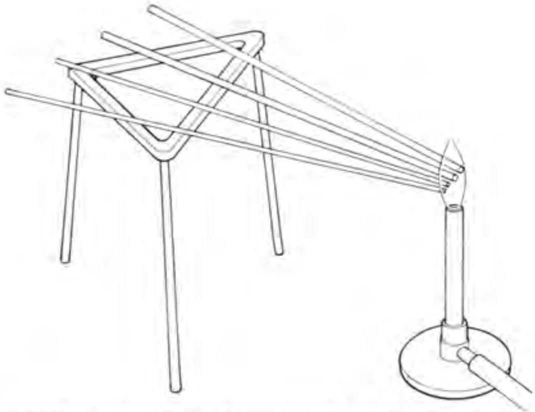
136a Experiment
Testing conductivities

First lay your hand on a number of different objects in a cool room, or out of doors in the shade. All these objects will be at nearly the same temperature. *Is this lower or higher than your own body temperature?* Some are cold to the touch; others feel warm.

Make a list of about a dozen different surfaces (e.g. various kinds of metal, wood, paper, cloth, glass, plastics) under two headings: *(i)* materials that feel cold to the touch; and *(ii)* materials that feel warm to the touch.

136b Experiment
Comparing conductivities

Set up a tripod stand near to a Bunsen flame. Put some rods of brass, copper, aluminium, iron, Pyrex glass (all of the same diameter) on the stand so that the ends are just in the flame.



When they have been in the flame a minute or so, run your finger along the rod from the outer end until you find the place where the rod is too hot to touch. See how far from the flame that place is.

How does that tell you which rod is best at conducting heat?

What really happens is that heat travels along in the rod rather like water in a pipe. It also escapes from the surface of the rod, so that after a time the rod reaches a steady state. It is very hot in the flame, quite hot some way out, fairly hot still farther out, and quite cool perhaps at the end.

Can you judge with your finger which is the best conductor and which is the poorest?

You might think it would be best to use a clock and time the speed at which the heat seems to run along the rod.

But scientists know from further work on conduction that the speed at which the heated region spreads along the rod does not just depend on how good a conductor it is. The speed depends on how greedy that particular material is for heat, how much heat it has to receive and mop up before it grows much hotter.

So the material's 'specific heat capacity', as we call it, affects the speed. But if you go on heating the rods they will reach a stage when they don't get any hotter. Each rod will be hot . . . warm . . . cold along its length. The heat fed in from the flame is lost from the surface of the rod as fast as it is fed in. At this stage of a 'steady state', you do just compare conductivities.

Instead of using your finger, try a match-head.

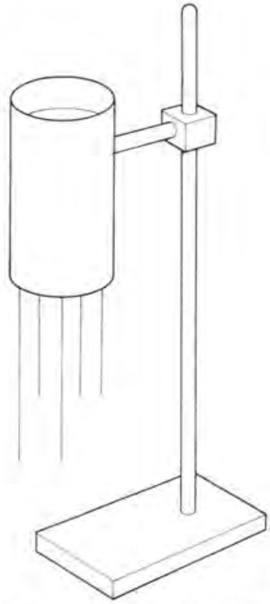
If you like, see what thinner rods do compared with the thicker ones. *Can you think of a commonsense reason for what you find?* Remember conduction of heat along a rod is rather like water flowing along a pipe.

Progress questions

Heat transfer

1. If I stand outside on a cold day, I get chilled. Heat is leaving my body. If I stand in the sunshine on a hot day, I get warm. I am gaining heat from radiation from the Sun. Give as many ordinary examples as you can of heat travelling towards something or away from something.

2. You may have done an experiment with this apparatus.



What did you do? What did you notice? What did you learn from the experiment?

3. We use the word 'conduction' for the way heat can travel through materials when the material itself does not move along. For example, when hot tea is put inside a teapot, the outside of the pot soon gets hot, and we can say, 'Heat has been conducted through the sides of the pot'.

Give at least one more example of heat being conducted.

Give extra examples if you can think of them.

4. In class you did an experiment to find out if heat travels along rods of different materials at the same rate or not.

a. How did you make sure that their ends were equally heated?

b. How did you tell how fast the heat travelled?

c. Which of the materials that you tested was the best conductor? Which was the worst?

5.

a. Copy and complete:

Heat travels quickly through copper. We call copper a . . . .

Heat travels slowly through . . . and we call substances like this . . . .

6. If you don't want to let heat travel easily, you have to use a 'bad conductor'.

a. What could you put under a teapot to stop too much heat getting to the table top?

b. You don't want to burn your hand when you pick up a hot saucepan. What could a saucepan handle be made of to prevent this?

c. Give an example of a useful material to put over your own skin if you don't want heat to get away from your body too easily. Discuss this with your teacher.

7. A saucepan of hot soup is standing on the stove, and has a wooden spoon and a metal spoon left in it. Which spoon handle feels hotter?

Copy and complete:

The heat travels from (*the soup/your finger*) to (*the soup/your finger*).

The metal spoon would feel (*hotter/cooler*) because heat travels (*easily/poorly*) through metal.

The wooden spoon would feel (*hotter/cooler*) because heat travels (*easily/poorly*) through wood.

8. A bowl of custard, with a wooden spoon and a metal spoon in it, has been standing in the fridge. You take the bowl out. Which spoon feels colder?

Copy and complete:

In this case heat travels from (*the custard/your finger*) to (*the custard/your finger*).

So because in a metal heat travels (*easily/poorly*), the metal spoon would feel (*warmer/cooler*).

Questions

9. The materials you felt with your hand in Experiment 136a may have included copper in group *(i)* and plain wood (unvarnished, unpainted, unpolished) in group *(ii)*.

Now try the following simple experiment if you can. If not, try to guess what happens. You need a copper wire about the same thickness as a matchstick.

Cut off a piece the same length as a wooden matchstick. Strike a match and hold the copper with the end right in the flame, keeping both of them horizontal.

The match burns down, but which do you drop first, the matchstick or the copper wire? Fill in the missing words in this sentence as the conclusion to your experiment:

a. Copper is a . . . of heat than wood.

b. Then use this conclusion to account for your observations in Experiment 136a.

10. If Experiment 136a had been done in hot sunshine, then the groups would have to be exchanged: copper and other metals would 'feel hot'; wood and cloth and so on would 'feel cool'. How do you explain this?

Look again at the lists you made when you did Experiment 136a. The substances that felt cold to the touch conducted heat away from your body well. They are good conductors of heat and are good materials for kettles, saucepans, and boilers.

The substances which felt warm to the touch were bad conductors. Some of these are used to keep heat in as much as possible – handles for kettles and saucepans, lagging for hot water cylinders, and so on. Many of these materials contain a lot of air (for example, expanded polystyrene, plastic blanket cloth) and air itself is a very poor conductor of heat indeed.

Question

11. Find out as much as you can about the ways in which heat transfer is reduced in a house. These may use a cavity wall, double glazing, roof-space lagging.

Convection

137 Experiment
Convection

Fill a beaker with cold water and stand it on a tripod. Let the water settle down and then, carefully, drop a single crystal of 'dye' (potassium permanganate) down the side of the beaker. Put a very tiny Bunsen flame under the edge of the

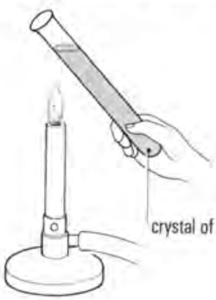
beaker as far away from that crystal as you can get it. *What happens?* Try again with some fresh cold water and a little sawdust, or even some very small scraps of filter paper.

138 Experiment
Heat transfer in a tube of water

Put some cold water in a Pyrex test-tube. To mark any currents in the water, drop a crystal of the dye you used before and let it fall to the bottom.

a. Hold the test-tube with your bare fingers near the top of the water but not above the water level. Heat with the Bunsen flame at the bottom of the tube for as long as you can hold it with bare hands. Then use a test-tube holder. Watch the 'dye'.

b. Pour the warm water away, cool the tube, and refill with fresh cold water. When that water is at rest, add a crystal of 'dye'. Do not stir. Hold the tube *at the bottom* with your bare fingers. Heat with a Bunsen flame up near the top of the tube, just below the water surface. Go on heating and watch.



In your notebook, write down in your own words what you see happening in each case, and draw a small clear sketch of each of experiments (a) and (b).

Then write down what conclusions you can squeeze out of the things you saw. *Just judging from your experiments, can you tell anything about convection? Can you tell anything about any other kind of heat transfer?*

In these experiments the hot water carries its own heat with it when it moves – that is the process we call convection. It may happen in any fluid, whether liquid or gas.

On a large scale, convection happens in the oceans; it happens in the winds. It happens in hot-water heating systems in houses and schools (although the natural convection is often helped along with a pump). It also happens in water-cooled petrol engines.

139 Demonstration
Shadow of a flame

See the demonstration sketched below, in which a small electric lamp casts a shadow of a flame.

You may also see a demonstration in which very light flakes show up convection currents in the air of the room.

Convection currents occur in the room near any warm or cool object. The warm air rises up above the 'convector', and cool air falls down elsewhere, often near the window.

This happens in the atmosphere as well. In the right conditions, convection currents in the atmosphere may be from 5 to 8 kilometres tall. Then they are often accompanied by very large, heaped-up 'cumulus' clouds. See the photograph overleaf.

Of course, as much cold air must come down as warm air goes up, so there is transfer both ways.

Cumulus cloud over Luqa Airport, Malta.
Photograph, R. K. Pilsbury.

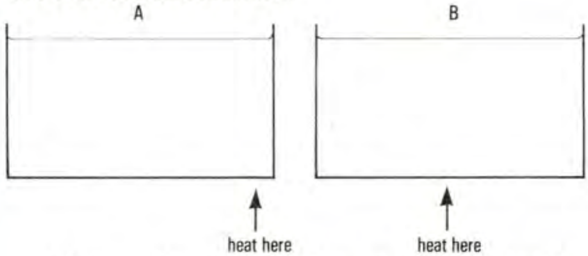
Progress questions

12. You have done an experiment to show the way water moves when it is heated.
a. Draw a labelled diagram of the apparatus used.
b. Why is a coloured crystal put in the water?
c. Show on your diagram how the water moves. The paths which the water takes are called convection currents.
d. Is it just *colour* rising, or are you seeing *water* rising?
e. Is the rising part warmer or colder than the rest of the water in the beaker?

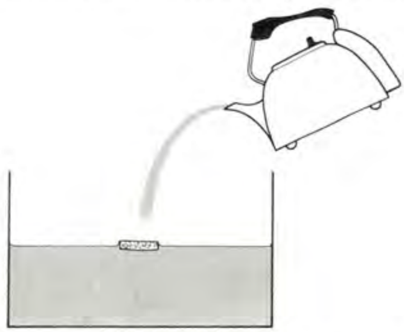
13. This is to help you to understand how and why hot water moves.
a. You pour some oil into water. You stir it up and let it stand. What happens?
b. Which is 'lighter' (less dense) – oil or water?
c. Does the less dense liquid float or sink?
d. Does the oil float, sink or mix with the water?
e. When you heat water, what happens to its volume? Is it more or less dense than cold water?
f. Now copy and complete:

When water is heated it (*expands*/*contracts*) so the molecules get (*more spread out*/*closer together*) and the hot water (*floats up on*/*sinks down in*) the cold water. When the (*hot*/*cold*) water rises, it carries heat energy with it. This movement is called 'convection'.

14. Think about which bit of water gets heated first in diagram A. Which way will it move when it is hot? Now copy diagrams A and B and draw in the convection currents.

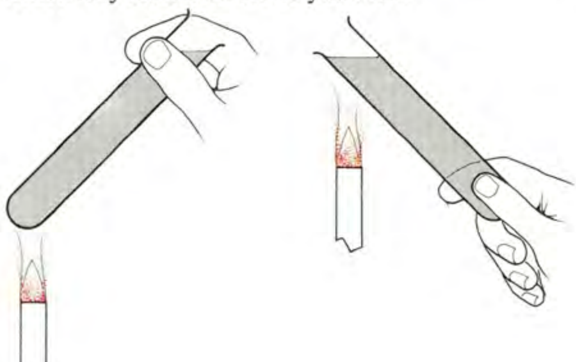


15. (*Try this at home*) Use an empty cocoa tin or similar tin. Fill it three-quarters full with cold water and float a cork in the water. Then pour hot water in a gentle stream on to the cork until the tin is nearly full. Move your fingers slowly up and down the outside of the tin for a couple of minutes.



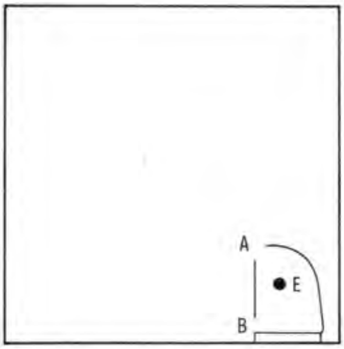
Then pour out the water and start again, but this time start with *hot* water in the tin, and pour cold water in at the top, again pouring gently onto the cork. Feel the outside for a little while.
a. Write down what you *felt* in the two experiments.
b. What difference did you notice the second time?
c. Try to explain this difference.

16.
a. You have a test-tube of cold water. You hold the top end with your fingers and heat the bottom with a tiny flame. What do you feel?



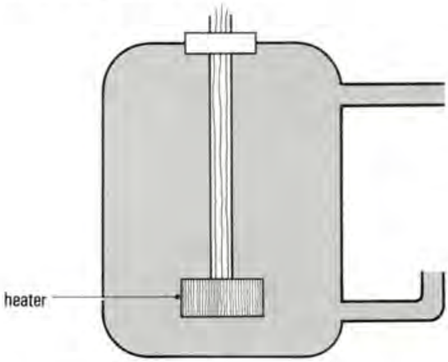
b. You have another test-tube of cold water. You hold the bottom end and heat the top just under the water surface. What do you feel?
c. If the test-tube were made of metal, what would you feel in (b)?

17. Here is a side view of an electric convector heater in a room. E is the hot wire or element.



a. Where does the hot air come out of the heater, at A or at B?
b. Where does the cold air get in?
c. Copy the sketch and draw arrows to show how the air in the room is moving.

18. The diagram shows an electric immersion heater in a big hot-water tank.

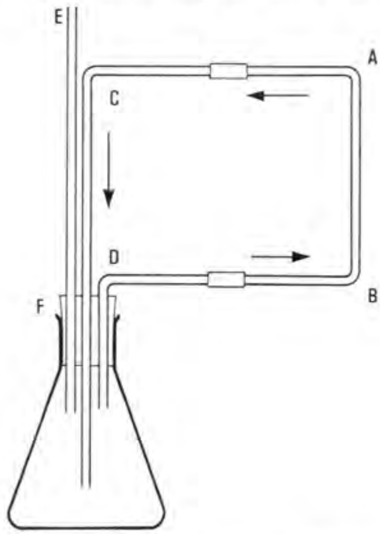


a. The water is cold and the heater has just been switched on. Copy the diagram and draw arrows to show which way the *heated* water moves.
b. After a while, half the water is hot. Copy the diagram again, and shade it to show where the hot water collects. Why does the hot water collect there?
c. The hot tap is turned on, so hot water runs out and cold water runs in. On your *second* drawing, label the hot-water pipe and the cold-water pipe.
d. Put in arrows to show the way the water moves.

19.
a. Air itself is a bad conductor of heat. However, hot-water tanks are often covered with thick padded jackets. Why?
b. Write down another example of a good insulating material being used to stop heat being lost.
c. If you want to keep warm, why is it better to wear several thin jerseys than one thick one?

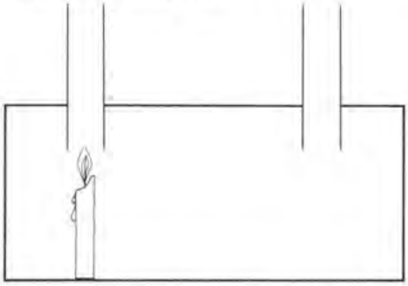
Questions

20. The sketch shows a model hot-water system. Bent glass tubing forms the water circuit.



A few crystals of dye (potassium permanganate) are dropped in to colour the water. When the flask is heated, the water begins to circulate (move round the circuit).
a. Explain why the water circulates.
b. The water will probably circulate in the direction ABCD, but to make certain it is better to warm gently the side AB. What would be likely to happen if you warmed the side DC?
c. What is the purpose of the tube FE? (A tube like FE is fitted in a real hot-water supply system for a house.)

21. A large box has two tubes fitted into the lid. The front is fitted with a glass or clear plastic window. A candle is placed under one 'chimney'. The candle burns brightly.



a. How does the air circulate in the box, and why does it do that?
b. How would you show the air moves like that?

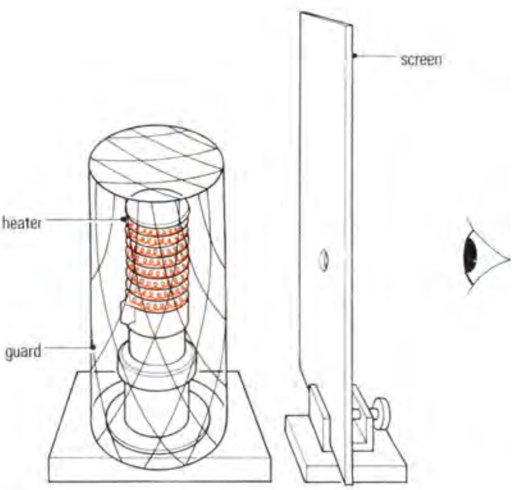
Radiation

Try some experiments with radiation, the third way in which heat is transferred. We get radiation from the Sun, and radiation is another name for sunshine. Much more radiation comes out from very hot things than from cold ones.

Look for some things that radiation can do.

140 Experiment
Detecting radiation

Use an electric heater as a source of radiation.
a. Use your eyes to look at the hole in the screen in front of the heater and see if any red-light radiation is coming through the hole.



b. Use the back of your hand. Hold it near the hole for 2 or 3 seconds and note what you feel.
c. Use your cheek as a detector. Place your face about 25 cm (10 inches) or more from the hole. *Can you feel any warming?* Now hold a book between the hole and your cheek. Take the book away and feel what happens. Put the book back.

Make notes of what you find out.
d. Move your face away from the hole until you can only just feel the warmth from the heater on your cheek. Ask your partner to put a book in the way quite near to your cheek. *Does the warming stop as soon as he does that?*

Now ask him to take the book away. *Does the warming start again immediately he does that?*

Next ask him to put the book in the way quite near to the hole itself and then take it away. *Does the warming stop and start again immediately or is there some delay?*

Suppose that the radiation which warms you travelled quite slowly. *Would the warming stop and start again at once?*

Make notes of your answers.

141a Experiment
Radiation and glass

Hold your cheek 25 cm (10 inches) or more from the hole in front of the electric heater. Hold a thick sheet of glass between the hole in the shield and your cheek. Take the glass away. Put it back. *What do you feel? What does that suggest to you?*

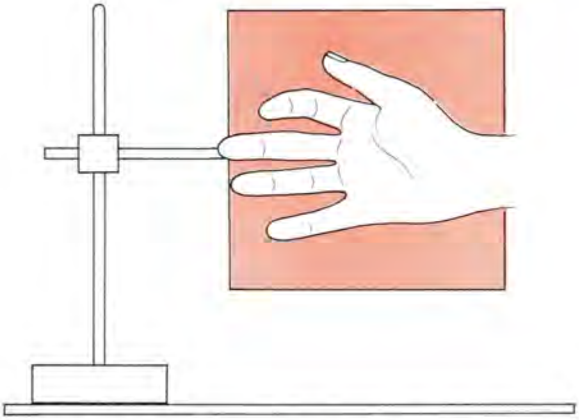
141b Experiment

Now try a different version of Experiment (a). Hold the sheet of glass beside your cheek and move up closer and closer to the hole by the electric heater, keeping the glass between you and the heater. Then take the glass away, only for a second or two.

Can you think what that tells you about the things glass will do with this thing we call radiation? Remember, you can see the red glow.

142 Experiment
Radiation coming from hot surfaces

Is there any difference between how much radiation comes from a bright surface and how much comes from a dull one or a black one? Try to find out by holding the back of your hand near to the sides of



a very hot sheet of copper. One side of the sheet is brightly polished and the other side has been blackened with soot. *What does that tell you about the way radiation comes from hot surfaces?*

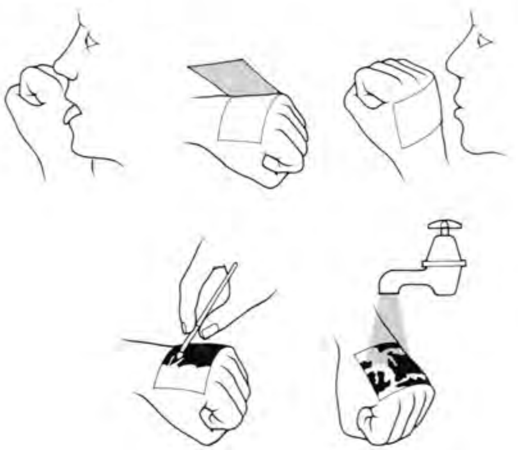
143 Experiment
Receiving radiation

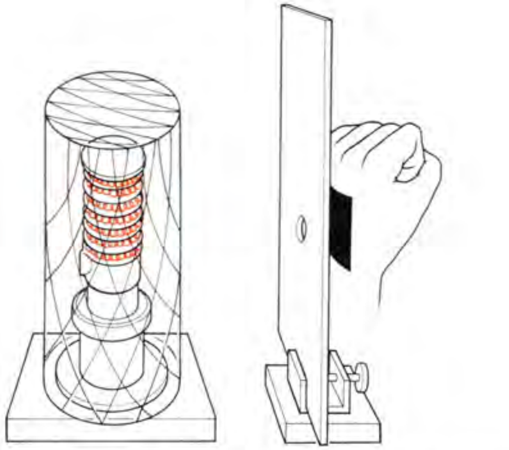
This time go back to the radiation coming out of the hole in the shield. In Experiment 140 you tried placing the back of your hand near to that hole for two or three seconds. Try this again.

Now ask your teacher to change the surface of your hand from bare skin to a 'silver' surface, and then to a black surface. He will cover your hand with some very thin aluminium leaf.

To help him do that, clench your fist and lick the back of your hand until it is wet all over. He will lay the sheet of aluminium leaf on top of the wet skin; and as he does so, you should relax your grip slightly.

Then try holding your hand with the shiny covering near to the hole in the shield. *What do you feel this time?*





When you are quite sure, go back to your teacher. He will coat the shiny metal leaf with some black paint made from soot. When the paint is dry, repeat the experiment by holding your hand just in front of the hole once more. BUT DON'T LEAVE IT THERE FOR MORE THAN, SAY, 5 SECONDS. *What do you feel now?*

NOW WASH THE METAL LEAF OFF UNDER A RUNNING TAP. DON'T TRY TO REMOVE THE METAL LEAF IN ANY OTHER WAY!

This important set of experiments tells you that shiny surfaces send the radiation back. But black surfaces stop the radiation and don't send it back. (That is called absorption.) The result is to warm the black surface up. Black surfaces, which are good absorbers of radiation, also emit radiation very well (Experiment 142).

Progress questions

22.

a. Heat travels by conduction through a copper wire – it cannot travel by convection. Why not?

b. Heat *can* travel by convection in water and in air. Why? (You should think about how the molecules behave.)

c. Heat cannot travel by conduction or by convection in a vacuum. Why not? (You must think what 'vacuum' means.)

23. When you stand in sunshine, you can feel your skin being warmed by something that comes from the Sun.

a. Is there anything between the Earth and the Sun which *conducts* heat to you?

b. Could the heat from the Sun be getting to you by *convection*?

c. The Sun is sending 'rays' towards you which warm you when they reach you. What name do we give to this process?

....

Questions

24.

a. Why are you sure that no heat from the Sun reaches you by conduction or convection?

b. Hold your hand close to an electric lamp without touching it. Switch on for only one second, so that you feel the warmth. Then switch off. Feel the lamp. Is the glass of the lamp warm or cool? Can you be sure that no heat has reached your hand by conduction? By convection? Why can you be sure of this?

c. We say that the warming we notice when we hold our hand near to the electric lamp, or when we sit in the sunshine, is the result of 'radiation' from the lamp or the Sun. But 'heat' is connected with the movement of molecules.

Why can we be sure that 'radiation' is not a process by which heat is transferred?

d. What is the result of receiving (absorbing) radiation at the skin?

25. One of two similar tin cans is bright, the other is blackened in a candle flame. Equal quantities of cold water are put in each; also a thermometer. The tins are placed on the window ledge in strong sunlight.

a. Which tin grows hotter more quickly?

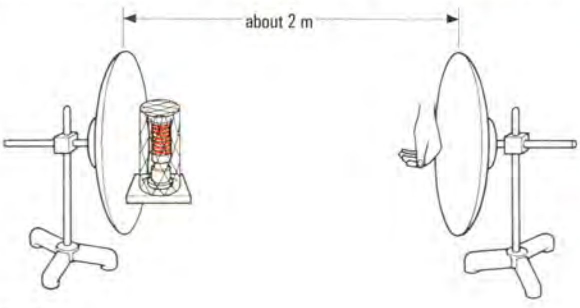
b. If the Sun 'goes in' which tin loses heat faster?

c. Why is this?

Some extra experiments

144 Experiment
The reflection of radiation *(Optional)*

a. You may see a demonstration with an electric heating element which has a curved reflector



attached to it. A metre or so away a second similar reflector is set up. Try placing your hand just in front of that second reflector. *What happens?*

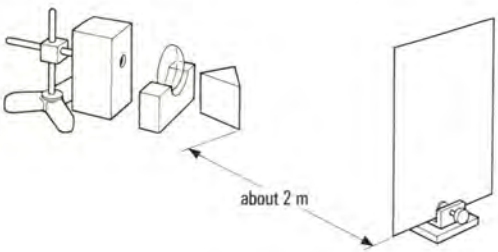
b. You may have a copper box which you can heat by pouring boiling water in it or by passing steam through it. These boxes usually have one face polished, one face blackened, and one face painted white. Using the back of your hand, compare the radiation from the faces of the hot box.

c. Put a thermometer in a bright metal can of hot water and time the water cooling. Then repeat the experiment with the same can after it has been blackened in a candle flame or painted with soot.

d. Some electric lamps have a vacuum inside them; others have a gas. Investigate one which is running by feeling it, carefully, with your fingers. *Can you decide whether there is a vacuum or a gas inside?* This is an example of good scientific detective work.

145a Demonstration
A spectrum

See a demonstration of a 'spectrum'. The radiation from a bright light is passed through a prism and a lens so that the light is focused on a screen. The prism splits up the white light into a band of colours – called a spectrum. *Are there any 'colours' that we cannot see?*



Invisible light? We have been talking about radiation. You know that it comes from glowing things, that it seems to travel straight and very fast, and you know that light, too, does these things. Perhaps light is a form of radiation, too – a form which our eyes detect. And perhaps there is also radiation outside the spectrum that we can see. Our eyes must be blind to that.

145b Demonstration
Heating in the spectrum

Try to stop (absorb) the radiation and look for some heating. *What should we stop it with?* Take a small, very sensitive thermometer and move it along the spectrum.

What colour would be best for this thermometer? Where does the thermometer show most heating – in the visible spectrum, or beyond the red end (= infra-red) or beyond the violet (= ultra-violet)?

....

Progress questions

26. Scientists picture the molecules in a solid vibrating all the time, although they do not move about from place to place.

a. When you heat a solid, what difference does it make to the way the molecules vibrate?

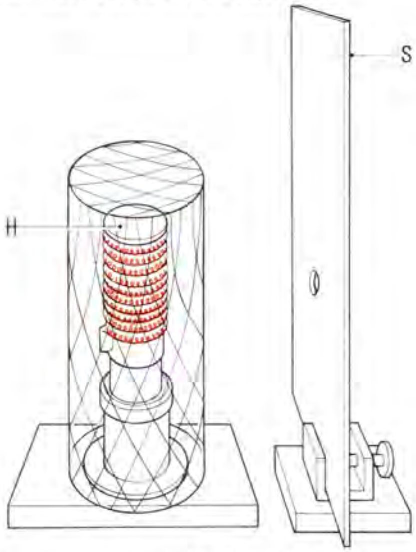
b. You put one end of a cold poker into a fire. What difference does the fire make to the way the molecules vibrate?

c. What will these 'hot' molecules do to their neighbours?

d. How does the other end of the poker eventually become warmer?

e. Why doesn't the handle end of the poker ever become as hot as the end in the fire?

27. H is a red-hot electric heater, and S is a heat-resistant screen with a hole in it.



a. If you move your cheek (or the back of your hand) up and down in front of the screen, there is just one place where you can *feel* the warming from the heater. Copy the diagram, and draw in your cheek where it can feel the warmth.

b. If you move your eye up and down, there is just one place where you can *see* the glowing heater. Copy the diagram again, and draw in your eye where it can see the heater.

c. What do (a) and (b) tell you about the route the radiation takes?

d. You can block off the radiation with a book. When you take the book away, you feel (and see) the radiation straight away. What does this tell you about the *speed* at which the radiation travels?

e. You may have done an experiment putting a sheet of glass in front of the screen. Write a sentence or two about what you did, and felt, and saw. Also say what you can work out from it.

28. Using the same heater and screen, put a thick glass sheet between you and the hole.

a. Can you feel as much heat when the glass is there as when it is not?

b. Can you still see the heater through the glass?

c. Does it make any difference to your answer to (a) if thin glass is used?

d. What can you feel or see if you use a book, or a plank of wood, instead of glass.

29. You are sunbathing; a cloud cuts out the Sun.

a. Your eyes tell you that the light is cut off. Your skin tells you that the warmth is cut off. Do these happen together, or a long time apart?

b. Does this mean that the radiation which warms you travels slower or at the same speed as the light which you see?

30. A big sheet of copper is first heated thoroughly and then turned on edge. One side is shiny and the other side black. You hold your hands near each side of it.

a. Is it fair to say that the copper must be at the same temperature all over, or could part of it be much cooler than the rest? (Remember that copper is a good conductor of heat.)

b. If you put your hands at equal distances from the sheet, which hand would feel hotter, the one in front of the black side, or in front of the shiny side?

c. Would more heat come from the black side or from the shiny side of the copper?

d. Copy and complete:

A hot thing radiates more heat if it is (*shiny/black*) than if it is (*shiny/black*).

31. You have two tins the same size, but the outside of one is shiny and the outside of the other is black with soot. Both tins are filled with boiling water, covered, and a thermometer is placed in each. The thermometers show that the water in one cools more quickly. Which one? And why?

32.

a. What do you see when *no* light gets to your eyes? Whiteness? Blackness?

b. A piece of really black paper is in a lighted room.

(i) Is the paper sending any light to your eyes?

(ii) Does thick black paper let any light go right through it?

33. You have:
an electric heater;
a heat-resistant sheet with a hole in it;
some thin aluminium leaf;
some vegetable black.

a. How would you show someone that shiny surfaces don't take in or absorb much radiation?

b. If these surfaces don't absorb much radiation, what happens to most of the radiation striking a shiny surface?

c. How would you show someone that dull black surfaces are good absorbers of radiation?

34. Copy and complete:

a. When radiation falls on something, more of this heat is taken in (or absorbed) by a (*shiny/black*) surface than by a (*shiny/black*) surface. When radiation is taken in by something, it gets (*hotter/colder*).

b. When radiation falls on a (*shiny/black*) surface, most of it bounces away again; but a (*shiny/black*) surface will hold the radiation.

35. A space satellite is likely to be out in full sunlight for long periods, with no breezes to keep it cool. Should it be made black or shiny on the outside to prevent it getting too hot?

36. Write out the following sentences, putting 'conduction' or 'convection' or 'radiation' in the spaces.

a. Heat gets through the bottom of a saucepan by ....

b. Heat from the Sun reaches the Earth by ....

c. When the water at the bottom of a saucepan is heated, heat gets all through the water mainly by ....

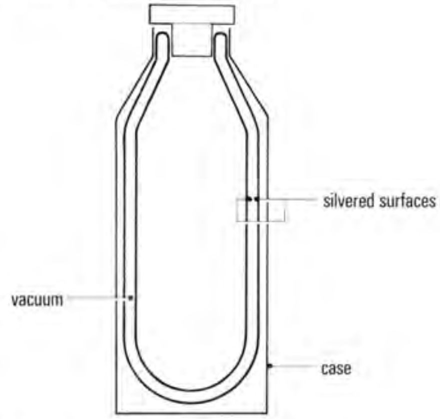
d. If I put my feet on a hot-water bottle, the heat gets into my feet by ....

e. If I hold my hands above a fire, I feel a warm draught of air. This movement is ....

f. I hold my hands in front of a glowing fire, on a level with it. The warmth gets to my hands by ....

g. If a teapot of hot tea is left with the lid off to get cold, the heat is travelling away from it by ... and ... and ....

37. Here is a diagram of a vacuum flask. What stops the hot liquid losing heat:



a. by radiation?

b. by convection and conduction?

c. by evaporation?

38.

a. If you put your hand near the side of a central-heating radiator, do you feel the radiation?

b. If you put your hand the same distance above the radiator it feels warmer. Why is this? (*Hint:* A radiator doesn't give off its heat by radiation only. How else could it lose heat?)

....

Questions

(Some of these questions are meant to start off a discussion rather than ask for a clear 'right answer')

Energy travelling

39.

a. You stand in sunshine and are warmed. The energy warming you comes from the Sun by ....

b. In what form (or in what way) does the energy that warms you travel to you from each of the following:

(i) a hot bath;

(ii) an electric bowl fire;

(iii) a gas fire;

(iv) a hot-water central-heating radiator nearby;

(v) a hot-water bottle warming your feet (in contact);

(vi) hot food burning your mouth.

40. A cake is baked in an oven.

a. How does the heat which bakes the surface of the cake travel to it? Answer this for several different kinds of stove.

b. How does the heat that cooks the inside of the cake get to it?

Radiation experiments

41. You did an experiment with aluminium leaf on the back of your hand. You felt very little warming when your hand was coated with bright leaf and held near the glowing heater.

The explanation of that *might be* that aluminium leaf is a very poor conductor of heat, so that the heating never got through to your skin underneath. What evidence can you quote, *from your own observations*, for or against that? (*Hint :* What does aluminium leaf do to green light or red light, or any kind of light? What do you think it probably did to the radiation that came to it from the glowing heater?)

42.

a. You held your hand near a very hot copper sheet. Which surface gave out more radiation to your hand, the bright one or the black one?

b. Which teapot would you expect to cool faster – a well-polished silver one, or one that had been allowed to tarnish and become grey?

43. Two families, A and B, each build a house with a flat roof. A covers the flat roof with black paint. B covers the flat roof with a very bright, smooth, chromium-plated metal sheet. Except for the different roofs, the two houses are just alike.

a. Suppose at the beginning of a cold, clear night both houses are at the same temperature inside.

(i) Which house will cool faster during the night?

(ii) Describe an experiment you have done or seen which illustrates that.

b. Now, suppose that the two houses are at the same temperature at the beginning of a very hot, sunny day.

(i) Which house will warm up faster?

(ii) Describe an experiment you have done or seen which illustrates that.

Two puzzles

44. Suppose you lived in a room without any fireplace and without any radiator or hot pipes to warm you, except for a steam-pipe that ran through your room from a boiler somewhere else to carry steam to another part of the building.

And suppose that the steam-pipe was properly protected by a wrapping of heat-resistant material with a cover of bright chromium-plate metal outside that. All you see is a bright, fat chromium-plated pipe going through your room.

What could you do, without cutting a hole in the steam-pipe, to get more warmth into your room? (Suggest several things if you can.)

45. You have seen in experiments that a surface which is good at taking radiation and turning it to heat, such as a black, sooty surface, is also good at giving out radiation.

And a surface that does not take in radiation but reflects it (as a bright aluminium surface does) is also bad at giving out radiation.

'Good absorbers are good radiators; and bad absorbers are bad radiators.'

a. If radiation from a glowing electric fire arrives at a sheet of glass, what does the glass do with most of the radiation?

b. Would you expect glass, when it is *very hot*, to be a good radiator or a poor one?

c. Green light is one particular form of radiation which happens to be in the region of the spectrum where your eyes can detect it.

(i) What happens when some green light falls on a sheet of clear glass?

(ii) Is glass a good absorber (stopper) of that particular kind of radiation, or a poor one?

(iii) How do you know?

(iv) Would you expect a very hot sheet of glass to be a good radiator of green light, or a bad one?

(You might test your answer to *(iv)* by heating a piece of glass tubing in a very hot flame. Hold a piece of black iron wire beside it in the flame for comparison.)

Conduction and atoms

46. Pokers for coal fires are usually made of iron. If left with one end in the fire for a few minutes, the end will glow red. It is red-hot. Suppose you used an exactly similarly shaped piece of copper, instead of iron, for your poker.

a. Would it get red-hot at the same time as the iron one? Or later? Or sooner? Explain in two or three sentences.

b. If you wanted to take the copper poker out of the fire, would you expect to be able to grasp the handle in your hand? Explain in two or three sentences.

47. We can explain how heat is conducted through a solid if we imagine that:

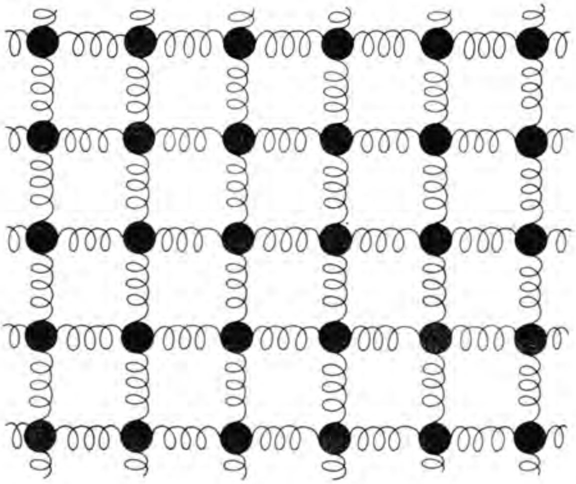
(i) the atoms don't move from place to place but oscillate and 'jig about';

(ii) the hotter the solid the greater this oscillation becomes; and

(iii) the atoms push and pull each other so that their movements can be transferred from one atom to the next.

a. Suppose this picture (or model) is a true one. Describe how energy can travel from the hot end of the poker to the cool end.

b. The diagram shows a web of balls joined together by light springs. Why is this sketch here? Does it help you write an answer to (a)?



Experiments

48.

a. Put a piece of ice in the bottom of a test-tube and wedge it there with a piece of wire gauze. Then fill the tube nearly full of cold water and hold the top part of the tube in a Bunsen flame. What happens to: *(i)* the ice, and *(ii)* the water? Why?

b. Fill another tube with cold water and put a small piece of ice in it so that it floats at the top. Then warm that tube in a Bunsen flame – but at the bottom. What happens this time? Why?

49. This is an experiment which you might be able to do – if not, you can imagine it. Drop a little aluminium powder into a wide test-tube. Then add a drop or two of detergent and fill the tube up with cold water. Cork up the tube and shake it hard. When the powder has stopped swirling around, put your thumb against the side of the tube at the bottom.

a. What do you expect to happen?

b. How do you explain this?

Keeping warm

50. Air is a bad conductor of heat. So air seems a very good material for keeping things warm. But convection takes place in air very readily.

a. Why is wool so good for keeping us warm?

b. Why are two layers of thin material better than a single layer which is twice as thick?

c. Birds 'fluff up' their feathers in cold weather. Why does this keep them warmer?

d. Hot tanks in a house's central heating system are often 'lagged' with glass wool. *Why?*

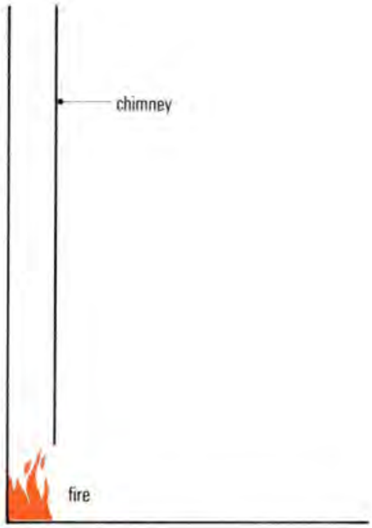
e. Refrigerators, too, are often 'lagged' with glass wool. Why?

51.

a. What part is played in the cooling of many motor car engines by: *(i)* the convection of water, and *(ii)* the convection of air?

b. In this case both forms of convection are best called 'forced'. Explain this.

52.



a. With the help of a sketch similar to the one shown here, explain why a tall chimney helps a fire to burn, and why a fire makes a draught in the room where it is burning.

b. Explain why a fire may be 'sulky' and difficult to get going when first lit, possibly with smoke coming out into the room.

c. If you prevented all draughts in the room with that fireplace, what would happen to the fire, and why?

Radiation

53.

a. Write three or four sentences describing an experiment which shows that radiation and light may occur together, that it seems to travel in straight lines, and to be cut off by obstacles. Suggested apparatus: an electric heater and a heat-resistant screen with a hole in it.

b. Describe a second experiment, with similar apparatus, to show that radiation energy of the same kind need *not* occur with light, but can come from a source which is invisible in the dark. An electric iron is a source like that. Can you name any others?

54. A cold object – anything will do, but let us say a teapot – is placed near an electric fire, or any other type of fire, and begins to get warm. After a time, although it is still much colder than the fire, it reaches a maximum temperature and stays at that temperature so long as the fire is switched on.

a. What can you say about the radiation received by the teapot and the radiation it gives out to the rest of the room while it was warming up *before* reaching the steady temperature?

b. What about the radiation received and given out by the teapot *when it has reached the steady, maximum temperature?*

c. What will happen if the teapot is now moved nearer to the fire?

d. The fire is switched off. What about the radiation received and emitted now?

e. *(This question is more difficult)* The fire has been switched off for some time, the room is cold, and so is the teapot. Is the teapot still emitting radiation? Is it receiving any radiation?

Note As a help in answering (e), consider the following: suppose the room gets a little colder than it was and the teapot, for the moment, is at the old temperature, so that it is a little warmer than the room. What happens? The teapot loses heat. But how did it know the room had got colder and that it ought to start to radiate? Is there a more reasonable explanation?

55. After answering Question 54, you should have no difficulty with this question, parts (a) and (b) at any rate.

a. The Earth is constantly receiving radiation from the Sun, and when the radiation is stopped (absorbed), the Earth is warmed. This goes on all the time. Why doesn't the Earth get as hot as the Sun?

b. Why is the planet Mercury hotter than the Earth whilst planet Jupiter is colder?

c. Our nights are colder than our days, but the difference is nothing like so big as it is on Moon. On the Moon, the day temperature is much greater than it is anywhere on Earth. And at night the temperature is much colder. Can you suggest a reason for this difference between the Earth and the Moon?

d. Why is there much more risk of a frost on a clear, cloudless winter night than on a cloudy one with an overcast sky?

56.

a. Does radiation pass through glass, or is it absorbed (stopped)? *(This question cannot be answered by a simple 'yes' or 'no'. At least two sentences are wanted.)*

b. On a hot day a bus is left standing in the sunlight with all the windows closed. When the passengers are allowed on board, they find the inside of the bus is considerably warmer than the air outside. There is nothing wrong with the bus – why has this happened?

57.

a. There are four ways by which a hot liquid (e.g. hot coffee) can cool down – conduction, convection, radiation, and evaporation. Find out about the inside of a vacuum flask and explain how each of the four ways is kept down to a minimum.

b. Your aunt says it is silly to take ice-cream for a picnic in a vacuum jar because everyone knows that these are specially made to keep things hot. What do you say? Explain your reply.

58. Explain the following observations:

a. In sunshine, dirty snow melts more quickly than clean snow.

b. You sit in the sunshine that has passed through a clear glass window and you soon feel very warm. But glass is also useful as a fire-screen, to screen you from the radiation from the fire.

APPENDIX

Thinking and guessing

Scientists make very careful measurements. They can measure the precise amount of energy needed to melt 1 kilogram of ice. They can measure the size of the Moon accurately, without going there. But scientists also make very rough estimates which are useful in engineering, in industry, in building up science.

Even when they do not know enough for a careful guess, scientists make a guess that is much better than nothing. They know their guess may be three times too big, or three times too small; but still their guess is 'in the right county'. Here is an example:

'How many pairs of spectacles in our school?'

Suppose two pupils try to make a rough guess at an answer.

GEORGE The school's far too big for us to go round looking and counting.

HENRY Yes, but we can look at the pupils in our class.

GEORGE No we can't. They've all gone to lunch.

HENRY Well, we know there are 30 of them, and us.

GEORGE *You* wear glasses. That is 50 per cent of us. We must say 50 per cent of all 32.

HENRY That's silly. You know we don't see half the boys and girls in the room with glasses on.

GEORGE All right. I am sure I see *more than three* – you and two others. And I agree: less that half. *Less than 16* wear glasses.

HENRY You were counting yourself as one. *You* ought to say *less than 15*.

GEORGE That's really silly. We are trying to make a guess for the whole school; and you are fidgetting about the difference between 16 and 15 out of 32. It will have to be a *rough* guess anyway.

HENRY You say *more than three*. We both say *less than 15 or 16*. Would you agree to 'about ten'?

GEORGE Yes. That's one boy or girl out of every three or so. But that's only for our class.

HENRY We had better guess the same for the whole school. Our class is like the rest.

GEORGE How big *is* the whole school?

HENRY There are four science classes. We are in one of them.

GEORGE We must work out four times 32.

HENRY No. This is going to be a rough guess. So four times thirty is near enough. In fact it's more honest. Choosing an easy number shows we remember it is to be a rough guess. Then there are 4×30, that is 120 pupils in our year.

GEORGE In this school, we come in at 13 and stay three years. There must be three times 120 altogether.

HENRY Don't forget the teachers. A lot of them wear glasses. Some have two pairs.

GEORGE Yes. Three times 120 for pupils is nearer 400 than 300. Let's lump the teachers in and say 400 people of all ages.

HENRY Then glasses for one out of every three. $400 \div 3$ makes about 130.

GEORGE Have we got it right?

HENRY We can't be sure but I bet we are not far wrong. I feel safe in betting it's more than 100 and less than 200.

(Their science teacher would express that estimate as 150 ± 50.)

We often have to make rough estimates like that in science. Try your hand at some of the ones asked for below.

Making rough estimates

(These are things to try in class or to think about at home)

Choose any two of the following things; and in *each case* make the best rough guess you can. That is something a good scientist often has to do.

How many eggs does a good hen lay in one year?

How many hairs are there on your head?

How many grams of stuff in a man's felt hat?

How many eggs do you eat in one year?

How many pencils are there in a kilogram of pencils?

How many electric lamps are there in your school?

How many cars pass your house in a day?

How many letters does a postman deliver in a week?

More estimates

Choose any two of the following which you have not tried before. Do the same for them.

How many teaspoonfuls are there in a cup of tea?
How many square millimetres are there on the surface of your finger nail?
How long would it take you to read aloud one page of a novel?
How long would 100 heartbeats take (when you are not frightened)?

This volume contains the introductory course of revised Nuffield Physics and it is intended for children aged between eleven and thirteen. The main titles of the chapters are for Year 1: Materials and molecules, Weighing small things, Rough measurement, Balancing a seesaw, Investigating springs, Air pressure and molecules, Measurement of a molecule, and Energy–a first look. For Year 2 they are: About forces, Electric circuits, Electric currents, More about forces, Using energy, Warming things up, and Heat transfer. There is also an appendix entitled Thinking and guessing.

General Editors
Eric M. Rogers
E. J. Wenham

Contributors
H. F. Boulind
Margaret Fawcett
Reinet Fremlin
Gwen Jones
Hilda Misselbrook

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