CHAPTER 5

GASES

Molecules in motion; molecule models; behaviour of gases

BEHAVIOUR OF GASES AND A PICTURE OF MOLECULES

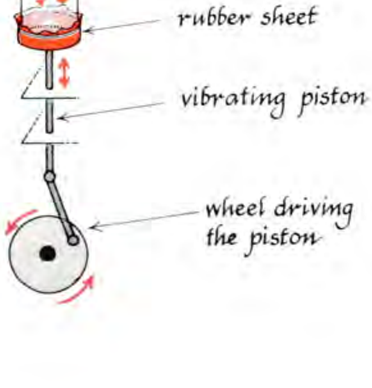
Experiments for catching up for revision

(If you HAVE NOT done these experiments before, you should try them now. If you HAVE done them before, there is no need to repeat them unless you wish to do so.)

Models We picture gases made up of tiny particles—molecules—in continual motion. When molecules collide with the walls of the container and bounce away, that makes the gas pressure. This is our 'thinking-model', our theory.

Demonstration 78
Model of Air Molecules

Watch the model sketched. That is a 'teaching-model'. Small balls are kept in motion by a vibrating piston. *Is this a good model of the atmosphere? Does the population density of 'molecules' in the model stay the same as you go up higher and higher?*



The real molecules of the walls of a room must settle down to being as hot as the air in the room. They are in constant vibration; so that when hit by an air molecule, they 'give as good as they get'.

From an air molecule's point of view, the wall is a sea of atoms bouncing about with a great variety of motions. Those motions are so violent that an air molecule arriving at the wall is bounced away with the same motion energy, on the average.

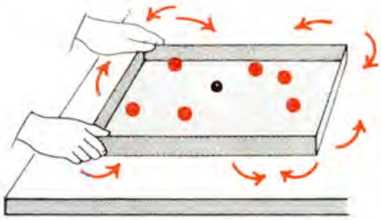
If you put a lot of warm air in a room with *very cold walls* the air molecules would soon lose some of their energy by giving it up to the walls. In the model, the balls find the walls 'cold'; and the 'cold' walls carry energy away. That is why we have to keep on supplying energy from outside if we want the model's 'molecules' to remain 'hot'.

But real air molecules in a room with warm walls have no opportunity to give energy away; so they keep going without help.

Why don't air molecules all fall down to the ground? Think of a sample of air some way up from the ground. That sample does not fall down crash to the ground. Molecules *below* it must somehow push it *up* more than the molecules *above* push it *down* with collisions. Yet the molecules below are no more violent, no hotter. Try to guess how it is that a molecule gets a supporting push upward on the whole. This is a puzzle for you to think about. (There would not be much point in just being given the answer; so keep it in mind and see whether you can puzzle out an answer. Test your answer by looking at the model you have just seen. Or test it with your own tray model (the next experiment).

Experiment 79
Marbles in a tray

Put two dozen marbles in a tray, to represent air molecules in the room—or any gas molecules in a box.

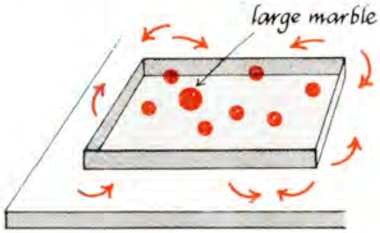


(i) Agitate the tray by sliding it about on the table with a rapid irregular shaking motion, to imitate the hot walls of the room. Watch.

(ii) How can you illustrate higher temperature?

(iii) Can you hear the different kinds of collisions, some on the walls, others between marble and marble?

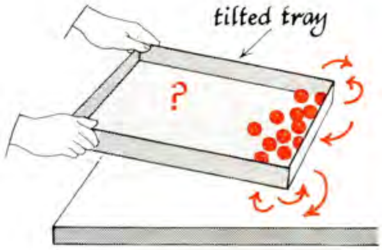
(iv) You can imitate the atmosphere, with its population thinning out higher up, by giving the tray a *very slight* tilt, and then keeping it tilted while you agitate it.



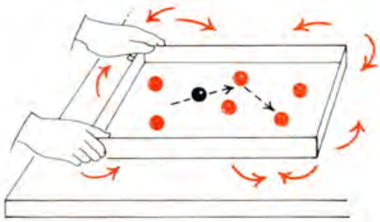
(v) Place a larger object, such as a big marble, among the marbles and watch what happens to it when you agitate the tray. That suggests what might happen to something much larger than an air molecule, if it is floating in air. You can see that by watching tiny specks of white smoke in air.

(vi) For a model of a compressed gas, add more marbles and agitate the tray. Crowd all the marbles into half the tray, with a ruler. Continue to agitate the tray and see the gas expand when you remove the ruler.

(vii) To make a model of a liquid add still more marbles; then tilt the tray and agitate it to make 'liquid with vapour above it'.

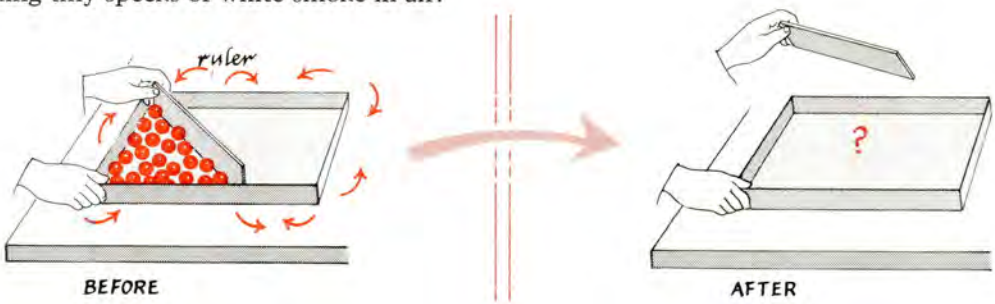


(viii . . .) There are still more things you can do, such as watching one particular marble.



Home Experiment H79
Model of Air Molecules

You might show this model at home and use it to illustrate many ideas about molecules. If so, you need a metal tray or a glass dish with *vertical* walls; because slanting walls do not bounce marbles back well enough.



Imagine a model Suppose your whole class wished to act a pantomine model of a gas. Pupils would have to slide about the room at random, on frictionless shoes, often colliding with each other. They would bounce away after a collision and continue to slide.

They would also collide with the walls of the room sometimes. You would have to borrow pupils from other classes to make the 'walls'. They should stand round the edges of the room, linking arms, closely packed together—as molecules of a solid must be.

If those wall 'molecules' all stayed still you would lose some motion-energy to them each time you collided with them—then you and all your fellow 'air molecules' would soon come to a stop. That would be like putting real air molecules in a container with *very cold* walls. But the real walls of a room are as warm as the air in it. So the close crowd of pupils who represent the walls would all have to be bouncing about, vibrating violently. Then at a collision that 'wall' could 'give as good as it gets'.*

Think of that human model of gas molecules: you and your class sliding about, colliding with each other without loss of energy and bouncing off the vibrating 'walls' without loss. Now suppose you wanted to represent a *hotter* gas. *What would you have to do?*

Suppose you put an elephant in the middle of your human model. *What would happen to him? What would that be a model of?*

*That is why you have to agitate your tray and marbles model all the time. The tray's walls and floor are not like the walls of a warm room: instead they carry away motion-energy. So you have to provide a continual supply of energy because the marbles give away energy in hitting the walls, in scraping the floor, and in warming the surrounding air.

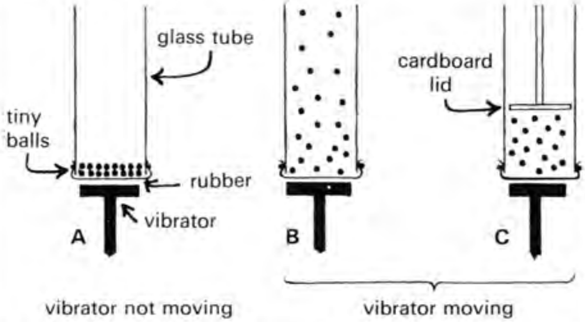
Progress Questions

MODEL OF A GAS

1. Molecules of a gas are continually dashing about at high speed, crashing into the walls of their container. The millions of crashes in a second make a steady outward push or pressure.

You can use a tray of marbles as a simple model of a gas.

How can you make the pressure of the marbles against the walls of the tray bigger? That is, how can you make crashes happen more often? (Try to think of more than one way.)



2a. In which of these are the little balls moving?

b. What makes the little balls go up, and why do some go higher than others?

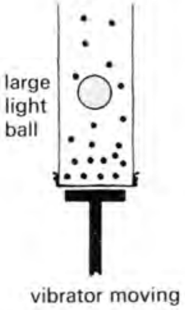
c. What keeps the cardboard lid up in C?

d. What differences does it make in C when you make the vibrator go

(i) faster

(ii) slower?

e. This apparatus helps us to understand about gases. In a real gas what corresponds to the little balls?



3a. What do you see the big ball doing?

b. What makes it do this?

c. How can you make a similar model to this, with a tray of marbles? What do you see?

Questions

GAS MODELS

(Do not answer these questions until you have seen the model with balls in a tall tube working.)

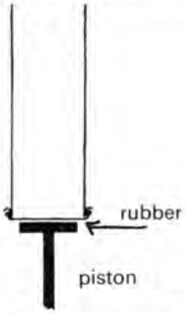
4. The diagram shows a wide tube with a base made of sheet rubber. The base is kept in rapid up-and-down motion by a vibrating piston. A lot of small balls are placed in the tube.

a. Sketch the tube, showing the balls inside when the vibrator is in motion.

b. Describe the position of the balls in your sketch (not more than two or three sentences).

c. In what way do the balls in the tube resemble the molecules of air in the atmosphere?

d. Mention some differences between this 'atmosphere model' and the real atmosphere of air.



5. The diagram shows a paper disk with a thin wire handle. The disk can be put in the tube to act as a ceiling or piston. First the vibrator is stopped and the balls lie at rest on the rubber. The disk is put in and falls down the tube till it rests on top of the balls.

a. What happens when the vibrator is switched on?

b. What happens if the agitation of the vibrator is made more violent?

c. What happens when a small extra load is put on the disk?

d. The balls in the experiment (Q.4), without the disk, resembled molecules in the atmosphere—in fact, that is a model of the atmosphere. What is this apparatus, *with* the disk, a model of?

6. Suppose you use the apparatus of Q.4 again. You put in one ball which is larger and heavier but still quite a light ball. The small balls are still there. What happens to this larger ball when the vibrator runs?

7. *(Model with marbles in a tray. Do not answer these questions till you have experimented with the model.)* You put some marbles in a tray and shook it to and fro.

a. What did the marbles do? (Tell this in a few words or make a rough sketch.)

b. What were the marbles meant to be a model of?

c. You started the marbles rolling by giving the tray a shove. What would the marbles do if you left the tray alone after that?

d. To make this a good model of the air in a room, you had to *keep on shaking the tray*. Why was that?

e. Suppose you put something larger in the tray, among the marbles (a box of matches or a larger marble). You could watch the larger thing while you kept the marbles moving. What would you see? That would be a model of something you saw in another experiment, a model of . . ? . . in air. What?

f. Suppose you almost *filled* the tray up with marbles, putting in almost as many as you could to cover its surface. You could still shake it and keep the marbles jostling. What would *that* be a model of?

g. When you had a few marbles in the tray and kept it shaking, what did you hear when you listened?

h. If you put twice as many marbles in the tray and shook it and listened the sounds you heard would be different. In what way different?

8. You are given a number of marbles and a suitable metal tray. Describe how you would use them for each of the following.

a. To illustrate what happens when gas molecules are in a box and the box is suddenly made twice as big. HINT. Imagine you start with all the marbles crowded into one half of the tray, by a ruler.

b. To illustrate a tall 'atmosphere' of molecules.

Brownian Motion

Experiment 80
Evidence of Air Molecules in Motion

Look at some smoke in a small tower (cell) in a black box. Smoke is made up of tiny specks of white ash, floating in the air. Watch the specks of ash with a microscope. You will see a strange motion; and you may believe you are seeing the effects of bombardment by invisible air molecules.

This is called 'Brownian motion', after the botanist Brown, who discovered it and thought at first he was seeing living things.

If you have not seen this before and clearly understood it, YOU SHOULD SEE IT NOW with a good microscope.

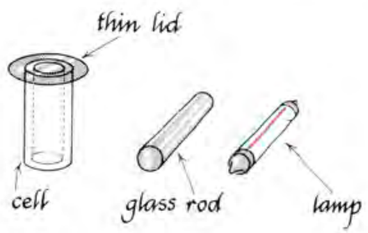
Microscopes need great care. To focus the microscope you must use a special method to keep the valuable lens from being hurt. If it touches the slide or some object on it it might be scratched. Squat down till your eyes are level with the smoke cell. Move the body of the microscope very slowly down until the bottom of the lens *almost* touches the cell. Then sit or stand and look through the microscope; and *raise* the body of the microscope until you see the smoke specks in focus.

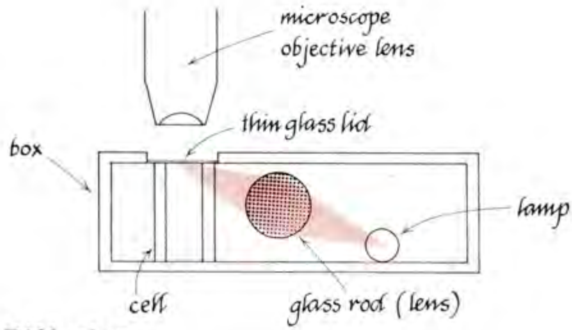
Put some smoke in the cell; or ask your teacher to do that for you. Then take plenty of time to watch the specks of ash. Think of the path that you see one speck take in the course of, say, a $\frac{1}{4}$ minute. *Could you draw it?*

If you see large round blobs of light you are looking at specks out of focus.

If you see all the specks marching across, that is just a hot-air current.

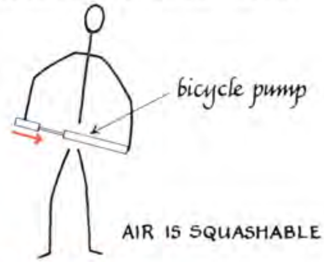
Evidence? This is the nearest thing to first-hand evidence of molecules that you are likely to meet; and it would be a great pity just to take it on trust from a book, or only to see it in a film, when you could watch the real thing with a microscope.





Diffusion

How do gases mix? Gases feel squashy. They are easily compressed to smaller volume. So we picture them made of tiny molecules far apart. Then if we give two gases a chance to mix, the molecules of each can wander through the spaces between the molecules of the other.

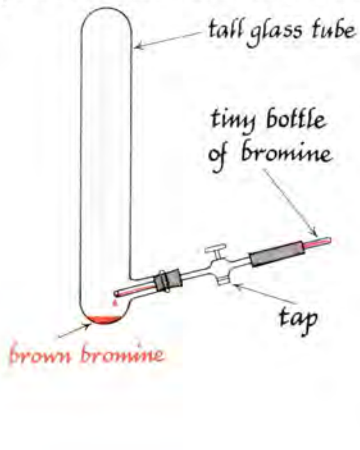


Demonstration 81a
Bromine 'Gas' Diffusing

Watch the progress of brown bromine vapour as its molecules diffuse through air. Unless you have seen that in an earlier Year, you should ask if you can see it now. (It will be used for an 'atomic' measurement in a later Year.)

Demonstration 81b
Another Experiment with Bromine?

Bromine molecules are more massive than air molecules, so their speed is smaller at the same temperature. Even so, they move very fast. (The method you will meet in a later Year predicts



average speeds of 500 metres/second for air molecules, 200 metres/second for bromine. Those are about 1800 kph or 1150 mph for air; 720 kph or 460 mph for bromine.)

When you have seen bromine diffusing through air, SUGGEST THE NEXT EXPERIMENT YOU WOULD LIKE TO SEE WITH BROMINE and see that too.

Progress Questions

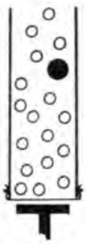
BROWNIAN MOTION

9. You have looked at smoke particles with a microscope.

a. How did you get the smoke particles?

b. How did you get enough light to see them separately?

10. You have looked through a microscope to watch smoke particles in the air.



a. What did they look like through the microscope?

b. Describe the way they moved.

c. In the model in the diagram, the big ball jiggles about because the tiny balls are moving all the time, and keep bumping into it.

Copy and complete:

In the smoke cell, the smoke particles are like the [/*big ball*/*tiny balls*/] in the model, and the air molecules are like the [/*big ball*/*tiny balls*/]. The smoke particles jiggle about because . . ? . .

GASES MIXING

11. *(Did you see bromine liquid turn into a brown gas in a tall tube? If so, try this question.)*

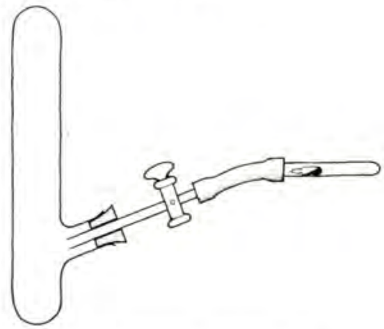
a. Fig. I shows the apparatus *before* the brown liquid was let into the tall tube.

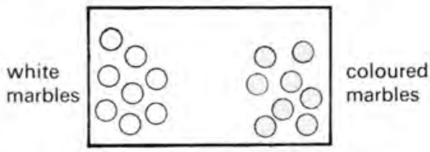
Make 3 copies of the tall tube alone as in fig. II. Mark your copies with pencil or crayon to show the liquid and brown gas:
(i) just after the liquid was let in;
(ii) about 1 minute later;
(iii) about 10 minutes later.

b. Guess what the tall tube would look like if you kept it for a whole day without moving it.

c. We believe the molecules of brown bromine gas move very fast (average speed 200 metres per second). What made them move differently from that in the tall tube? (HINT. Look at your answers to (a) and think about them.)

d. Did you see a second experiment with bromine? If so, say what happened.





12a. This is a tray of marbles. Draw it to show how it looks after it has been shaken for a while.

b. This is a model of the bromine experiment in Q.11. What do the coloured marbles correspond to? and the white ones?

c. In the bromine experiment we kept the tall tube still. Why did we not need to shake it?

d. How does this model help you to understand what is happening in the bromine experiment?

Questions

BROWNIAN MOTION

13. You can use a microscope to look at smoke specks in a small box. You could see a few of those specks of ash doing something that we call the 'Brownian motion'. *(If you have actually seen this experiment try the questions below. You should not try them if you have only heard about the experiment, or just read about it.)*

a. Describe *(i)* in words, *(ii)* by a sketch, the motion of one speck. (Make the sketch big enough to show the story.)

b. Explain why the motion of the ash specks suggests that air molecules are also in motion.

c. If you watch smoke specks of different sizes, you may notice that they seem to move with different speeds. Which do you think moves faster, a large speck or a small one? Arguing from your answer to that, do you think air molecules move much faster than the smoke specks, or much slower, or at about the same speed? (Remember that air molecules are too small to see, even with a powerful microscope.)

14a. Particles larger than the smoke specks you looked at would be easier to see. What two disadvantages would there be in using larger particles? (Guess.)

b. Suppose you hang a table tennis ball on a long fine thread in a closed room with no drafts in it. Would the ball remain *completely* at rest?

c. Write a sentence or two explaining your answer to (b).

15. In modern science, we picture air and other gases as made up of many molecules, each invisibly small, and moving at high speeds in all directions.

Gas pressure is made by bombardment by molecules. Molecules hit the walls of any container and bounce away again. And those hits, add up to make a steady pressure.

Why is that pressure quite steady—not jumping like the Brownian motion of a smoke speck?

16. Suppose someone feels doubtful about the 'picture' of molecules in gases, and asks you 'Why do you believe that?' What have you seen to support that idea?

17. *(ADVANCED)* Gases can turn to liquid if you cool them enough. (Example: steam condenses to water.)

What happens to the molecules of a gas when it turns to liquid? Are they still there? What do they do? Make guesses. Imagine a picture of liquid greatly magnified and sketch your picture.

18. You agitate a tray, containing many white marbles. There is also one red marble of exactly the same size and mass as the white ones. You continue to agitate the tray.

a. Sketch a tray about 10 cm long (4 inches); and draw a line to show a likely path you might see the red marble following.

(You need not draw the other marbles, and you need not draw the red marble either—just draw a line to show a likely path for it as it flies along among the other marbles making collisions sometimes.)

b. Would one of the white marbles follow the same kind of path as the red marble? Or would you expect it to behave differently? Give a reason for your answer.

c. Suppose you take out the red marble and put in a *larger* green marble having much more mass than a white marble.

(i) Would the path of the green marble *look* different in any way from what you drew for the red marble in (a)? Describe any difference you expect to see.

(ii) What does a smoke particle do when it is among air molecules?

DIFFUSION

19. *(If you saw liquid bromine released in a tall tube of air, try this question.)*

a. Describe what you saw happen when the liquid bromine was let into the tall tube.

b. *(ADVANCED)* Suppose both bromine and air molecules were *much* smaller than they really are—just pinpoints—so that they had very little chance of colliding. Would you expect to see what you saw in the experiment? If not, what would you expect to see?

c. *(ADVANCED)* Think about your answer to (b) and about the real experiment. Can you guess something about gas molecules?

20. *(If you saw a second experiment with bromine, in which a vacuum pump was used, try this question.)*

a. Describe what was done.

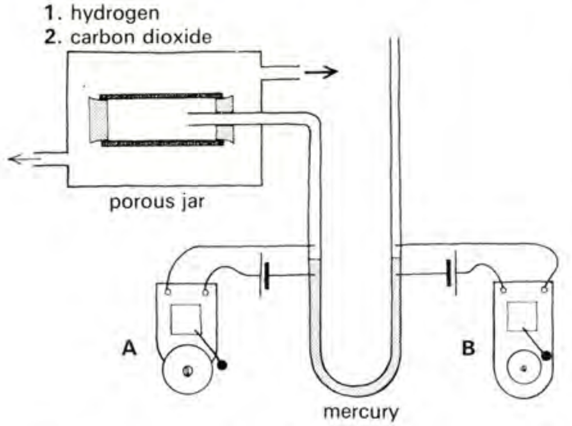
b. Describe what you saw happen.

c. Say what that told you about bromine molecules. (As a good scientist, you should be careful only to say what you found out from the experiment.)

21. The diagram on the next page shows an apparatus including two electric bells A and B. Each bell, with its battery, is joined to two wires sealed in the side of a U-tube. The tube contains mercury. A is a big bell that rings with a deep bass note. B is a little bell making a high note.

One side of the U-tube is open to the air. The other side can be joined to a closed porous jar—

that lets air leak through, like a flowerpot. At first there is air *inside* the porous jar *and outside* as well.



a. When the porous jar is first shoved onto the tube bell B rings. Why?

b. After a short time the mercury comes to the same level on both sides and bell B stops ringing. Why does the mercury return to equal levels?

c. Hydrogen is now passed in a very slow stream through the box surrounding the porous jar. What happens then and why?

d. The box containing the hydrogen is removed, and the porous pot is just held in air. What happens and why?

e. The box surrounding the porous jar is put back (after the hydrogen has been emptied from it) and carbon dioxide is passed into the box. What happens and why?

Progress Questions

MATERIALS AND HEATING

22. Make three lists in your book, of

(i) solids,
(ii) liquids,
(iii) gases.

(Choose the ones you know about, or meet at home; NOT strange ones from a book.)

23. When you heat solid candle wax, it turns into liquid candle wax.

a. Make a list of other solids that melt into liquids when you make them hotter than the room.

b. Make a list of liquids that turn into solids when you make them colder than the room.

24. When you heat liquid water, it turns into a vapour (like a gas) and that goes into the air.

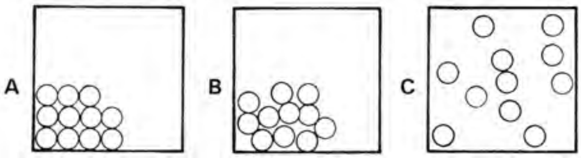
a. How do you know the water turns into a gas? (Guesses and reasons welcome.)

b. The gas from water is called water vapour. How can you turn it back into liquid?

c. Have you seen any other liquids turn into vapour or gases? If so, give their name(s). If you can, say how you can tell they make a gas.

SOLID: LIQUID: GAS

25. Here are some sketches of marbles in trays.



a. Which of these gives us a picture of molecules in a liquid: A, B or C?

b. Which of these gives us a picture of molecules in a gas?

c. Which of these gives us a picture of molecules in a solid?

d. If you were handling the trays, what would you *do* to change the 'solid' model to a 'liquid' model?

e. What would you do to change the 'liquid' model to a 'gas' model?

26. Copy the remarks below and continue the story. Say as much as you can about how we think the molecules move:

a. In a gas, the molecules . . ? . .
When you heat a gas, the molecules . . ? . .

b. In a liquid, the molecules . . ? . .

c. In a solid, the molecules . . ? . .
When you heat a solid . . ? . .

27. What would you do to change ice to water? What would you do to the water to change it to vapour (gas)?

HEATING AIR

28. You close the lid of a cocoa tin and put it on a tripod with a bunsen flame beneath it.

a. What is likely to happen?

b. We think that heating the tin makes the air molecules move faster. How does this lead to the result in (a)? (HINT. There are *two* good answers.)

Questions

HEATING A GAS

29a. The lid is put firmly on a clean 'empty' syrup tin. The tin is placed in a hot oven. What happens? (As usual, an 'empty' tin contains air.)

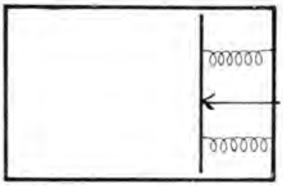
b. Then what can you say happens to the pressure of air in any closed box when the air is heated?

c. At 9 a.m. in the morning, before setting off on a long drive, a man tests the air pressure in his car tyres. They all show 17 N/cm^2 ($\approx$ 25 pounds per square inch) on his gauge. He drives for three hours, then tests the pressure again. It is 20 N/cm^2 ($\approx$ 30 pounds per square inch.) Explain this change.

Questions for Thinking Ahead

PRESSURE IN THE MARBLES MODEL

30. *(The experiment described here is a 'thought-experiment'. You are not likely to have done it but you can easily suggest what would happen if you did do it.)*



This is a tray with marbles. The marbles are kept in the tray by a 'movable wall' at one end held in position by two springs. The diagram shows the position of the movable wall when the tray and marbles are agitated.

a. What happens if the agitation is increased by shaking more violently?

b. What happens if the agitation is slowed down? Stopped altogether?

c. What happens to real gas molecules if the gas is made hotter?

d. What happens to the pressure which a gas exerts on the walls of a container if it is made hotter?

e. Did you see an experiment that illustrates your answer to (d)? Describe it (or sketch it).

31. In answering Q.29a you might conclude that the pressure of the air is increased when it is heated. In Q.30 we concluded that the 'pressure' of the marbles increased when they were agitated more strongly.

a. How do we explain the fact that a gas such as air exerts pressure?

b. What, then, do we think happens to the motion of gas molecules when the gas is warmed?

c. What happens to the motion of molecules if the temperature of the gas falls?

ABSOLUTE ZERO?

32. *(This is a question for 'guessing ahead'—a good scientific road to discovery. Guess now, then wait for clearer answers later when you have made measurements and discussed them.)*

a. Following from Q.31c, guess what 'absolute zero' of temperature might mean for a gas.

b. Why would real gases not follow your guess if they were cooled down towards absolute zero? Guess what air and carbon dioxide actually do. (HINT. Steam from a boiling kettle is like a gas form of water. What happens when . . . ?)

c. *(ADVANCED)* The idea of 'absolute zero' of temperature, applied to gases is useful. Can you foresee a use?

Heating a Gas

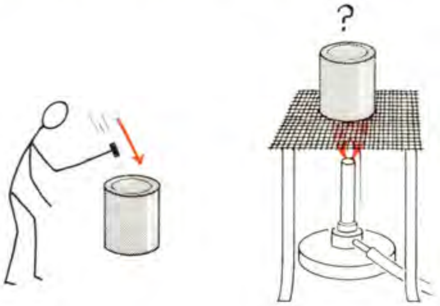
What happens to the PRESSURE of air when it is heated? The answer is 'nothing', if the sample is open to the atmosphere! If you heat a sample of air or another gas in a loose plastic bag (or in a syringe with a free piston) it will just increase its volume. It remains at atmospheric pressure.

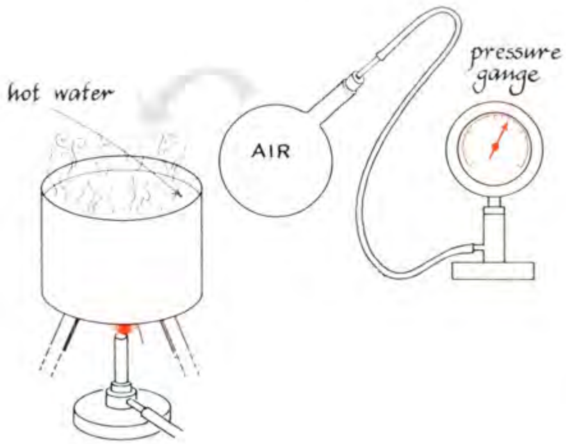
But what happens if you don't let the air expand but keep its volume constant?

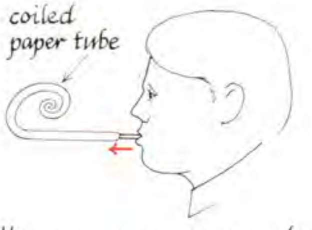
Demonstrations 82 and 83
Air heated but not allowed to expand

You may see one or both of the experiments sketched.

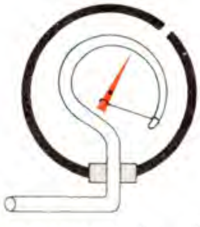
Heating and molecules What happens to the pressure of air *when heated like that?* If pressure is just the result of molecules bombarding the walls, *why does the pressure change?*







How a pressure gauge works


Pressure gauge seen from the back

How can the molecules make a bigger pressure? There are just as many as before. (We doubt if the heating can manufacture extra molecules.) So the same lot of molecules make more pressure. How?

Discuss your reasons with your teacher.

Imagining and guessing What must happen to the *motion* of air molecules when you heat some air? What happens to their motion when you *cool* the air?

Think of cooling the air in a bottle more and more: colder . . . colder . . . colder . . . Could you cool it till its molecules had no motion at all?

Suppose there were such a temperature, somewhere far down on the scale of the thermometer, at which molecules would have (for practical purposes) no motion. What would the PRESSURE be like at that temperature? . . .

Of course before they got down to that temperature real air molecules would form a liquid and then a solid. Yet you can imagine an 'ideal' gas; and discover what the temperature *would* be at which that gas would collapse with no useful motion.

Even real air can help you to find out about that strange interesting temperature by doing your own experiment.

Watch how the pressure of air in a closed bottle changes as it cools down. Then calculate on down to find out the temperature at which the gas *would* have no pressure (if it continued its simple behaviour!).

Experiment 84
Measurements on Air being heated

Try the experiment sketched. Make sure that ALL the flask, INCLUDING ITS NECK, is under water—otherwise your measurements will have little value.

Take a few pairs of measurements of TEMPERATURE of water and PRESSURE of air sample shown by the gauge. Stir the water thoroughly, all the time.

Take the flame away and continue stirring for a minute or two before you take each pair of measurements. The air in the flask takes time to catch up with the temperature of the water.

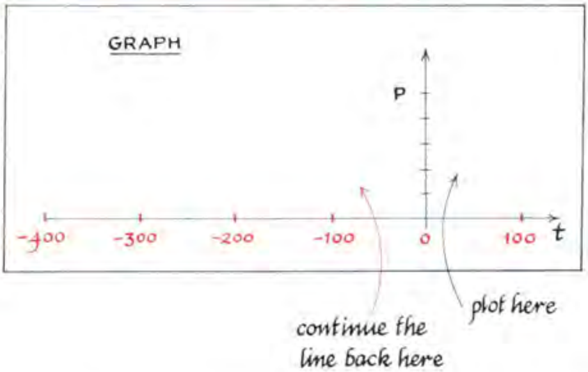
Plot a graph of the measurements, with PRESSURE upwards, and TEMPERATURE along.

Thinking about the Gas Pressure Experiment

Ideal gas: absolute zero? Now try continuing your graph-line backwards to find the very low temperature at which the air in the flask *would have no pressure at all.* (That is, if the air kept up its simple behaviour.)

We call that temperature 'absolute zero'.

Experiment 84X
Graph of [Experiment 84 + Imagination]



Plot your own measurements again, with different scales:

the vertical scale, for PRESSURES, must run all the way from 0 to the highest pressure you measured

the horizontal scale, for TEMPERATURES, must run to the right of zero up to the highest temperature you measured; but it must also extend to the left of zero to about -400 °C.

Plot your measurements and draw the fairest straight line.

What does *your* line give you for 'absolute 'zero'?

(Carrying the line all that way back cannot give a very accurate estimate: you should be charitable towards your own experiment.)

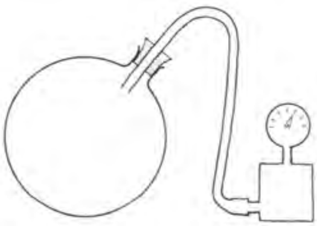
Ideal gas: real gas? If you tried to cool down a sample of real air, it would collapse to a liquid long before it reached absolute zero.

Scientists find it useful to imagine an 'ideal gas' which would continue the simple behaviour right down to 'absolute zero' at which its pressure would be 0. Its molecules would have to be extra simple in *behaviour*. We find that some real gases (including air) are not very different except when very cold.

Progress Questions

AIR PRESSURE AND TEMPERATURE

33. A round flask is closed with a bung and tube which joins it to a pressure gauge. Before the gauge was joined to the flask, the reading on its scale was 1.0 because it was open to the atmosphere.*



a. When the pressure gauge is joined to the tube, what will it read?

b. You put the flask into boiling water. Will the pressure gauge reading go up, go down, or stay the same? Use the idea of molecules moving to explain your answer.

c. You put the flask into ice-cold water, so that the air inside is cooled. Will the pressure gauge reading go up, down, or stay the same? Use the word molecule, to explain your answer.

*The gauge should be marked in newtons per square metre (N/m^2), but here we do not need the actual measurement. We just call it 1 atmosphere.

34. Copy and complete:

a. When you make some trapped air *hotter* its pressure gets [/*bigger*/*smaller*/], because the molecules are moving [/*faster*/*slower*/]. When you COOL trapped air, the pressure gets [/*bigger*/*smaller*/] because the molecules are moving [/*faster*/*slower*/].

b. You did an experiment to see how the pressure of some trapped air in a flask varies with temperature. You took several precautions to make the experiment as accurate as possible.

(i) Before taking temperature readings, you removed the burner. Why?

(ii) You stirred the water well. Why? You made sure the water came right up to the top of the flask. Why was that necessary?

(iii) Can you think of improvements to the apparatus which would make the readings even more accurate?

35. Suppose the pressure gauge reads 0.9 when the flask of Q.33 is in ice-cold water. Then, when you heat the water to boiling, the reading goes up to 1.2—that is, a rise of temperature from 0 to 100 °C makes the pressure rise by 0.3 units.

What do you think are the *most likely* answers to the following questions?

a. If the temperature were raised to 200 °C, what would the pressure rise to?

b. The temperature is made to fall to −100 °C (which is 100 degrees COLDER than melting ice). What will the pressure be?

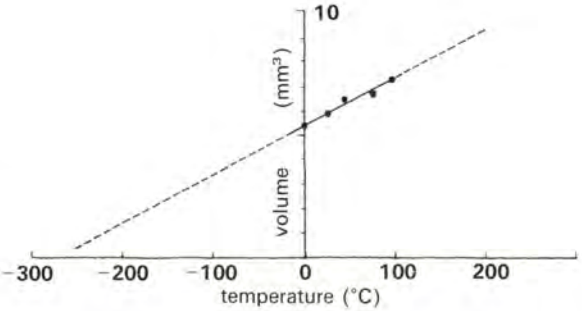
c. What is the temperature when the pressure is just 0.3 unit. How would the air molecules be moving to make a very low pressure like this?

d. What is the temperature when the pressure drops to zero? How would you expect the air molecules to be moving them?

AIR EXPANDS

36. Here is a graph of some measurements which were taken of the volume of some enclosed gas at different temperatures. The pressure was not allowed to change.

a. Read from the graph the volume at *(i)* −20 °C; *(ii)* −100 °C



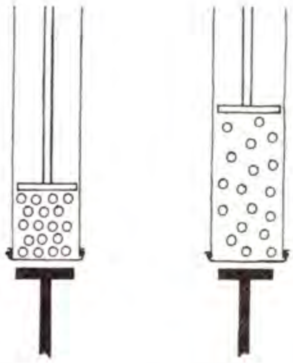
b. What is the temperature when the volume is 2 mm^3? How must the molecules be moving, to take up a tiny space like this?

c. What is the temperature when the volume goes to 0? How are the molecules moving now?

MODEL OF AIR EXPANDING

37. Look again at the tube with little marbles in it, where the marbles are given energy to move by a vibrator.

There are the SAME number of little balls in A and B, and the cardboard disks are the same size.



a. How is it that the cardboard disk doesn't fall down?

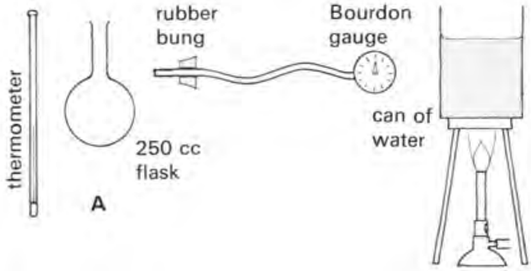
b. Copy and complete the remark below:

The little balls take up more volume in B. The vibrator must be moving faster in [*A*/*B*] so the little balls are moving faster in [*A*/*B*]

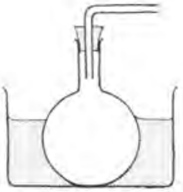
c. Remember the cardboard disks are the SAME in A and B. What can you say about the pressures in A and B?

AIR PRESSURE AND TEMPERATURE

38. Fig. A shows a collection of apparatus you could use to find how the pressure of a sample of air changes when it is heated.



A


B

a. Draw a sketch showing the apparatus properly assembled for this experiment.

b. Say how you would take a set of readings like those below.

c. Here is a possible set of readings:

Thermometer reading in °C	Gauge reading in newtons/m^2
0	100 000
25	110 000
50	118 000
75	127 000
100	136 000

(i) Plot these readings on a graph.
(ii) Find from the graph the temperature at which the pressure of the air would be nothing at all. This is the temperature called 'absolute zero'.

(You may *either* plot a graph which goes, horizontally, from -300 °C to $+100$ °C, and then produce the graph backwards till it cuts the horizontal axis, *or* you may draw a graph from 0 °C to 100 °C and *calculate* the temperature for no pressure.)

d. Fig. B shows part of the experiment. Why is that badly arranged? (That is, what is wrong?)

39. The following questions refer to the 'pressure and temperature' apparatus of Q.38.

a. Why have a NARROW tube between the flask and the gauge? Why should it not be a wide tube?

b. What difference would it make to the readings obtained if the flask held 500 cubic centimetres instead of 250 cubic centimetres? (Assume that it can still be properly surrounded by the water.)

c. Suppose we had compressed the air so that the pressure at 0 °C was 200 000 instead of 100 000 (see Table, Q.40). What would be the pressure at 100 °C?

d. Would using air at double the pressure make any difference to the value found for absolute zero of temperature?

e. Suppose the flask had been rinsed out with water and emptied, but not dried. What difference would this make to the readings obtained? (Think and guess.)

AIR THERMOMETER

40. Given the apparatus of Q.38 *but no mercury thermometer*, how would you use it to measure
(i) the boiling point of a saturated solution of salt,
(ii) the temperature of a 'freezing mixture' of ice and salt?

You may assume that a plain ice and water mixture is at 0 °C and that the water boils at 100 °C.

41. In the answer to Q.40 you were using the flask and gauge apparatus as an 'air thermometer', which is one kind of 'gas thermometer'. Actually, gas thermometers are used as 'standard' thermometers, and we test mercury thermometers and other types by comparing them with gas thermometers.

a. What are two advantages a gas thermometer has over a mercury thermometer for use as a STANDARD of temperature measurement?

b. Why not scrap mercury thermometers and use only gas thermometers? (Give one good reason.)

The Kelvin scale of temperature If you continue your own graph for air backwards you will find that 'absolute zero' should be somewhere between $-200\,^{\circ}C$ and $-300\,^{\circ}C$. With careful measurements, and allowing for the failure of air to be ideal, scientists find absolute zero is $-273\,^{\circ}C$. That is, 0 on the Kelvin scale, written 0 K.

Then it is convenient to arrange a new scale of temperature, 'absolute temperature', that begins with its 0 at absolute zero. On that scale, called the Kelvin scale, ice (which has a melting point of $0\,^{\circ}C$) melts at 273 K. And water boils on an ordinary day, at 373 K.

The Kelvin scale has several advantages:

Advantage (1). If we keep the volume of a sample of gas constant, its pressure goes up *in direct proportion* to the Kelvin temperature. (This is *automatically* true for an ideal gas; and fortunately many gases have almost ideal behaviour, except at very low temperatures.)

Advantage (2). For our standard thermometers, we can change from ordinary mercury thermometers (which are convenient but temperamental) to a gas thermometer. This is a bulb and pressure-gauge, like the apparatus you have just used. But, instead of using it to investigate a sample of air, we turn the argument round and say: 'Henceforth we choose to measure temperatures on a scale that uses a gas thermometer with an ideal gas in it.'

Then, with that Kelvin scale declared by law to be the standard, we must not be surprised to find that real gases give an *almost* straight line graph when their PRESSURE is plotted against KELVIN TEMPERATURE.

(The expansion of mercury happens, by mere lucky chance, to give a fairly straight line when plotted against Kelvin temperature measured by a gas thermometer.* That lucky chance makes it comfortable to use mercury thermometers for measuring ordinary temperatures in the lab. If the early thermometer-makers had chosen some other liquid, such as alcohol or glycerine—or, worse still, water—their temperature readings would not have agreed so well with our standard gas scale.

For higher temperatures—Bunsen flames, furnaces, . . . , stars—mercury thermometers are obviously useless. And in very cold winter weather the mercury freezes. Yet the Kelvin scale can be extended as high as you like—in recent experiments on nuclear fusion, measurements have run up to millions of degrees.)

Advantage (3). We have a very fruitful theory of heat engines, 'Thermodynamics', which offers many remarkable predictions, all of which *necessarily* use the Kelvin scale. Without the idea of that scale, and without practical gas thermometers for measurements, the predictions of thermodynamics would be useless, just hot air.

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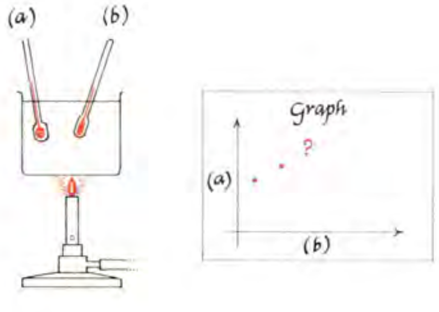
*You can say, 'Mercury expands almost uniformly *compared with gas-thermometer temperatures* or the Kelvin scale.' But it would be a bad mistake to think that mercury was originally chosen for thermometers 'because it expands uniformly'. Think of the old days when temperatures were always measured by a mercury thermometer. Then an experiment to test the expansion of mercury would have:

a. a mercury-expansion-apparatus (a bulb and tube, with mercury), hung in a bath of water that is being heated;

b. a thermometer (bulb and tube, with mercury) hung beside *a*.

Is it surprising that readings of the mercury levels in these two, (*a*) and (*b*), gave an excellent straight line when plotted against each other on a graph?



Theoretical Thoughts: Extrapolation

A risky guess Look back at what you have done. When you continued your graph (or calculated) on down to find absolute zero, you were making a risky guess that the behaviour would stay the same. Continuing beyond all measurements like that is called '*extrapolation*'.

Extrapolation is a risky business, trusting or pretending that what you have observed continues on and on.

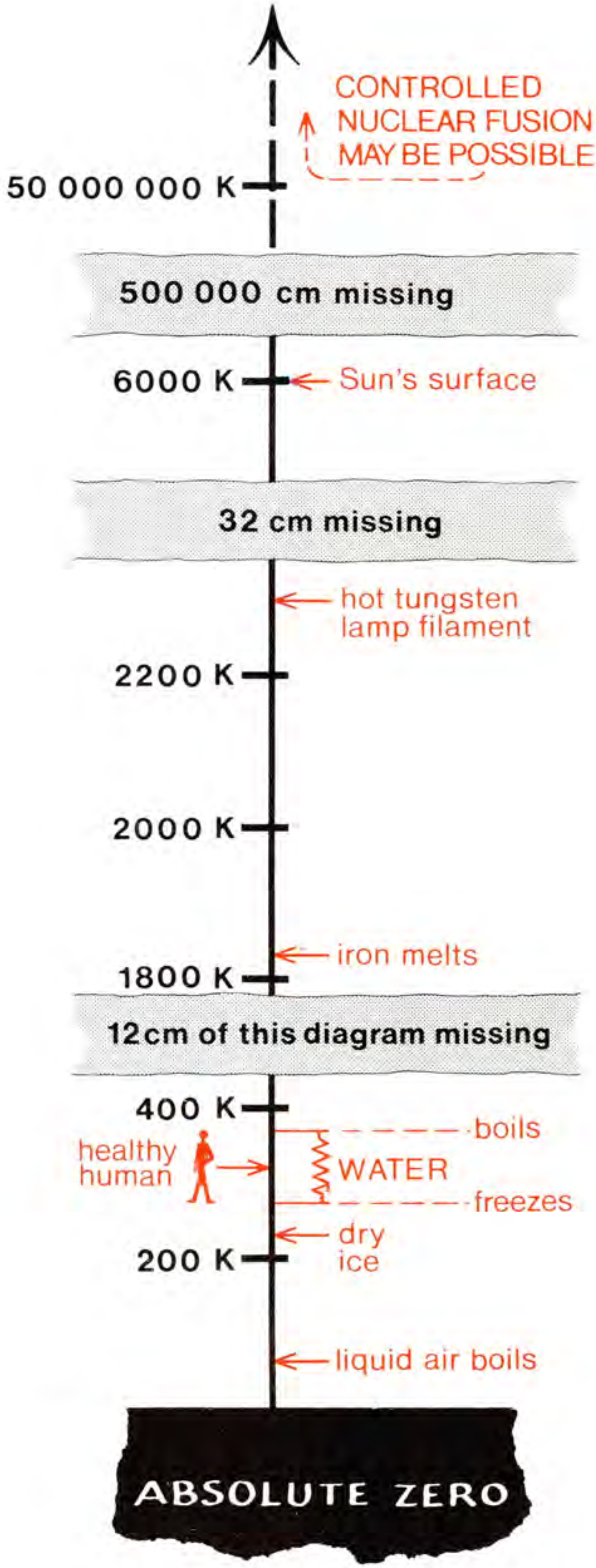
Did the Sun rise in the East this morning? Did it rise in the East yesterday? Did it rise in the East many a morning before that? Are you willing to *extrapolate* these observations into the future and say that you are *sure* the Sun will rise in the East tomorrow? Are you *quite sure?* . . .

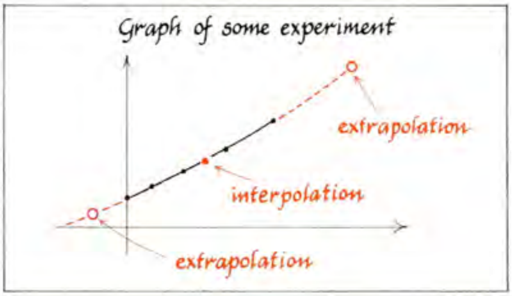
Suppose you were not a human being but were a butterfly who emerged from a chrysalis on a warm day in early summer and flew about from flower to flower, day after day. What would you observe about the weather? A fine day, another fine day, another fine day, . . . If you were that insect, you might extrapolate and predict that every day in the future would be fine. You would not foresee the wintry day which would end your happy flights.

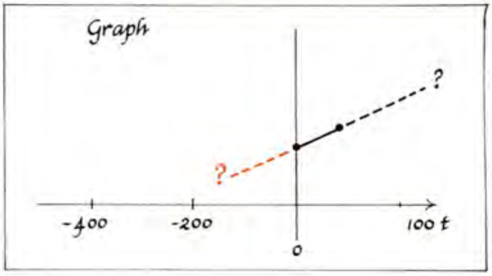
Extrapolation and interpolation Extrapolation would be very risky, if we trusted it for the molecules of a real gas like air or carbon dioxide. If we cool any gas enough, it fails to remain a gas. You may have seen carbon dioxide jammed together into cold solid crystals of 'dry ice'. Some day you will see air that has been cooled down and pushed together so that its molecules (having less energy of motion at that low temperature) hang together in a liquid.

Yet we can safely make the extrapolation *in imagination* and find a useful 'absolute zero' as a starting point for the grand Kelvin scale of temperature.

'Interpolation' means reading something off a graph between two measured points on it. (Or you can calculate an intermediate value between two values given in some table.) Interpolation is useful in science and engineering; and, if carefully done, it is safe. But in developing new science and technology, extrapolation is more important.







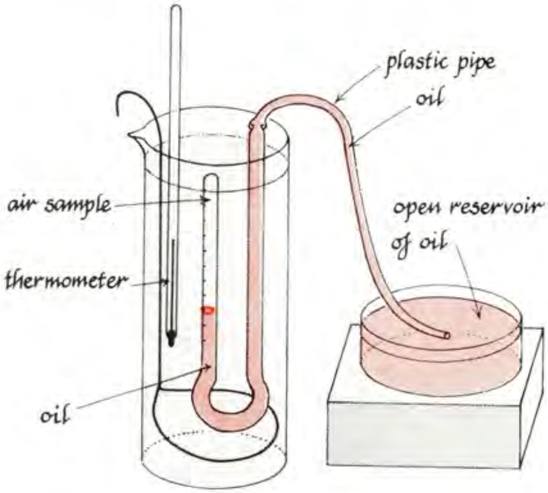
Although extrapolation is risky; *it is the way in which some of the great discoveries have been made.* Scientists guess what might happen if they continued our knowledge into an unknown region; then they try to test their guess by experiments. And sometimes those experiments lead them in quite a new direction of knowledge.

Extrapolation is rash but sometimes very fruitful; interpolation is safe but dull.

Gas Volume and Temperature

Demonstration 85
Air Expanding at Constant Pressure

See the demonstration sketched. The VOLUME of the sample of air is represented by the LENGTH from the closed end of the tube to the movable piston of oil. Plot for yourself the sample's VOLUME against its TEMPERATURE.

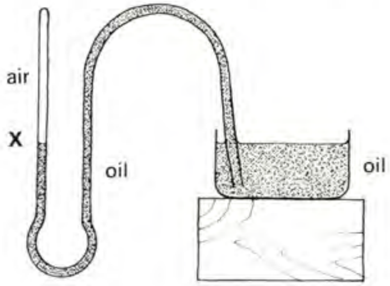


The graph can be extrapolated back to an absolute zero. Careful measurements lead to the same absolute zero as that from the graph of PRESSURE plotted against TEMPERATURE.

Progress Questions

EXPANSION OF AIR

42. The diagram illustrates a U-tube which has some air in one side. The other side is full of oil, and it continues over into a bath of oil.



a. Do you think that the pressure of the air trapped inside the tube is equal to, greater than, or smaller than the pressure of the outside atmosphere?

b. When the trapped air is warmed up, which way does the oil at X move, *up* or *down*?

c. When the trapped air is cooled down, which way does the oil at X move?

d. Suppose the oil at X moves down a little and is then steady at the new level. Is your answer to (a) still true? or very nearly true? or quite wrong?

'AIR THERMOMETER'

43. Here are some measurements from an experiment like that shown in the sketch for Q.42.

At 0 °C the length of the trapped air was 16 cm.
At 100 °C the length of the trapped air was 18 cm.

What do you think the length would be at:

a. 200 °C;

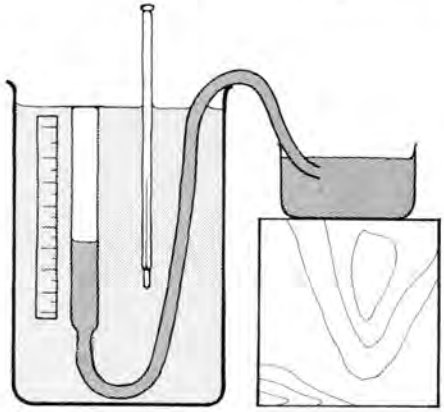
b. −100 °C? (Think and guess.)

Questions

EXPANSION OF AIR: CHARLES' LAW

44a. With the apparatus shown in the diagram, you could carry out an experiment. The title of the experiment would be:

To investigate how the .. ? .. of air increases with .. ? .. when the .. ? .. is kept constant.



Write the above sentence and fill in, in their correct positions, the words TEMPERATURE, PRESSURE, VOLUME.

b. The following readings were obtained in one experiment.

Temperature in °C	Length of air column in cm
0	12.2
25	13.3
50	14.4
75	15.7
100	16.7

Plot these readings on a graph. Predict the temperature at which the volume of the air would be nothing at all.

AIR THERMOMETER

45a. How would you use the apparatus of Q.46 to find the temperature outside, in the playground? (Suppose you are not to use a mercury thermometer at all.)

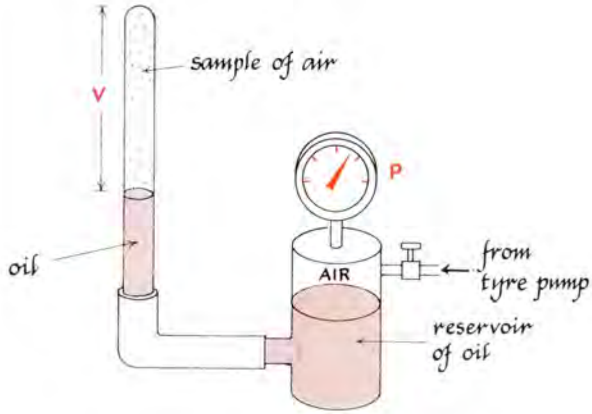
b. Why would the air thermometer be no use for finding the temperature of liquid air? (Neither would a mercury thermometer!)

c. But the gas thermometer *would* measure the temperature of liquid air fairly well *if it had helium gas in it*. What can you guess (conclude, or infer) from that?

Gas Volume and Pressure

Demonstration 86
Boyle's Law

Suppose you compress a sample of air but do not let the temperature change. *How are its pressure and volume related? Does it behave like a steel spring being compressed in a smooth glass tube—which would give you Hooke's Law?* See the demonstration sketched.



Use arithmetic or plot a quick graph to test Boyle's relationship between PRESSURE and VOLUME.

Three hundred years ago Robert Boyle tried this experiment, with apparatus of his own making. He had to use a piston of mercury to compress his sample of air as he looked for its springiness. He hoped his experiments would help him to improve the crude pumps that were being used to safeguard the lives of miners.

He discovered a law relating to PRESSURE and VOLUME: not Hooke's Law but what we now call Boyle's Law. That gave him great pleasure and later some fame. When he found he had guessed the correct law he said he observed his successful experiment to test it 'not without delight and satisfaction'.

Progress Questions

BOYLE'S LAW

46. *(Did you see a pressure-gauge measuring the pressure of air while the air was being squashed to smaller volume? If so, try this question.)*

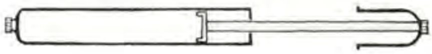
a. There was a sample of air in the tube. Oil was driven up the tube.
(i) What happened to the sample of air?
(ii) What happened to the pressure?

b. When the oil pushed the sample to half its original height:
(i) How much had the volume of air changed?
(ii) How much had the pressure changed?

NOTE. The story of changes like that is called Boyle's Law.)

47. Suppose you are pumping up your bike tyre. You start with the pump's piston (handle) full out. The pump is full of ordinary air, at pressure 1 atmosphere (fig. I).

You push the piston slowly in. (Slowly, so that the air in the pump does not stay hotter for long.) The valve on the bike tyre stays shut; so no air can get out of the pump.



a. When you have shoved the piston half way in (fig. II), the pressure of the compressed air in the pump is greater. How big is the total pressure then (in 'atmospheres')?

b. As soon as the piston is half way in, the valve on the tyre opens, and you push all the air into the tyre.

You then pump air in like that, stroke after stroke, for 10 strokes. But at the eleventh stroke the valve doesn't open when the piston is half way in. (Then you have to drive the piston farther in before the valve opens.) What is the pressure of the *air in the tyre* after 10 strokes?

48. When I tried pumping up my bike tyre, a friend brought a tyre-gauge to measure the pressure. After the 10 strokes, the gauge read 100 000 newtons per square metre (15 pounds per square inch in the old units).

'But,' I objected 'that is only ONE atmosphere, just the pressure of the ordinary air, before I pushed the pump piston in.' And yet my tyre was pumped up fairly hard. What would you expect the gauge to read?

a. *Where* was the 'mistake', in my reading or in the marking on the gauge?

b. *What* was the 'mistake'?

Questions

BOYLE'S LAW

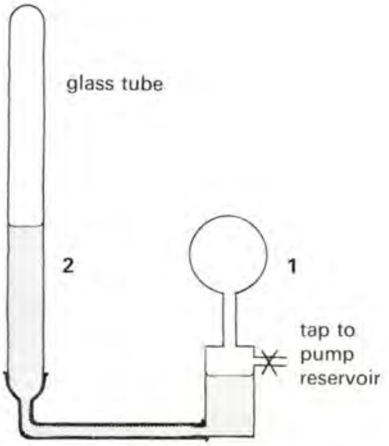
49a. Draw a sketch of the apparatus you used to show how the volume of a sample of air is related to its pressure, provided the . . ? . . remains the same.

b. What word should be inserted in the blank space above?

50. This is a simplified diagram of an apparatus you used to find out how the volume of air changes with its pressure. Copy the diagram, and answer (a) and (b) by writing on your sketch.

a. What is it that arrow 1 is pointing at?

b. What liquid is in the glass tube (arrow 2)?



c. Say what was done with this apparatus, and how the readings were taken, in order to make a table of values of pressure and volume.

d. When the pressure is doubled (for example, from 100 000 newtons per square metre to 200 000) is the volume doubled? Or halved? Or does the volume remain the same?

e. If the pressure is made 3 times as big, what happens to the volume?

51. In an experiment the VOLUME and the PRESSURE of some dry air were measured. Care was taken not to change the temperature, and not to let any gas in or out. The measurements were recorded. Here is the record but some of the results have been left out. Copy out the table and fill in all the blank spaces, using your knowledge.

Pressure, P in special units for pressure	Volume, V in special units for volume	Pressure × Volume $P \times V$
10	6	60
12		
	4	
20		

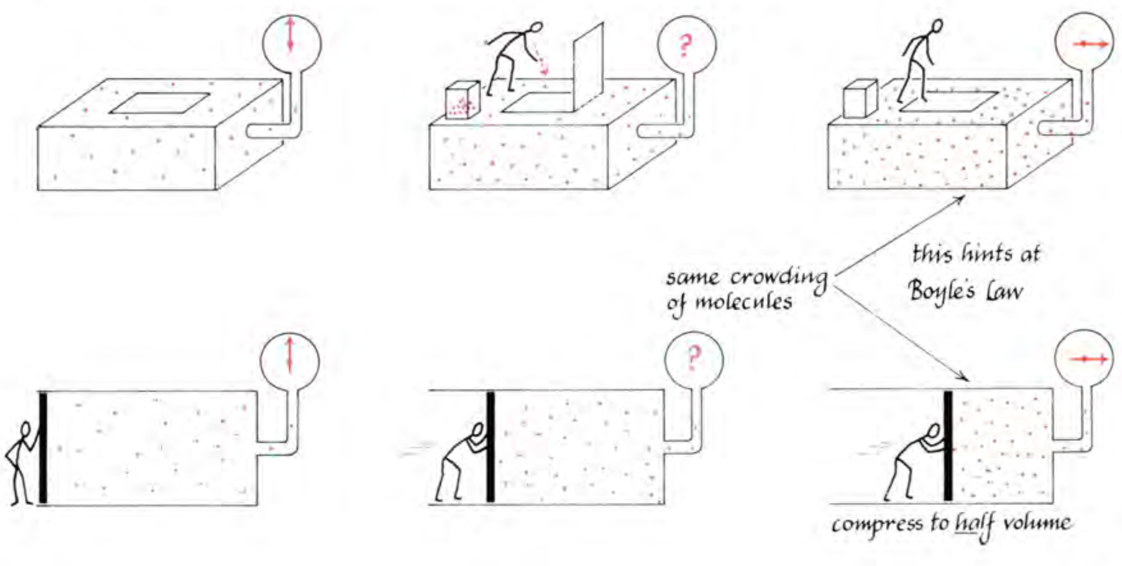
A Theory

Could a theory of molecules predict Boyle's Law? Think of our picture of molecules flying about with rapid motion in all directions and making pressure by bombarding the walls of the container. Suppose you have a box of gas like that and carefully put more molecules in (like a collector putting more beetles in his box) until there are just twice as many in the box as before. What would that do to the pressure?

(When there are more molecules, they will collide with each other more often and may even get in each other's way. But does that matter? Think of a molecule flying along on its way to hit a wall and make a contribution to the pressure. Suppose that molecule does meet another on its way, head-on. They collide and bounce away in opposite directions: they simply exchange jobs.)

So, with twice as many molecules in the box to do the bombarding, we should expect double the pressure.

If you could see the population of molecules, it would look twice as crowded—twice as many molecules in each cubic centimetre in the box. But there is another way of crowding molecules till there are twice as many to the cubic centimetre. Start with the original (single) lot of molecules in the box and push one end of the box in with a piston until the volume is halved—just as you saw in the Boyle's Law demonstration. Then once again you would have twice as many molecules *in each cubic centimetre*.



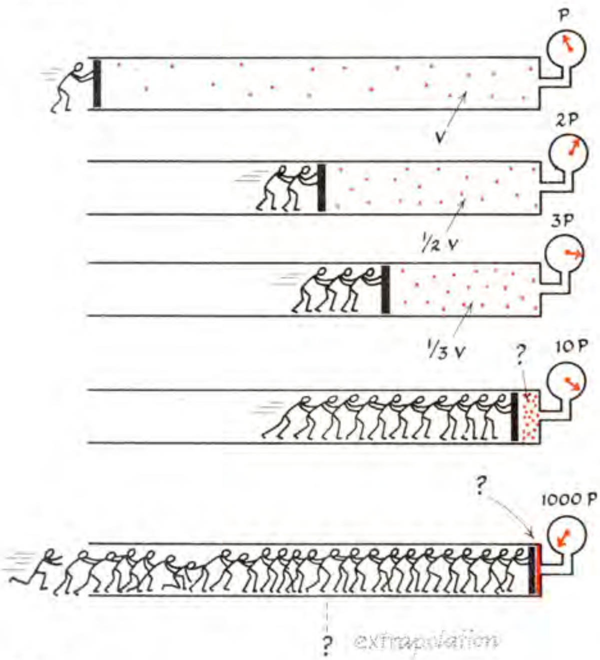
The pressure-gauge could not know any difference between those two ways of doing the crowding. So you may expect *double pressure* with *half the volume*. And that is just what Robert Boyle found.

That is the kind of thing we like a theory to do for us. We like it to predict something that we already know, because then we think we are making a helpful picture. Then we ask new questions about the picture; we let it help us to make further predictions.

For example, we could ask how a gas would behave if it had very fat molecules; or if its molecules attracted each other when quite far apart. Think about such a gas. *How would that change our prediction of Boyle's Law?*

Actually, we find that real gases do not quite fit with Boyle's Law in their behaviour: and, with the help of imaginative thinking, we can understand their misbehaviour and find out very interesting things such as the size of a single molecule.

Compressing air: a question for thinking Suppose you could make the pressure of air ten times as big . . . a hundred times as big . . . a thousand times as big, and so on, would the volume shrink to $\frac{1}{10} \cdots \frac{1}{100} \cdots \frac{1}{1000} \cdots \frac{1}{1\,000\,000}$ without limit? That is a question to think about for the future.



Change of Volume: Liquid to Gas

You can see water changing to large bubbles of steam in any beaker of boiling water. How big do you think the change in volume is, 1 of water into 10 of steam, or 1 into 100, or 1 into 1000? Actually it is even bigger, about 1 into 1600; but it is difficult to arrange a demonstration to show that clearly.

However, you may see a demonstration, now or in a later year, of *petrol* changing from liquid to gas (vapour). This is an important expansion for car engines.

Demonstration 85X
Change of Volume, Liquid to Gas
(OPTIONAL NOW)

A tall glass measuring jar is filled with hot water and closed except for an overflow pipe.

One drop of petrol, one-tenth of a cubic centimetre, is injected into the top of the jar with a small hypodermic syringe. Watch the expansion as the petrol turns from liquid to vapour.

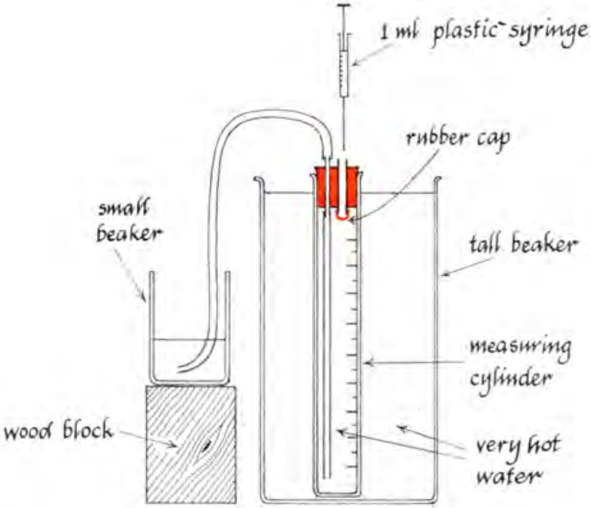
You may be lucky enough to see liquid *air* turning to air! You will find a need to know that change of volume in *Pupils' Text 4*.

An Important Use of Theory

The thinking-model of molecules in motion can help you to understand liquids evaporating and boiling.

Evaporation Remember how you used your tray of marbles to illustrate a liquid. Try it again if you like. Then think about some water in an open beaker. In any liquid the molecules are crowded much closer together than in a gas. They collide with neighbours much more often. Between collisions they move at about the same speeds as in a gas at the same temperature; but they are often in the field of attraction of neighbours, and that makes the liquid hang together.

At the surface of liquid some molecules are bounced outward by collisions with neighbours. They are like rockets fired into space, on a tiny scale. Real rockets are pulled down by gravity and most of them come back to Earth: only a few have more than escape velocity and get away altogether. Water molecules that are bounced out are



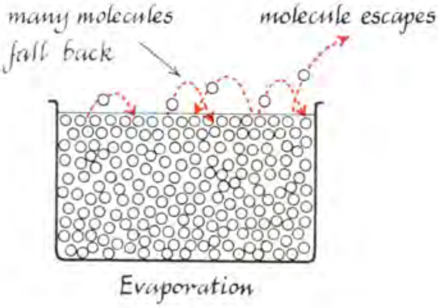
pulled back by the attraction of many water molecules in the liquid near the surface; and most of them fall back again. Only a few molecules that have been bounced out extra hard can escape. That escape *is* evaporation.

A molecule that does escape has to give up some motion-energy in escaping. In other words, an escaping molecule has to pay an 'exit-tax' out of its store of motion-energy. Only a molecule that happens to have, AT THE MOMENT, *much more than average motion-energy* has enough to pay that tax.

If only those 'extra rich' molecules escape, what happens to the temperature of the liquid that remains? Think about this very important question. Then discuss your answer with your teacher. Can you invent an experiment to test your answer? (HINT. Lick your finger.)

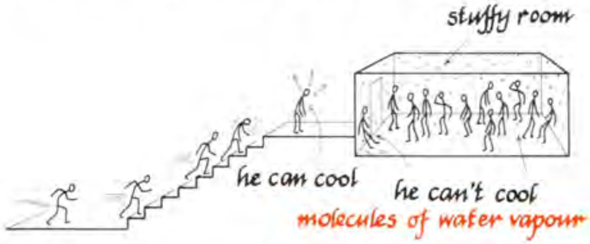
Keeping cool When you run or climb or do any other energetic job you not only draw upon food-energy for your muscles to do the job; you also turn a lot of food-energy into heat. Whether you like it or not, you over-heat. Or rather you *would* over-heat, and feel uncomfortable with a fever, if your body did not run an automatic cooling system. You sweat and where your damp skin is exposed—face, hands, arms—water evaporates. And that cools you.

In very damp weather or in a very crowded room, water condenses again on your skin almost as fast as it evaporates. Then sweating no longer cools you; and you feel uncomfortable. (The air in a stuffy crowded room is not rich enough in CO_2 to make you uncomfortable: it is the water vapour in the air—from people's breath—that makes your head ache. You still sweat, but the water cannot evaporate successfully and cool you. You develop a temporary fever.)



Evaporation

Boiling Evaporation also acts as a thermostat for a boiling liquid. A boiling liquid always makes bubbles of vapour (steam). Once the liquid is boiling, supplying more heat simply equips more molecules with enough motion-energy to evaporate into bubbles of vapour. Therefore the temperature stays constant at the 'boiling point'.



Progress Questions

EVAPORATION

52a. What does 'evaporate' mean?

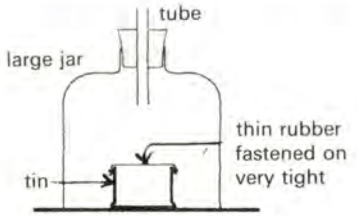
b. When you are hot, you sweat. As the sweat dries up, you are cooled.
(i) If the weather is humid, you feel hot and sleepy. Why?
(ii) If you are in a room with a lot of people, and there are no windows open, you feel hot and sleepy. Why? (It is NOT because you are short of oxygen—there is always plenty of that—and it is NOT because there is too much CO_2 (carbon dioxide) in the air there!)

53. When water is heated up and boils, it reaches 'boiling point'. After that it goes on boiling. But its temperature stays the same. What stops it getting hotter? (HINT. *How do you know when it is boiling?*)

Progress Questions for Looking Back

AIR AND PRESSURE

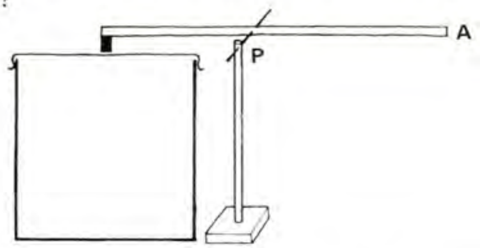
54. The diagram shows a tin placed inside a big jar. The tin has of course got air in it. The open top is covered with thin rubber so that this air cannot get out.



a. You blow air *into* the big jar.
(i) Will there be more or less air molecules bumping on the outside of the tin and rubber?
(ii) Will the rubber bulge *out*, or bulge *in*?
(iii) Copy the drawing, but show what the rubber will look like.

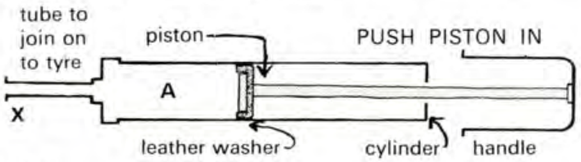
b. You suck some air *out* of the big jar.
(i) Will there be more or less air molecules bumping on the outside of the tin and rubber?
(ii) Will the rubber bulge *out*, or bulge *in*?
(iii) Copy the drawing, but show what the rubber will look like.

55. You have the same box as in Q.54 but not in a jar. This time you arrange a lever so that one end rests on the rubber. The lever turns easily on the pivot P. What will the end A of the lever do (rise or fall a bit) if the air pressure *outside* the box rises?



56. This is a diagram of a bicycle pump.

When the pressure in A is bigger than the pressure of the atmosphere outside, the leather washer gets pressed against the sides of the cylinder. Then no air can get out.



When the pressure of the atmosphere is bigger than the pressure in A, it presses the leather *away from* the cylinder. Then air can get past.

Suppose you press your finger on X so no air can get out.

a. You push the piston *in*.
(i) Does this make the volume of the air trapped in A bigger or smaller?
(ii) Does the pressure of the gas trapped in A get bigger or smaller?

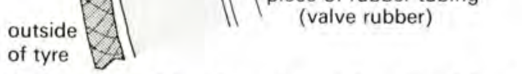
b. You pull the piston *out*.
(i) Does this make the volume of the air trapped in A bigger or smaller?
(ii) Does the pressure of the gas trapped in A get bigger or smaller?

c. Copy and complete:

> When you push the piston *in*, you make the pressure in A bigger than the pressure of the atmosphere. So the leather washer gets pressed [/*against*/*away from*/] the sides of the cylinder, and air [/*can*/*cannot*/] get in. When you pull the piston *out* you make the pressure in A bigger than the pressure of the atmosphere. So the leather washer gets pressed [/*against*/*away from*/] the sides of the cylinder, and air [/*can*/*cannot*/] get in.

d. Draw a diagram, showing the leather washer pressed *away* from the sides of the cylinder. Show (with a colour) where the air goes past it. Draw an arrow to show which way you move the handle.

57. This is a diagram of part of a bicycle wheel.



a. The valve rubber lets air *in* when you blow air into the valve. *How?*

b. The valve rubber stops air getting out of the tyre. *How?*

c. Why do you have to push the pump handle harder when the tyre is nearly pumped up?

WET AIR: DRY AIR

58. The ordinary air in the room—and outside! —has several different gases in it. One of the gases is water vapour.

Sometimes there is a lot of water vapour: we say the air is very 'humid'. Water cannot evaporate quickly when the air is humid.

Sometimes there is hardly any water vapour in the air: it is very dry.

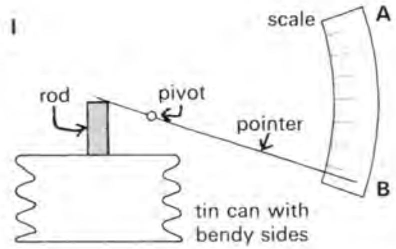
Water molecules are lighter than most of the other molecules in air, so they do not bump so hard into things. The air pressure is lower on a humid day than on a dry day. During fine weather the pressure is high but if the pressure starts to fall, you know you may expect damp weather. You can measure the pressure with a barometer.

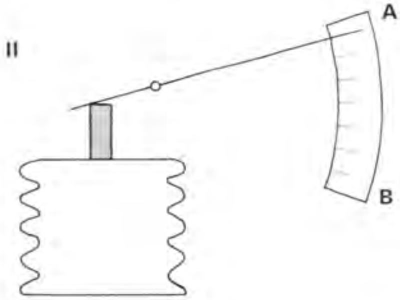
a. Write down the names of any gases you know are in the air.

b. 'The air is very humid': what does this mean?

c. Will your washing dry better when the pressure is high or low? Explain.

59. Fig. I shows the main parts of one kind of barometer. When the air pressure is high, it squashes the tin a little bit, and the rod on the top moves the pointer. When the pressure is low, the tin stretches out again, and the rod moves the pointer the other way.





a. What is the job of a barometer?

b. Which figure, I or II, shows the barometer on a *dry* day?

c. Copy and complete:

On a fine day, the air pressure is [/*high*/*low*/] and the pointer will be near [/*A*/*B*/]. On a humid day the air pressure will be [/*high*/*low*/] and the pointer will be near [/*A*/*B*/].

d. Copy one of the sketches. Label it carefully. Write 'Fair' 'Wet' 'Changeable' in the right place on the scale. (HINT. See Q.58.)

Questions for Looking Back

MOLECULES

60. You have been building up a picture of *moving molecules*. The air around you consists of a mixture of molecules moving all the time.

a. Why do they keep moving all the time and not stop eventually?

b. Are they moving as fast on a cold day as on a hot day?

c. What happens when one of these molecules hits the ceiling? Does it just stick there or what?

d. Suppose some of these molecules hit the hot top of an electric cooker, or the outside of a hot kettle, do they move away from it at the same speed they hit it, or do you think something like that could change their speed?

61. Think about one molecule in a room full of air.

a. Does it move in a completely straight line from one side of the room to the other? How would you expect to see it moving *if* (impossible!) you could make it visible?

b. Suppose you sealed up all cracks under doors, windows, etc., and could pump all the air out of the room except that one molecule (also impossible!)

(i) Could that solitary molecule move straight across from one side of the room to the other, sometimes?

(ii) It would not always move with the same speed, even though the temperature of the room stayed constant. Explain why.

c. *(ADVANCED)* Invent a test of your answer to (a) that does not make us imagine impossible things.

62. Suppose a room full of air has open a small window.

a. Say whether each of the following is *the same* or *larger* or *smaller*, compared with the value on an average warm day.
(i) The number of molecules in the room *on a very cold day*.
(ii) The number of molecules in the room on a warm day *when the barometer reading is unusually high*.

b. *(ADVANCED)* You know what each of the questions *(i)* and *(ii)* just above means. But the questions are not scientifically accurate. (Scientists are expected to give all the details, so that their questions are completely clear.) What is missing in the wording of question *(i)*; of question *(ii)*? Could the questions, as they are printed here, sometimes have a different answer—because something is missing?

63a. What do you think is the length of the side of the smallest square which, when you see it with the naked eye, *still looks like a square*? Try drawing small squares with a sharp pencil. Make a sensible estimate in factions of a millimetre.

b. With a high-powered microscope you could see a square whose side is only 1/500th as long as that in (a).

About 100 000 000 ($= 10^8$) atoms placed side by side in a row, cover 1 centimetre. How many atoms are there along the side of the smallest square you can just see with the microscope?

c. Most of the molecules in air are nitrogen or oxygen. How many atoms are there in one of *those* molecules? How many of those molecules would fit along your smallest square?

64a. How does a molecule-in-motion model (thinking-model) explain the fact that gases exert pressure?

b. How does a molecules-in-motion model explain the fact that a gas exerts a bigger pressure when you squeeze it to a smaller volume?

65a. You probably have a very good vacuum in your house—inside a television picture tube. Air has been removed from this tube until a *very* low pressure is reached. Is the average distance between the molecules in the tube less than the distance between the molecules in the air outside? Or greater? Or the same?

b. The TV picture is made by a stream of electrons which shoot along the tube and fall on the coated screen, thus making it luminous. What might happen if the pressure in the tube were *not very low*?

More Advanced Questions

*NOTE. Questions **66** to **71** are more advanced questions concerning gases and Boyle's Law. If you enjoy making calculations with algebra you may like to try some of these. Otherwise postpone them to Year 5.*

BOYLE'S LAW

66. Suppose an experiment is done to measure P and V for a sample of air (at constant temperature). When the pressure is doubled, what happens to:

PRESSURE × VOLUME, PV

Is PV doubled? Or halved? Or does PV remain the same?

67. The experiment of Q.51 is done to find how the volume of air changes when its pressure changes. The final conclusion of experiments like this may be the equation:

PRESSURE × VOLUME (PV) = constant

a. Another pupil who is not very good at algebra asks 'What does that mean?' Explain to him.

b. This equation can only be true if we keep the same amount of air all the time, that is, the same MASS of air. How could you find out, at the end of the experiment, whether any air had leaked out during the experiment?

c. Also the TEMPERATURE must not change during the experiment. What would happen to (PRESSURE × VOLUME) if the temperature *increased* while you changed to greater and greater pressures? Do you guess that PV would increase, decrease, or stay the same?

d. Give a clear reason for your answer to (c). *(This is difficult.* Do not bother too much about it.)

68. If a spring follows Hooke's law, equal *increases* of pull produce equal stretches in the spring. (Hooke said, in Latin, 'as the force so the extension'.)

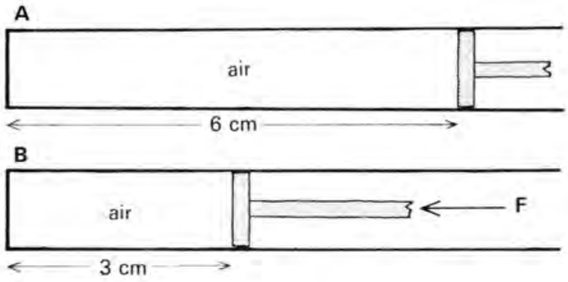
Similarly, for a compression spring, equal loads on the spring produce equal compressions. Thus, if a 1 kg load compresses the spring by 0.5 cm, a 2 kg load compresses it by 1.0 cm, 3 kg by 1.5 cm, and so on, so long as the spring follows the simple law.

Does a gas that is being compressed also follow Hooke's law? If you increase the pressure from 1 atmosphere, to 2 atmospheres, to 3 atmospheres, is the *change* of volume (decrease) the same each time? (Think carefully before answering, and give a clear reason for your answer.)

69. Fig. A shows air in a cylinder fitted with an air-tight frictionless piston. Inside and outside the cylinder the pressure is atmospheric. With no extra force applied, the piston stays where it is.

In fig. B the piston has been pushed in so that the enclosed air occupies half the original length. The temperature has returned to the same value as before. A force F must be applied now to hold the piston in place.

Compare fig. A with fig. B. When you give each answer, give a clear reason for your answer as well.



What can we say about:

(i) The total number of molecules in the cylinder after the piston was pushed in, compared with the number before? (Is it the same, twice, half, one-third, or what?)
(ii) The volume of the air in the cylinder?
(iii) The number of molecules in each cubic centimetre in the cylinder?
(iv) The average speed of a molecule in the cylinder?

70. 'The height of the water barometer is 10 metres.' This means that the pressure of the atmosphere is equal to the pressure of a column of water 10 metres high.

In a lake 30 metres deep a bubble of gas rises from the bottom of the lake to the top. When the bubble reaches the top, its volume is 12 cubic centimetres. What was its volume at the bottom? Explain carefully how you get to your answer. (The answer is NOT 4 cubic centimetres. If you decided on 4, you forgot part of the pressure.)

MOLECULES: PRESSURE AND TEMPERATURE

71. This question does not need an answer in numbers. Answer each part *(i)* to *(viii)* by writing 'greater', or 'less' or 'the same'.

A tyre is pumped up to a pressure of 20 N per square cm at midday, when the temperature is 15 °C. That night the temperature falls to 5 °C.

The tyre does not leak. Pretend the volume of the tyre remains the same.

What happens, in the change of temperature, to:

(i) the number of air molecules inside the tyre;
(ii) the average speed at which an air molecule moves;
(iii) the *average* distance a molecule moves in the tyre between one collision with another molecule and the next;
(iv) the average *time* between one collision and the next;
(v) the air pressure in the tyre? Give a careful reason for your answer to this.

The driver pumps up the tyre to 20 N per square cm again. On that cold night the temperature is still 5 °C. Compared with the state of affairs when the pressure was 30 lb per square inch on the warm day at 15 °C, what has now happened to:

(vi) the number of air molecules in the tyre;
(vii) the average speed of air molecules in the tyre;
(viii) the average distance an air molecule moves between one collision and the next in the tyre?

CHAPTER 6

ELECTROMAGNETISM

Experiments with magnetic fields, currents, forces, meters, motors and electromagnetic induction

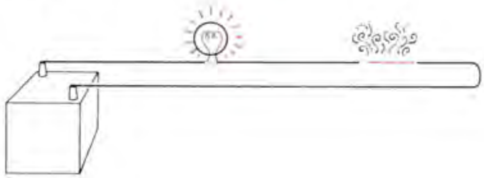
ELECTRIC CIRCUITS AND MAGNETISM

Catching Up or Overlap from Earlier Years*

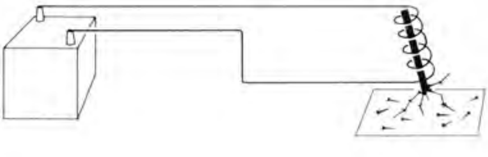
Remember what Electric Circuits do Before you begin new experiments with magnets and electric currents, see how much you remember of earlier things about circuits. If some of the questions are about things you do not remember, or have never done before, you should see or try the following:

Reminder Notes and Questions

(1) There are three things that electric currents can do. These are called the 'effects of a current' and they are really the only things we know a current by.



(a) HEATING. A current makes wires hotter, the thinner the wire the hotter. We can see wires glowing white hot in . . ? . .

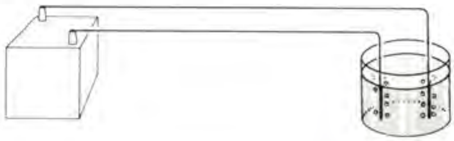


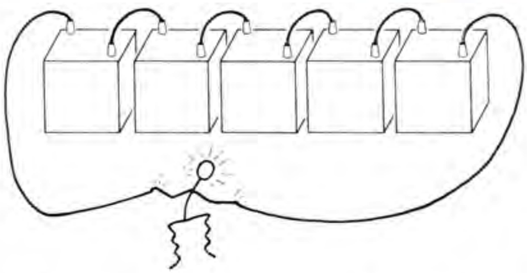
*If the electrical names seem strange, or if you have not done electric circuit experiments before, consult the Dictionary of Electrical Words at the end of this book.

(b) MAGNETIC EFFECTS. We wind wire to make a coil round an iron rod, or we put the rod inside a long ready-made coil of wire.

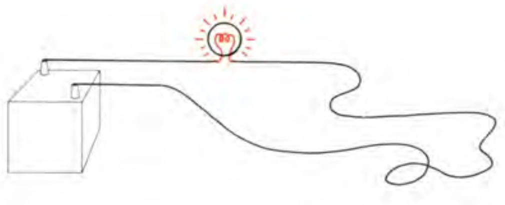
Nothing happens to the rod until we connect ends of the wire to a battery. Then the rod becomes . . ? . .

(c) CHEMICAL EFFECTS. We cut the wire of a circuit and dip the ends in salt water. We see . . ? . . rising in the water, showing that there are chemical changes. (Nerves in your body act by electrical-chemical methods. That is how an electric shock hurts.)





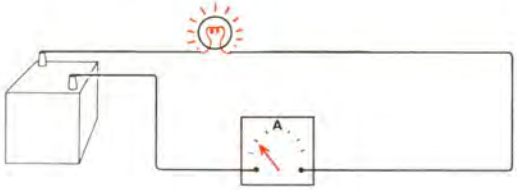
(2) A battery provides a current if there is a complete circuit of metal all the way round, from the battery through various things and back to the battery.

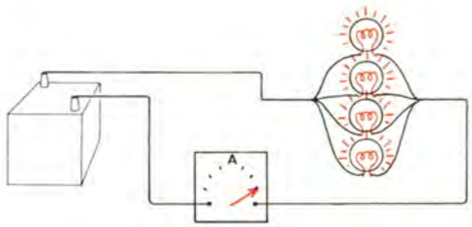


(3) A switch can stop the current by making a . . ? . . in the circuit.

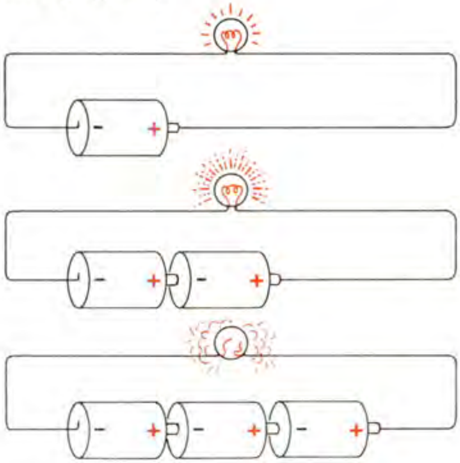
(4) A 'short' circuit can do damage because the current is too . . ? . . and the wires get much too . . ? . .

(5) Several lamps in parallel take [/*more*/*the same*/*less*/] current compared with a single lamp.





(6) The more cells in series, the [/*smaller*/*larger*/] the current that the battery drives through a lamp. But if one cell is connected *backwards* among others, the push of that cell is [/*added*/*subtracted*/*without any effect*/].

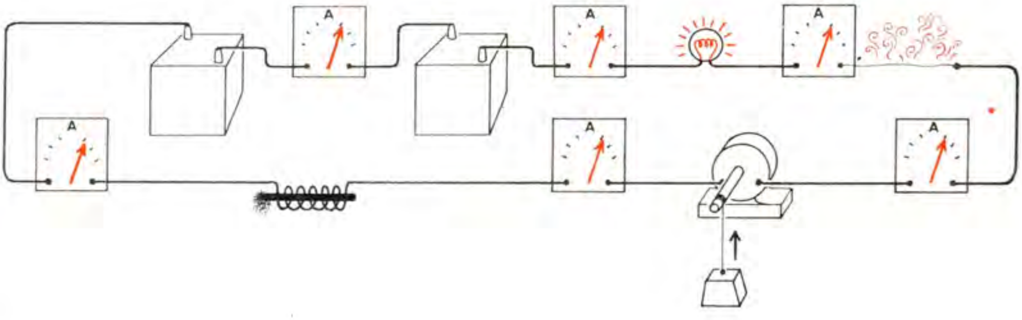


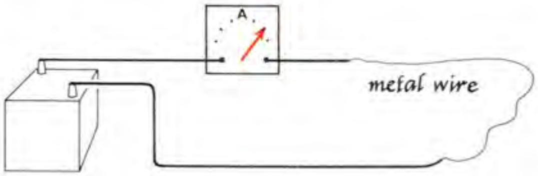
(7) Of the three effects, *heating, magnetic, chemical*, the effect that is used to make an ordinary ammeter measure the current is . . ? . .

Some things which you need to be quite sure about

(8) By putting an ammeter at different places in a circuit we find that the current is the same *at all places, all the way round a circuit*.

This is useful when we want to test the accuracy of several . . ? . .



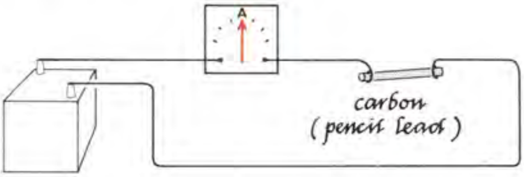


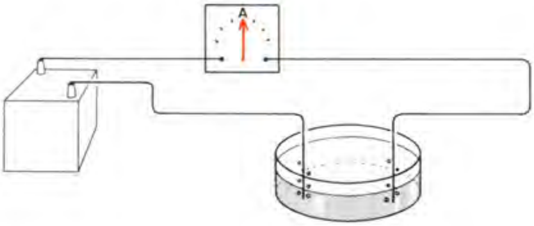
(9) When we test various materials for conductivity, to find out how well they carry electric currents, we find that:

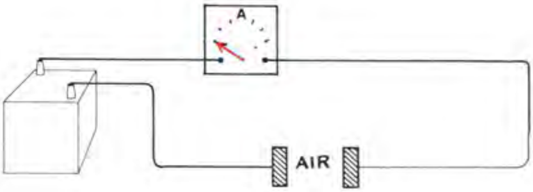
(a) metals conduct very well;

(b) carbon and some solutions of salt in water conduct well;

(c) gases do not conduct, unless we do something special to them.



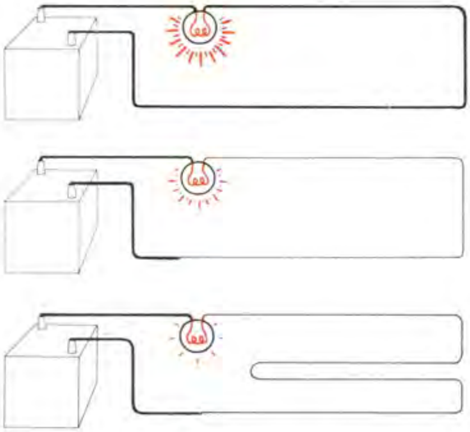




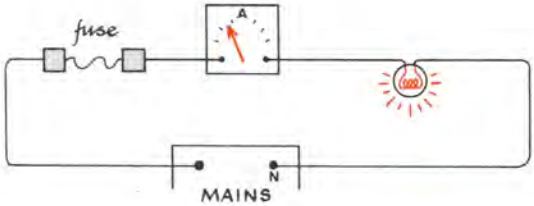
(10) By passing a current through a blue solution of copper salt we can do copper plating.

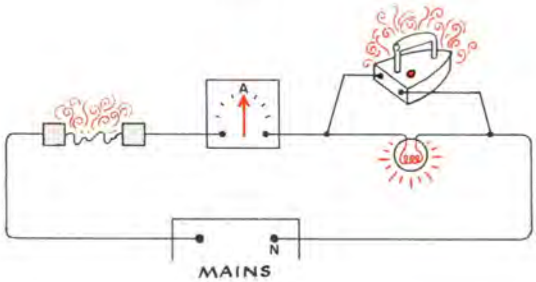
(11) Thin wires have more resistance than thick wires. Long wires have more resistance than short ones.

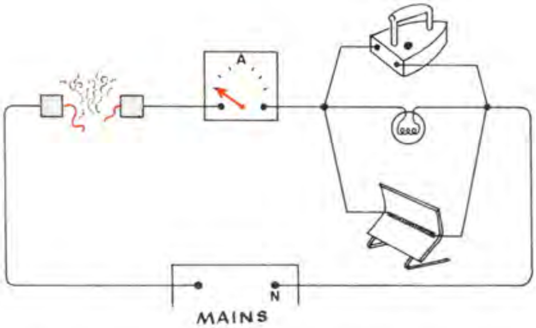
When we put more resistance in a circuit, the current is smaller; but it is the *same* small current *all the way round the circuit.*



(12) When a metal wire is made hotter, its resistance usually increases.







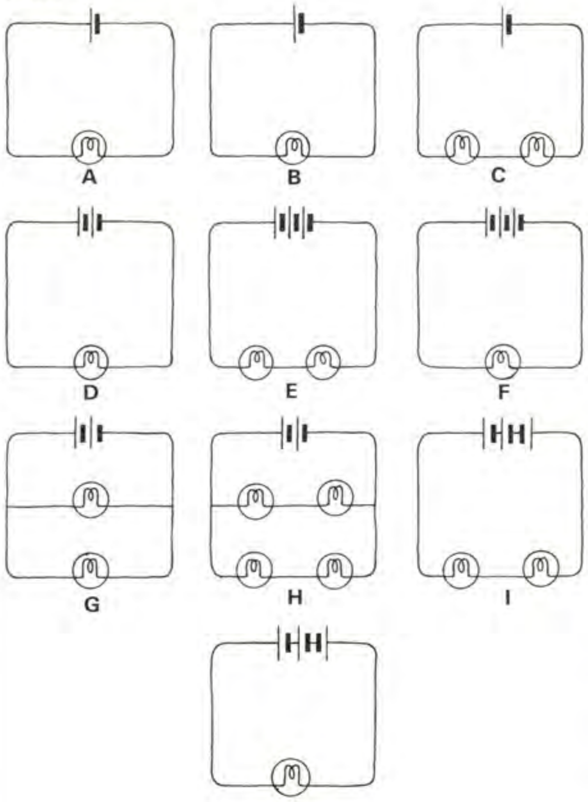
(13) The heating effect of a current is used in fuses. A fuse is a thin wire that melts when the current grows too large by accident. It acts as a safety switch; it switches off automatically when the current is so big that it might heat the wires in the walls of the house dangerously.

Progress Questions

ELECTRIC CIRCUITS

1. When a lamp lights up, you know an electric current is going through it. The brighter the lamp looks, the bigger the current must be.

A is a circuit with the lamp at NORMAL BRIGHTNESS.



Look at the circuits B to J. For each of those circuits say whether the lamp(s) will look BRIGHTER than the lamp in circuit A, or DIMMER, or the SAME as the lamp in circuit A.

Also say whether the current through the lamp(s) will be BIGGER than, the SAME as, or LESS than, the current in circuit A.

2. When a lamp lights, the filament gets hot.

a. Make a list of other things besides lamp filaments that turn electric energy into heat.

b. What else can an electric current do besides producing heat?

3. Suppose you wanted to connect two lamps in a circuit so that you could switch EITHER lamp off and leave the other lamp alight. Which of the circuits in Q.1 would you choose?

 is the sign for a switch.

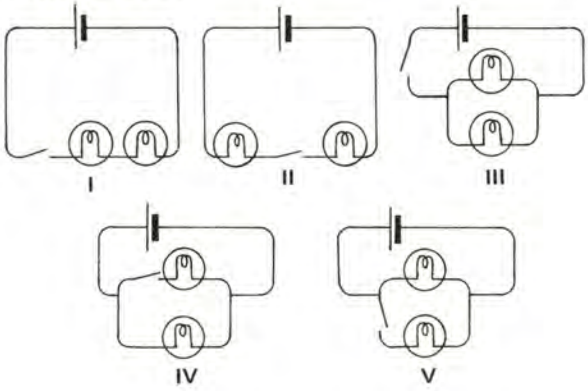
Draw that circuit, with the switches in it. Label the switches:

A—to switch one lamp on or off;

B—to switch the other lamp on or off.

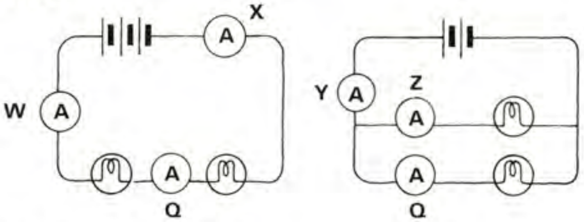
And put in a switch C to switch BOTH lamps off together.

4. The diagram shows five circuits, I to V. For each circuit say what you would see when the switch is OFF.



CURRENT ROUND A CIRCUIT

5. In each of these circuits, the ammeter Q reads $\frac{1}{2}$ amp. What will the other ammeters W, X, Y, Z read?



6a. Copy and complete:

Conductors are things that [/*let*/*do not let*/] electric current get through them.
Insulators are things that [/*let*/*do not let*/] electric current through easily.

b. Which of the following materials are conductors: wood, copper, silver, polythene, rubber, carbon, iron, bakelite?

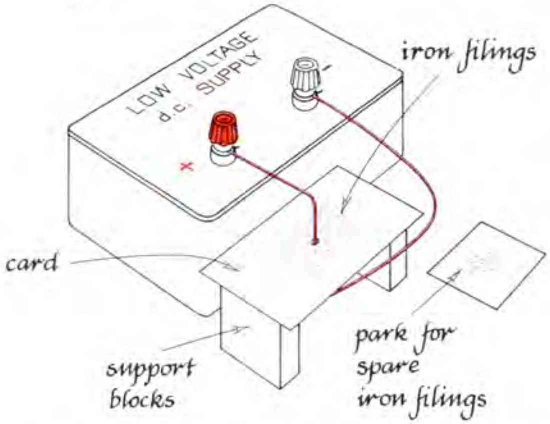
c. Make a list of 4 more conductors.

d. Make a list of 4 more insulators.

Electric Currents make Magnetic Fields

Experiment 87a
Look at the Magnetic Field of a large Current in a Straight Wire

Arrange your circuit as in the diagram. Take the current from an accumulator or low voltage d.c. supply.*

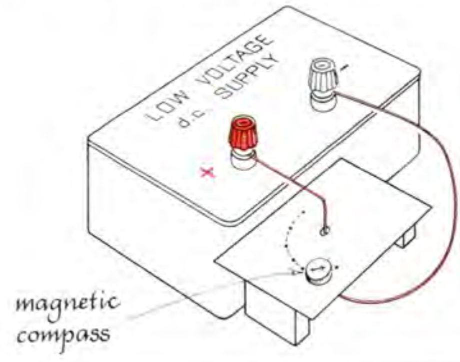


Make a hole in the centre of a piece of card or board. Place the card on support blocks.

Take about $\frac{1}{2}$ metre of insulated wire, run it through the hole in the card, and connect its ends to the supply.

First, strip the insultation off the wire at each end. Ask your teacher to show you how to use wire-strippers.

(i) Switch on the current and sprinkle iron filings on the card. Tap the card gently with a pencil or finger and watch. Do not keep the current running for long. (*Why?* Feel the wire.)



*For the following experiments you need only 1 or 2 volts but you need large currents, 8 to 10 amps. So you must have a supply with little resistance inside. The cells used in earlier experiments with circuit boards will not do—their high resistance would limit the maximum current you could draw.

(ii) Park the iron filings on to a spare sheet of paper. Now explore on the card near the wire, using a small magnetic compass.

(iii) If you have time, try making the current go the opposite way through the wire.

Magnetic fields When we find a place where iron filings line up in patterns and compass needles turn and point we say *there is a magnetic field* in that place. That does not explain what a magnetic field is: we are just saying the field is something that makes magnetic things happen. The field is an invisible state of affairs, ready to push or pull or turn a magnet; even ready to manufacture a magnet—as you will soon see.

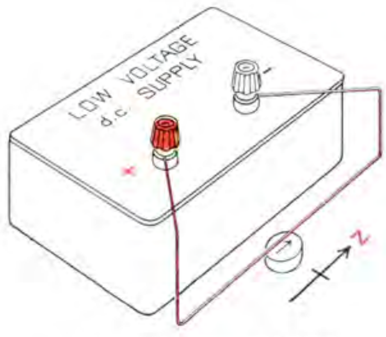
The magnetic effect of a current is not just used to make a pretty picture with iron filings. It makes ammeters and electric motors and loud speakers work, and dynamos and telephones and television tubes use it.

Œrsted's Discovery

When people began to do experiments with batteries and circuits (nearly two centuries ago) they did not know there was any connection between electric circuits and magnets. Then 150 years ago the scientist Œrsted in Denmark made the discovery in the middle of giving a physics lecture. He did an experiment like the one you have just tried. He had a compass needle on his table and happened to hold a wire carrying a current above it.

Experiment 87b
Œrsted's Experiment

If you like, try the experiment that made Œrsted famous for all time, his discovery of electromagnetism.



OERSTED'S EXPERIMENT

Take about 40 cm of wire. Hold it over a compass needle. Move the wire until it lies just above the needle, ALONG THE NATURAL DIRECTION OF THE NEEDLE. Turn on a large current in the wire.

If you like, you can use some iron filings as tiny compass needles at the *surface* of the wire. Sprinkle them over the wire itself while it carries a large current.

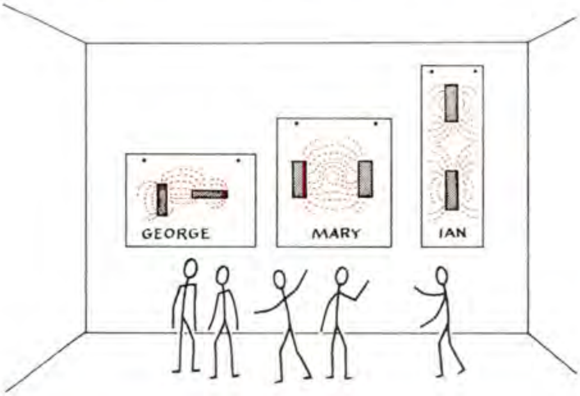
Notes? or Sketches?

In all these experiments with magnetic fields you might wish to sketch the patterns you see. But it would take you a lot of time and care to sketch the fields at all truthfully. That would delay your experiments and it might keep the apparatus away from other people who needed it.

So, for these experiments it is much better not to draw sketches now, but to wait until later and then make some large posters that can stay in the lab to remind you of the patterns.

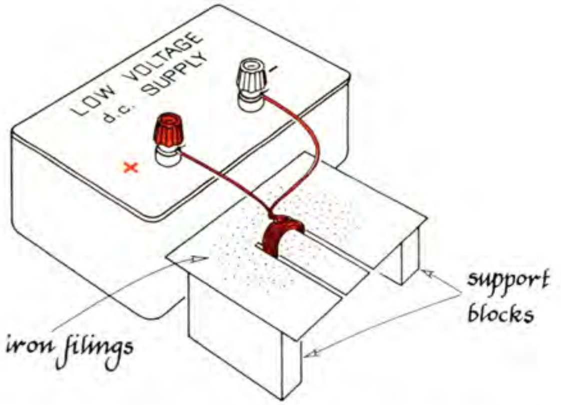
Exhibit 87c
Posters of Magnetic Fields

There are tricks for making these with photographic paper or waxed paper, to preserve the pattern. If possible choose a field and make your own contribution to the exhibit.

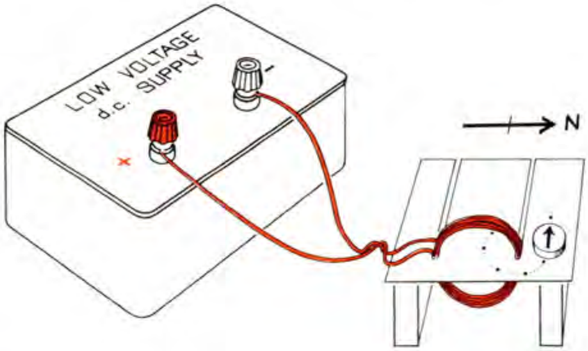


Experiment 87d
Magnetic Field of Hoop Coil Carrying Current

Take about 80 cm of wire. Wind a coil like a hoop: five or six turns of insulated wire on a thick wooden rod. Twist the ends of the coil together so that it does not unwind. Slide the coil off the rod and fit it into slots cut in a card.

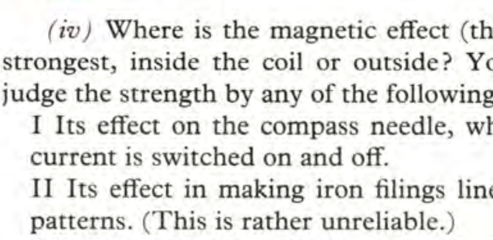


(i) Connect the coil to the low voltage supply and use iron filings as before.



(ii) Tip the iron filings on to a spare sheet of paper. Explore the magnetic field with a small compass. (For that, you should set the coil with its plane in the North–South direction.)

(iii) Try reversing the current.



(iv) Where is the magnetic effect (the field) strongest, inside the coil or outside? You may judge the strength by any of the following:

I Its effect on the compass needle, when the current is switched on and off.

II Its effect in making iron filings line up in patterns. (This is rather unreliable.)

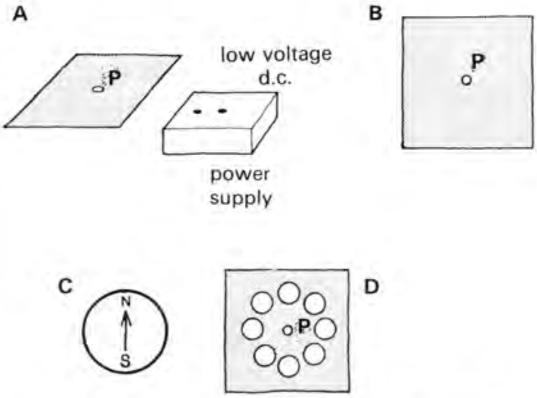
III The crowding of the lines of the iron filing pattern. Where the lines crowd closest, the field is strongest.

(v) (Optional) With a compass *inside* the coil, try switching the coil on and off. Then add a variable resistance in series with the coil, to change the current. Watch what happens when you make the current larger and smaller. You have now got an instrument to show larger and smaller currents. This is an ancestor of *ammeters*, now quite out of date.

Progress Questions

MAGNETIC FIELD OF A CURRENT

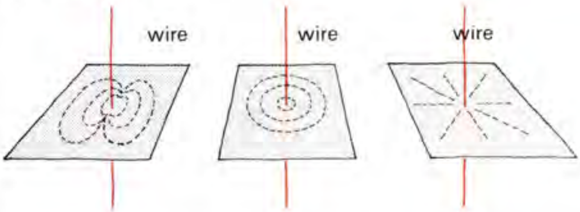
7. P is a hole at the centre of a piece of card. A wire carrying current from an electricity supply goes down through P, at right angles to the card. There are some compasses in a ring round the wire.



NOTE. When a compass is drawn like this the arrow's head shows its North pole (that is its North-seeking pole). So its poles are as marked in fig. C.

Copy fig. D, and show how the compass needles point when the current is:
(i) on,
(ii) off,
(iii) going the *opposite* way in the wire.

8. Write down the number of any drawing in fig. A which shows correctly the 'pattern iron filings make' near a straight wire which has an electric current in it.

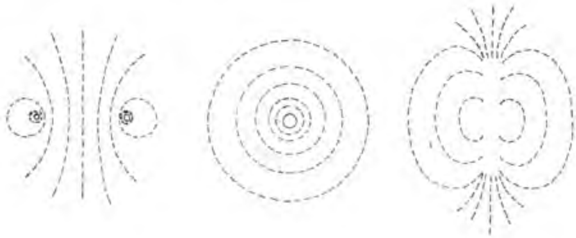


9. A compass is put just above a wire (see fig. A). A current is going from left to right, as shown.

a. Copy fig. A, and show which way the compass needle points when the current goes the other way.

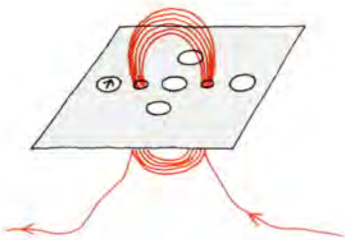
b. Now the compass is put *underneath* the wire (see fig. B). Copy fig. B, and show which way the needles point.

10. You can use iron filings to show a field pattern. The diagram shows some field patterns of wires and coils carrying currents.



a. Copy the drawings and mark X on them at the places where the field is strongest.

b. Label each drawing 'This is the field of . . ? . .' (Complete the label.)

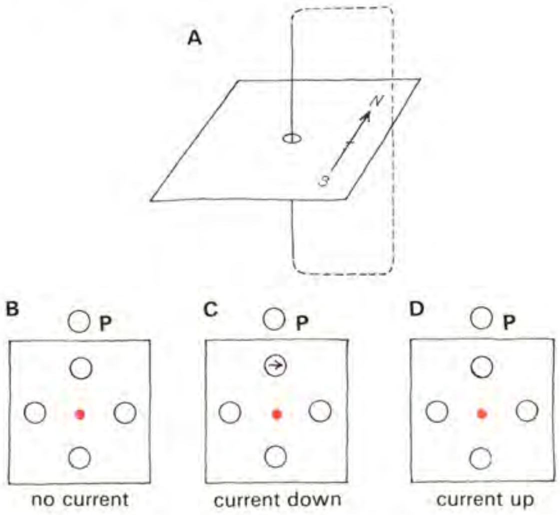


11. This drawing shows a large coil of wire threaded on a card. There are are also 5 compasses on the card. Sketch the diagram, and put in all the compass needles. (Note that one compass needle is already shown.)

Questions

MAGNETIC FIELDS OF CURRENTS

12. A piece of wire goes straight up and down vertically through the centre of a horizontal square of card (fig. A). Four compass needles are placed on the card, as shown in fig. B. A fifth compass is placed farther away, at P.



The wire is connected to a battery. When the current goes *down* through the board, as in fig. C, the compass needle North of the board points to the East, as shown.

In fig. D the current has been reversed so that it goes upwards.

In fig. B the current has been switched off altogether.

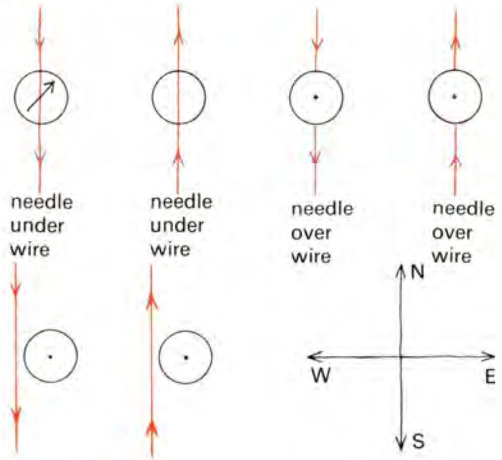
Draw three diagrams showing how all five of the needles point in each case. You need not draw them very beautifully—a rough sketch will show what you know.

13. The compasses in Q.12 are removed and now the pattern of the magnetic field near the wire is shown by sprinkling iron filings on the card. (Do not trouble about what happens out at P.)

a. What advice would you give another pupil who asks how to get a very clear pattern from this experiment?

b. What would the filings show in each of the experiments shown in the diagram?

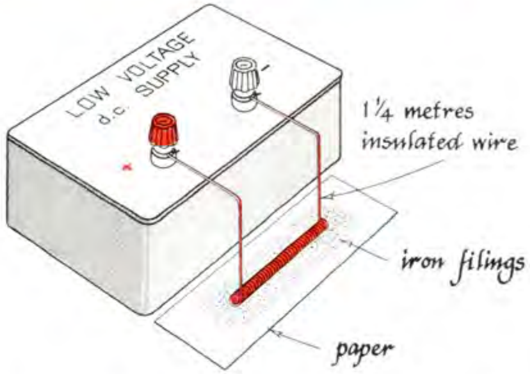
(Suggestion: draw a sketch for B. Then you can answer A and C in a few words. And remember to draw *what you yourself have seen,* not what the filings *might show* if they were as sensitive as compass needles.)



14. *(Œrsted's experiment)* Copy the six diagrams of wire and compass needle. The direction the needle points is given you for the first diagram. Put in the rest correctly. In the last two diagrams the needle is level with the wire and is East of the wire.

[*IMPORTANT NOTE. In examinations, you will NOT be asked to remember any rule at all about directions in which compass needles turn for given directions of electric current. But you ARE expected to know that reversing the current reverses the field. And you need to remember the magnetic field pattern for an electric current in a straight wire (that is, circles round the wire in planes perpendicular to the wire).*]

Experiment 87e
Magnetic Field of Current in a Long Close-wound Coil



Take $1\frac{1}{4}$ metres of wire. Wind 20 or 30 turns closely on a pencil.

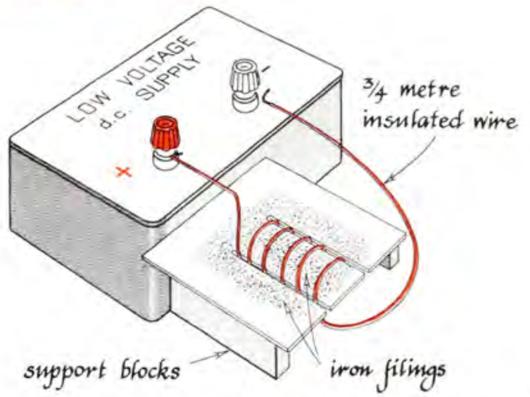
Take the coil off the pencil; lay it on a card and sprinkle iron filings over the card.

Try this with no current; then with the current switched on.

If you have spare time, try a small compass.

Have you ever seen this pattern (the magnetic field of current in a long coil) anywhere else? If so, where? If not keep an eye open for it.

Experiment 87f
Magnetic Field Inside an Open Coil carrying Current



Take about 80 cm of wire. Wind five or six turns, spaced well apart, on a large wooden rod. Slide the coil off the rod and fit it in slots in a card.

Connect the coil to the low voltage supply. Sprinkle iron filings.

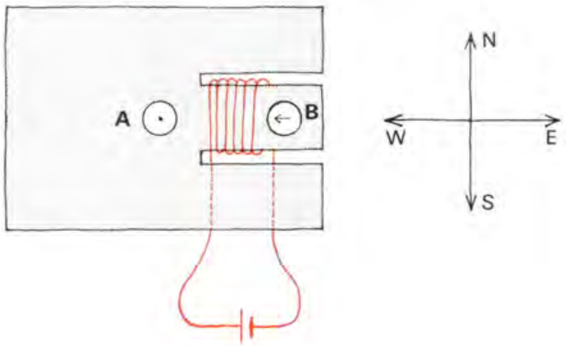
Also try a small compass.

Questions

FIELD OF A LONG COIL

15a. In the figure, the compass needle B is East of the coil and it points West. Which way does compass needle A point?

b. If the current direction is reversed, which way does A point? Which way does B point?

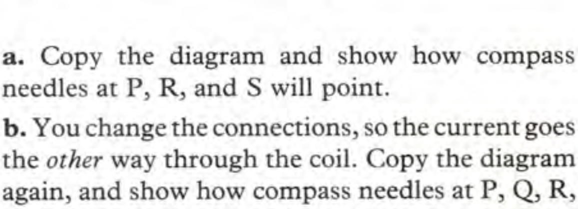


16. When a long coil carries a current, there is a magnetic field *outside* the coil. There is also a magnetic field *inside* the coil

a. Describe how you found out about the magnetic field INSIDE such a coil.

b. Describe the pattern of the field inside the coil as clearly as you can. (A sketch would be best but it needs to be large enough to show the story clearly—at least as big as the palm of your hand.)

17. This a long coil carrying a current.

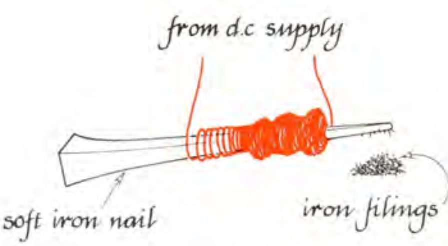


a. Copy the diagram and show how compass needles at P, R, and S will point.

b. You change the connections, so the current goes the *other* way through the coil. Copy the diagram again, and show how compass needles at P, Q, R, and S will point now.

18. How would you magnetize a rod of hard steel?

Experiment 87g
Simple Electromagnet



ELECTROMAGNET

Take $1\frac{1}{4}$ metres of insulated wire. Wind a few dozen turns round an iron nail. Send a large current round the coil. *Is the nail a magnet?* Try it with iron filings. Turn the current off.

Also offer your electromagnet some larger bits of iron, such as tin-tacks or paper clips.

What happens each time you turn the current off?

Most nails are made of iron or fairly soft steel (which is iron with some carbon melted in with it to add some strength). An iron nail or any other core of soft iron seems to stop being a magnet when you turn the current off. Soft iron makes a good *temporary* magnet.

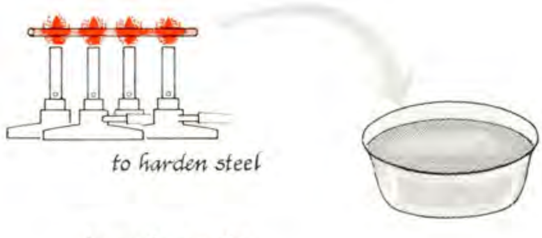
The iron filings you have used are chips of soft iron and they become temporary magnets when they are in a magnetic field. You can see that they stop being magnets when the current is turned off, or when a permanent magnet is taken away, since they no longer cling together strongly in patterns.

Experiment 87h
Making a Permanent Magnet

You can make a permanent magnet if you use a rod of hard steel. Hard steel is steel of a suitable composition that has been heated and suddenly cooled.

The rod may be a knitting needle or a piece of clock spring, or even a short piece of hardened springy steel wire.

Take $1\frac{1}{4}$ metres of insulated wire and wind a few dozen turns round the rod.



MAKING A MAGNET

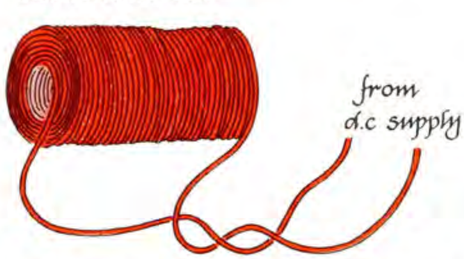
Test the rod with iron filings before you turn the current on. Then send a large current round the coil.

What do you see when you turn the current off again?

(If your hard steel rod is already a magnet before you start, ask your teacher to de-magnetize it before you do the experiment. Watch that being done!)

Experiment 88
Magnetizing Coil *(OPTIONAL)*

MAGNETISING COIL



A good, but lazy, way to magnetize is to have a large ready-made coil that allows you to magnetize steel rods without having to wind wire round each of them. The open coil that you have tried showed the pattern of magnetic field that we use for making permanent magnets.

With a large coil, where would you put the bar of steel that you wished to magnetize? Outside the coil, just at its mouth, or inside? Ask if you may try a magnetizing coil.

Experiments with Permanent Magnets, for Catching-up or for Overlap from Earlier Years

Experiment 89a
Permanent Magnets

If you have not done experiments with magnets before, try to find out some things about them on your own.

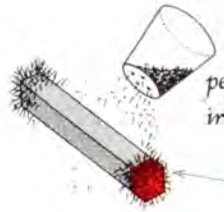
Explore the behaviour of magnets. Use several bar magnets, iron filings, and a sling of threads to suspend a magnet.

Then try Experiments 89b *(i)–(iv)*, 89c, 89d.

Experiment 89b
Magnets: Quick Reminder Experiments

If you have already explored the things magnets do, at some earlier time, try these experiments quickly now.

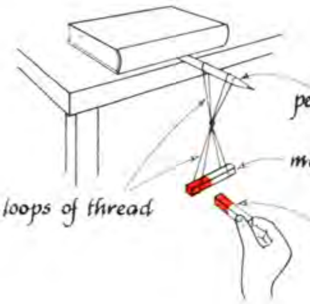
(i) Poles. Put iron filings on a bar magnet. It seems to have special places that we call 'poles'.

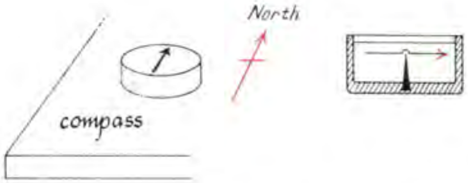


What happens at the poles? Where are the poles, usually?

(ii) Poles and Compass. Hang a magnet in a cradle on a thread so that it can twist and point in any direction.

The sketch shows how to make a cradle of thread.





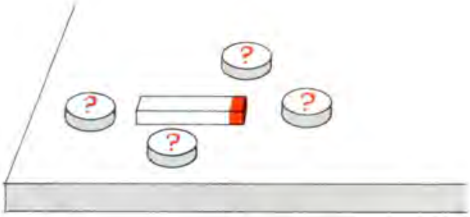
It turns round until it points roughly North–South. We call the pole which turns and points towards North 'the North-seeking pole'.

A compass is just a small magnet on a sharp pivot. So the end of a compass needle that points North is a *North-seeking* pole.

(iii) Forces between Poles. Feel magnet poles exerting forces on each other. Use some small strong bar magnets. (These may be made of special material called ticonal.)

Do two North-seeking poles pull (attract) or push (repel) each other?

What does a North-seeking pole do to a South-seeking pole?



magnet and compasses

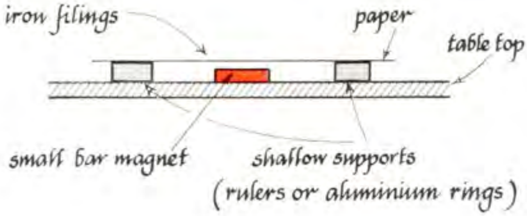
(iv) Testing Poles. Use a compass needle, whose North-seeking pole is marked, to find which is the North-seeking pole of a bar magnet.

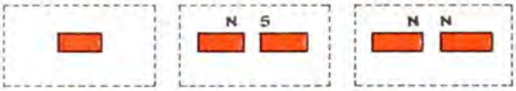
Exploring the Fields of Permanent Magnets

Experiment 89c
Fields of Bar Magnets

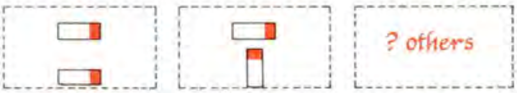
Use iron filings to show the magnetic fields of:

(i) A short bar magnet. *(Where else have you seen this pattern?)*

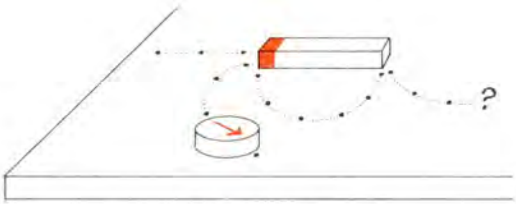




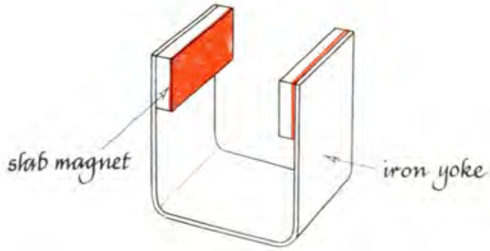
(ii) Two bar magnets near each other in various positions.



Also try placing a compass needle near a short bar magnet. Push the compass along the table, 'sailing due North by the compass'.

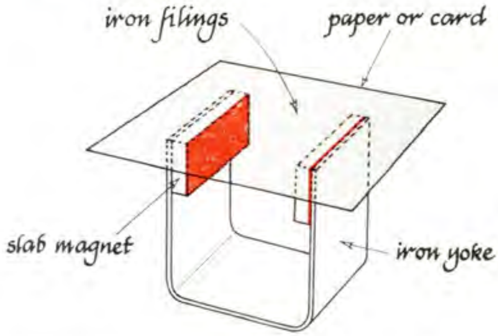


plotting field lines



Experiment 89d
Slab-shaped Magnets

(i) Explore the behaviour of the *slab* magnets which you are going to use for future experiments. (These strong magnets are not likely to lose their magnetization; but they may chip or break if allowed to bang together.)



(ii) Use two slab magnets and a U-shaped 'yoke' of iron to make a modern form of the old horseshoe magnet. Attach the slab magnets to the inside faces of the U. Make sure you have got the slab magnets the right way round to make a strong magnetic field in the space between them.

Progress Questions

MAGNETS

19. A magnet will pick up an iron nail.

a. Will both ends of the magnet pick up the nail?

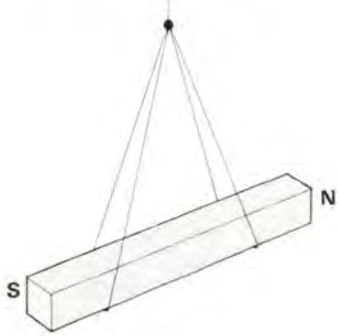
b. Will the middle of an ordinary magnet pick up the nail?

c. What other materials will the magnet attract?

d. Must a magnet actually *touch* an iron nail before it lifts it up? Can a magnet act through air or vacuum? Can it act through paper or wood or your handkerchief?

20a. If you hang up a magnet as shown, far from any other magnetic material, in which direction will it point?

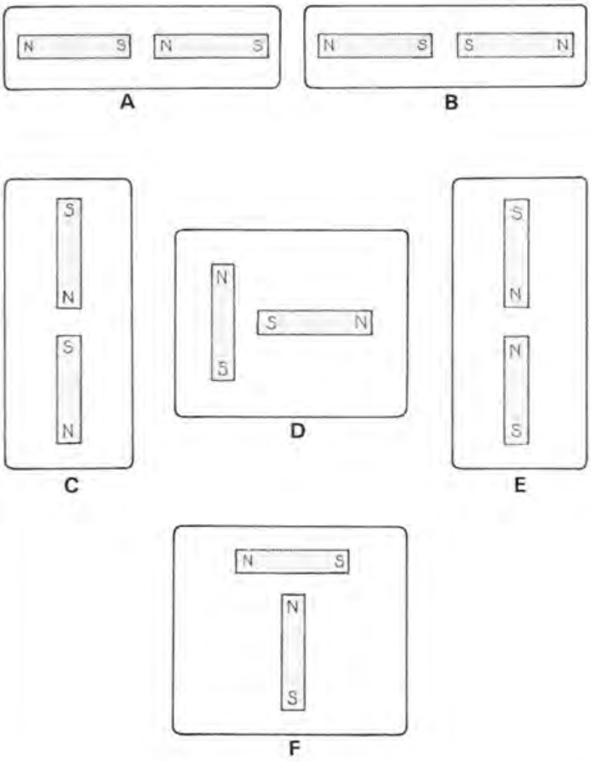
b. Why do we call one end a North-seeking pole (N pole) and the other end a South-seeking pole (S pole)?



c. A compass needle is a convenient arrangement for allowing a small thin magnet to turn freely. What does it do if left with no other magnet near it? One end is marked or painted. Is it the North-seeking pole or the South-seeking pole?

21. You normally label the two ends of a bar magnet N and S. What do you *mean* by the label N?

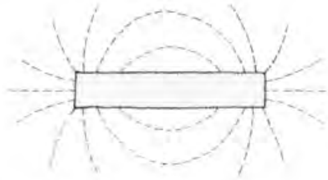
22. The following diagrams show two magnets near one another.



Use the words: PULL TOGETHER (or ATTRACT)
PUSH APART (or REPEL)
TURN ROUND
to describe what happens in each case.

TWO KINDS OF MAGNET

23. The drawing shows an experiment you have done.



What is the thing in the middle? (*Two* answers are possible.) What do all the dots represent?

24. Fig. A shows some compasses near a long coil with a current going round it. Fig. B shows some compasses near a bar magnet.

Copy the drawings and show how the compass needles will point. One needle in A is correctly drawn.

FIELDS OF MAGNETS

25a. The compass needles in fig. A are quite a long way apart.

Copy fig. A, and show the way the other needles point.

b. Copy fig. B, and show which way the needles point now.

c. I have magnetized a nail. How can I tell which end is its North pole?

Questions

FIELDS OF MAGNETS

(There are many questions about magnets because some people like one kind of question and some like another. There is no need to try all these questions. Choose a few, to make sure of your knowledge.)

26. In the figure, NS is a strong bar magnet. AB is part of the magnet's central magnetic field line.

(You need not worry about any effects of the Earth's magnetic field, which is quite weak.)

a. What do the arrows on AB represent? (Your answer should mention a compass needle.)

b. Copy the sketch (about the same size). Add to it two magnetic field lines in the top half above the magnet; and two in the lower half. Put two or more arrows on each line to show the field's proper direction. (That is always FROM the N pole round TO the S pole.)

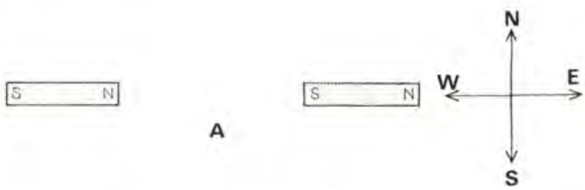
c. The magnet in the sketch lies East–West. Mention *two* places in the diagram where you could put a compass needle so that it would point WEST.

d. Mention two places where a compass needle would point EAST.

e. Draw (as a separate sketch, but near the first one) a long coil which would give almost exactly the same magnetic field as that of the bar magnet. You need to think of *size* as well as *shape*.

27a. Copy the diagram and draw a compass needle at A, showing the direction in which it would point.

(Remember there are three magnets in this story; the two that you see in the sketch *and* the Earth. Imagine that the two bar magnets are weak, so that the Earth's magnetic field has a noticeable effect on the needle.)

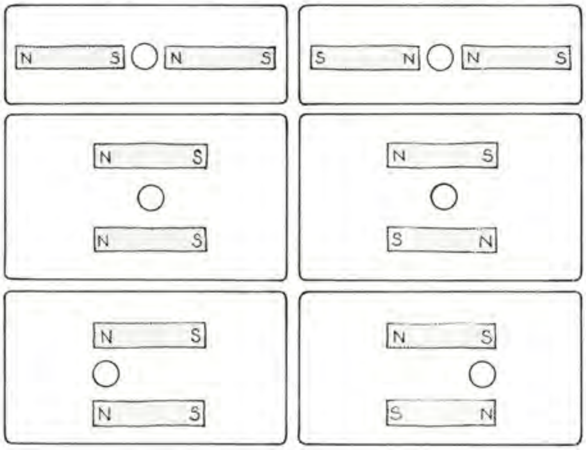


b. Suppose you reverse one of the bar magnets, end for end. Suppose the two magnets are equally strong; and the point A is exactly mid-way between them. In what direction would the compass needle point if you placed it at A?

c.What happens if you reverse *both* bar magnets?

d. Draw a diagram showing two coils carrying currents that could produce the same effect as the two magnets in the original arrangement of the figure. (Just sketch the coils. You need not bother to decide which way the current is flowing.)

28. Pairs of magnets are placed together in different ways shown in the diagrams. The circles show compasses. Copy the diagrams. In each circle draw an arrow showing which way the compass needle points. (Or you may say in words what the needle would do.)



A COLLISION

29. Two powerful horseshoe magnets are mounted, each on a small toy railway truck. The trucks are placed on a track with the open ends of the magnets facing each other.

a. The trucks are given a push straight towards each other. Two quite different things may happen as the magnets approach each other, depending on how the magnets are arranged. Describe *one* possibility.

b. One magnet is then turned over and fixed on its truck again. What happens this time when the trucks are again given a push towards each other?

c. How would you use pieces of sponge rubber and a piece of elastic (instead of the magnets) to show similar kinds of 'collision' with two trolleys on a level runway?

POLES

30. A bar magnet is dipped in iron filings, and then taken out and shaken.

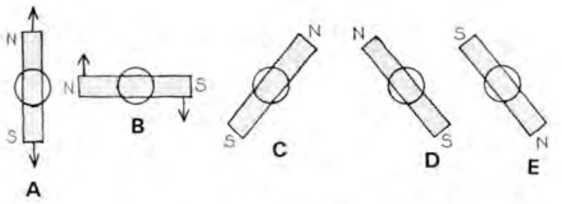
a. What do you see the filings do?

b. Why do filings do that? What is happening to each small chip of iron?

31. Suppose you have a magnet with no paint on it, with nothing to show which pole is N. How would you find which is the North-seeking pole without making use of a compass or any other man-made magnet?

THE EARTH AS A MAGNET

32. Figs. A to E show five positions of a very short bar magnet which is placed on a flat piece of cork floating on water in a big glass trough. Two arrows in A and B show the forces, due to the Earth's magnetic field, which act on the magnet when it is placed in these two positions.



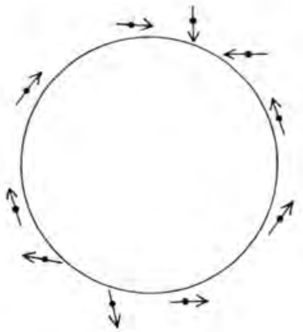
a. Copy the sketches and add suitable arrows to C, D, and E.

b. The magnet in fig. A stays in this position and does not move in any way. What does this tell us about the strength of the two poles, N and S, 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 'anticlockwise', according to whether you think the magnet will turn in the same direction as the hands of a clock, or in the opposite direction. (If you like you may use a curved arrow instead, like this ↻ or this ↺. That is how engineers show directions of turning.)

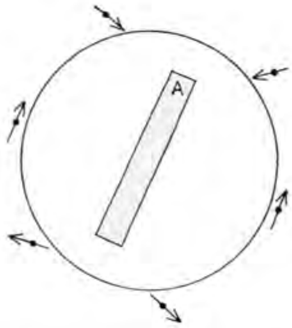
MAGNETIC FIELD PUZZLES



33. This is a round box with a bar magnet hidden inside it. Compasses are placed outside.

Copy or trace the sketch, and then draw in the bar magnet. Mark its poles sensibly.

34. There is a magnet buried inside a ball of solid wood. When you put compass needles near it they point as shown by the arrow.



a. Should the end A of the magnet be labelled N? or S?

b. Suppose you guessed that there was no magnet at all in the ball, but there was something making an electric current. To make the same effect on the compass needles outside would it have to be current going *straight through* the ball, or *in circles*, or *what?*

c. Exploring over the face of the Earth with a compass gives results like the sketch. Can you tell, without digging down deep, what makes the Earth's magnetism? Can you tell whether there is magnetized iron, etc., or an electric current inside?

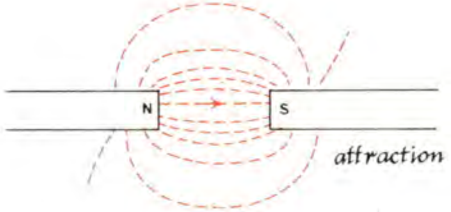
d. The Earth has a 'magnetic pole' deep down under northern Canada. Is that a North-seeking pole or a South-seeking one?

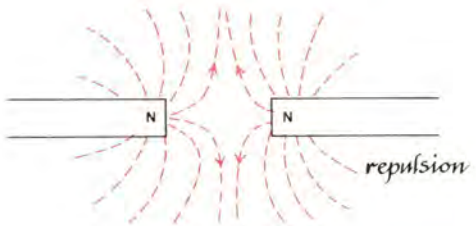
Field Patterns Illustrate Forces

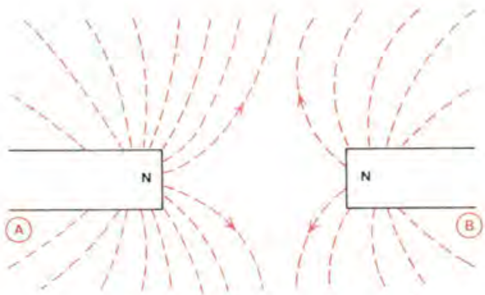
Some scientists say that the patterns of magnetic fields give clear hints about the forces magnets exert on each other. This is important for electric motors and ammeters.

Long ago, Faraday made a tremendous discovery about magnetic fields, which led to the invention of dynamos. In thinking about his discovery, he liked to imagine that these patterns were pictures of elastic tubes. He imagined such tubes pulling along their length and pushing sideways, elbowing each other away. If you like Faraday's idea:

(i) You can see the lines that run from a magnet's North-seeking pole to another magnet's South-seeking pole clutching and pulling the poles towards each other.

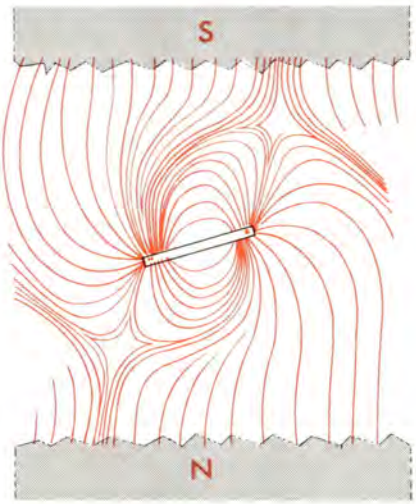






Which pole is the stronger ?

(ii) You can see the lines from two North-seeking poles swinging away from each other, elbowing the poles apart.



(iii) You can even make predictions when you see a field pattern. Imagine a small magnet placed across the uniform field between large North and South poles. The combined field seems to tug at the small magnet's poles to wrench it round. That is the picture of a small compass needle being pulled round till it points along a magnetic field.

Faraday carried his picture of tubes still farther and used it to make his discovery of dynamos clearer. Tubes or lines of force are useful for thinking; but it would be a mistake to think they are really there.

Thinking about Coils and Magnets

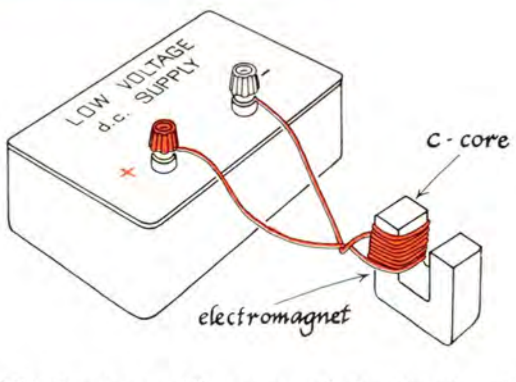
Did you notice that a coil carrying a current has a magnetic field that looks like the field of a bar magnet of the same shape and size as the coil?

You know that the current produces the coil's magnetic field. Perhaps there are electric currents in a bar magnet also. If there are, they are not like the currents in a simple electric circuit of wires—currents which continually produce heat. The currents in a bar magnet must be frictionless electric currents which just go on and on.

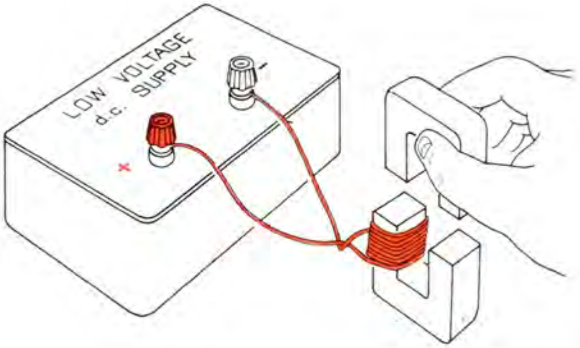
Those currents cannot be electrons staggering in jolting progress through a forest of atoms in a wire and making the wire hotter. Perhaps they are some much smaller motion of an electron which continues with no collisions. *Can you guess what that motion might be?* Leave that as a puzzle until later.

EXPERIMENTS WITH ELECTROMAGNETS

Experiment 90a
Large Electromagnet: Forces



Wind about 20 turns of insulated wire round one leg of a *soft iron* C-core from your kit. Send a large direct current through that coil. Offer this electromagnet some iron nails.



Then offer your electromagnet another C-core (without any coil) and feel the force.

What happens when you switch the current off?

(The end faces of both C-cores must be very clean for this experiment to do well. Before you try it, wipe any grit or iron powder off those faces with a piece of tissue or with your thumb. To make quite sure, hold the two C-cores tightly together (with the current off); slide a clean piece of paper between the faces and pull it out again while you hold the two C-cores together. The paper will wipe the faces clean.)

Progress Questions

ELECTROMAGNETS

35. A much younger pupil asks, 'How can I make an electromagnet?' You give him a long piece of insulated wire, a suitable metal rod, a battery, and a switch.

What would you then tell him to do? (Write the instructions as simply as you can.)

A friend is making an electromagnet. You give him a metal rod to use as the core. How will his electromagnet behave if the rod is made of:
(i) Soft iron?
(ii) Hard steel?
(iii) Brass?

36. Suppose iron filings are scattered all over the tables and floor of a lab. How would you use an electromagnet to clean them up and get them back into the jar?

37. A tea exporter uses nails to hold his crates together. Where they have split he repairs the damage with tintacks. The importers who unpack the tea can remove the nails; but tintacks are hard to see among tea leaves and a few of them may get left in the tea. How would you catch those tacks as the tea leaves run down a chute into paper bags?

38. Magnets are used in junk yards to carry scrap iron from a pile on the ground to lorries that carry it away to a foundry. Why are *electromagnets* used, instead of *steel bar magnets* which would not cost anything to run?

Questions

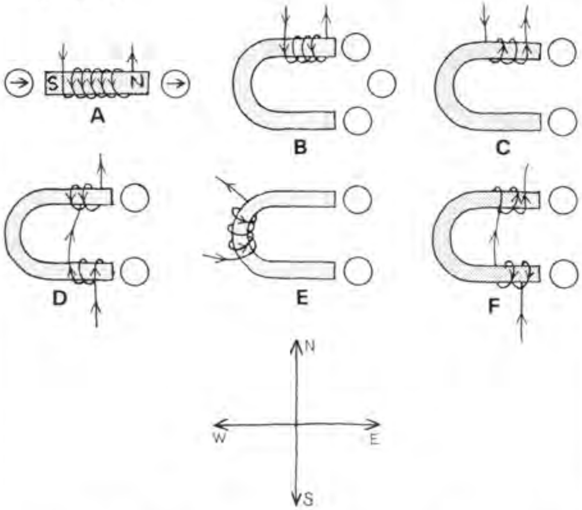
ELECTROMAGNETS

39. Fig. A shows a soft iron bar with a coil wound round it. When a current flows round the coil in the direction shown, the compass needles both point towards the East, because the bar is a *temporary* magnet. The letters N S show the temporary North-seeking and South-seeking poles of that magnet.

a. How do you know from the sketch that the N and S poles of the bar are correctly labelled? (The answer needs words. A sketch would be difficult.)

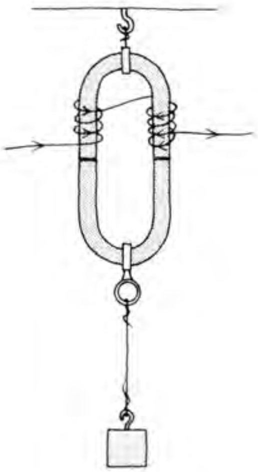
b. Copy fig. B and show the needles of the three compasses pointing in the correct directions. Also mark the N and S poles of the 'horseshoe' electromagnet. (The C-core is made of soft iron.)

c. Copy and complete the other figs. C to F in the same way. (In each case the C-core is made of soft iron.)



IMPORTANT NOTE. You are *not* expected to remember any rules about current directions and compass needle directions. All the answers can be worked out from what you are shown in fig. A. The only doubtful one is the centre compass in B; guess at that by common sense.

40. An iron C-core (or 'horseshoe') has coils wound on its legs. It is hung from the ceiling as shown in the diagram. A large current runs through the coils. It easily holds up a second C-core (without coils) with an extra load of 2 kilograms on it.



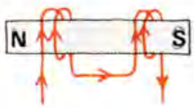
a. What happens when the current is switched off?

b. Suppose the smallest current which will hold the lower core with its 2-kilogram load is $2\frac{1}{2}$ amps. A current of 3 amps holds a bigger load, and 4 amps a still bigger load. Will the magnet hold *any* load—as big as you like—hung on the lower C-core if we can supply a large enough current? What do you say, and why?

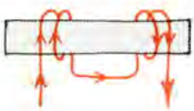
c. Reversing the current, or reversing the direction of winding of *both* coils, makes no difference to the lifting strength. What would happen if you reversed only one coil? Why? Give a reason for your answer.

41a. Fig. A shows the poles that appear on an iron bar when the current runs through the two coils as shown. How would you use a compass needle to discover what happens with the arrangement shown in fig. B?

b. What positions of poles would you expect to find?



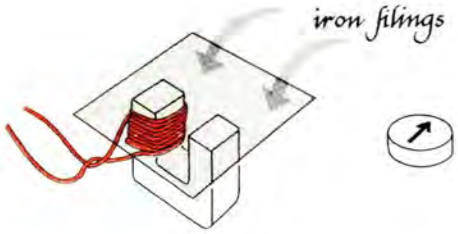
A



B

Experiment 90b
Field of Big Electromagnet

Place your C-core electromagnet on the table with its end-faces upward. Put a card on top of its faces and sprinkle iron filings.



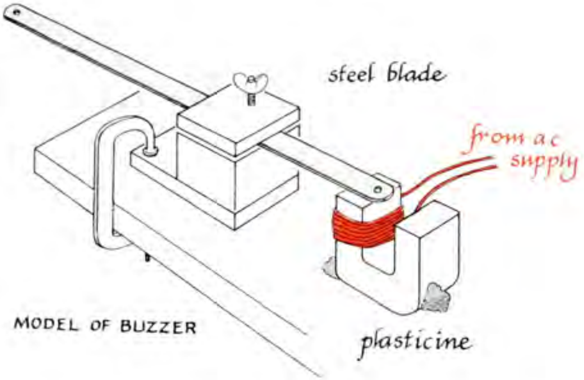
Do you see any field when the current is off? What do you see when the current is on?

You can find whether the poles at the faces are North-seeking or South-seeking by bringing a small compass near.

Applications: Using Electromagnets

Experiment 91
Making a Buzzer

Clamp a steel hacksaw blade in a support block about one third of the way from one end. Place the electromagnet just under the blade, near the other end. Anchor the C-core to the table with a lump of plasticine.



When the electromagnet is switched on (with direct current) it will pull the blade a little and bend it.

To make the blade vibrate a lot you must change to low voltage *alternating current* supply.

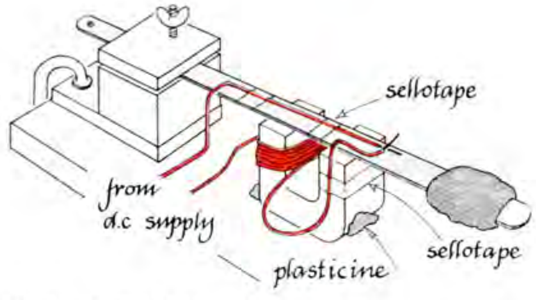
Can you feel the blade vibrating when you switch on?

To make the blade vibrate a lot you must tune it to the alternating supply.

If the blade is too short it naturally vibrates too fast—faster than the switching to and fro of the alternating current. If it is too long it vibrates too slowly. Loosen the clamp and move the blade until you find the best length for a good buzzer. Tighten the clamp fully every time.

Experiment 92
Model Electric Bell

Clamp a hacksaw blade firmly in a support block near one end. Place your electromagnet just under the blade, near the other end.



MODEL OF ELECTRIC BELL

Anchor the C-core to the table with the lump of plasticine. Load the free end of the blade with a block of metal or a lump of plasticine so that it vibrates naturally quite slowly, only a few times a second.

Make a 'contact-breaker' by fixing two pieces of bare wire with sellotape, one on the blade, the other on a leg of the electromagnet, so that when the blade bends it breaks the contact and turns the current off.

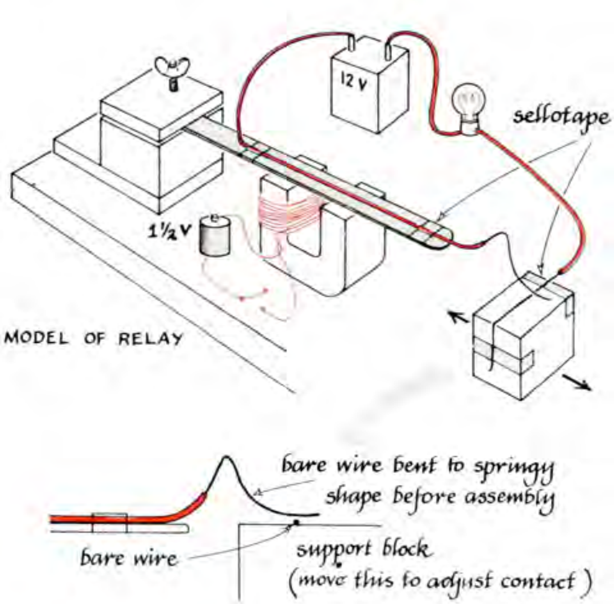
Connect up to a low voltage d.c. supply. The blade should almost touch the electromagnet core when it breaks the contact. To complete your bell, let the vibrating blade hit a tin can or something else to make a noise.

Experiment 93
Making your own Relay

A relay is an automatic electric switch. A small current sent through the relay's coil makes the relay switch on (or switch off) a big current.

Or a small current may make a different relay connect up *several* other circuits.

A relay hands a switching signal on from one circuit to another. That is why it is called a relay, after a *relay* race in which one runner hands the torch on to the next.



You will find relays by the thousand in a telephone exchange, and huge relays in a power station, and controlling relays in any factory with automation.

Convert your model electric bell into a relay. For the small control current to operate the relay connect the electromagnet coil to a $1\frac{1}{2}$ volt cell, in series with a switch. (You will need a switch of some kind for this, to turn the control current on and off.)

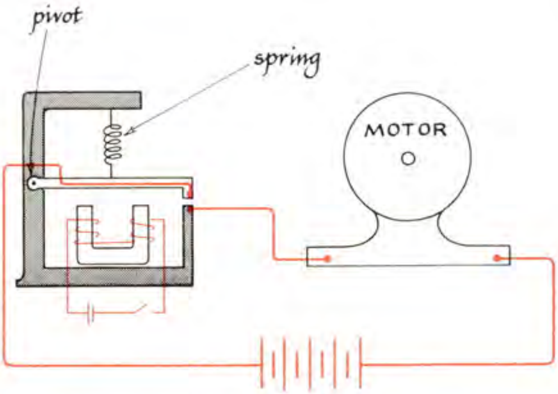
Disconnect the contact-breaker wires of your electric bell, and re-arrange them so that when the blade is pulled by the electromagnet the wires *make* contact. (Follow the sketch.) Connect them in a separate circuit with a battery and a lamp (or an electric motor).

Adjust the contact of the two bare wires by moving the plain support block nearer to the electromagnet or farther from it.

When you press your switch in the control circuit the lamp in the other circuit should light up.

If you like, convert your relay into a 'locking relay' which will keep a motor running once you have pressed the switch. For that, you need to connect the two 'contact-maker' wires to the terminals of your switch in the control circuit. Then once contact is made it will not matter whether the control switch is on or off!

Optional Demonstration 94
Commercial Relay



COMMERCIAL RELAY

If a small relay is available, see it use a tiny control current to start a large electric motor.

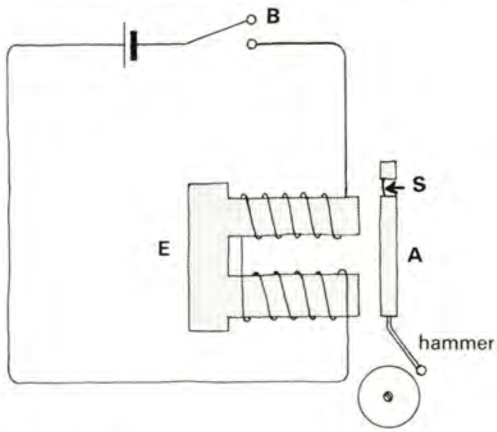
Special Optional Project 94X
Relays and a Computer

If you have a lot of spare time, ask for some commercial relays and special instructions for putting together a simple computer.

Progress Questions

BELL

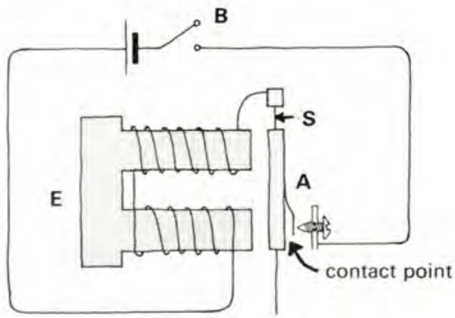
42. E is an iron core, with a coil of wire wrapped round it. A is a piece of iron. It is held by a steel strip S, and it has a small hammer attached to it.



When the current is switched on at the button B, there is a 'ting' as the hammer hits the gong.

a. Explain why this happens.

b. What happens when the current is switched off?



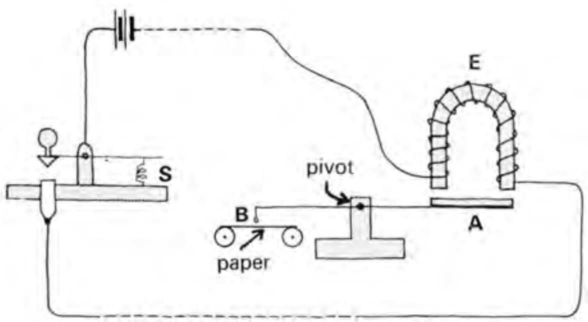
43. The bell in the previous question (Q.42) gives only one ting when the switch at B is pressed down. We can make it give a continuous ringing by adding a contact point, as shown in the diagram.

Explain how this bell works.

44. Suppose an electric bell doesn't ring? What might be wrong with it? Give as many troubles as you can think of.

TELEGRAPH

45. The diagram shows a way to send messages in Morse Code (dots and dashes).



T is a switch, called a 'tapping key'. It has a weak spring S in it to pull it up again. You send the message by tapping T. You hold it down a short time for a dot and a long time for a dash.

B is a small inky brush and it writes the message on a paper tape underneath. The paper moves steadily along under the brush, on rollers.

E is an iron core, with wire wrapped round it.

A is a small iron bar. A is joined onto a long rod that can pivot in the middle.

The shaded parts are made of wood or plastic.

The transmitter and receiver may be miles apart. The dotted lines show the long wires joining the transmitter to the receiver.

a. The way the diagram is drawn shows the circuit when *no* current is flowing.

Explain what happens to the circuit when T is closed, by pushing the knob down.

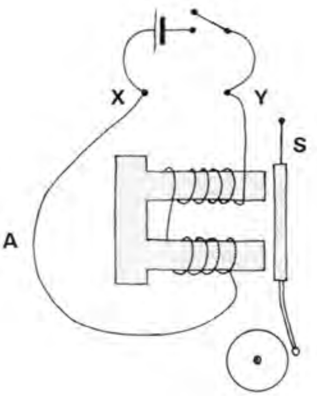
(HINT. What will happen to E when a current is present through its coil and how will this affect A and B?)

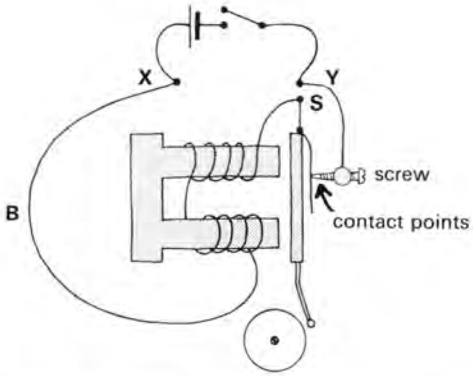
b. Now explain in your own words how the apparatus works.

Questions

ELECTRIC BELL, ETC.

46. Fig. A shows a simple form of electric bell. The shaded parts represent soft iron. S is a piece of steel spring; X and Y are terminals to which a battery and a switch can be connected.





a. Describe carefully what happens when the switch is closed. Give reasons.

b. In fig. B some extra parts have been added, as shown. What happens now when the switch is closed, and why?

47a. What difference in construction is there between an electric bell and a buzzer?

b. Where does the noise come from in a buzzer?

c. If you can, write a few sentences explaining what would happen if the platinum points got covered with dirt or oil.

d. Mention some other pieces of machinery you, perhaps, make use of quite often, which has platinum points in it.

e. The 'contact points' are made of tiny pieces of tungsten or platinum. What would happen if copper or iron were used?

48. Suppose another pupil, who missed seeing a relay, asks you:

'What *is* a relay? What does it *do*? How does it work?

Tell him, in your own words. Add a sketch to make your description clearer.

49. There are relays in a Laundrette washing machine. Guess some of the things they do.

50. If you have a chance to visit a radio or television repair shop, ask to look at a broken loudspeaker. See how its magnet and coil are arranged. Make a sketch of them.

51. *(ADVANCED)* A circuit-breaker is a switch that takes the place of a fuse. A large current through it makes it switch off the supply of that current.

Try to design a circuit-breaker.

Remember it must *keep* the circuit switched off after it has been tripped by the large current.

CURRENTS MAKE FORCES

Electric Motor Forces

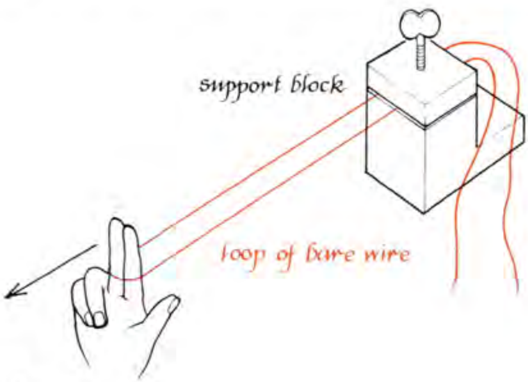
Try the next two experiments yourself, without knowing quite what will happen. Just see what you can find out, without any help.

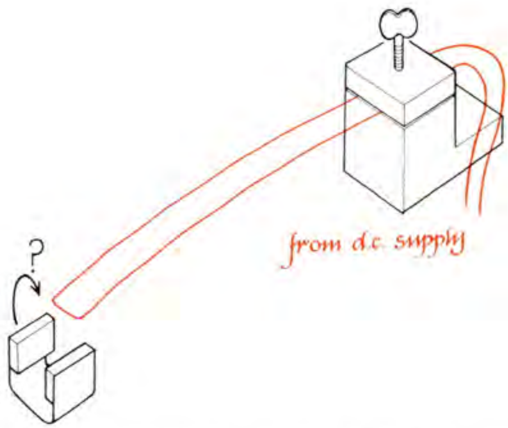
Experiment 95
Wire carrying Current across a Magnetic Field

95a Simple Introduction

Have a 'horseshoe' permanent magnet ready: this should be an iron yoke with slab magnets on its inner faces, to make a wide gap for the field between N and S poles. (Make sure you have N and S poles facing each other across the gap, and not N and N by mistake.)

Take about $\frac{1}{4}$ metre of 26 gauge *bare* copper wire. Connect the ends to your low voltage d.c. supply. With two fingers, pull out into a long narrow loop. Anchor the two sides of the loop with a support block as in the sketch. Let the loop run





out and sag far beyond the block. Hold the 'horseshoe' magnet so that the end of the wire loop is in the space between the poles.

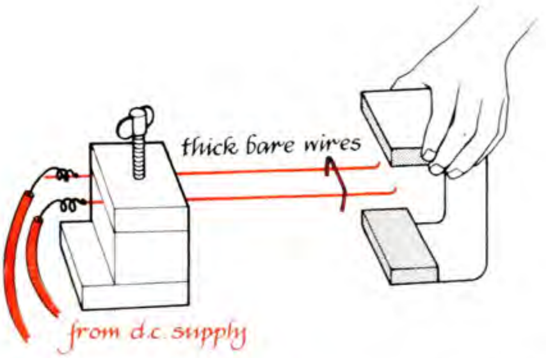
Turn the current on and off and watch what happens.

Try holding the magnet pointing in several different directions.

Draw some rough sketches to record what happens. BEFORE YOU DRAW ANY CONCLUSIONS, GO ON THE THE NEXT EXPERIMENT.

95b Movable Bridge

Use the 'horseshoe' magnet as before. Using 26 gauge (or thicker) *bare* copper wire, make two straight rails and a movable crossbar that can slide on the rails, as in the sketch. (You need fresh clean wire to make good electrical contact between the crossbar and the rails.)



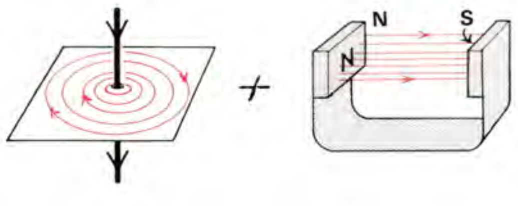
Hold the 'horseshoe' magnet as shown in the sketch; and turn on a large direct current.

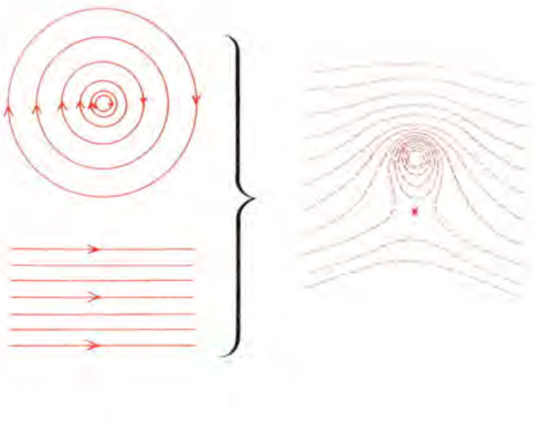
Repeat the experiment with the magnetic field reversed, downward instead of upward or vice versa.

WHEN YOU HAVE CARRIED OUT YOUR INVESTIGATION, DISCUSS YOUR RESULTS WITH YOUR TEACHER.

The Catapult Field Pattern

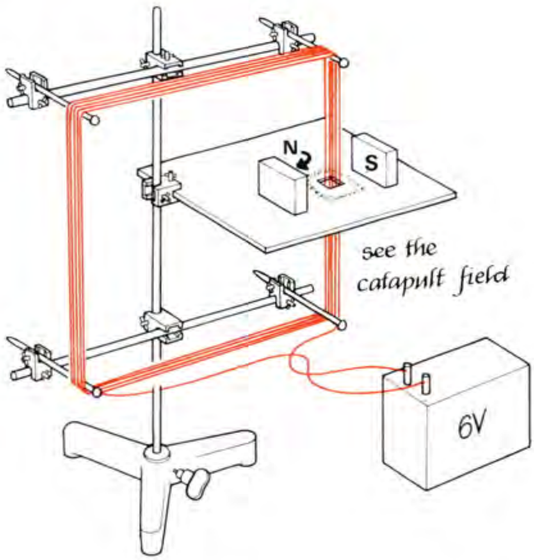
The current in the movable crossbar in your second experiment makes a magnetic field of circles round the wire. The 'horseshoe' magnet makes a magnetic field of almost straight lines across the gap from one pole to the other. When we have both magnetic fields together the combined pattern is a very strange one, which we call the 'catapult' field.





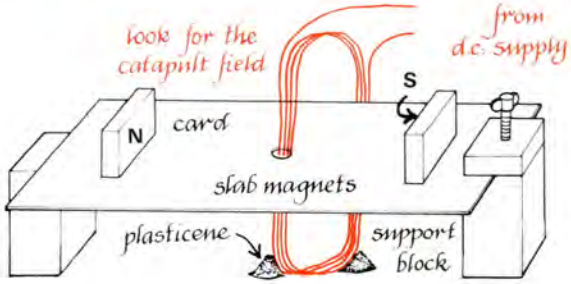
Demonstration 96a
Catapult Field

See this demonstration.



Can you see a strong hint in the pattern, that tells you about the force on the movable bar or flexible wire of your earlier experiments?

Experiment 96b
Catapult Magnetic Field



If you have time, set up your own version of that demonstration. Place a long card on support blocks. Place two slab magnets upright on the card about 25 cm apart. Use 1 metre of insulated wire to make a 3-turn hoop coil of diameter about 10 centimetres. Look for a field like that in the sketch.

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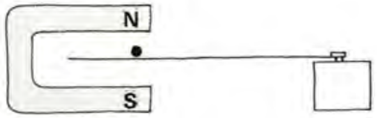
*'Magnetism is electricity viewed sideways.' Sir Lawrence Bragg in a lecture at the Royal Institution.

Progress Questions

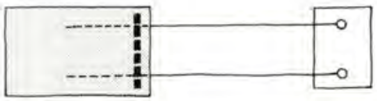
CATAPULT FIELD

52. *(Do this if you have seen the 'jumping wire' or catapult experiments.)*

A short wire is free to move along two long straight wires, that are joined to an electricity supply. Fig. A shows a side view of the apparatus, with the magnet in place. Fig. B shows a view from above—but the magnet has been left out.



A



B

a. Copy the diagrams and label:
(i) the free wire,
(ii) the long straight wires,
(iii) the d.c. supply.

b. When the current is turned on, the free wire goes to the *right*. Show this on your diagrams, with arrows.

c. You turn the magnet upside down. What does the free wire do now?

d. You put the magnet back as in fig. A. But you turn the battery round so that the current in the free piece of wire goes the opposite way. What does the free wire do now?

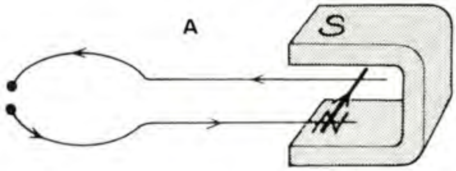
Questions

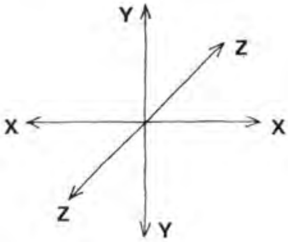
CATAPULT FIELD

53a. Give a brief description of the apparatus drawn in fig. A. Say what happens when the current is switched on.

(The arrows on the wires give the current direction. The field direction is upwards, from North-seeking pole to South-seeking pole. The direction of motion of the free wire is to the right, shown by the arrow marked M.)

A

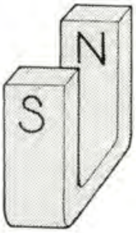




b. What happens to the direction of motion of the free wire:
(i) if the magnet is reversed so that the N pole is at the top;
(ii) if the current direction is reversed;
(iii) if *both* are reversed?

c. Suppose somebody tries the experiment and nothing happens to the free wire when he turns the current on. Can you suggest any reasons?

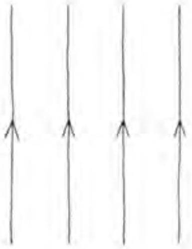
d. What happens if you hold the magnets so that the field is horizontal as in fig. B?

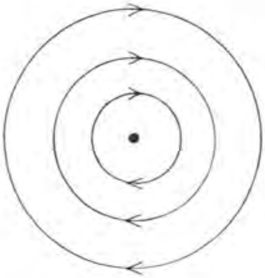


B

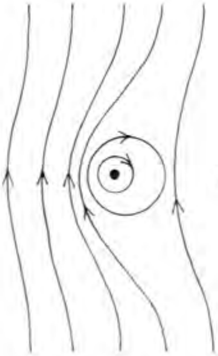
54. What sort of arrangement of magnets or currents give magnetic field patterns like each of figs. A, B, C? Answer by diagrams if you prefer.

A





B



C

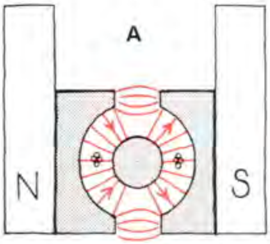
55a. The dots (·) in figs. B and C of Q.54 represent a wire carrying a current *down into the paper*. Suppose in C the lines had been pieces of stretched elastic, instead of magnetic-field lines, but the dot still represented the current-carrying *wire*. Which way would the elastic push the wire?

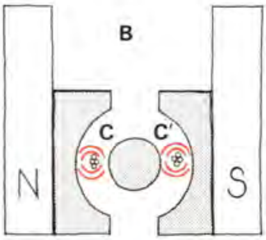
b. Suppose you reversed the magnetic field so that its lines went *downward* on the paper (instead of upward on the paper as in A above). Assume the current direction is still the same as in B.

(i) What would fig. C look like now? (Give a sketch.)

(ii) Which way would the wire be pushed now?

56. *(ADVANCED)* The coil of a moving coil ammeter moves in a cylindrical gap between horseshoe magnet and an iron core. Fig. A shows the magnetic field in the gap.





C and C′ are the wires of the moving coil. Fig. B shows the magnetic field of a current in the coil.

a. Copy fig. B and add arrows for the field near C′.

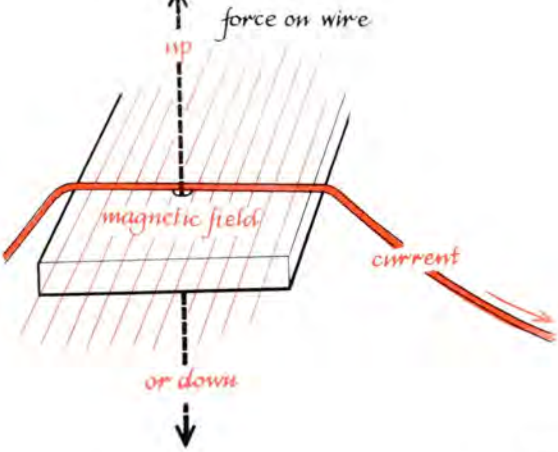
b. Sketch the magnetic field made by combining the two fields (fig. A and fig. B).

c. What happens to the coil? Let your new sketch tell you.

The catapult force This is a sideways force. It does not act *along* the wire carrying the current. Nor does it act *along* the magnetic field. IT ACTS PERPENDICULAR TO BOTH THE CURRENT AND THE MAGNETIC FIELD.

Suppose the wire carrying current is horizontal, and runs North–South; and the magnetic field is horizontal, and runs East–West, the force on the wire is vertical, up or down!

A rule? There are rules for remembering which of the two directions, up and down, is the correct one, when you know the directions of



current and magnetic field.* But you should not expect to remember such a rule. It is far more important to know clearly that the force is in the 'up-or-down' direction, perpendicular to both current and magnetic field.

Discuss catapult forces with your teacher; and see how they show the way a magnetic field can turn the coil of an ammeter or an electric motor.

Model Ammeter

Experiment 97
Making an Ammeter

In the ammeters that you use for d.c. the current goes through a coil, which is called the 'armature'; and the field of a permanent magnet makes catapult forces on that coil. The armature can revolve on pivots or an axle.

If catapult forces acted alone they would turn the coil until it got to a neutral position—the same for any current. So that would not *measure* the current. But springs oppose the twisting of the coil. Then, the stronger the current, the bigger the catapult forces, the more strongly the coil is pulled round, and the farther it turns round against the increasing opposition of the springs.

*If you must decide the direction of the force, much the best way is to sketch the catapult field. Then your sketch will show whether the force is 'up' or 'down'. The lines of the outside magnetic field run from North pole to South pole. The circles of the current's magnetic field have their direction given by the righthand rule which says:

'Curl the fingers of your right hand round your thumb. Point your thumb along the current. Then the curled fingers point the way round the wire in which the circles of the magnetic field would make a compass needle point.'

In our model, the armature is a wooden block with the coil wound on it and a narrow metal tube fixed in it. Then a knitting needle through that tube will serve as axle so the coil can turn freely.

Take about $2\frac{3}{4}$ metres of insulated wire to make the coil. Keep about $\frac{1}{2}$ metre of wire to spare at each end. Wind 10 turns on the wooden block. Wind an extra half turn, so that the coil starts at one end of the block and finishes at the other end.

Wind a couple of tight turns round the metal tube at each end, to hold the coil on the block.

Make the opposing springs which measure the catapult forces. Coil some of the spare wire at each end into an open flat spiral of 4 or 5 turns.

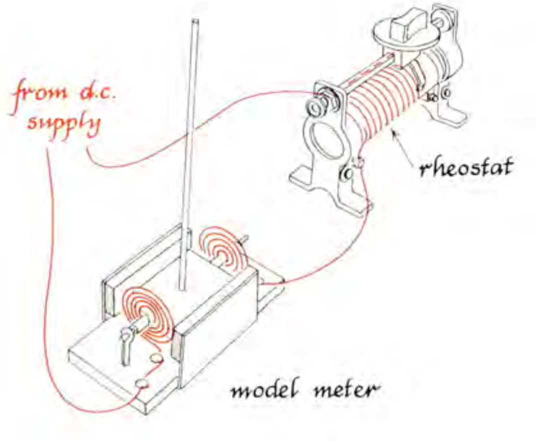
Hold the armature in position and slide the knitting needle through the tube in the wooden block. Support the knitting needle with a 'split pin' stuck in the base board at each end. Anchor the ends of the springs with rivets pushed into holes in the base board.

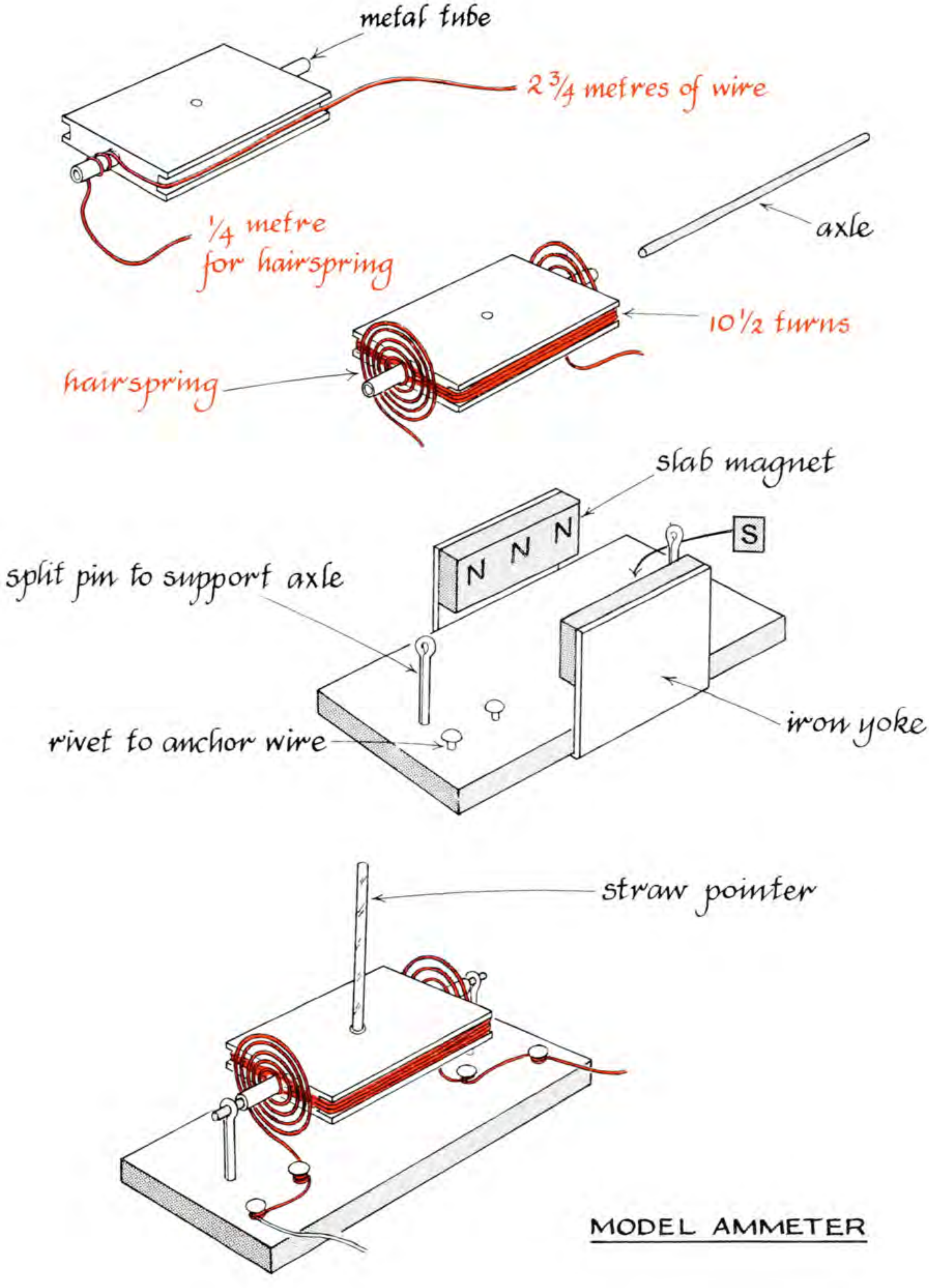
The magnetic field to make the catapult forces is provided by a pair of slab magnets on a U-shaped yoke of iron.

Give your ammeter a pointer by sticking a straw in the wooden block.

Connect your ammeter to a low voltage d.c. supply, with a rheostat to vary the current.

If you like, try your meter with an alternating supply.

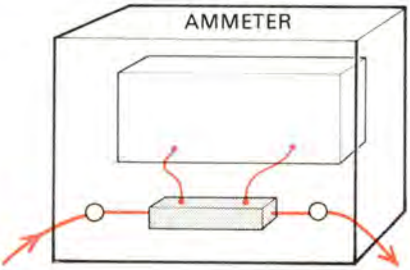




MODEL AMMETER

Experiment 98
Examining Commercial Ammeters

Look at the 'works' of an ammeter in your lab. The coil swings round in a curved (cylindrical) channel or gap between an inner iron core and an outer iron assembly.* Either the inner core or the outer assembly contains a magnet. The rest is iron, kept magnetized by that magnet. That makes a uniform *radial* magnetic field across the gap where the coil moves. Then the ammeter has a uniform (evenly spaced) scale. And the field is strong, so the instrument is very sensitive.



Currents of a few amps would ruin the delicate coil. So, except for very low ranges (a few milliamps) the coil carries only a small sample of the current. The rest of the current goes through a bypass called a 'shunt'. Look for the shunt on (or in) an ammeter.

*In most older ammeters there is a horseshoe magnet in the outer assembly. Many modern ones have a small strong magnet in the core instead.

Progress Questions

MODEL AMMETER

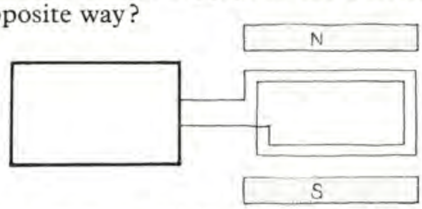
57. *(These questions are about the model ammeter you made.)*

a. What is an ammeter used for?

b. Draw a large sketch of your model ammeter, and label the important parts. (You can draw a side view and a top view, if you like.)

c. The coil turns more for a large current than for a small one. Which part of the model stops the coil going too far?

d. What happened when you reversed the connections to the d.c. supply, so the current went the opposite way?



58. This shows a coil in a magnetic field. Copy the diagram and put in arrows to show the way the current goes in the long sides of the coil.

a. Why does one side go up and one side go down?

b. What happens when you connect your ammeter to a supply giving alternating current? If you haven't seen this, make a sensible guess.

59. Many real ammeters are made, like yours, with a coil in a magnetic field. Some coils turn only a little way for a fairly large current, say 10 amps. Some of them move quite far for a small current, such as say 0.01 amp—we say those are more *sensitive*.

What things in the model could you alter to make the ammeter more sensitive? For example:

a. Would it be better to have stronger magnets or weaker magnets?

b. Would it be better to have the magnets closer together or further apart or wouldn't that make any difference?

c. Would it be better to have more turns on the coil or fewer or wouldn't it matter?

d. Would it be better to have the spiral springs at the ends of the coil weaker or stronger or wouldn't it matter?

e. Are there any other useful changes you can think of?

Questions

AMMETER

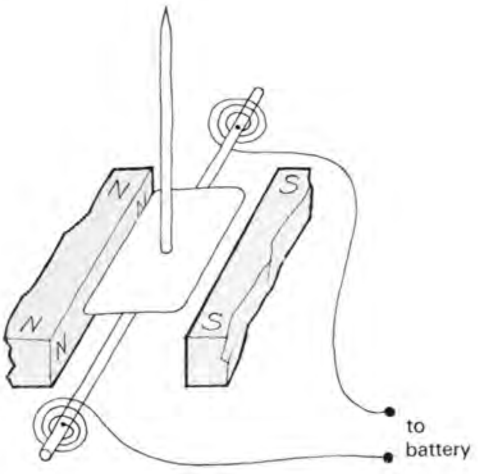
60. Here is a list of the parts you used when you made a moving-coil ammeter:

Wooden base with holes for split pins and rivets.
2 split pins, 4 rivets.
Wooden armature with metal tube pushed through it.
Knitting needle.
Insulated copper wire.
Two slab magnets ('magnadur') with iron yoke.
Drinking straw.

a. Describe, with diagrams if you like, how you made the ammeter. (You should describe what *you* did, *in your own words*. Do not just copy out instructions from this book, or from any other book.)

b. What would happen if you made the spiral springs of thinner wire (but with the same number of turns in the spiral)?

61. This is a diagram showing parts of a moving-coil ammeter.



a. Copy this sketch.

b. Label the following parts. (Use arrows to show clearly which part each name refers to.)
C, the moving coil;
M, M, the two magnets;
S, S, the two controlling springs;
P, the pointer.

62. Suppose a friend asks you about your ammeter. He has never made one; but he sees yours and asks how it measures currents. Explain to him in a few sentences how it works. (Assume he knows very little about currents or magnetic fields.)

63. What will happen when you are using a moving-coil ammeter, if:

a. You reverse the current?

b. You use slow alternating current, in which the current's direction changes to-and-fro *very slowly?* (For example, current from a bicycle dynamo turning slowly.)

c. You use rapidly alternating current? (For example current, through a resistor, from the a.c. mains.)

64. You may have seen inside a commercial moving-coil ammeter—if not, go and look at one.

Mention *two* ways in which it has been made more sensitive than the one you constructed.

(NOTE. 'More sensitive' means the pointer moves the same amount for a smaller current or it moves farther for the same current; so you can measure smaller currents with it.)

65. A boy in your class says, 'My father is an Electrical Engineer. He says *real* ammeters have a SHUNT inside.'

a. Find out from other books what a shunt is, and what it does. Write half a page to explain about a shunt to other pupils.

b. Set up your model ammeter. Use a short piece of wire as a shunt, and install it on your model ammeter. Try it.

Experiment 99
Making an Electric Motor

A motor has a coil built on an axle so that it can revolve freely. That coil, with its supporting core, is called the 'armature'. A magnet (which is an electromagnet in big motors) provides a magnetic field which makes catapult forces on the coil.

In our model, the armature is a wooden block with a narrow metal tube fixed in it. Then a knitting needle through that tube will serve as axle for the spinning armature.

Take about $2\frac{1}{4}$ metres of insulated wire. Wind 10 turns of wire on the wooden block. Make sure that your coil begins and ends at the same place, one end of the block. Have about 10 centimetres of wire left over at each end of the coil. Wind those ends once or twice tightly round the tube to hold the coil firmly in place.

Slide a knitting needle through the tube in the block. Support the knitting needle with a 'split pin' stuck in the base board at each end.

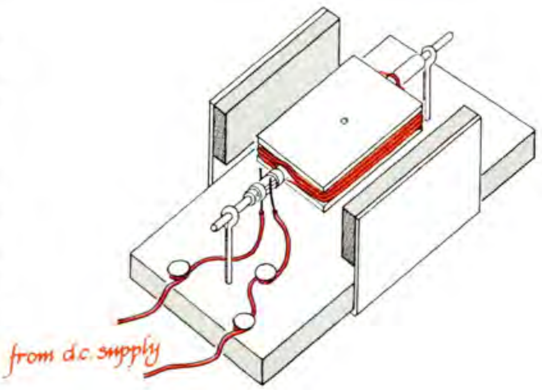
How will you get current in and out of the coil as it spins? Worse still, you will need to *reverse* the current in the coil again and again at the right moment if you want the catapult forces to go on pulling the coil round. Those two jobs, feeding the current in and out and the reversing of the current, are both done by brushes and commutator.

The commutator (reversing switch) is made as shown in the sketch. Take the end of the metal tube where the ends of the coil have finished; and insulate the tube there by winding some sellotape on it. Then make two tiny rubber bands by cutting slices of small rubber tubing. Slide those bands over the end of the metal tube so that they rest on the sellotape. Strip the wire that comes out from one end of the coil. Loop it as shown. Fix it in place on the tube with tiny rubber bands.

Strip the other end of the coil's wire and loop it. Slide the rubber bands out of the way. Place the new loop on the sellotape, on the opposite side of the tube from the first loop. Move the rubber bands back so that they hold both loops in place.

Make sure the bare wire of those coil ends does not touch the bare metal of the tube at any place.

The brushes are two upright pieces of wire, anchored by rivets that fit onto holes in the base board. Take two pieces of insulated wire, long enough to connect to the low voltage supply. Wind them round the rivets, as in the sketch. Bring the ends up beside the commutator. Strip those ends. These are the brushes.

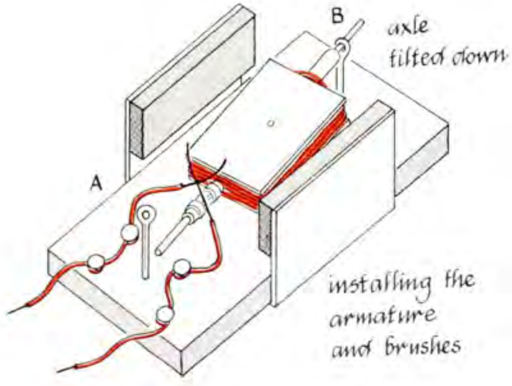


The brushes will not make good contact if you just bend them to touch the loops of the commutator. They must press on the loops firmly. Therefore proceed as follows:

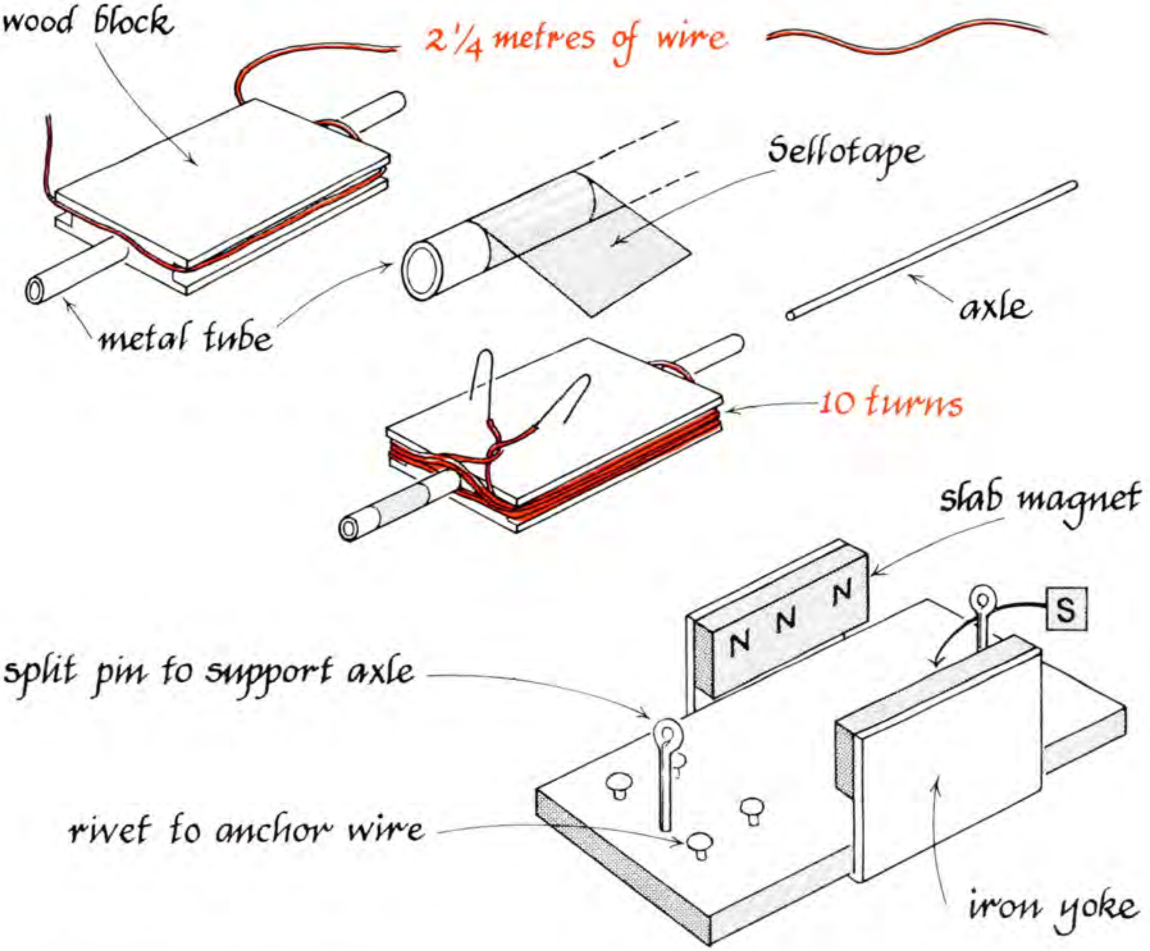
(i) Bend the brushes over till they cross as in the diagram.

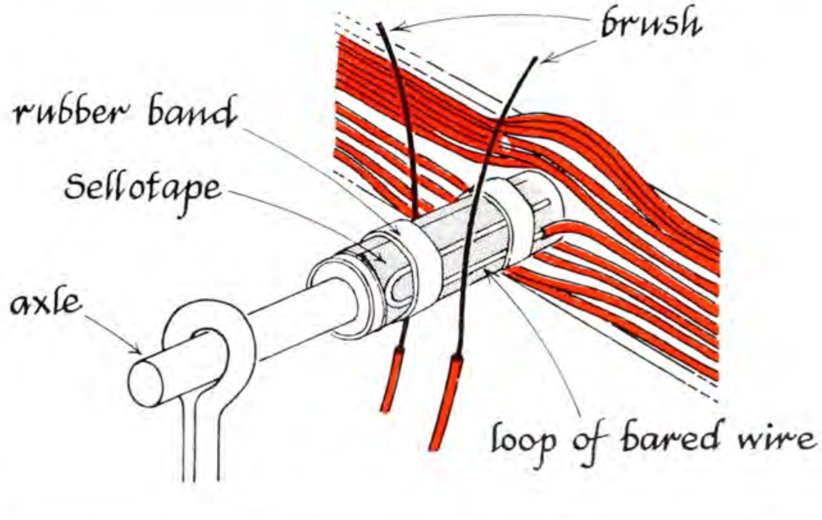
(ii) Slip the commutator end of the armature below the brushes where they cross; and insert the other end of the knitting needle axle into the split pin, B.

(iii) Lift the armature, forcing the brushes to bend apart and push that end of the axle into split pin A. That will provide good contact because the brushes will be 'spring loaded'.



CONSTRUCTION OF MODEL MOTOR





DETAILS OF COMMUTATOR AND BRUSHES (MAGNIFIED)

Make sure that the brushes press on the commutator loops *when the coil is horizontal.*

Install the field magnet. In this model it is a permanent magnet made by putting slab magnets on a U-shaped yoke of iron. When the motor is assembled make sure the axle is firmly supported. See that the brushes make good contact, and connect them to a low voltage supply.

Home Experiment H99 Motor

If you are allowed to borrow the magnet and the rest of your motor for the weekend, you could run it at home on a small battery.

Demonstration 100 Commercial Motor

If a commercial electric motor is available, see it running and watch it haul up a load. Put an ammeter in the circuit and see how the current changes when you make the motor do a job.

If the outer case of the motor can be opened, look at its commutator. In such a motor, there are many coil windings so that it will run smoothly. In your model motor, you wound *one* coil on the wooden block. In a commercial motor, the coils are wound in slots (channels) in a soft-iron block, at many angles round the axle. So the commutator has to have many pairs of copper connecting strips to bring the current in and out through the brushes.

Only small motors have permanent magnets. (Small electric trains and other toys often have them.) Large motors have an electromagnet to pull the armature round.

Progress Questions

ELECTRIC MOTOR

66. You made a model electric motor. Why did it need a commutator? What would happen if you just connected a battery to the coil?

67. You made a model electric motcr. Write down some of the things you found out about your motor. Say what you did, and what you saw. Try to give an explanation of how it works.

68. When you make an electric motor, you connect the coil to the electricity supply through 'brushes'.

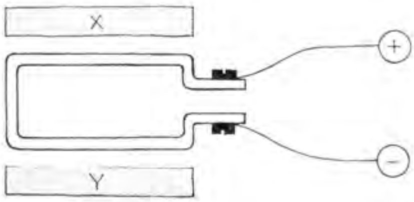
The diagram is a very simple top view of a motor. Both brushes are marked in black.

a. Copy the diagram. Colour one of the long sides of the coil red and the other long side blue (or use any other two colours!). Put an arrow on each side to show the way the current goes.

b. X and Y are poles of a horseshoe magnet. They are arranged to make a strong field in the gap. The side of the coil near X moves UP. Which way does the side of the coil near Y move—up, or down? Why does it go this way?

c. Draw another sketch for a later time when the coil has gone *half* way round—so the red side is where the blue one was: and the blue one is where the red one was.

Put an arrow on each side of the coil to show which way the current goes.



d. Which way will the side near X move—up as before, or down?

e. Which way will the side near Y move?

f. Why are brushes used?

69. Many real motors are made like your model one, with a coil in a magnetic field.

a. What changes could you make to your model, to make it more powerful and efficient?

b. In powerful motors, the coils are wound on an *iron* core. Why do you think that is?

c. All electric motors need a magnetic field inside to make them work—but some don't have permanent magnets. What do they have instead?

70. Have you anything at home which has an electric motor inside it?

a. Make a list of all the things you know at home or anywhere else, which use electric motors.

(NOTE. They may not all be the kind of motor you made. Any equipment which turns something round when an electric current is switched on contains an electric motor.)

b. Where does the energy come from to make a motor work?

Questions

ELECTRIC MOTOR

71. Suppose a friend asks you about the motor you made. He has never made one but he sees yours and asks how the battery makes it spin. Explain to him in a few sentences how it works. (Assume he knows very little about currents or magnetic fields.)

72. Suppose you take your model electric motor home, and show it to your younger sister who is very interested. You use a battery to make it turn, and you explain how it is made. Then you take it to pieces, so that she can put it together again. She puts it together and, at a quick glance, it looks all right. But nothing happens when you join up the battery to it.

Mention three things that might have gone wrong, and say what you would do to put each of them right.

73. Suppose one pupil in your class says, 'I made the coil for the model motor, and put it on the axle. But then I was ill and missed the next class so I never made the commutator. I don't understand what the commutator does or why it is needed.'

Write half a page or less to tell him about the commutator.

74. A pupil decides to make a model motor at home. She saw that the model she made at school ran unevenly, in jerks. So she arranges a long axle which will take *two* coils, each fed by commutator and brushes.

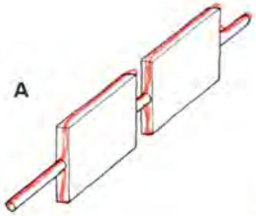
a. Should she arrange the two coils like fig. A or like fig. B?

b. Give a good reason for your answer to (a).

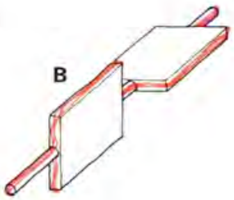
c. Fig. C shows a short piece of wooden broom handle. Could that be used instead of the flat block of wood as a frame for the two coils? Copy fig. C and show two coils on it.

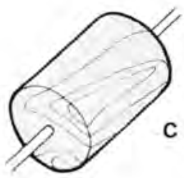
(If you have a chance, now look at a large commercial electric motor.)

A



B





C

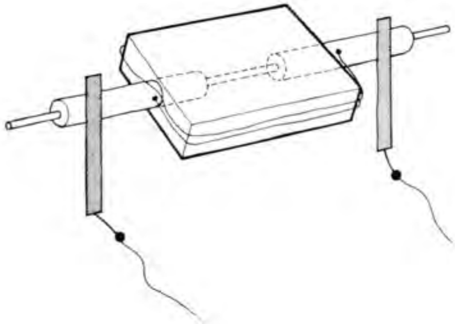
75. A pupil making his model motor is impatient. He says, 'I don't need commutator and brushes. I have made my coil and I have put it on the axle. It spins nicely. Now I am just going to bring out thin wires from the ends of the coil, straight to a battery.'

a. Tell him what you think his motor will do.

b. Explain to him why it does not do what he hoped.

76. *(ADVANCED)* A boy suggested the following method of making the motor which, he said, would be easier.

'Don't bother with the sellotape and the wires on opposite sides of the axle. Simply cut the metal axle-tube in the middle and separate the two parts so that they are insulated from each other. Then connect one half-tube to one end of the armature coil, and the other half-tube to the other end (see the diagram). And use a *plastic* knitting needle as axle. Then use wire brushes bearing straight on the pieces of tube.'



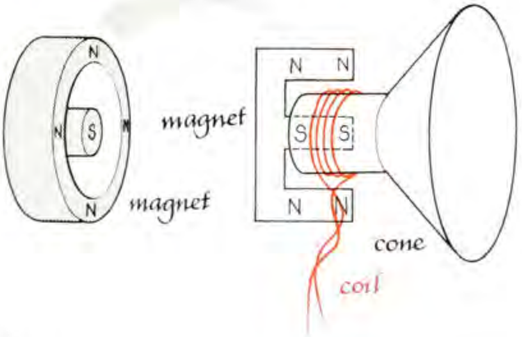
a. He tried this, and the motor did not work. Why not?

b. He did find that the coil made little jerky movements, sometimes almost half a turn. Why was this?

c. A friend told him to give it a start by spinning it very fast with his fingers. Could that succeed?

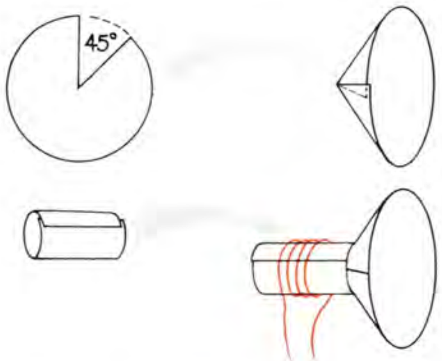
Loudspeakers Most loudspeakers have a permanent magnet of special shape, a sort of all-round horseshoe. A small coil lies loose in the magnet's gap and is attached to the loudspeaker's paper cone, which gives out the sound you hear. A catapult force acts on the coil and that pushes or pulls the cone.

A radio or a record player drives a rapidly changing current through the coil. That current follows the vibrations of music or speech; the catapult force follows the current's changes; the paper cone follows the catapult force; the air in front of the loudspeaker follows the cone's motion. So sound waves travel out carrying the music or speech.



Experiment 101
Model Loudspeaker *(OPTIONAL)*

Make a simple loudspeaker with paper and sellotape:



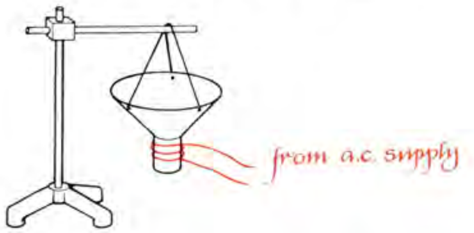
(i) Cut a circle of fairly stiff paper. Cut a 45° wedge out of the circle. Bring the cut edges together to make a shallow cone. Tape those edges together so that the cone will keep its shape.

(ii) Cut a strip of the same paper about 4 cm by 20 cm. Roll the strip up to make a tube about 3 cm diameter, and tape it to keep it like that.

(iii) Place the tube on the point of the cone and fix it there with several strips of tape.

(iv) Wind two dozen or more turns of thin insulated wire (SWG 36) round the tube.

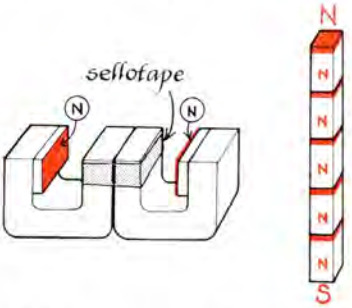
(v) Support the cone by its edges.



(vi) Make a strong magnet with a gap in which the coil is to be placed. The proper shape of magnet would have a central North pole inside the coil with a ring of South poles outside it. Then the lines of the magnetic field would all go radially outward, all perpendicular to the coil, all crossing it the same way. And the catapult forces on the coil would be in the same direction on all parts of the coil. They would all push the cone out or all pull it in.

With the apparatus you have, you must make a rough substitute for that. Here are two good ways of making a suitable magnetic field: use *either* I *or* II.

(I) Use two C-cores side by side so that they form a 'W'. (You may tie the central pair of legs together if you like.) Make the paper tube wide enough to fit over that pair of legs.



Place slab magnets on the *inside* faces of the two outer legs. Make sure the slabs have the same poles pointing inward.

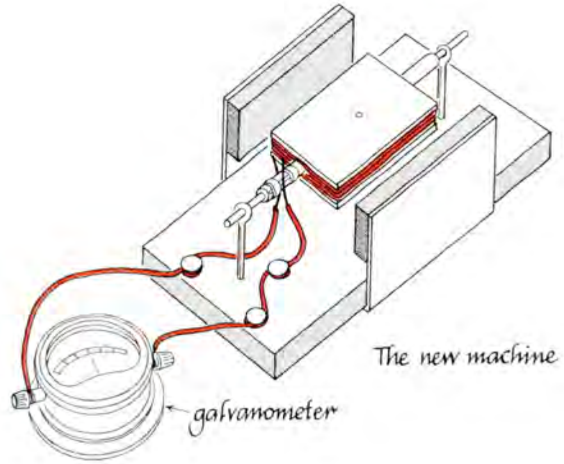
(That is *not* how you placed the slab magnets on an iron yoke to make a U-magnet. Then you had N and S poles facing inward to make a strong field across. Now you need N and N poles facing inward, with the central pair of core legs acting as SS poles.)

(II) Make a long magnet by placing 3 or 4 small ticonal bar magnets head-to-tail in a line. Put the head of this long magnet inside the tube and coil. Then you have a N pole inside with magnetic field lines sprouting out across the coil's wires, like spokes of a wheel.

(vii) Attach the coil to a low voltage a.c. supply. *Can you make the coil broadcast a buzz?* (To make your model broadcast music or speech from a record, you would need an amplifier and probably a small transformer.)

ELECTROMAGNETIC INDUCTION

Experiment 102
The mysterious machine



Put your model electric motor to a new use.

(i) First set up your motor again, with its commutator arranged for d.c. Test it with a low voltage d.c. supply to make sure it runs well.

(ii) Then disconnect the motor's wires from the supply. Connect them to a galvanometer (a very sensitive ammeter).

Spin the coil ('armature') with your fingers; and watch the galvanometer.

(iii) Try spinning the coil the opposite way.

(iv) (Optional.) If you are careful not to damage your machine, you can spin it faster. Wrap a piece of thread once round the tube, hold it taut, and pull it to and fro.

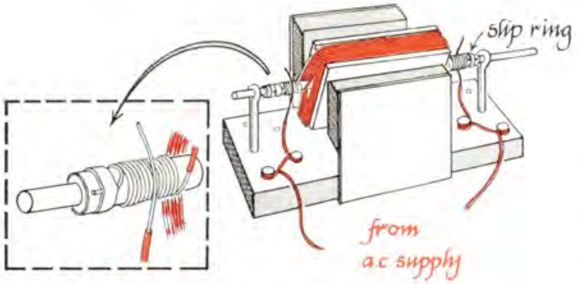
(If you have been running your machine as a motor for a long time, the brushes and commutator may be covered with dirt, whose resistance will spoil this experiment. If so, you should strip down the assembly and scrape the brushes and commutator with glass paper. Commercial dynamos and motors need cleaning like that from time to time.)

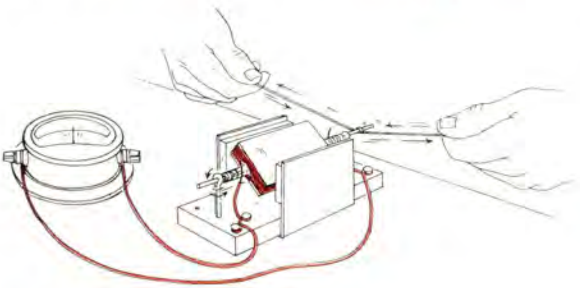
The New Machine What *is* the machine you have now made? It is not a motor because you are not feeding it from a battery and making it do a job. Instead, *you* are doing a job in spinning it; and it is sending a current to the outside world. You have a dynamo (or, as it is sometimes called, a generator) like those in big power stations, but in simple form on a small scale.

Did your model dynamo produce direct current (d.c.) or alternating current (a.c.)?

Experiment 103
Model Dynamo, a.c. Form *(OPTIONAL)*

Most modern power stations produce a.c. To make a model a.c. dynamo, you must change from your commutator to two 'slip-rings'.





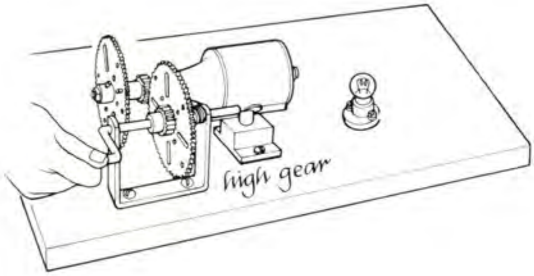
driving the a.c dynamo fast

Bring out the two ends of the coil's wire to *opposite* ends of the metal tube that carries the coil. Near each end of the tube put a wrapping of sellotape as insulation. Wind a *bare* end of the coil's wire round the sellotape at each end of the tube.

Move one of the brushes to the other end; so that you have a brush at each end.

Then connect the brushes to a galvanometer. Try spinning the coil.

Experiment 104
Bicycle Dynamo and Lamp



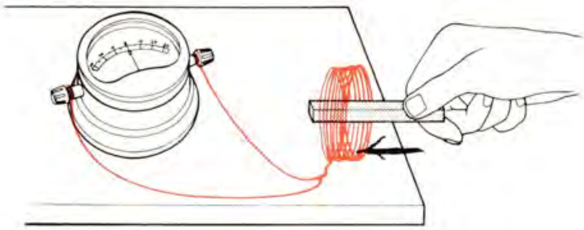
Try driving a commercial dynamo. The easiest form for you to try is a bicycle dynamo. Make it light a lamp.

Investigating Electromagnetic Induction

Simple apparatus How can we make the apparatus simpler to find out what is really happening in the dynamo? When you turn your model and find it produces a current, you are using a magnet and a coil; there is motion and there is an electric current: too many things all at once.

Try taking a magnet in one hand and a coil in the other. You had better use a straight bar magnet. Then you can poke it *slowly* in and out of the coil, instead of the complicated arrangement of twisting the coil in the field of your horseshoe magnet. And you do not need a commutator.

Experiment 105
Moving Magnet and Coil

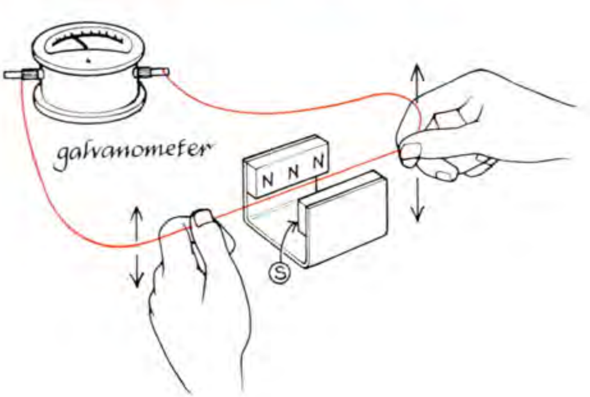


Take about $2\frac{1}{4}$ metres of insulated wire. Wind a small hoop coil of many turns, big enough to put your thumb through. Have plenty of spare wire (say 30 centimetres) at each end of the coil.

Connect the ends of the coil to a galvanometer. Try moving a small bar magnet towards the coil and away from it, *slowly*. Try moving it a little faster. Try moving it *through* the coil.

What else can you move instead? Try all the things you can think of.

Experiment 106
Wire Moving across Magnet Gap



Try the experiment sketched. Make a horseshoe magnet by putting two slab magnets on the inside faces of an iron C-core. Take about a metre of insulated wire and connect its ends to a galvanometer. Try moving the wire slowly in the gap between the faces of your horseshoe magnet.

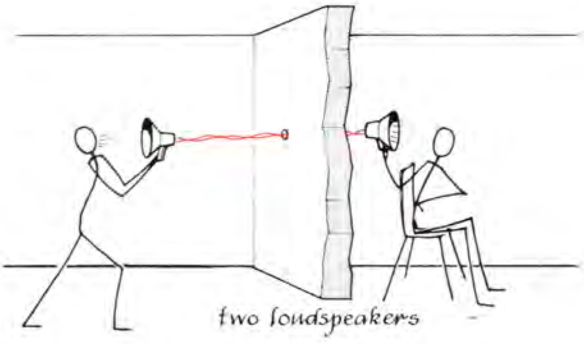
Experiment 107
Loudspeaker as a Dynamo *(OPTIONAL)*

You can use a loudspeaker as a microphone. Then it is acting as a dynamo.

Most loudspeakers have a coil that is held in the gap of a permanent magnet. Then the loudspeaker acts like a specially shaped electric motor. Instead of spinning, the coil is attached to a paper cone which it can push in and out to make sound waves. A radio drives changing currents through the coil and those currents and the permanent magnet together make catapult forces which act on the coil and make the loudspeaker broadcast sound waves.

Since a loudspeaker is like a special form of electric motor you might expect it could act as a dynamo if you drive it suitably. Shout at a loudspeaker and your sound waves will drive its cone in and out. That will move the coil in the gap of the permanent magnet; so you *will* have a dynamo effect. The coil should drive a current through any circuit that you connect to it.

Connect another loudspeaker to the coil of the one that you shout at and let the dynamo currents from the first loudspeaker drive that second one as a 'motor' to broadcast sound.

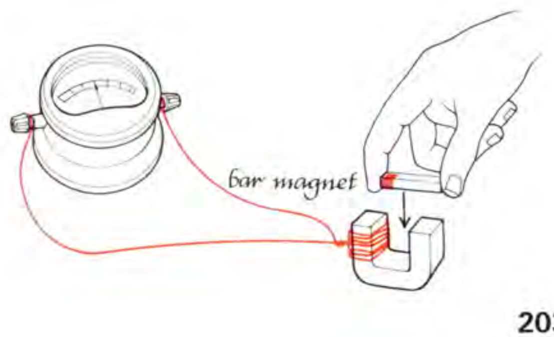


(Of course you must have the two loudspeakers well apart, so that people listening to the second one do not hear the shouting at the first one by direct sound waves.)

Three more dynamo-effect experiments
In each of these you will be changing the magnetic field that runs through a coil.

108a Dynamo Effect in Coil on Iron Core

Take about 2 metres of insulated wire. Wind a coil of about 20 turns on a C-core. Leave plenty

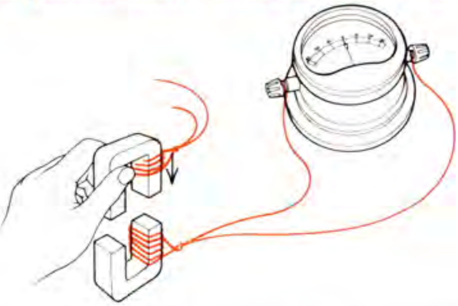


of spare wire at each end. Twist the wires together where they leave the coil, to prevent the coil unwinding.

Connect the ends of the wire to a galvanometer. Bring a small magnet near.

Now you have a coil with an iron core. *Does the iron make any difference? Does the galvanometer show more, or less, or the same effect when you bring the magnet near?*

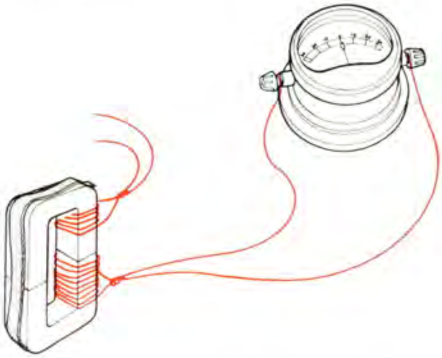
108b Dynamo Effect using Electromagnet



Instead of the small magnet, bring an electromagnet near. For that electromagnet, wind 10 turns of wire round another C-core. Connect the ends of that coil to a cell.

108c Dynamo Effect by switching an Electromagnet

Instead of bringing the electromagnet near, leave it touching the C-core. (Use a clip to hold that together if you like.) Now switch the current in the electromagnet on and off. Watch the galvanometer.



You have a simple kind of transformer. This would be a more truthful model if you could switch the current on first one way and then the opposite way, then the first way . . ., and so on. Then you would have an 'alternating current' in the electromagnet's coil and you would be producing an alternating effect in the secondary coil connected to the galvanometer. That *is* a transformer.

Induced Currents

What makes induced currents? In each of the experiments you have been doing, there were three pieces of apparatus:
(A) a permanent magnet or an electromagnet,
(B) a wire or a coil of wire,
(C) a galvanometer (or a lamp) to show when something was produced.

Was any current produced when (A) and (B) were held near each other WITHOUT MOVING (and without the electromagnet's current changing)?

Was any current produced when the magnet, (A), was moving?

Was any current produced when the wire or coil, (B), was moving?

Was any current produced when the electromagnet was growing stronger or weaker because the current in it was changing?

The answers to these questions—which you should discover from your experimenting—will give you the greatest discovery in the whole history of electric power. The discovery was made by Michael Faraday in London a century and a half ago.

When Faraday made his discovery, an important Personage asked him, 'What is the use of it?' He replied, quoting Benjamin Franklin, 'What is the use of a new-born baby?' Without the behaviour which Faraday discovered, we would have no electric power stations, no electric lights for homes or power for industry, no ignition for cars; but only a few small lamps and toy motors run by batteries.

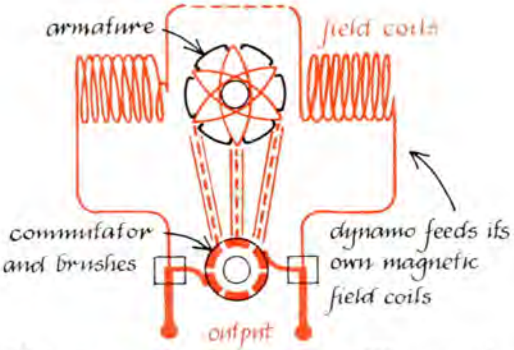
Discuss Faraday's discovery with your teacher. *How can the results of all those experiments be put together in one clear statement?*

What does a dynamo really produce? If you investigated the dynamo action of coils and magnets fully, you would find that what is really produced (or 'induced', as scientists say) is a definite *voltage* rather than a definite *current*.

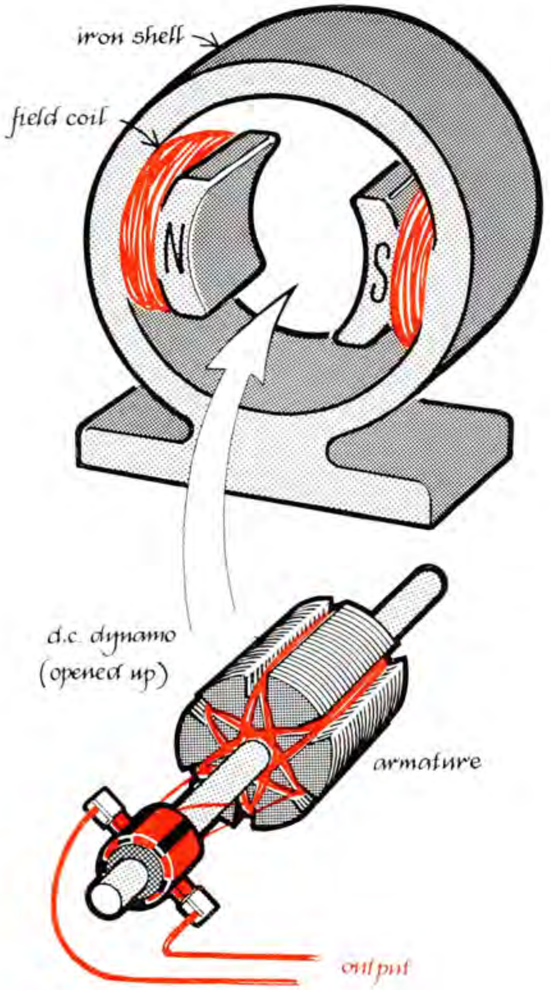
A dynamo spinning at constant speed with its field magnet kept at constant strength produces a constant voltage—like a well-behaved battery of cells.

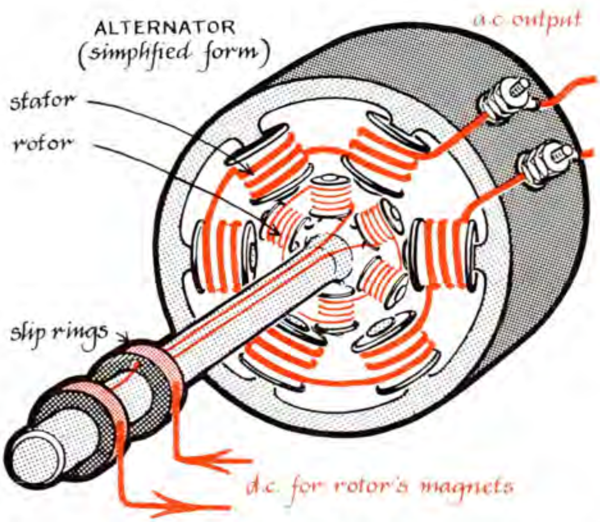
Even if there is no output current, a dynamo still produces that voltage (called its e.m.f.). It is *ready* to drive a current. When we let it drive a current, by connecting something to its output terminals, the amount of current depends on the resistance of the thing we connect.

Large dynamos Only small dynamos have *permanent* magnets to make the magnetic field. Large one have *electromagnets* whose coils are fed by a little of the dynamo's own output current.



Power station generators The very large a.c. generators in power stations are called 'alternators'. In them, the assembly of field electromagnets rotates, driven by a turbine; so that is called the 'rotor'. The armature coils, in which the output voltage is generated, are held in a frame *outside* the rotor and remain stationary. So they are called the 'stator'.





This arrangement, which is the opposite of your model, is more convenient for big machines because it does not need brushes and commutator or slip-rings. Wires from the stator carry the output current straight out to the consumers.

The spinning rotor's electromagnets are supplied with the small direct current they need through brushes and slip-rings. That direct current usually comes from a small d.c. dynamo on the same spinning shaft as the big generator.

Experiment 109
Bicycle Dynamo (a.c.)

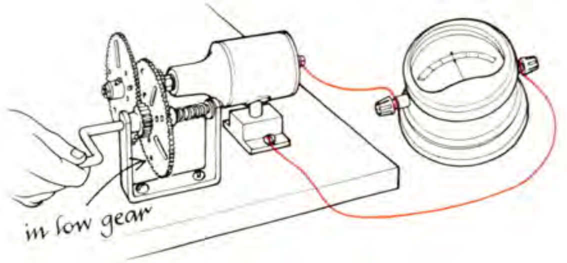
Drive the dynamo SLOWLY by hand while its output is shown on a galvanometer (sensitive ammeter). (Do not drive it fast or use the high gear while you are using the galvanometer or you may do some damage.)

Is the output alternating current or direct current?

Can you guess, before you see it, what the meter will do when you drive it a little faster? Try that.

Disconnect the meter and try making the dynamo light a lamp. Now drive it fast with high gear.

This is an 'inside-out' form of generator in which the field magnets spin round, while the coils where the current is produced to light the lamp stay at rest. So this is like the power station generators that produce large alternating currents.



Progress Questions

DYNAMO

77. Example: 'The steam engine of a steam-roller drives the wheels of the steam-roller to make the roller roll along the road.'

Copy the following remark, filling in the gaps. (Make a guess if necessary.)

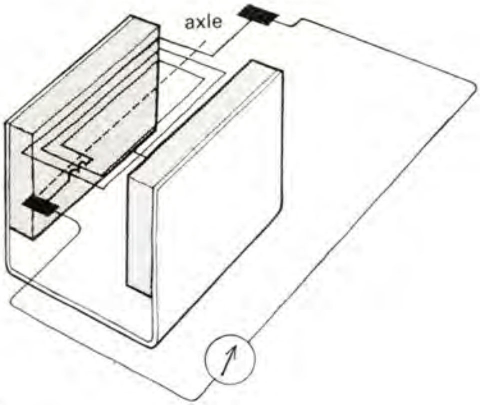
The steam engine in a power station drives . . ? . . to produce . . ? . .

78. You tried spinning your model electric motor by hand, without a battery.

a. It had been a motor, but now it acted as a . . ? . .

b. You connected the motor to a galvanometer (sensitive ammeter). What happened?

79. This is a sketch of a model a.c. dynamo or generator, with only one turn of the coil drawn for simplicity.



a. Copy the diagram and label:
(i) the slip rings,
(ii) the brushes,
(iii) the magnets.

b. What happens if the coil is spun steadily slowly?

c. What happens if the coil is spun very fast?

d. Why are slip rings used? (Think what would happen if you joined the brush to one end of the wire forming the coil.)

80. A bicycle dynamo is connected to an ammeter.

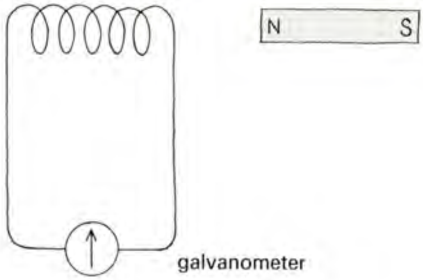
a. What does the ammeter needle do when the dynamo handle is turned slowly?

b. What happens if the handle is turned very quickly?

c. A bicycle dynamo produces 'alternating current', or a.c. What is the difference between a.c. and the sort of current you get from a battery?

MOVING MAGNETS AND WIRES

81. When you move the magnet sharply towards the coil, the galvanometer needle flicks to the right.



a. How could you make it flick to the left? (There are two ways.)

b. Can you think of a third way of producing the result in (a)?

c. What happens if you just hold the magnet stationary inside the coil?

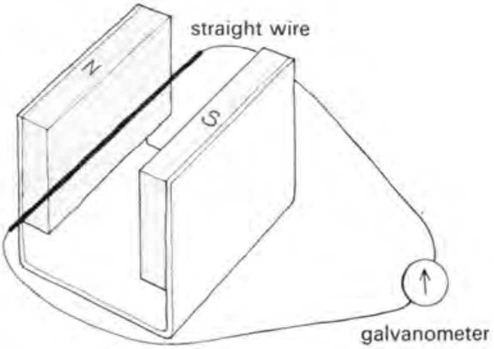
82. When you move a straight wire *down* quickly through the magnetic field, the galvanometer needle flicks to the right.

What does the needle do when you:

a. move the wire up quickly,

b. move the wire down slowly,

c. turn the magnets round and move the wire down,



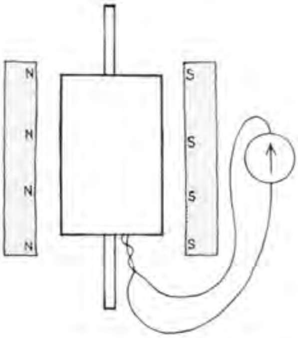
d. keep the magnets turned round and move the wire up,

e. move the wire across from N to S?

Questions

THE FIRST DYNAMO

83. Suppose you join the electric motor you made to a sensitive galvanometer. You spin the armature coil round with your fingers with no battery in the circuit.

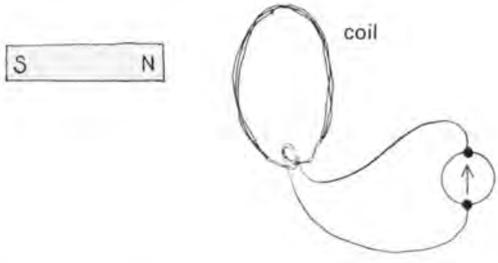


a. What does the pointer of the galvanometer do?

b. What difference does it make if you spin the armature in the reverse direction?

c. Next, you simplify the experiment: you do without the commutator. You keep the slab magnets on their soft iron U-yoke. You just hold a coil between the poles and rotate the coil in that magnetic field. Join the ends of the coil to the galvanometer by long loose wires. What does the galvanometer pointer do now, as you rotate the coil?

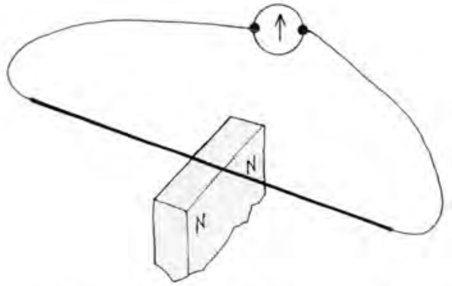
84. In some positions of the coil (Q.83c) a bundle of magnetic field lines ran through it—like a girl's arm through a bracelet. As you rotated the coil you cut that bundle down to zero; then you took in more and more lines, the opposite way. You were changing the amount of magnetic field passing through the coil. That can be done more simply by holding the coil still and moving a magnet near it.



So you tried an arrangement like the diagram. What experiments did you try with this apparatus, and what did you find out?

MOVING MAGNETS AND COILS

85. You went farther still with the simplification, doing away with the coil and having only a magnet and a wire as in the diagram. (We often find out

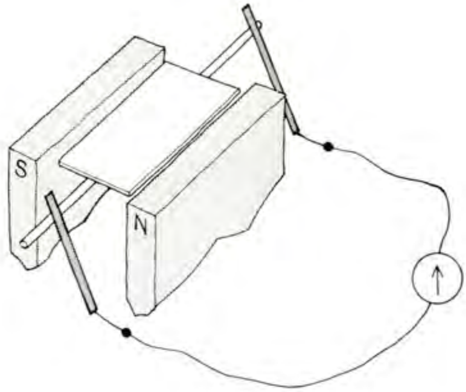


important things in science by making them more simple, NOT by making complications.)

What did you find out with this apparatus?

86. The diagram shows a dynamo. If you have made a dynamo like that, copy the sketch (or draw your own form if it is not the same). Explain how it was constructed. (Be brief, but give special attention to the slip-rings and brushes.) Say what happened when you spun the armature.

87a. What would happen if you kept the coil in Q.86 fixed, and *rotated the magnet* round the coil instead?

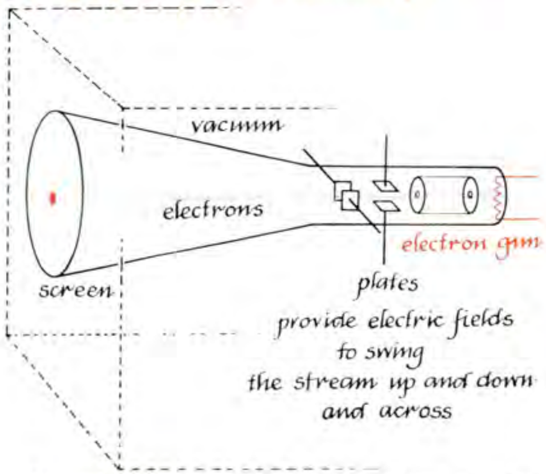


b. Supposing that, instead of rotating the coil clockwise and keeping the magnet fixed, you rotated the *magnet* clockwise and kept the coil fixed. This would NOT give quite the same result. Why?

88. A bicycle dynamo is of the 'fixed coil' type. What advantage is there in this, as compared with a 'fixed magnet' type?

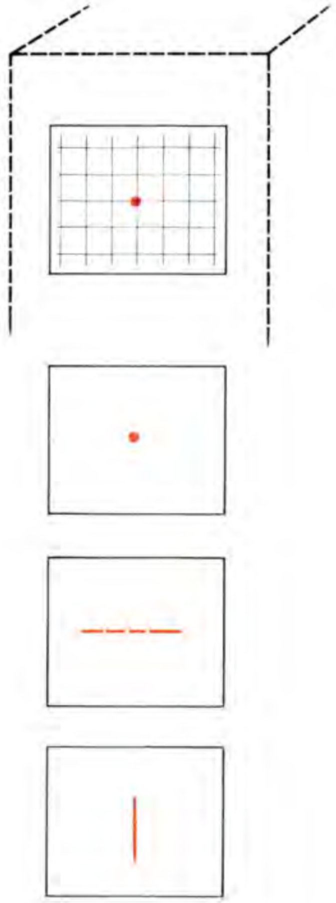
Electronic Graph Plotting: Oscilloscope

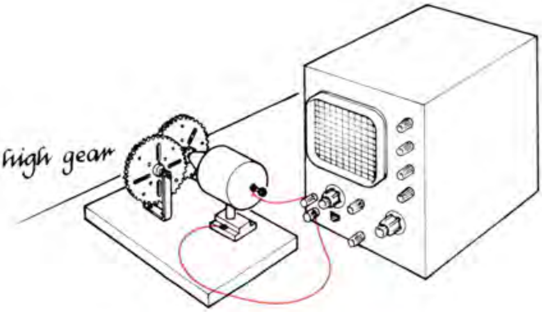
Demonstration 110a
Bicycle Dynamo and Oscilloscope



An ordinary ammeter fails us when an alternating current switches to and fro very fast. An ordinary voltmeter fails too, with alternating supply. Instead, we can use a cathode ray oscilloscope (C.R.O.). That is an electronic graph-plotter, the ancestor of television picture-tubes.

An electron gun (whose working you will learn about later) shoots a thin stream of electrons straight at the front screen. They bombard the





screen and make it glow with a bright green or blue spot.

The electron stream obeys instructions very quickly indeed; it can follow changes far better than any coil and pointer.

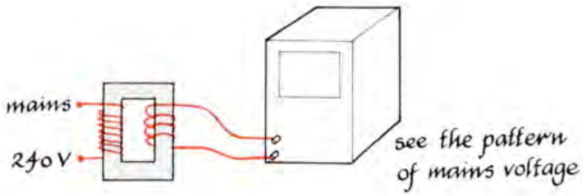
The control-box has a special circuit to sweep the electron stream from left to right at a steady rate, again and again, to represent TIME on the graph. So the spot traces out a 'time base'. Then we apply any voltage we want to examine, in a way that makes the spot move up or down. The spot plots a graph of VOLTAGE (up) against TIME (along).

See the C.R.O. plot a time-graph of the bicycle dynamo's output.

Demonstration 110b
Graph of Mains Voltage with Oscilloscope

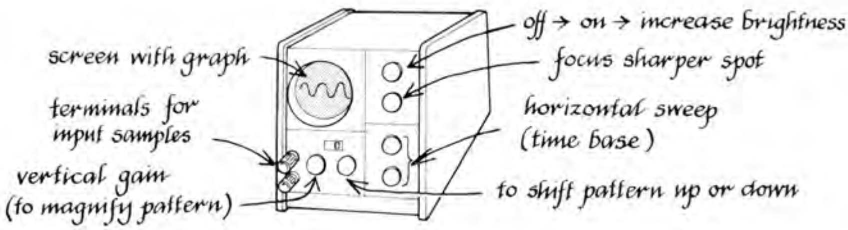
The electron stream in an oscilloscope can easily follow the rapid alternations of the a.c. mains.

For safety, use a transformer to step down from the mains voltage of 240 volts to about 6 volts. The pattern will be the same.



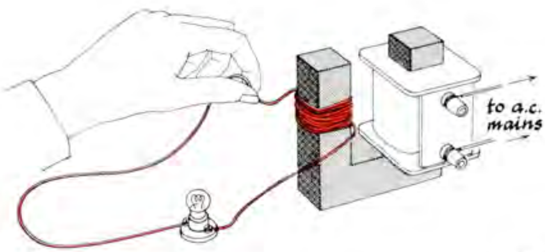
Extra Experiment 110c *(OPTIONAL)*
Class Oscilloscope

If a small oscilloscope is available for you to use with a few partners, try applying a small alternating voltage to the vertical input. Change the speed of the repeating horizontal sweep, and see how the pattern changes.



Demonstration 111
Winding a Transformer Turn by Turn

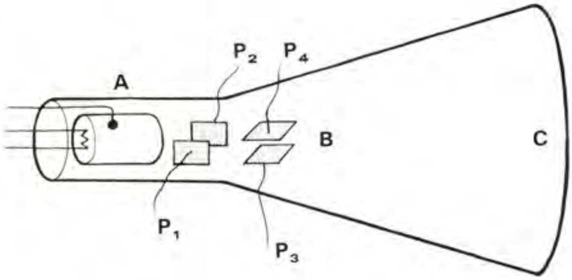
You may see the demonstration shown in the sketch. Every extra turn wound on the leg picks up an extra tenth of a volt (a.c.).



Progress Questions

OSCILLOSCOPE

89. The sketch shows the glass tube of an oscilloscope, like the picture tube of a TV set. The screen is at the wide end, C.

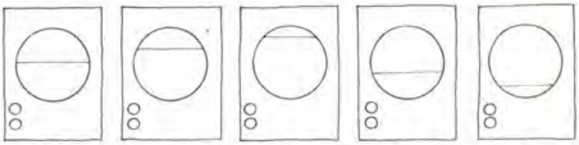


a. Where is the gun, at A, B, or C?

b. What does the gun shoot out? (You need to answer this with a guess or from hearsay. You will find the scientific answer in a later chapter.)

c. The plates P_1 and P_2 can be charged + and − to swing the electron stream sideways. What do you think happens when the plates P_3 and P_4 are charged + and − by a battery?

d. What makes the glowing spot on the screen?

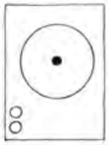


A B C D E

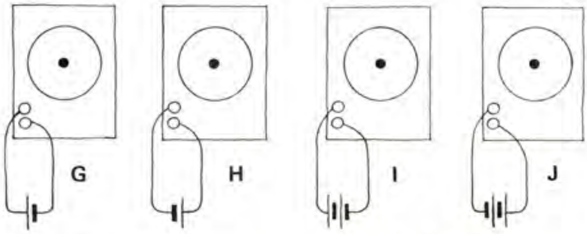
90. These are sketches of the screen of an oscilloscope. The time base is switched on.

When nothing is connected, the spot moves across the middle of the screen, as in A. When one torch battery is connected, it goes across higher up, as in B.

What do you think was connected to make it move as in C, D, E?



F



91. When the time base is switched off, the spot does not move across the screen.

When there is no voltage applied to the Y plates, the spot stays still in the centre, as in F.

Copy and complete G, H, I, J.

K L M

92. On your oscilloscope screen you might have seen the following.

a. What do you think was connected to the Y-plates in each of the cases K, L, M.

b. Say in each case whether the time base was on or off.

Questions

OSCILLOSCOPE

93a. Sketch the pattern you saw on an oscilloscope screen when you joined it to the output from your a.c. model dynamo, or from a bicycle dynamo.

b. Write two or three sentences explaining how *alternating current* differs from *direct current*.

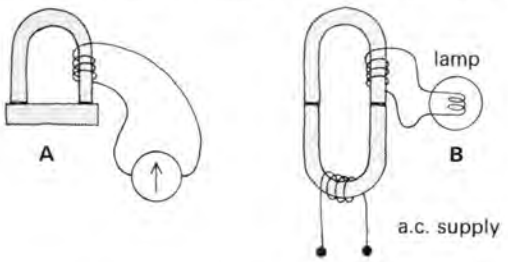
c. Which type of current do you get from a dry battery? Draw what you would see on an oscilloscope if you replaced a '6-volt' bicycle dynamo by a '6-volt' battery.

TRANSFORMER

94a. Fig. A shows a C-core of iron with a coil wound on it. The ends of the coil are joined to a galvanometer. What would you see the galvanometer do if you put a bar magnet on the core, take it out again, put it on again, and so on?

b. Fig. B shows the same C-core with the four-turn coil joined to a small lamp instead of a galvanometer. A second C-core is now attached to the first; this second core also has a four-turn coil, which is joined to a low voltage a.c. supply.

The lamp lights up just as brightly as if it were joined to the a.c. supply, yet it is not connected directly by wires to the a.c. supply. How do you explain this?



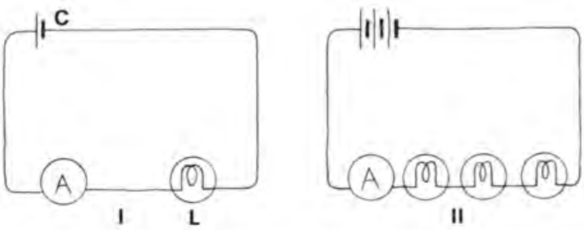
95a. Suppose, in fig. B of Q.94, you had only two turns in the coil joined to the lamp, still with four on the coil joined to the a.c. supply. What difference would this make to the brightness of the lamp?

b. Suppose you had six turns on the coil joined to the lamp. What then? And what would happen to the lamp if you had eight turns or more?

Questions for Looking Back

CURRENT

96. In the diagram, A is an ammeter. In fig. I the ammeter is joined in series with a single cell C and a single lamp L. In fig. II it is joined to three similar cells and three similar lamps, all in series.



a. In arrangement I the ammeter reads 0.5 amp. In arrangement II, will it be more than 0.5, or less, or the same? Give a reason for your answer.

(NOTE. There are two possible answers; one is good, the other would be even better but it would need an explanation.)

b. If you reverse *two* of the cells, what will happen to the ammeter reading?

c. If you reverse two of the lamps, what will happen to the reading?

DISASTER

97. Imagine an old power station in which the machinery is not well protected. A steam engine drives a large d.c. dynamo whose output current is carried away by two large horizontal copper rods (the bus-bars). Suppose that one day when the machinery was running full tilt, a loose metal girder fell from the roof and landed across the bare bus-bars, and made good contact with both.

a. Give a name for the 'trouble' caused by the falling girder.

b. Describe what you imagine then happened.

SAFETY IN HOUSES

98. Suppose one electric light goes out in a room in your house, but not the others in the same room. That might be due to any of the following causes:

(i) The filament of the bulb may be broken.
(ii) The switch may be broken, and remain in the OFF position.
(iii) The wires that enter the lampholder may have lost their rubber insulation so that they touch each other.
(iv) The wires in the wall, leading to and from the lamp may have lost their insulation and bare copper may be touching bare copper.
(v) One of the flex wires on which the lamp hangs from the ceiling may have pulled out of the ceiling fitting.

a. Say which of those are cases of a 'short circuit'.

b. Say why a short circuit is NOT likely to be the cause in this case.

99a. You know that when the same current runs through a piece of thick copper wire and a piece of thin copper wire, joined in series, one of those wires gets hotter than the other. Which one gets hotter?

b. In a house, copper wires run all the way from the electric supply to a lamp filament of thin tungsten metal. Should those copper connecting wires be thicker than the filament or thinner?

c. Give a clear reason for your answer to (b).

d. Suppose the lampholder is damaged and the two copper wires touch each other just where they enter.
(i) Why does the lamp not light when you switch it on?
(ii) Is the current in the supply wires larger than before, the same, or smaller? (Pretend that there is no fuse in the circuit!)
(iii) Give a reason for your answer to *(ii)*.
(iv) Will the copper wires in the house walls be hotter or cooler than before?

100. Suppose that at the point where the wires enter your electric iron, they have been damaged (when the iron was dropped on the floor); and you can see bare copper on each of them, where it should be covered. If those bare parts of the two wires touch:

a. What is the name for that disaster?

b. What happens to the iron?

c. What happens MOMENTARILY to the wires in the house leading to the iron?

d. What prevents the trouble in (c) continuing?

SPECIAL ELECTRIC MOTOR (ADVANCED)

101. You have made an a.c. dynamo with slip-rings and brushes. Suppose you try to run that as a motor.

a. If you connect the brushes to a battery (or any other d.c. supply) what will happen?

b. If you connect the brushes to a low voltage a.c. supply (from a transformer on the mains) the machine will just buzz or vibrate. Explain why.

c. The mains supply of a.c. makes 50 cycles per second (50 hertz). (That is, the voltage and current switch forward–backward–forward–backward– . . . making 50 forward–backward 'cycles' in one second.)

An Engineer tells you, 'If you could start the machine by spinning it VERY fast with your fingers it would run.

How fast (that is, how many revolutions per second) should it spin for success?

d. Engineers usually give the speed of a motor in revolutions per *minute* (R.P.M.). Now give your answer to (c) in revolutions per minute.

(NOTE. You can buy electric motors designed for various speeds:
300 R.P.M. is very slow;
3000 R.P.M. is average for workshops, etc.;
30 000 R.P.M. is extremely fast—it would need special materials to be safe.)

TELEPHONE

102. Find out from books in the Library how a telephone works. Write a short explanation of its working, *in your own words*. Give some large simple sketches to make your explanation clearer.

TELEVISION

103. The picture tube in a TV set is like the tube of an oscilloscope. But instead of having pairs of plates charged + and − to swing the stream, a picture tube has coils of wire outside the tube. Currents through the coils make magnetic fields.

a. Can magnetic fields get through the glass of the tube? (HINT. Did you ever try an experiment that answers that question?)

b. *(i)* What will a magnetic field inside the tube do to the stream of electrons?
(ii) What is our name for the kind of force that a magnetic field applies?

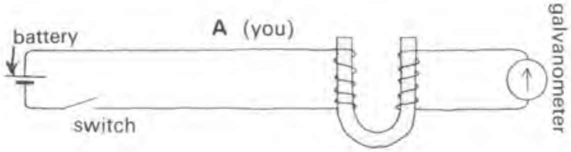
c. One pair of coils carrying current make a HORIZONTAL magnetic field across the tube. Which way will that field swing the stream?

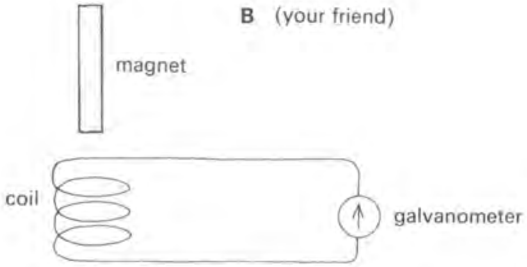
d. Another pair of coils carrying current make a VERTICAL magnetic field. What does that do?

104. Here are sketches of two experiments A and B. You do A; and your friend does B.

You set up an iron C-core with two separate coils wound on it as in fig. A. You close the switch to connect the battery; and you see your galvanometer needle flick to the right.

Suppose your friend has one coil and a strong magnet as in fig. B. He pushes the magnet into his coil, and sees his galvanometer needle move.





a. What do *you* see in YOUR experiment when the current is running steadily?

b. What do you see when you open the switch again, so that the current stops?

c. When the current is running in YOUR experiment it makes the C-core turn into a . . ? . . When you switch the current on it's like your friend moving a . . ? . . into the coil.

CHAPTER 7

VOLTAGE AND POWER

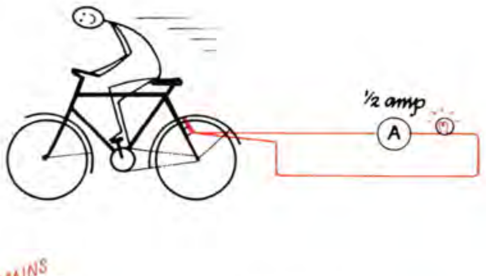
Introduction to voltmeters; model power line; household electric supplies and safety

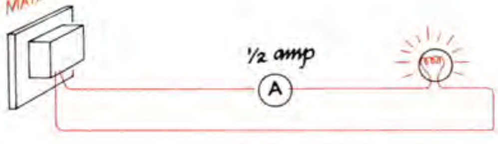
VOLTAGE

You have met the word 'volt' in ordinary life. You see it on transistor batteries; you know that the small cell that you use is labelled $1\frac{1}{2}$ volts. You probably know that the mains electric supply voltage provides 240 V and you may have seen the label on a pylon carrying cross-country power lines saying, 'Danger; High Voltage 132 000 V'.

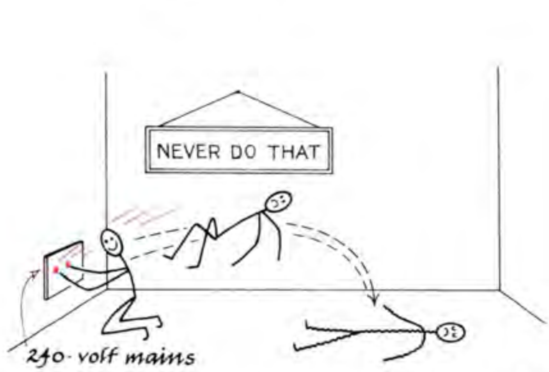
What kind of thing is a volt? Is it important in electric circuits like an amp?

The bicycle dynamo driven fast would light a small lamp with a current of about $\frac{1}{2}$ amp. A 100 watt bulb running on the mains also takes almost $\frac{1}{2}$ amp. Would you expect the bicycle dynamo to run that mains lamp?





The current, $\frac{1}{2}$ amp, does not tell you all about the lamp and its use of electric energy. You need to know the voltage as well. If you wanted a very rough description of voltage we might say it is rather like pressure, something that tells you the force with which currents are driven round the circuit. But it would be unwise to think of voltage as exactly electrical pressure—in fact if you took that idea too seriously it would make the learning of more advanced electricity difficult.



You might also describe voltage vaguely by thinking of shocks. Volts 'bite': the bigger the voltage the bigger the current that can be driven through you if you form part of an electric circuit by accident, and the worse the shock.

A $1\frac{1}{2}$ V cell cannot bite enough to hurt. You cannot feel it with your fingers. But if you take wires from a $1\frac{1}{2}$ V cell to your wet and sensitive tongue you will feel a sharp tingling. That is the beginning of a tiny shock. $1\frac{1}{2}$ volts can bite your tongue a little. Do not try that with higher voltages. They would bite much harder. The 240 volts of the mains will bite even dry horny fingers dangerously—that is why modern appliances have a third wire attached as a safeguard against getting fingers involved in the mains—see the separate note about earthing.

The real meaning of voltage is that it tells us the energy-transfer FROM electrical form TO heat, etc., for each unit piece of electricity passing through your house or an appliance or lamp. So to understand volts and the meters which measure volts you will need to know about units of electric charge that run in a circuit and about the energy-transfers.

All that will be discussed fully in Year 4; but you may want to know about the practical use of voltmeters now. If so, try some of the following experiments. At the end of them there is a specimen experiment and calculation to show how you could measure power taken by a lamp. When an electric light bulb is labelled 40 watts that is a statement of power, or rate of transfer of energy. If the lamp has no label you could find the correct label by using a voltmeter and an ammeter.

Experiment 112
The Voltmeter as a Cell Counter

Set up a circuit with three cells and three lamps in series, as in the diagram. Attach two leads to a voltmeter. Now connect these two leads across one cell, then across two cells, then across three. Record each voltmeter reading.

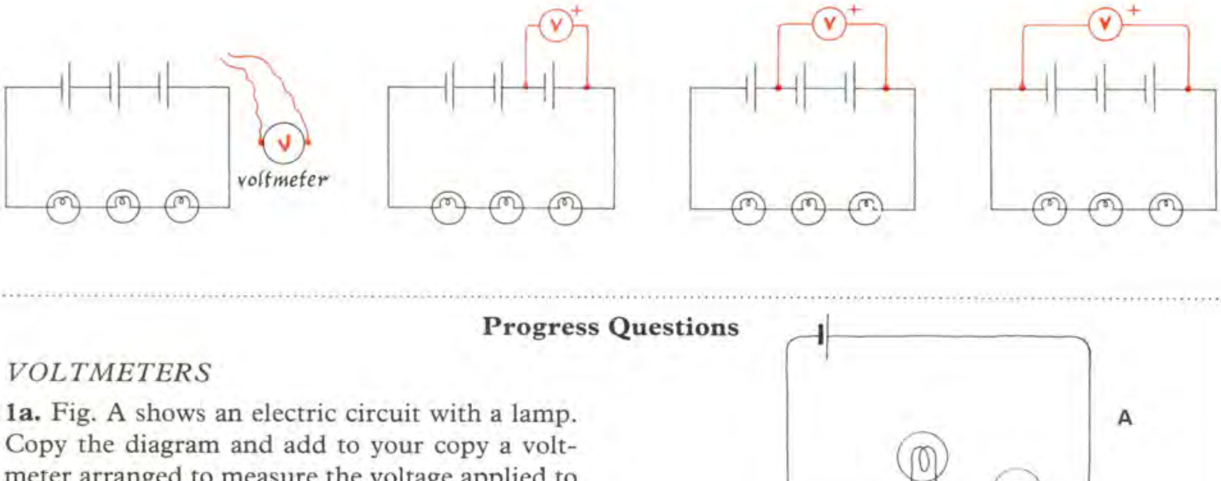
What are the three readings of the voltmeter?

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? What does it count?

Is the voltmeter connected in series with the lamps or in parallel?

Is an ammeter connected in series with the lamps or in parallel? What does an ammeter count?



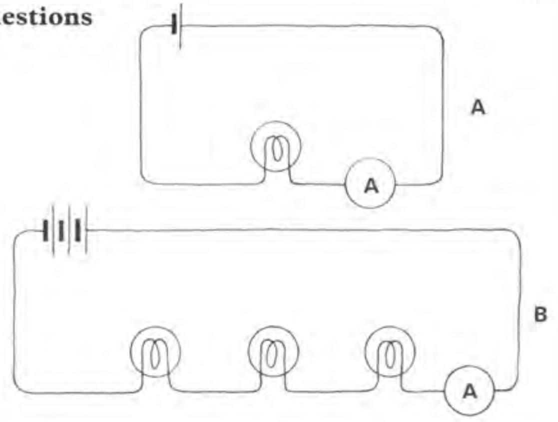
Progress Questions

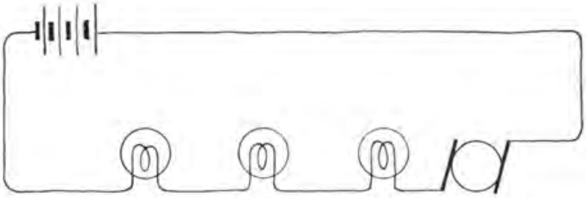
VOLTMETERS

1a. Fig. A shows an electric circuit with a lamp. Copy the diagram and add to your copy a voltmeter arranged to measure the voltage applied to the lamp.

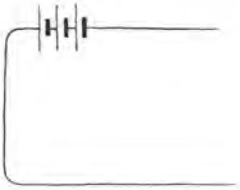
b. Fig. B shows a circuit with 3 lamps in series. Copy the diagram and add a voltmeter arranged to measure the voltage applied to TWO of the lamps (not all three).

c. Fig. C shows a circuit with lamps and an electric motor. Copy the diagram and add to your copy a





C



D

voltmeter arranged to measure the voltage PROVIDED BY THE BATTERY.

2. Fig. D shows a circuit containing a battery of 3 cells.

a. Copy the diagram and add a voltmeter arranged to measure the voltage provided by ONE cell.

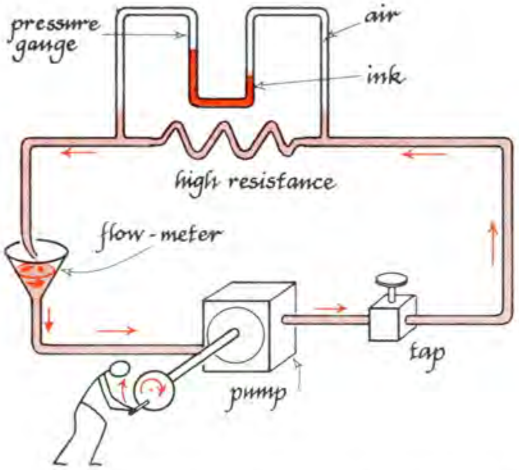
b. Suppose the voltmeter you added in fig. D reads 2 volts. Suppose you arranged it to measure the voltage provided by the WHOLE BATTERY. What do you expect it to read?

Water circuit When people first discovered that the electric current is the same all the way round a circuit, they thought electricity might be somewhat like water. That was because when water is pumped round a circuit of pipes the flow rate *is* the same all the way round the circuit. (If the flow is *not* the same everywhere in the circuit, water must be leaking out somewhere, or being pushed in at some point.)

Demonstration 113
Water Circuit

You may see a demonstration of a water circuit as in the diagram.

If you want to know how much water *pressure* is used to keep the water flowing through some part of the circuit, such as a long thin pipe which offers a lot of resistance, you could add a pressure gauge. This would really be a device to measure PRESSURE-DIFFERENCE. A U-tube with some ink in it does well for that, as in the diagram. The



corresponding instrument in an electric circuit is a voltmeter.

Note how the U-tube is connected to the water circuit, 'across' the piece of pipe you are investigating. That gives a hint of the way to connect a voltmeter.

Questions

WATER CIRCUIT

3. In the water-circuit model:

a. The pump keeps the water running round the circuit. In an electric circuit, what corresponds to that pump?

b. Suppose you had a tap in the water pipe that could be turned off to stop the flow completely. What would correspond to that in an electric circuit?

What corresponds to the funnel and ball carried round by swirling water? (Or to the tapered pipe with a ball in it, if you have seen that form?)

PRESSURE GAUGE

4. There is a toy which is a simple model of a pressure gauge. It is a flat tube of paper curled up in a spiral as shown in the diagram. If you blow into the mouthpiece it uncurls and shoots out.

a. Does this 'pressure gauge' indicate the full pressure you apply or only some DIFFERENCE of pressure?

b. Give a clear reason for your answer to (a).

(NOTE. Pressure gauges on steam boilers, etc., work in this way. They have a metal tube which is partly curled up. The tube uncurls more and more as greater and greater pressure is applied.)

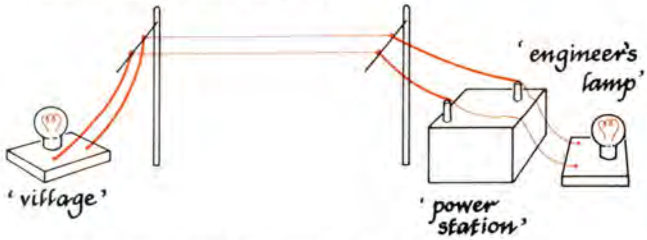
Power Transmission

In your bicycle, the chain carries energy from the pedals to the back wheel. In factories, a moving belt carries energy from an engine to a machine such as a lathe. In electricity supply, an invisible moving belt of electrons carries energy from the power station to your house. That moving belt, the electric current, wastes some of the energy that the power station gives it in the wires. How big is the waste which just warms the air?

Try the following important experiment. It will show the importance of VOLTAGE. After that we will discuss voltage and you may use voltmeters.

Experiment 114a
Model Power Line

Set up the experiment sketched. Use a 12-volt battery (or similar power supply) as your 'power station'. Connect the 'power station' to the terminals on a pylon nearby.



Run two thin wires from that pylon to a second pylon at a 'village' far away. Those wires are your model power line. (The wires would have to be thin for a real power line many kilometres long: copper is expensive; so is aluminium.)

At the 'village', connect a 12-volt lamp to the power line.

How well is the village lit?

Install an extra lamp at the power-station end. That is the station engineer's lamp to read his meters by. You can use it for comparison.

Demonstration 114b
Model power line with High-voltage Supply

See what happens when the power station is changed to a 240-volt supply, like our mains. The lamps must be changed too, but the new ones can have about the same wattage. Then they take about as much power as the ones you used and give out about as much light. *How well is the 'village' lit with high-voltage power line supply?*

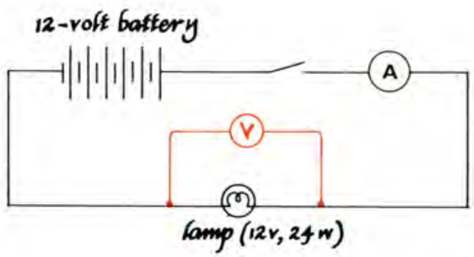
When overhead power lines hung on great pylons cross the country from big power stations, they are often fed at 132 000 volts. *Can you see now why that dangerous high voltage is used?*

For use in our houses a transformer changes the voltage down to *240 volts. Why is that change made?*

Voltmeter used to measure power *(Optional Advanced Extension)* You may have seen a pressure gauge added to the water circuit. A voltmeter is added to an electric circuit in a similar way. If you have time to spare, try the following experiment.

Experiment 115
Using a Voltmeter *(OPTIONAL NOW)*

First, make a lamp light, as you have done before, but use a larger lamp: 12 volts 24 watts. You will need a 12-volt accumulator or some other 12-volt d.c. power supply. Include an ammeter.



When you have got your lamp to light, add a voltmeter to the circuit. You may take it for granted, just for now, that a voltmeter has to be connected like a pressure gauge: connect it 'across the lamp'—as electrical engineers would say—to measure the 'voltage' being applied to the lamp.

The experiment is just for practice; to learn how a voltmeter is used. If you want to know what a voltmeter *does*, read the next section.

Voltage and Current *(OPTIONAL NOW)*

You know that an ammeter measures a CURRENT in *amps. But what is an amp?* It is our unit for the flow-rate of something we call electricity flowing round the circuit. We measure ELECTRICITY, the stuff that flows, in *coulombs*.

A current of 5 amps is a name for a flow of 5 coulombs per second; 5 coulombs passing *each* point in the circuit *in every second.**

A coulomb is a chunk of ELECTRICITY, of ELECTRIC CHARGE. It is enormously bigger than the charge carried by a single electron. It is the total electric charge carried by about 6 000 000 000 000 000 000 electrons.

What does a voltmeter do? It measures how much ENERGY each coulomb changes FROM electrical form TO other forms such as mechanical energy or heat.

One volt is one newton·metre of energy-transfer for each coulomb. That is, one joule for each coulomb. Volts are joules/coulomb.

A voltmeter reading of 5 volts means that each coulomb delivers 5 joules in travelling through the region across which the voltmeter is connected.

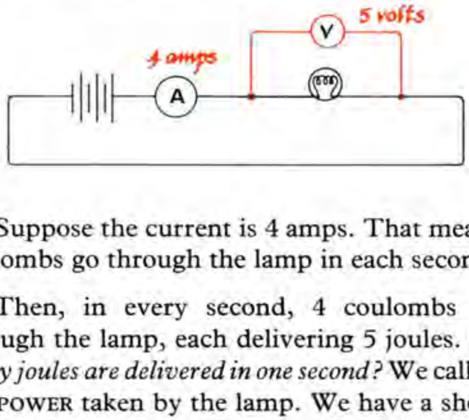
Example. Suppose a voltmeter reads 5 volts when connected across a lamp. You may picture the coulomb—a chunk of electricity, a vast horde of electrons if you like—collecting 5 joules of energy in the battery and carrying it on round the circuit, and letting those 5 joules change to light and heat in the lamp.

The mains voltage is 240 volts. That means every coulomb comes out of the power station ready to deliver 240 joules.

A car battery provides only 12 volts; each coulomb comes out of the battery ready to deliver 12 joules—twenty times less. So, if you want your car starter to put as much mechanical energy into starting the car in the same time as a big mains electric motor would, your car battery must supply coulombs much faster. *How much faster? How many times as big a current for the same power?*

Experiment 116
Using a Voltmeter to measure Power *(OPTIONAL NOW)*

Go back to your measurements of CURRENT and VOLTAGE. Suppose your voltmeter reads 5 volts, when across the lighted lamp. That means every coulomb delivers 5 joules of energy in passing through the lamp.



Suppose the current is 4 amps. That means 4 coulombs go through the lamp in each second.

Then, in every second, 4 coulombs pass through the lamp, each delivering 5 joules. *How many joules are delivered in one second?* We call that the POWER taken by the lamp. We have a shorter name for a *joule per second*, we call that a *watt*. So when you have measured VOLTAGE and CURRENT you can calculate the 'WATTAGE'* of your lamp.

---

*Nowadays we take one amp as our *standard* unit of electric current. Then we describe one coulomb by saying one *amp* is the same as one *coulomb passing per second*. So 1 coulomb is the same as 1 amp·second.

*'WATTAGE' is not a proper scientific name, nor is 'VOLTAGE'. Both are working names, useful in technical talk—like 'FOOTAGE' in the film industry. The formal name instead of 'WATTAGE' is POWER.

Questions

ENERGY FOR ELECTRIC POWER
(An Optional Topic Now)

You may have learned about forms of energy and energy-changes in an earlier year of Science. There is an extra chapter (E) in this book for you to read about forms of energy and energy-changes if you have missed those topics before. And Pupils' Text 4 treats energy in a fuller, more advanced way.

You may like to try the questions below, or you may prefer to leave them till Year 4.

5. In a power station, electric power is produced by coils moving in a magnetic field. This is done on a large scale, and a lot of energy is needed to move the coils. Some power stations use steam engines run by coal fires to produce this energy. What other ways of running power stations have you heard of?

6. Example: 'Some power stations turn the coils with steam engines that run on coal. So *chemical* energy from COAL turns into *electrical energy*.'

There are lots of different ways of turning the coils. Think about the following. Then copy each one and complete the gaps. (See the list below for names of forms of energy.)

a. I turn a bicycle dynamo when I pedal along. So .. ? .. energy from -- ? -- turns into .. ? .. energy.

b. A car dynamo works all the time the car is moving. So .. ? .. energy from -- ? -- turns into .. ? .. energy.

c. In Scotland, Canada, Norway, where there are big waterfalls, water is used to turn the coils. So .. ? .. energy from -- ? -- turns into .. ? .. energy.

d. Remote farms sometimes use small windmills to turn their own dynamos. So .. ? .. energy from -- ? -- turns into .. ? .. energy.

e. Some power stations drive their dynamos with steam engines that run on coal. So .. ? .. energy from -- ? -- turns into .. ? .. energy.

f. Some power stations run on oil, not coal. The oil is used to work .. ? ? .. engines, that turn the dynamos .. ? ... So, energy from -- ? -- turns into .. ? .. energy.

Informal names for forms of energy

Uphill energy (gravitational potential energy) is energy gained when a load is raised against the pull of the Earth.

Chemical energy is energy stored in molecules of fuels, explosives, food for animals or people.

Electrical energy is energy delivered by a battery to a circuit, or energy stored in the electric field of charges.

Motion energy (kinetic energy) is the energy a moving object has on account of its motion.

Springs energy (elastic potential energy or *strain energy)* is the energy stored in a stretched or compressed spring, a compressed or twisted solid, etc.

Radiation energy or *light energy*, is energy carried by electromagnetic waves throughout the spectrum from radio waves to X-rays.

Heat is a very important form of energy, which we believe is held in the motion of molecules. *Heat* has, in the past, been measured differently; and such measurements have been very important in building our belief in Conservation of Energy. You will find a full discussion of the status of *heat* in *Pupils' Text 4*. For now, simply assume that *heat* is a form of energy.

Economy: the Earth Return Wire

Can the Earth carry a big current? It can. The soil beneath your feet does a good job of carrying current, although as a material it is a poor conductor. How, and why?

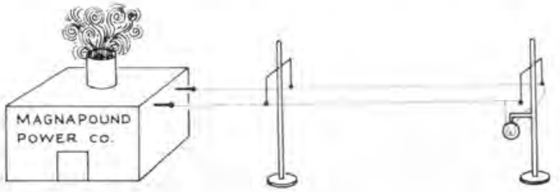
You know that:

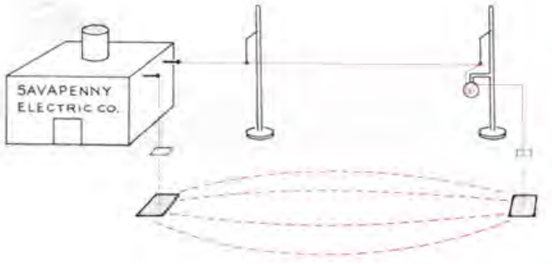
A long piece of wire has more resistance than a short piece of the same wire.

A piece of thick wire has less resistance than the same length of thin wire.

Copper is a good conductor, iron a poorer conductor; so an iron wire has more resistance than a copper wire of the same size.

What about the Earth itself as a conductor for currents? If you test a chunk of earth you will find that it is a very poor conductor, *far* poorer than iron. And if it is *dry* earth it is an extremely poor conductor—you might almost call it an insulator. Yet some telephone systems, and some electric power systems, use the Earth itself as a conducting 'wire'. They do that successfully because the Earth provides an ENORMOUSLY FAT 'WIRE'—its cross-section area is very wide and very deep.





Look at the two arrangements sketched, for lighting a lamp far away from a small power station, 5 kilometres away.

In A, the current runs to the lamp through copper wire and the return current runs through copper wire—10 kilometres of copper wire in all.

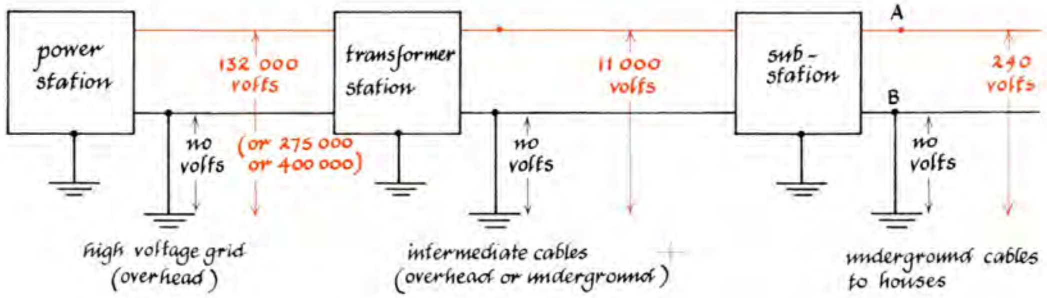
In B the return current runs through the Earth. It is carried down into the ground by metal water piping that runs down deep enough to be in moist earth which will conduct well. Then a huge 'wire' of wet earth carries the return current—so only 5 kilometres of copper wire are needed in all.

(Sometimes a water-supply system has pipes made of plastic instead of metal. Then the earth connection goes by copper wire to a metal plate deep in the ground.)

Mains, sub-circuits, fuses, and circuit-breakers Two wires come into your house from the supply system outside, the 'live' wire and the 'neutral'. The live wire goes through a main fuse or circuit-breaker.*

*If some damage or fault makes a short circuit, the current grows too large. If that large current continued to run it might start a fire or do some other damage. But a fuse cuts off the dangerous current by melting.

A circuit-breaker does the same thing. It is a trip-switch pulled by an electromagnet which carries the current. That switch is held ON by a spring. If the current grows too large, the electromagnet becomes strong enough to pull the switch off and the dangerous current is quickly stopped. We say the circuit-breaker is then 'open'. And it is held open (off) by a small catch until we press a button to unlatch the catch and switch it on again.



Then the supply divides into several sub-circuits all in parallel, each with its own fuse or small circuit-breaker. Some sub-circuits supply appliances such as electric cookers, irons, heaters. Other sub-circuits supply lamps. All the lamps on a sub-circuit are in parallel.

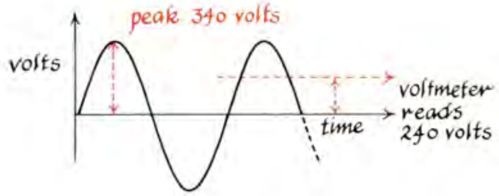
Mains voltage The most common form of electric supply is alternating current (a.c.) at about 240 volts.* With simple precautions in the work of installation, supply at 240 volts is quite safe; but there are some household conditions under which there is danger—and these are described here.

The mains you have in your house come from the secondary coil of a transformer at a sub-station. The primary coil of that transformer is usually fed by a 6000-volt or 11 000-volt supply, which in its turn comes from a transformer on a still higher voltage system, the Grid.

The local transformer's output coil (secondary) has 240 volts (average) generated in it. One terminal of that output, the NEUTRAL, is connected to earth.

This output voltage, which supplies your home or lab, is alternating. It swings between extremes of +340 volts and −340 volts. This maximum, 340 volts, is called the 'peak' voltage.

Voltmeters read a special kind of average value, called the *effective* (or 'root-mean-square') value, which is about $\frac{7}{10}$ of the peak. The effective voltage of your house supply is $\frac{7}{10}$ of 340; that is 240 volts. In considering dangers of electric shocks, *think of the peak voltage, because that hurts most.*



Since one end of the transformer coil which supplies your home is connected to earth, the highest voltage between any part of the coil and earth is 340 volts. In the diagram, that occurs between terminal A and earth. The voltage of A is alternately positive above the earth potential and negative below the earth.

Electricians call the wire A the 'LIVE' wire, or the 'LINE'. They call wire B the 'NEUTRAL'.

(In each stage of transformers from power station to your house, one end of every primary coil is connected to earth; and so is one end of every secondary coil.

That is a general safeguard against troubles. If insulation breaks down, or if a loose wire makes a wrong connection, keeping one side of each stage connected to earth will make a circuit-breaker fly open and switch off at once, for safety.

But the important thing for household safety is that your own electric mains in the house have one side connected to earth.)

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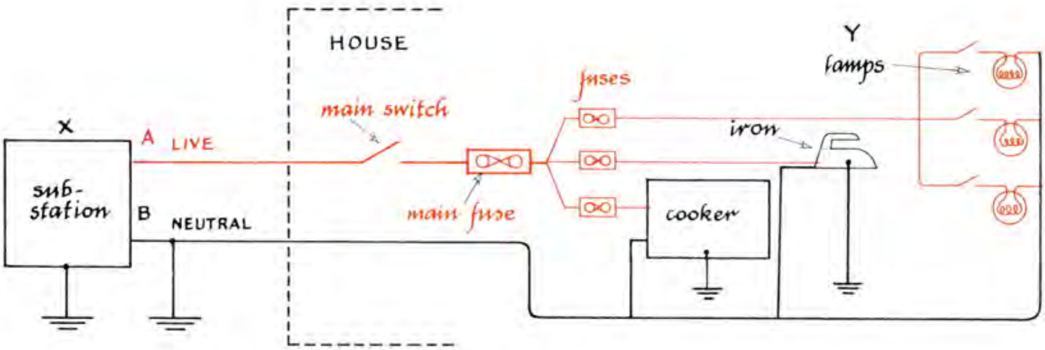
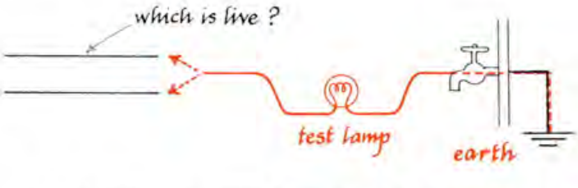
* *Note about 'three-phase' supply.* For economy and convenience, engineers usually arrange three simple a.c. circuits together, and make sure that the changes of voltage in the three circuits occur in sequence, one after the other like a choir singing a round. They call this combined system a 'three-phase' supply. Consumers who use only a little power are connected to only one of the three circuits. Your own home supply will be single-phase.

In large buildings—such as schools and factories—all three circuits are usually brought in. The building is divided into three sections and each section gets one phase. Here we shall discuss only a single-phase supply.



Which wire is live? In your house, the connection to a plug which you are using for a lamp or some appliance should be like the diagram. Of course the sub-station transformer and its earth connection may be in a different part of the building or half a mile away in another building at X. But the main switch in your house, and the main fuses or circuit-breakers are within your control—as well as the switch and socket at Y.

With the help of a test lamp we can find which supply wire is connected to earth. See this done by your teacher. He will connect each supply wire in turn *through a lamp* to earth. (It must be a 240-volt lamp.) He should make the connection to earth *before connecting to the supply wire.*



Better still, he can first make the connection with the switch open, and then switch on. The lamp will light from one wire to earth but not from the other wire to earth.

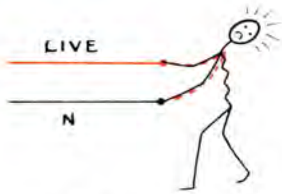
When a lamp is connected between LIVE and NEUTRAL, the lamp lights. That is the proper way to connect lamps.

When a lamp is connected between LIVE and EARTH, the lamp lights. That is because there is a return route, via earth, to NEUTRAL at the sub-station.

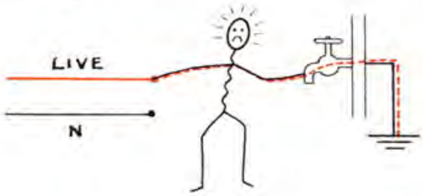
When a lamp is connected between NEUTRAL and EARTH, it does not light, because neutral is already connected to EARTH (at the sub-station).

Shocks

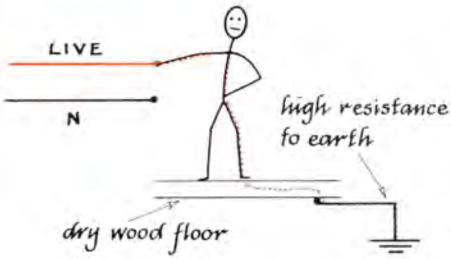
Live to neutral. If you were to join LIVE to NEUTRAL through your own body instead of through a lamp you would get such a shock that you would never do it again deliberately. And if your hands were wet and the connections were *firmly* made, it would be a dangerous shock.



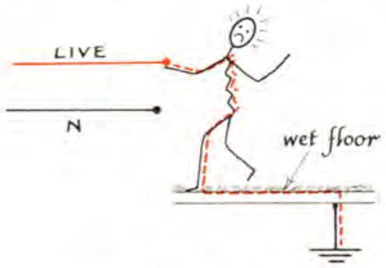
But you need not take such risks. With 6 or 12 volts, there is no risk. Such a small voltage does not drive enough current through you for you even to feel it.



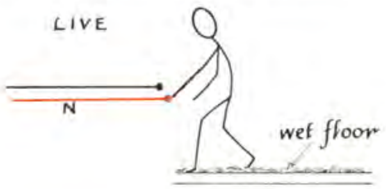
Live to earth. If you were to join LIVE to EARTH through your body you would get the same bad shock as with LIVE and NEUTRAL, if the contact were good.



Fortunately, it is not easy to make a *very good* connection to earth. If you stand on a dry wooden floor you are fairly well insulated from earth. The things which make good connections to earth are water pipes, gas pipes, heating pipes and radiators, and concrete floors (especially when wet).



So you can get a shock if you touch the LIVE wire and have your wet feet on a damp floor. Then you would be joining LIVE to EARTH through your body instead of through a test lamp. But if you touch NEUTRAL and EARTH: no shock.



Since both wires may look the same, you must not touch either unless you are certain that the supply has been switched off by the main switch.

The switch for a lamp or appliance should always be put in the live wire, the 'line'. But if the electrician has been careless and has put the switch in the neutral wire, you could get a shock even if the switch is off, if you touched the *inside* of a lampholder or a wire *inside* an appliance. But appliances have an outer case of metal which, as you will see, is connected to earth; and that keeps you safe from any shocks.

An electrical engineer made some specimen tests. He *measured* the electrical resistance of his body, between his right and his left hand, in various conditions. (He used a safe low-voltage supply for that.) He then *calculated* the current that a maximum 340 volts (peak) would drive through that resistance—if he were foolish enough to try it. The table shows his measurements and predictions.

The lesson from that is ALWAYS switch off the main switch before handling any of the wiring.

Bathroom switches are placed out of reach of people standing near the bath or the basin or any taps. The switch is placed high up, with a long hanging cord to work it. *Why is that?*

NEVER handle an electric shaver or hair-dryer in a bath—the bath and water in it and water pipes outside offer an easy path straight to earth.

Safety: the earth wire Suppose the insulation breaks down inside an appliance and the *live* line makes contact with the outer metal case. That might be very dangerous if you touched the metal case and at the same time made a good connection to earth with your hand or foot. But electricians take away that danger. They install a third wire which is connected direct to earth. They connect that earth wire to all the metal casing round their wiring and to the metal housing of switch-boxes, electric kettles, irons, washers, water heaters and other appliances. The outer metal frame of each of those is thus connected straight to earth.

So long as that earth connection is good, nobody can get a shock by touching the metal case, with their hand or foot connecting to earth. Even if the insulation inside the appliance has broken down, so that the live line has made connection with the outer case, there is no danger because current would go straight to earth through the third wire and not through you. You run no risk because you offer a much poorer alternative route through your body and the floor, etc.

And if it is a bad fault the current running from the casing to earth will blow a fuse or trip a circuit-breaker in the supply system and cut off the supply. That is why house wiring has three wires instead of two.

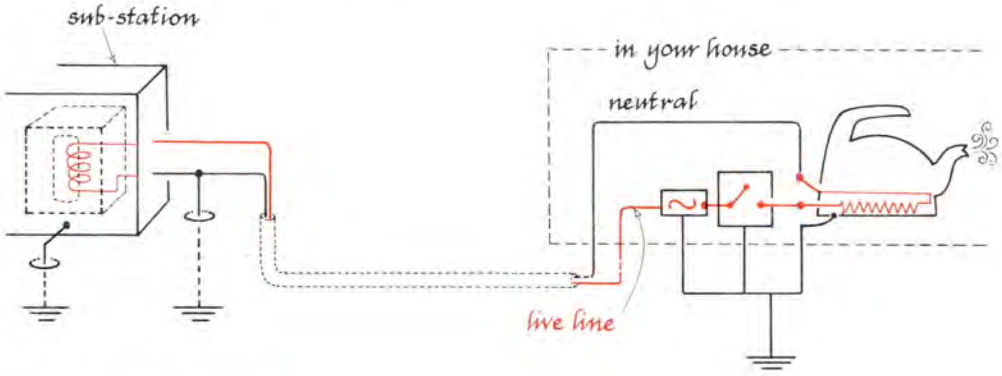
The three wires: colour code

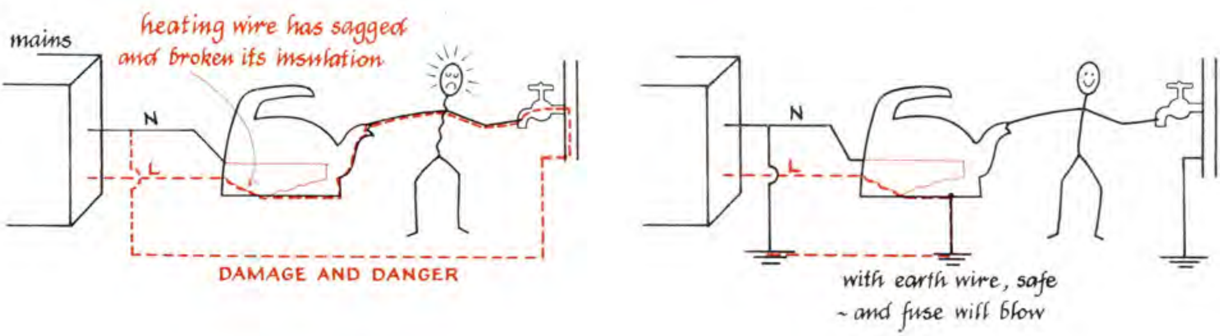
THESE ARE THE TWO WIRES FROM THE SUPPLY	'LIVE', the live wire direct from the supply. This is marked LINE, coloured brown. 'NEUTRAL', the return line to the supply, also connected somewhere to earth, but perhaps only at the power station. This is marked NEUTRAL, coloured blue.
THIS IS THE THIRD WIRE TO EARTH FOR SAFETY	'EARTH' connected to earth (often by water-pipes), and connected directly to the case of an electric appliance. This is marked EARTH, coloured green and yellow.

EXPERIMENTAL CONDITIONS	RESISTANCE (varies from person to person. These are measurements of the engineer as a typical person)		MAX. CURRENT with (peak) voltage 340 V	EFFECT
		ohms	**amps**	
Hands *very* dry	Between one hand and the other	80 000	0.004	He would feel a small shock and would jump away
Hot day: hands moist	Between one hand and the other	12 000	0.030	A very bad and dangerous shock which would hurt a lot and might do serious harm. Do not try this.
Each hand in a bowl of salt water	Between one hand and the other	1000	0.30	Almost certainly fatal
Standing in salty water on concrete in ice factory	Between one hand and floor	2000	0.17	Probably fatal

Calculating the current, with the same resistances, for 12 volts (as with a car battery) gives the following effects:

Very dry hands .... too small to feel
Moist hands .... probably not noticeable
Hands in salt water .... small shock: jump
Hand to feet (standing on a floor wet with salty water) .... tiny shock: jump





All modern wall-plugs have three pegs. Two are for LIVE and NEUTRAL. The extra one is for the wire from earth to make sure the outer case of an electric iron, kettle, etc., is connected to earth.

Progress Questions

POWER LINE

7. To carry power a long way from a power station to a town we make a large voltage between the two wires of a power line.

a. What is the *advantage* of using a large voltage there (say 30 000 volts)?

b. Suggest some *disadvantages*.

SAFETY IN HOUSE WIRING

8. Before mending a fuse, or undoing the wiring of a switch or lamp, ALWAYS .. ? .. What are the words that should go in that gap?

9a. Why do bathrooms have the light switch *outside the door*, or else worked by a cord hanging from the ceiling?

b. An electric iron has three wires running to it from the wall socket. Two come from the mains (the live and the neutral from the power station).
(i) What is the other end of the third wire connected to?
(ii) What is the use of that third wire?

c. Suppose there are two families A and B; and each family has an electric iron. Suppose in each iron a piece of wire from the live line gets loose inside and touches the case (unlikely but possible).
(i) Family A has the iron connected to the wall socket by three wires, properly connected. What will happen?
(ii) Family B has their iron connected by *two* wires to the wall socket. What may happen?

Questions

POWER LINE

10. Describe the experiments with a model power line: with low voltage, then with high voltage. What did you learn from those two experiments?

11a. How can we change an a.c. electric supply from low voltage to high or from high to low without paying a lot for people to look after the machinery?

b. *(OPTIONAL. A question for guessing.)* How can you make changes from low voltage to high, or from high to low, in a DIRECT CURRENT supply? (This is probably something that you have not seen or read about or heard about. But it is very important—for example in sending electric power under the sea between England and France. Just use your knowledge of electrical machinery and make a guess.)

12. The POWER taken by a lamp is measured by CURRENT (through the lamp) multiplied by VOLTAGE (across the lamp).

A 24-watt lamp designed to run on a 6-volt supply takes 4 amps (6 volts × 4 amps makes 24 watts).

a. A 24-watt lamp designed to run on 240 volts takes .. ? .. amp (240 volts × .. ? .. amp makes 24 watts).

b. If a house is supplied by a long power line from a power station, the current for the lamp has to pass through the long wires of the power line.

Suppose a power line of copper wires has already been put on poles, from the power station to the house. There is a choice between 6-volt lamps and 240-volt lamps.
(i) In which case will the power line be heated more? (HINT. Look at your answer to (a).)
(ii) What happens to the heat developed in the power line wires? Where does it go?
(iii) Who pays for the heat developed in the power line?

13. A 'lie-detector' is a fairly simple electrical instrument. Guess what it is and explain how it works. (HINT. There are some statements about people and electric currents in this chapter.)

CHAPTER 8

ELECTROSTATICS

A stream of electrons, charges, forces and fields

ELECTRIC CHARGES, ELECTRIC FIELDS, AND ELECTRONS

Electricity

You have been making electric circuits and have heard of 'electricity' or 'electric charges' running round a circuit.

You also read in newspapers about 'paying for electricity', 'wasting electricity', 'generating electricity'; but those are really unscientific uses of the word electricity. From the scientific point of view, 'electricity' *in those remarks* must mean *electric energy*.

Scientifically, the stuff that flows round circuits is called electricity or electric charge. When there is a current in a wire, electric charges—bits of electricity—drift along the wire, usually in the form of tiny electrons staggering through a network of massive nuclei of atoms.

Electrons

So far you have done experiments with electric circuits without needing to talk about electrons moving in the wires. *Something* happens, but if you just judge by results—which is good science—you can only say 'An electric current is just our name for some things that happen together: heating, magnetic fields, and sometimes some chemical changes.'

However, you have heard that the current in a wire is a stream of electrons; and in your cathode ray oscilloscope the current is a stream of electrons all by itself without any copper wire.

Now you should make acquaintance with electrons; also with electric charges at rest.

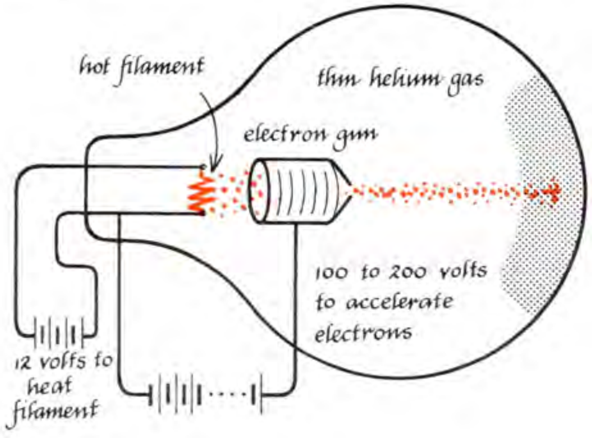
First 'see' a stream of electrons shooting across a 'vacuum'.

Demonstration 117
The 'Naked Oscilloscope': Fine-Beam Tube

See this running in the half dark. At one end of the tube there is a little rocket-shaped 'gun'. In that gun a starting plate is heated by a tiny electric drill.

The plate has a special surface that lets electrons loose rather easily. Electrons boil off that plate. They are speeded up in the gun by a large voltage between that starting plate ('cathode') and the gun muzzle ('anode').

Electrons come out at high speed through a tiny hole in the cone-shaped gun muzzle.



(We can calculate their speed from some measurements. It is more than 5 000 000 metres per second!)

The electrons continue at that constant speed to the end of the tube and make a bright spot where they crash against the mineral screen.

You can see that this is like an oscilloscope tube, but naked so that you can see inside.

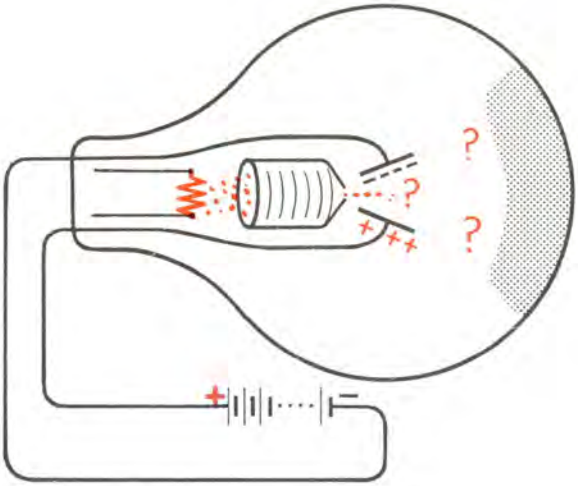
The tube in a cathode ray oscilloscope has an electron gun just like that: but in this case the stream from the gun muzzle is made visible. This glass globe has been pumped out to a very good vacuum to remove air, which would soon slow electrons down by collisions. But then a *very little* helium gas is let in, because the helium atoms give out a green glow when hit by electrons.*

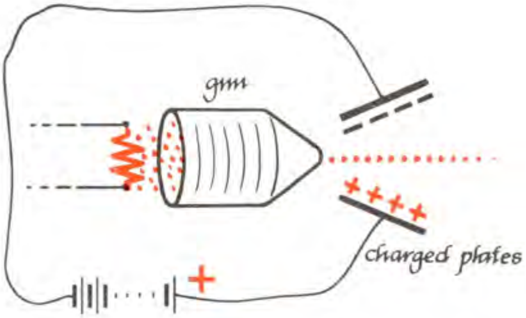
So you can see the path of the stream made visible as a thin line of glow.

Look at that carefully. You are seeing the path of electrons flying through thin helium, almost a vacuum, all by themselves, with no wires there.

Electrons in an 'electric field' Just after the stream comes out from the muzzle, it passes between two small metal plates. Connect those plates to a battery. The battery will put positive and negative charges on them.

*A similar tube of another make has hydrogen, which makes a faint blue glow, instead of the green glow of helium.





What do those electric charges do to the electrons in the stream?

To answer that question, you need to learn about electric charges at rest, and the forces they exert.

Questions

FINE-BEAM TUBE

1. *(Do not try this question until you have seen the 'Fine-beam tube' in action—without any magnetic field. You should look at it from close by, so that you can see what the stream does.)*

a. Was the path of the stream straight or curved, or did it wobble about?

b. What happened where the stream hit the globe inside?

c. Does something *like* that happen when the stream in a TV tube hits the end of the tube? In what way does the TV tube behave differently?

d. The stream came out of the gun. It passed between two metal plates nearby.

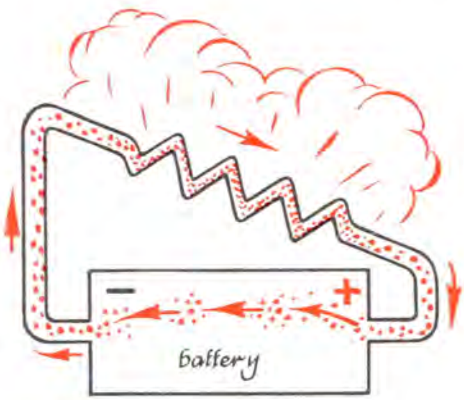
(i) What happened to the stream when those plates were connected to a battery?
(ii) After the stream had left those plates, what was its path like: straight ahead, straight but slanting, or curved?

2. Suppose you could have the box of a TV set opened up while it is running (very dangerous). And suppose you could look into the picture tube from the side (impossible because the tube is coated inside). You might *hope* to see the stream inside the tube. But in fact you would not see it at all. Why not?

(There are two answers. Try to guess them both. HINT. One is concerned with what is in the whole space inside a TV tube.)

Pumping up electric charges; a preliminary explanation If you live in a country village, a pump pushes water for you up into a water tower on a hill, or into a tank at the top of your house. The water then runs down through baths and basins and drains to the ground again. Then more water—the same lot of molecules or another lot—has to be pumped up to the top.

You may picture a battery pumping electrons up to the top of an electrical hill. When you connect up a circuit electrons run downhill, round the circuit, and have to be pumped up again.



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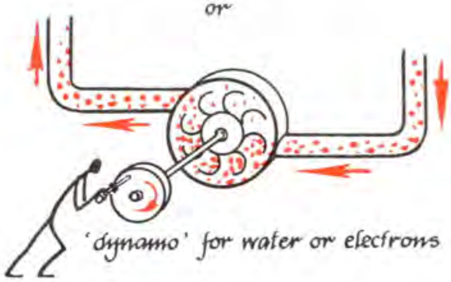
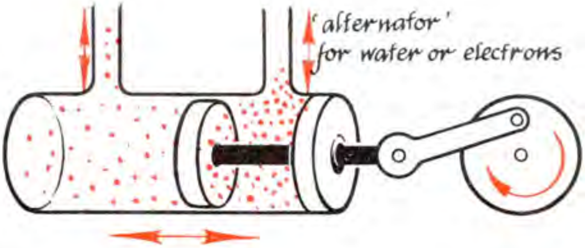
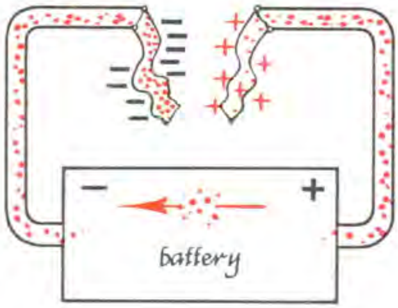




A d.c. dynamo pumps up electrons like a battery. (An a.c. dynamo is like a reciprocating pump, driving forwards and backwards, forwards and backwards, . . .)

The water pump gives the water up-hill energy, which the water spends on the way down in making a little heat. A dynamo or battery gives electrons some up-hill electrical energy, which they spend on their way down round the circuit, often as heat.

If the circuit is *not* complete—the switch is not turned on—the electrons have to stay pumped up, like water waiting in the water tower. You can find them there if you attach a battery to two pieces of metal held apart in air. There will be extra electric charges waiting on the metal surfaces, waiting to go somewhere.



The battery pumps electrons onto one piece of metal and pumps them out of the other, making negative and positive charges on the pieces of metal. We call those '*electro-static*' charges, because they are at rest, stationary or static. But they are the same kinds of charge, measured in coulombs, that run round a circuit when there is a current.

You may see that there are charges stored up, by letting them make a spark.

Nowadays we know that in copper wire it is negative electrons that run round the circuit. There are positive charges there also, but those are locked in a crystal lattice of copper atoms.

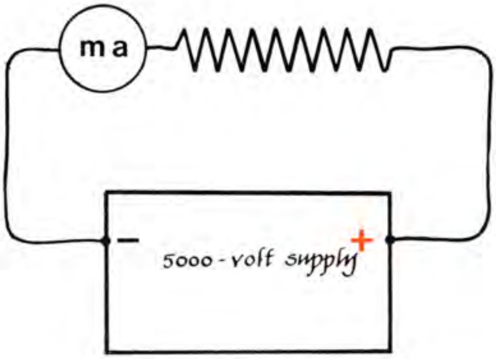
Positive and negative There are two kinds of electricity or electric charge. We need names to distinguish them. Long ago the names *positive* and *negative* were chosen. You will find them marked on cells, + and −.

The two kinds are equally strong. Negative charges are not weaker or inferior! Equal quantities of + and − seem to neutralize each other's effects.

Demonstrations 118
Electric Charges and Forces

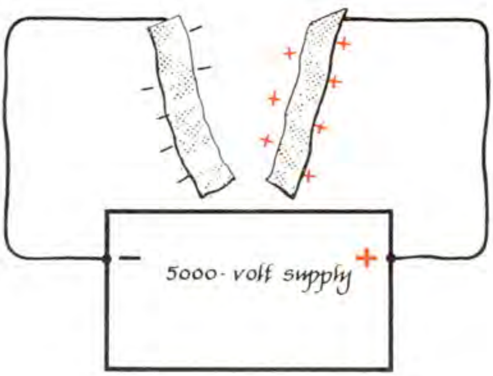
118a A Current

Connect a 5000-volt power supply (equivalent to a large battery) to a large resistance (2 000 000 ohms) and a milliammeter. You will see the power supply driving a current.



118b Charges at Rest

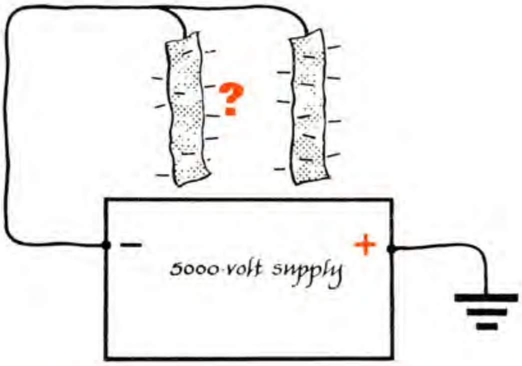
Let the same power supply pump charges onto two metal strips. The strips should be thin and flexible. Metal-coated plastic cling-film does well.



Hang the strips well apart so that there is no complete circuit. Let the power supply pump electrons off one sheet and onto the other, so the sheets gain + and – electric charges. Then you can see them ATTRACT.

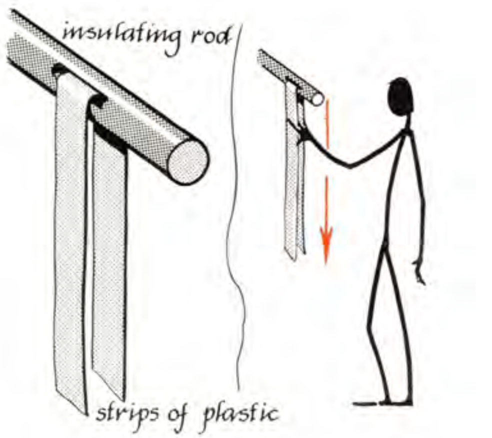
118c Charges of the Same Kind

Try two strips with *negative* charges pumped onto *both*. *What do they do to each other?*



118d Charges made by 'Friction'

Fasten the top ends of two strips of thin flexible plastic to a rod and let them hang down together. Run *dry* fingers of the other hand down them, with one finger between. The strips will scrape* electrons off your skin, and both will be left with negative charges. (The strips should not be metal coated this time because the metal will undo the result of scraping.)



This is a giant model of the ancient instrument (now really out-of-date) called a gold-leaf electroscope. You may see a small one.

*'Scrape' is rather misleading. Electrical forces *pull* electrons off.

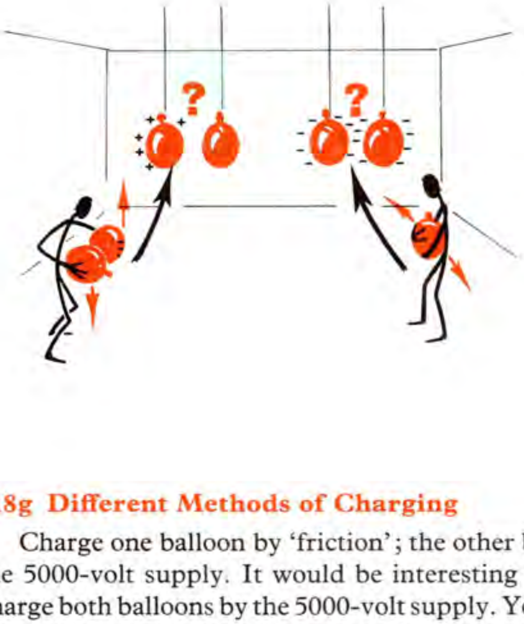
Home-made Electroscope. You can make a large electroscope at home with two strips of thin paper (newspaper will do). Dry the strips in an oven or by holding them in front of an electric heater. Hold the top ends together and run *dry* fingers of the other hand down them with one finger between. The paper scrapes electrons off your fingers.

118e Charging Balloons by 'Friction'

Suspend two balloons by long nylon threads. Rub each on a wool jacket or pullover. The balloons will scrape electrons off the wool.

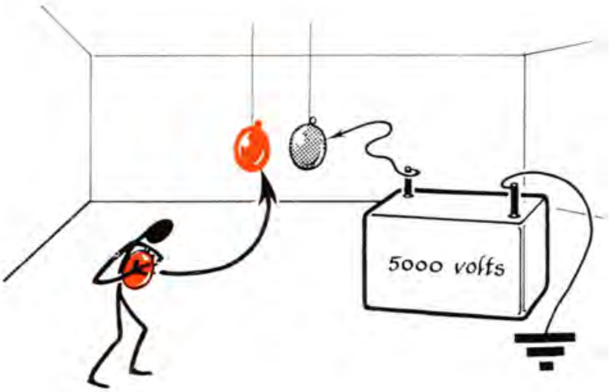
118f Unlike charges

To charge balloons + and −, instead of − and −, rub two balloons together. One balloon will, somehow, scrape electrons off another. Hang them a short distance apart. *What do they do?*



118g Different Methods of Charging

Charge one balloon by 'friction'; the other by the 5000-volt supply. It would be interesting to charge both balloons by the 5000-volt supply. You would have to coat the balloons to make them conducting so that the supply could put charge onto them all over. But even then the charges would be too small to have noticeable effects. However you can see the effect of forces if you mix the two methods: give one balloon a charge by rubbing it on wool—that will be a big charge—and suspend it. Give the other balloon a charge from the 5000-volt supply—that will be a small charge—and

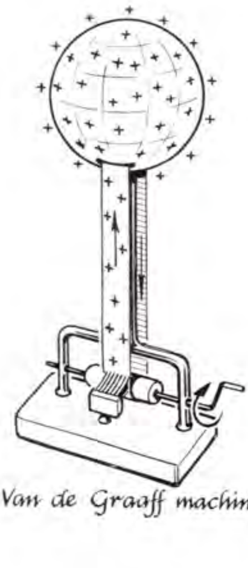


carry it near the suspended balloon. See what they do to each other.

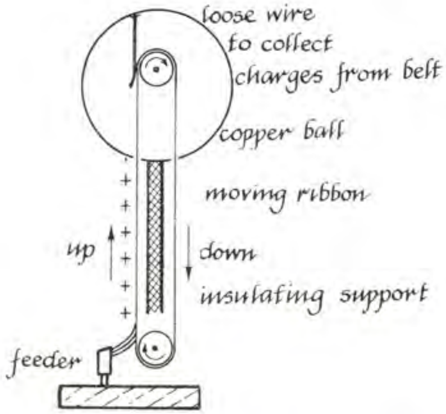
The second balloon will have to be made conducting or it will collect too little charge from the 5000-volt supply. That is done by coating it with black carbon or spraying it with wetting spray. Then it is carried on a long insulating rod as a wand.

118h Van de Graaff Machine

You may see charges taken to thin plastic strips or balloons from a big charge stored up by a moving machine. There are many ancient machines for collecting electric charges at rest. Some use 'friction' to separate + and − charges and then collect one of them; others use electrical forces to do the same thing in more ingenious ways. A modern form is the Van de Graaff generator.



Van de Graaff machine



Continuous elevator for charges: Van de Graaff machine Huge Van de Graaff machines are used to pump charges up to millions of volts for use in nuclear research.

If a small one is available, watch it at work. An endless belt of insulator such as rubber collects charges by friction (or other electrical methods) and carries them up into a hollow metal globe. Inside the globe, the charges are collected by a brush and since they are all of the same sign (say negative) they repel each other out to the surface of the globe.

As charges accumulate on the surface, they build the globe up to higher and higher voltage above earth: 100 000 volts is easily reached—more still on a dry day. Yet the total charge is so tiny that you feel only a small shock if you let the globe drive current through you to earth.

You can let the big ball give some of its charge to a small metal ball which can carry charge to other things. Just bring the small ball up to the

Progress Questions

CHARGES

3. A power supply was used to pump charges onto two flexible metal strips hung near each other.

a. One strip was charged + and the other −.
(i) What did the strips do, when they were charged like that?
(ii) If the strips were then allowed to touch each other (after the supply was taken away) what did they do?

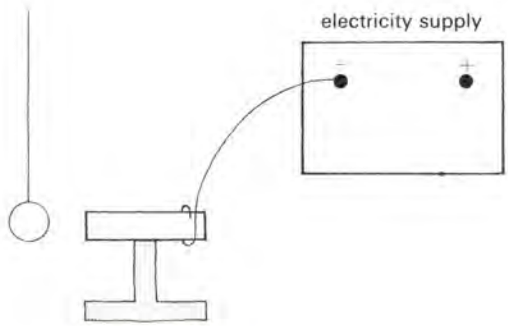
b. Both strips were given negative charges.
(i) What did the strips do when charged like that?
(ii) Suppose the strips were allowed to touch each other (after the charging supply was taken away). What would you expect to see them do? (Think and guess.)

4. On a cold dry day, a girl combs her hair with a dry comb. She moves the comb quickly, and then notices some of the hairs flying out in different directions. Suggest an explanation.

5. If you take a piece of nylon knitting yarn and draw it between your finger and thumb, you can charge it electrically. Now you bring that piece of yarn near a plastic pen you have rubbed on your jersey; and you find the pen attracts the nylon.

(If you can get hold of nylon yarn, you can try such an experiment at home. You can also find out what happens when two bits of rubbed nylon are brought near one another, or near a balloon that you have rubbed on your jersey. Your hands should be perfectly dry when rubbing the nylon yarn.)

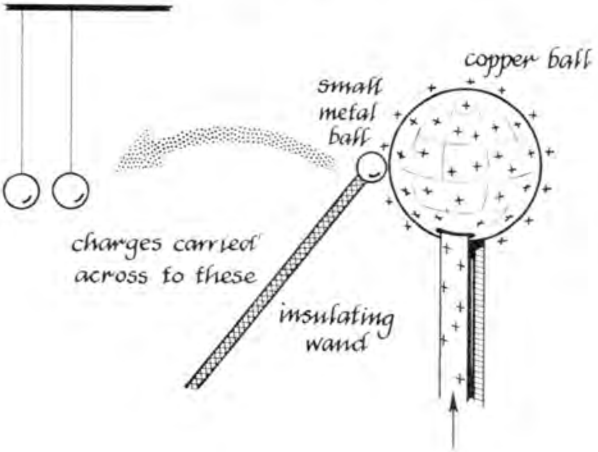
6. We believe that the charges we get on acetate and polythene are electric charges just like those from a battery or electricity supply.

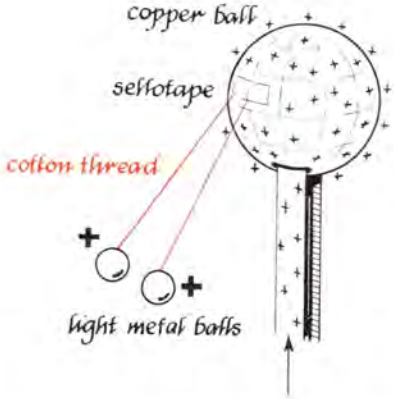


A metal rod (on an insulated stand) is connected to the negative terminal of a 5000-volt power supply. A light ball with a metal coating is hung on a nylon thread. It is not charged. It is brought near the metal rod. Two things happen to the ball one after another. What are they?

7. Why does a metal object have to be held by an insulating handle if you want it to hold electric charge? What happens to the charge if you do not have the insulating handle?

big one on the machine and let it touch the big ball so that some charge runs on to it.





Or you can let the big ball share some charge with many small bits of paper or light metal balls.

You may see a Van de Graaff machine used for experiments with electric charges, as a rival to a 5000-volt power supply (equivalent to a big battery).

Static charges are put on the belt at the lower end by 'friction', but they can be pushed on to it by a power supply instead.

The power supply which can drive currents round a circuit can also pump electric charges up into storage. Those electric charges are the same kind of thing as electric charges separated by rubbing plastic on wool, and as charges carried up and stored by a Van de Graaff machine.

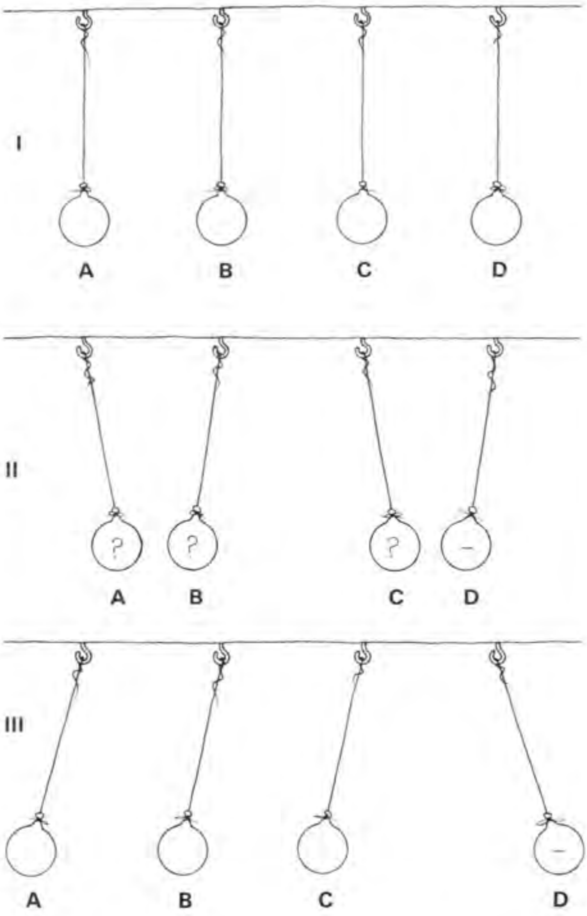
On the other hand, a Van de Graaff machine can drive charges round a circuit; but the current is too small to measure easily.

These experiments should show you that there are just the two kinds of charge, positive and negative; and they exert the same forces whether they come from friction, or from a battery (or power supply).

Questions

ELECTRIC CHARGES

8. Balloons A, B, C, D are hung near each other by nylon threads as in fig. I.



Balloons A, B, C are given some charges and hang as in fig. II. Balloon D is given a negative charge by being touched with a wire from the negative terminal of a 5000-volt supply.

Copy fig. II and label the charges on A, B, C with the proper + and − signs.

9. Suppose the balloons of Q.8 hang as in fig. III. Copy fig. III and label the balloons A, B, C with the proper + or − signs.

Electric Charges

When we rub things and find they attract or repel other rubbed things, we say the things are 'charged'. But such experiments do *not* tell us that being charged means having gained or lost electrons. Such experiments just show us some forces, and do not help us to find out what electricity really *is*.

'Charged' simply means 'ready to make forces'. (That is rather like the meaning when soldiers say a gun is 'charged': they mean 'ready to make forces on a bullet'. The gun is charged with explosive and in that case we know what explosive is. But in our electrical experiments we say charged with electricity without knowing what electricity really is—we only know it by what it does.) A charge's forces act on other charges.

Electric charges at rest have been known much longer than electric currents. Many centuries ago, Greek philosophers collected charges by rubbing amber. Rubbed amber could pick up small things just as a plastic pen picks up scraps of paper after you have rubbed it on wool. (Our word 'electron' comes from the ancient Greek for amber.)

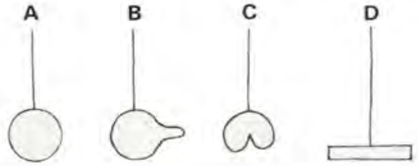
Two centuries ago, Benjamin Franklin in America tried experiments with charges. It was he who named the two kinds of electricity *positive* and *negative*. He even collected electric charges from thunderstorm clouds through a wet string from a kite.

Questions

ELECTRIC CHARGES

10. You are given two pieces of information:
I. All ordinary electrons have negative charges.
II. Electrons can run about freely on any metal surface.

Predict how the charges will arrange themselves in each of the following cases. In each case a metal object is hung on a long nylon thread. (A sketch will show your answer well.)



a. A negative charge is given to a metal ball (fig. A).

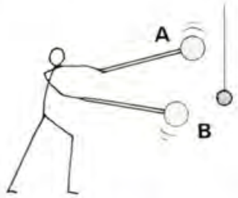
b. A negative charge is given to a metal ball with a long snout (fig. B).

c. A negative charge is given to a metal ball with a deep dimple in it (fig. C).

d. A negative charge is given to a short metal rod (fig. D).

11. You have a small table-tennis ball hanging on a long nylon thread. You give it a small negative charge.

You also hold two large metal balls, A and B, on insulating wands. You give them negative charges.

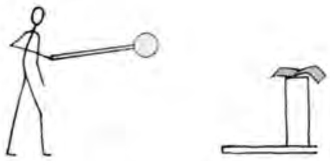


a. How would you find out by experiment which ball, A or B, has the *larger* negative charge?

b. Still holding the wands, you make the two metal balls touch each other for a moment. How would you show that they now have *equal* negative charges?

c. Then you do the following experiment. You keep ball A charged, on its wand. You make ball B touch a water pipe (or anything else connected to earth). Then, still holding the wands, you make balls A and B touch each other.
(i) How would you show that the charges on A and B are now equal?
(ii) How would you show that each of those charges is smaller than before?
(iii) Some charge has disappeared. What do you think has happened to it?

12. Remember that we believe electrons can run freely on the surface of a metal. You have a metal ball on an insulating wand. The ball has a negative charge. Suppose you bring the ball near one end of an *uncharged* scrap of metal held on an insulating stand. Although the scrap of metal had no charge before, there now will be charges on some parts of it. Why?



a. What kind of charge, + or −, would you expect to find on the end of the scrap nearest the ball?

b. What kind of charge would you expect to find on the other end of the scrap? (Remember the scrap started with no charge altogether.)

c. The forces between electric charges are smaller when the charges are farther apart.

Why does the charged ball *attract* the scrap?

d. Ordinary paper is not metal. But even dry paper has enough moisture in it to let electric charges move. It *is* a conductor, though a poor one.

Suppose a friend says 'I don't see why a charged plastic rod (such as a pen) attracts scraps of paper. The paper isn't already charged.'

Write a short explanation for him, in your own words.

WHAT DOES 'CHARGED' MEAN?

13. Suppose a friend hears you talk about things being electrically charged. He asks 'What does "charged" mean?' Write in your own words, TWO replies to him:

a. Just describe some *experimental facts* about charges or charged objects. (These are facts, things you know for certain.)

b. Describe the *picture* you have read about (or have been told), of what electricity does when you make things charged, and when you take charges away. (These are fancies, things we imagine to help our thinking—but we may later verify them. These help us to think, remember, perhaps understand.)

Currents and charges Electric currents were not fully investigated until batteries were invented, about 1800. When currents pass through salt solutions we find there must be two kinds of carrier, positive and negative. But the carriers that boil out of white hot metals are negative electrons and we think it is electrons that do all the current-carrying in a cool metal wire.

For a time, electric currents seemed so different from electric charges at rest that the two were studied separately. It seemed as if there were *four* kinds of electricity:

'Electrostatic' charges: positive and negative
'Moving charges' in currents: positive and negative

But we now know better: you have seen just two kinds, + and −, exerting the same kind of forces whether they were 'electrostatic' charges from 'friction' or 'current' charges from batteries or power supplies.

When charges are at rest, they exert the forces you have just seen.

When charges move there is a current. They still exert forces on each other, but we see some new effects of their motion as well.

Electric forces are the forces that hold atoms and molecules together, the forces that hold solids and liquids together, and the forces that push things apart in collisions—those are all electric forces.

Electric Fields

Just as we talk of a *magnetic* field in the space between two magnets—and perhaps inside a magnet too—we talk of *electric* fields between electric charges.

Faraday used pictures of magnetic fields to help his thinking about magnets and motors and dynamos.

An electric field is quite a different kind of field—do not confuse it with a magnetic field. Yet electric field patterns can be used similarly to picture the way charges exert forces on each other.

And, in the last century, Maxwell was able to predict waves travelling out along the lines of force of electric fields. So our pictures of fields are useful and important, even if their lines are imaginary.

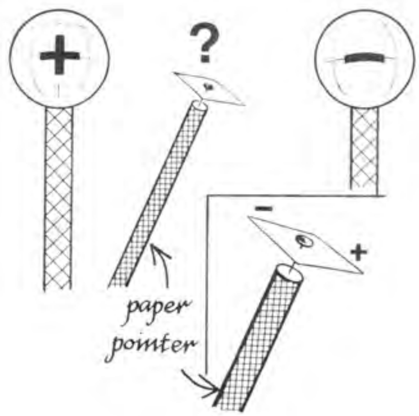
You should see some experiments to show the pattern of an electric field. When you see that pattern, pretend the field lines are elastic like great tubes of rubber spreading out from a charge as Faraday thought of them. Imagine that you hold the charge and shake it to and fro very rapidly. You might imagine waves travelling out along the field lines. Then you are guessing at Maxwell's prediction.

In this century we manufacture such waves: every radio and television station sends them out as broadcasts. Curiously enough they travel with the same speed as light. As Maxwell also predicted, light consists of electromagnetic waves, though of extremely short wavelength.

Electric Field Patterns

Demonstration 119a
The Electric Compass Needle

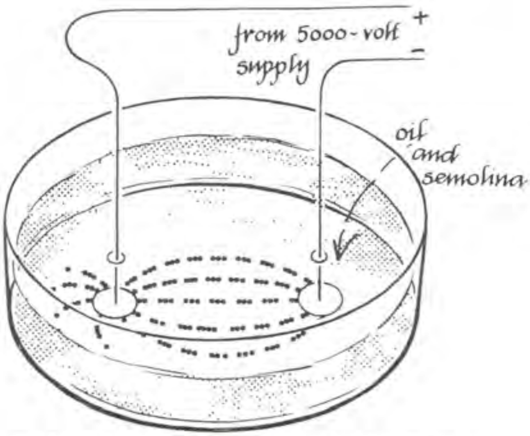
You may see an electric field explored with a little piece of paper on a pivot. In *magnetic* fields, a compass needle, already magnetized, points along the lines of the field pattern. In an *electric* field, the paper pointer is not already charged but it develops + and − charges on its ends. The paper is a little damp so it is not a perfect insulator and the electric field pulls + and − charges to its ends. Then the pointer turns and points along the electric field.



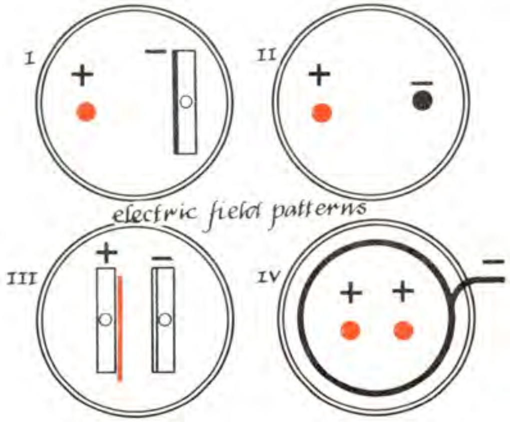
See the paper pointer map the lines of electric field between two balls with + and − charges.

Demonstration 119b
Electric Field Patterns

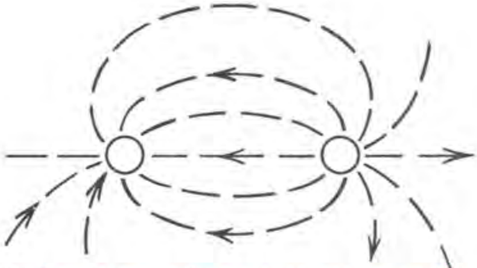
You may see some patterns made visible by semolina grains in oil. The grains play the part played by iron filings in magnetic fields. Iron filings are magnetized temporarily by a magnetic field and act as tiny temporary compass-needles to map the field. Here, each grain of semolina has charges pulled across it by the electric field so that it becomes a temporary field-marker with a + charge on one side of the grain and a − charge on the opposite side.



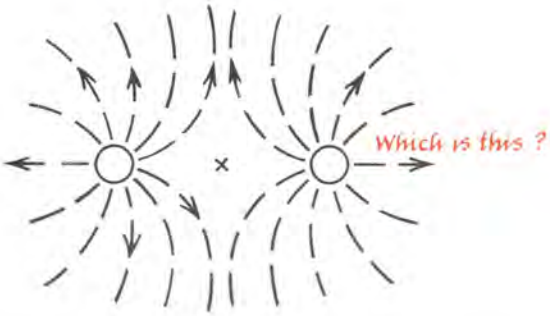
patterns made by grains of semolina

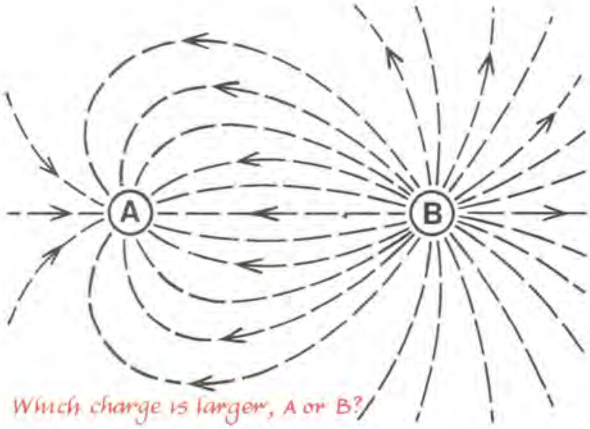


We give large electric charges to metal plates placed in the oil. Then the semolina grains line up to show the pattern of 'lines of electric force'.



Which pattern is this - I, II, III, or IV ?





See the pattern of the field between two round balls, one charged + the other −. *What magnetic field has a pattern like that?*

See the pattern between two parallel plates charged + and −. *Have you ever seen such a pattern among magnetic fields?*

Questions

ELECTRIC FIELDS

14a. A charged rod will pick up uncharged scraps of paper. (A plastic pen that you have rubbed on wool will do that.) How does it manage to pick up *uncharged* scraps? (HINT. Paper is usually slightly moist. So it *is* a conductor, though a poor one.)

b. What happens to the *uncharged* paper needle (the electric compass needle) when you hold it in an electric field?

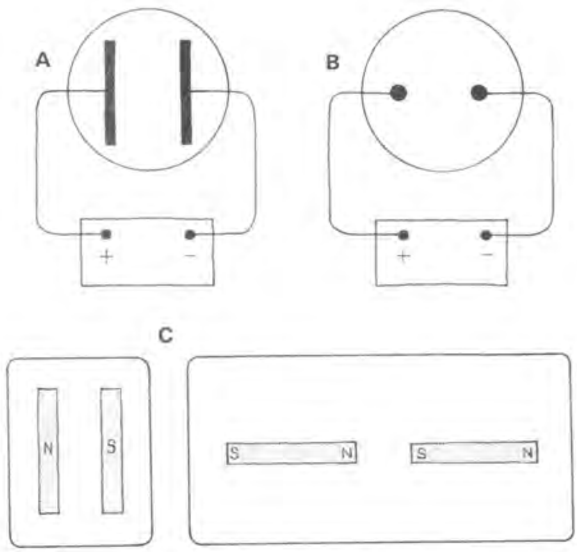
c. We say the electric compass needle points along the lines of the electric field.

Suppose you had a tiny floating balloon, only *1 millimetre in diameter*. If you gave that balloon a + charge and put in an electric field, how would it move?

d. If you gave the tiny balloon a *negative* charge, how would it move in the field?

15. Fig. A shows a dish viewed from above containing two metal plates connected to a power supply. Some light particles float in some liquid in the dish. When the supply is switched on, the particles show the pattern of the electric field between the plates (or electrodes).

a. Copy fig. A and sketch on it the pattern of field lines that you saw.



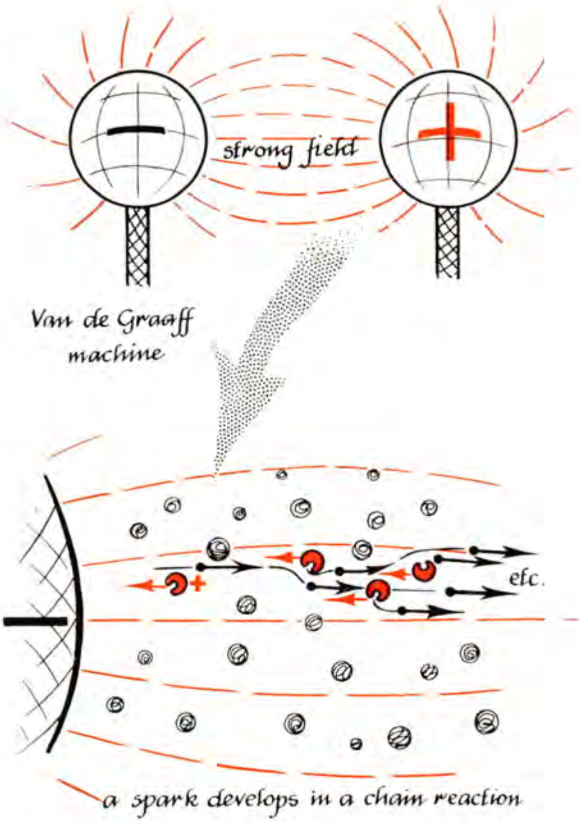
b. What difference does it make if the plates are closer together?

c. Copy fig. B and sketch on it the pattern you saw.

d. These patterns should remind you of magnetic fields. Draw the magnetic fields between N and S in the arrangement of magnets shown in fig. C.

A PUZZLE

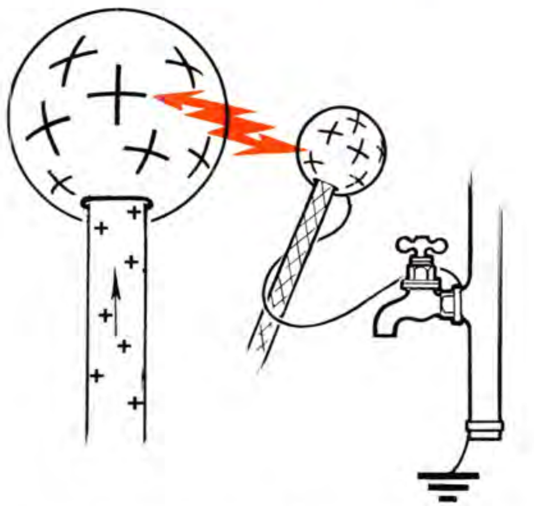
16. *(ADVANCED)* Suppose you *never saw* the pattern of electric field between two charged parallel plates but *did* see the pattern between two metal balls charged + and −. How could you discover the pattern of field between the flat plates JUST BY THINKING, BY USING ARGUMENT AND IMAGINATION? If you can think out the answer, you are being a good theoretical physicist.



Strong electric fields Near large concentrations of charge, the electric field can be very strong. If a charged conductor has sharp points the field is extremely strong near those points. It may be strong enough to tear electrons off molecules nearby. Then there may be sparks.

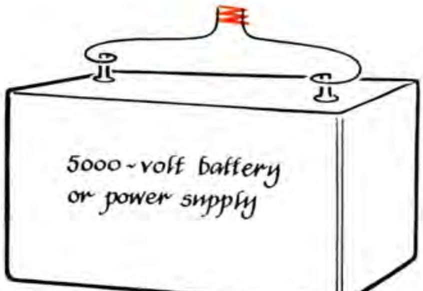
Demonstration 120 Van de Graaff Machine and Electric Sparks

If you see a Van de Graaff machine in action, you will certainly see it making sparks. As it runs, the charge on the big globe may grow so great that its electric field charges the air molecules around it, by dragging or pushing electrons. Then a spark carries the charge away to the earth.



Sparks A spark starts when a strong electric field rips electrons off some surface. Each electron flies away, pulled by the electric field. Soon it smashes into an air molecule. If it has gained enough energy as it accelerated in the intense electric field, it can knock an electron off that molecule. Then there are two electrons that fly onward to make collisions . . . then more . . . and more—a chain reaction. That *is* a spark. You will learn more about sparks in *Pupils' Text 5.*

You may also see the 5000-volt power supply making sparks. You need to bring wires from its two terminals very close together, because with only 5000 volts, the electric field is not strong enough unless it is concentrated in a very short gap.



Using electric fields to prevent smoke pollution If a Van de Graaff machine is available, see a strong electric field driving smoke particles to the sides of a chimney.

Optional Demonstration 121
Clearing Smoke

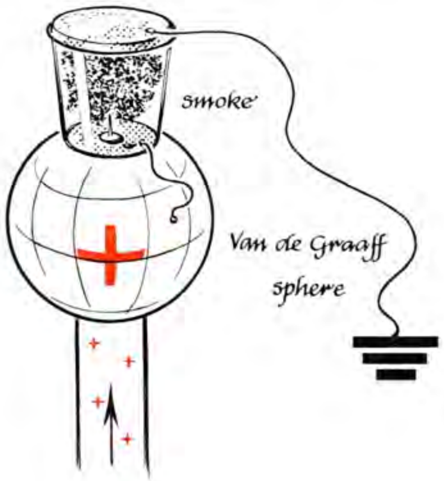
Place a transparent plastic cup on top of the Van de Graaff sphere. Put a piece of metal foil at the bottom of the cup. Run a wire through the bottom to touch the sphere. Place a metal lid on top of the cup and connect that to ground.

Then when the machine is running there will be a strong electric field inside the cup from the bottom to the lid.

a. Jumping particles. Place a few small light balls, coated to make them conducting, inside the cup and run the machine. The balls pick up charges from the bottom of the cup or the lid—whichever they happen to touch—and are driven by the electric field.

This is just a preparatory model; but you might take it as a model of ions moving in an electric field, as in electrolysis.

b. Smoke. Change from the balls to still smaller smoke particles. To make sure the field is intense, place a drawing pin, point upwards, in the cup. Fill the cup with cigarette smoke, put the lid on and run the machine. Watch what happens to the smoke.



This is used in one scheme for clearing smoke in a factory chimney: a wire is strung inside the chimney and a high voltage is applied between the wire and the chimney walls.

Now you know something about forces between electric charges: that + and − charges *attract* each other, + and + *repel*, − and − *repel:* so you should look at the fine-beam tube again.

Electrons in Electric Fields

Demonstration 122
Fine-Beam Tube: Second Look

See the tube in action. Turn on a deflecting electric field between the two little plates just outside the gun muzzle.

If you look at the connections you will find that the lower plate, which is attached to the gun muzzle, is connected to the *negative* of the battery or power supply that charges those plates. The upper plate is connected to the *positive*.

Which way is the stream deflected by the positive and negative charges on the plates (that is, by the electric field between them)?

Now you can decide from that deflection whether the things in the stream carry + charges or − charges.

When you have made that decision, think which way round the voltage must be between the cathode source of electrons and the gun muzzle. *Must the muzzle be connected to the positive of the high voltage or the negative?* Look at the connections to see whether you have argued correctly.

More knowledge of electrons This tube will be used again in Year 5, to make measurements on the electron stream. A magnetic field will deflect the stream into an orbit, and measurements of that will give you more knowledge of electrons. Their speed can be calculated; and you can prove that they must have a tiny mass—far smaller than the mass of an atom.

Questions

STORM

17a. Who first showed that thunder clouds carry electric charges?

b. How did he show that by experiment?

c. Suppose a great thunder cloud is hovering over the Earth. And suppose its water drops carry positive charges. What charges will travel along the Earth until they sit on the ground just under the thunder cloud?

d. In a lightning flash there is a current, between cloud and ground. Which way will the current run, upward or downward, on the whole, if the cloud is charged +?

A QUESTION FOR GUESSING

18. The current in a lightning flash may be as big as a million amps. (It is carried by electrons that have been chipped off air molecules, and by air molecules that have gained or lost electrons.)

What must happen to the surrounding air near the flash? What is thunder? (HINT. How does gunpowder make a noise like thunder?)

CLEARING SMOKE

19. *(Do not answer this unless you have seen a clear demonstration.)*

A friend says, 'How can electricity clear smoke? That sounds like a silly superstition'.

Tell him what you saw and explain how it is done. (Your explanation should include the words conducting particles, electric field, force, and perhaps, charge.)

Then you will know that an electron is only a chip off an atom—but you should not just take that knowledge from a book: you should see in Year 5 the experiments that tell you that.

Atoms and electrons The modern thinking-model of an atom is the *nuclear* atom: a tiny massive core (nucleus) carries a positive electric charge; it is surrounded by negative electrons, far out from it. There are enough electrons to make a neutral atom—their negative charges balance the positive charge on the nucleus. (The number of electrons ranges from few to many: 1 for a hydrogen atom, 2 for helium, . . . 88 for radium . . . just over 100 for new elements manufactured in some nuclear reactors.)

Electrons are fairly easily removed from an atom: knocked off by bombardment, torn off by strong electric fields, boiled off at high temperature, whipped off by ultraviolet light or X-rays, . . . When you collect electric charges by 'friction' you are using local electric fields between atoms to tear electrons off some kinds of atom.

Chemical reactions are mostly made by electron-swapping-and-grouping among atoms—electrical forces at work again.

CHAPTER 9

A FRUITFUL THEORY

A simple theory of magnets to show what a theory can do

A Theory of Magnets

Experiment 123
Breaking a magnet

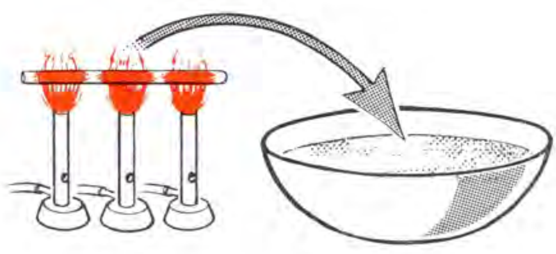
Can you get a magnet with a North pole at one end and no South pole at the other end or anywhere else? Try breaking a long thin magnet in half.

For this experiment you need a thin rod or wire of hardened steel,* so hard that it is brittle and can be snapped with your fingers.

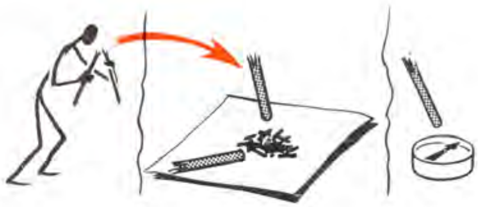
(1) Before you break your magnetized steel rod, try it with iron filings to see where its poles are.

(2) Also bring each end of the rod near a small compass needle so that you know which pole is North-seeking.

(3) Then snap the rod in half and again look for poles. Try further snapping and testing.



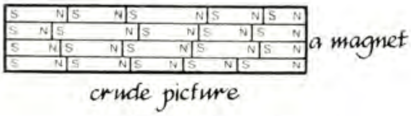
*Carpenters nails (also the soft iron wire used for tying up flowers) make good cores for *electromagnets*, because soft iron can easily be magnetized strongly. But soft iron loses its magnetization equally easily when the magnetizing field is switched off. Steel, which is iron mixed with some carbon, makes a better permanent magnet, particularly if it is very hard. We harden it by first heating it red hot and then quickly cooling it in water or oil.

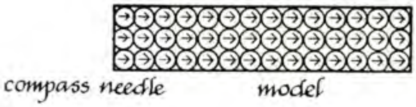


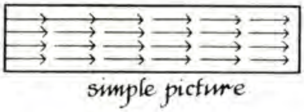
The way your magnet behaves when you break it seems to be true of all magnets. That is different from the way electric charges behave. You can separate positive and negative charges and obtain a positive charge alone on one piece of metal (and a negative charge on another). But magnets seem to have their poles in pairs.

Thinking about magnets: theory Start with that piece of experimental knowledge, and try to make a 'picture', an interesting 'theory', of what a magnet is like inside. Imagine you go on cutting up a magnet into smaller and smaller pieces. If you always found little magnets as the result, you might pretend those little magnets were there already inside the big magnet before you started.

The sketches show an imaginary picture of many small basic magnets inside a big bar of magnetized steel. To sketch the many basic magnets, we need not draw each as a small block as in A. We might draw each basic magnet like a small compass needle, as in B. Simpler still, we show them just by an arrow, as in C.

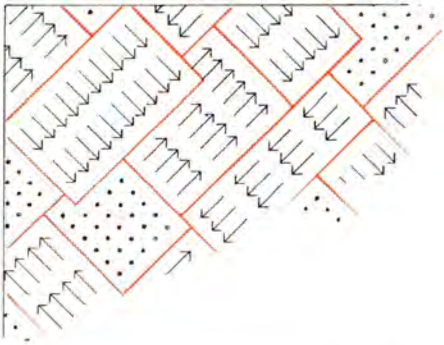




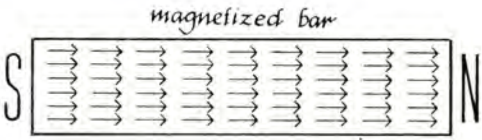


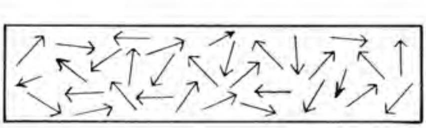
In answering questions, you should use method C.

(In fact scientists have found that there *is* some such structure inside a magnet, though the full story is more complicated. We now know that the basic magnets are not individual atoms of iron, but are large groups of atoms all arranged to point magnetically the same way.



Some of the groups point one way and other groups other ways. Very fine iron filings can be used to show the boundaries between such groups. The atoms in a group are like people in a country, all voting the same way; while people in a neighbouring country vote a different way. We shall just call the groups 'basic magnets'.)

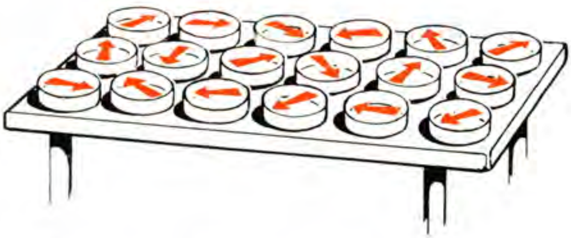




You might imagine the basic magnets to be there inside a bar of steel or iron, *even when it is not magnetized.* They would be disarranged, all pointing in different directions—or rather they would be arranged in small closed chains pointing head to tail. The diagram shows that.

Experiment 124
Giant Model of a Magnet

Get as many small magnetic compasses as you can and make a model of a bar of steel. Try to 'magnetize' the model by waving a large magnet over it. As a better way of magnetizing hold a coil carrying a current near the collection of compass needles.



You can also 'demagnetize' your model. Wave a big magnet near it in all directions and take the big magnet slowly farther and farther away while you continue to wave it.

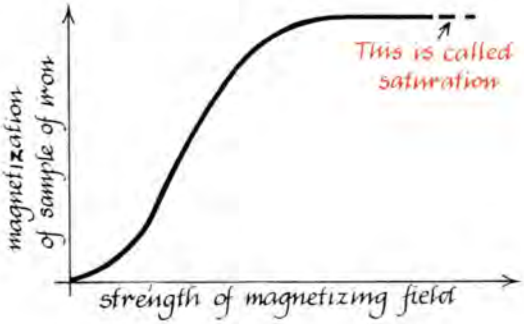
Our theory of basic magnets inside a big magnet is just a picture to help us think about magnetism and discuss experiments with magnets. Having made the picture, we can ask our theory some questions.

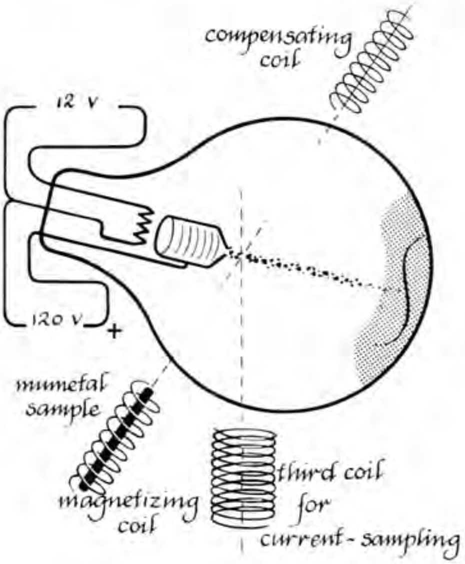
QUESTION A: 'Is there a limit to the strength of a magnet that you can make out of a steel bar? (There is probably no limit to the strength of the electric current that you could drive through a wire, provided you could cool the wire to prevent it melting.) Given a steel bar, *can you make as strong a magnet as you like out of it,* supposing you have a suitable magnetizing coil?'

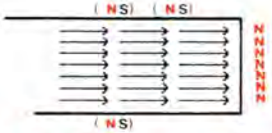
Engineers designing transformers and things like that already know the answer to that question because it is important for their designs.

Demonstration 125 *(OPTIONAL)* Magnetization of Soft Iron

You may see the demonstration sketched. The electron stream will plot a graph to test your answer to Question A. Otherwise, look at the graph of such a test.







What does this theory suggest ?
What happens in real magnets ?

QUESTION B: 'Does the theory tell you what will happen when you cut a magnet in half?'

(Be careful about your answer to that. You should not rejoice when your theory just gives back the experimental fact which you used to construct the picture!)

QUESTION C: 'Suppose we have a bar magnet with poles at the very ends, just on the end faces. What is likely to happen to those poles?'

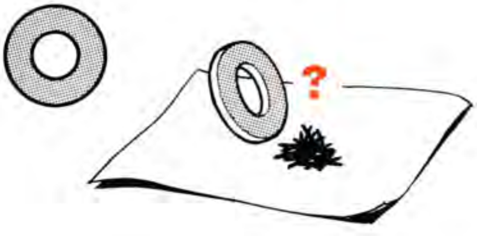
(Remember that, *inside* a magnet, the South pole of a basic magnet has the North pole of the next one just behind it, so the two will practically neutralize each other as regards any outside effect. But those poles will also hold the basic magnets in line. However, at the end face, the North poles have no South poles of basic magnets just in front of them. What do a lot of North poles do to each other?)

OTHER QUESTIONS: 'Can your theory make predictions about the effect of heating or hammering or twisting a magnet?' 'Can your theory suggest the best way to store a lot of bar magnets on a shelf, so that they do not get demagnetized by accident?' 'Can your theory suggest the difference between the basic magnets in soft iron and the basic magnets in hard steel?' 'And if so, suppose you use an alternating current in a coil to magnetize a bar to-and-fro in rapid succession, which of those materials will heat up more?'

Those are examples of using a theory to suggest answers to questions. But it would hardly be worth while to make up the theory just for those questions, because you could find the answers by simple experiments. However the next question shows a use of theory which goes far beyond that.

Experiment 126 Is the Ring Magnetized?

Ask your teacher for a ring of thin steel that is believed to have been magnetized. He will have done special things to it which should have succeeded in magnetizing it. Look for poles; and you will see no clumps of iron filings hanging on the ring when you dip it in filings.



QUESTION D: Then here is the question for theory: 'Is it possible that in any reasonable sense of the word, the ring is magnetized?'

Without a theory, the answer is clear: 'no poles, no magnet', therefore NOT magnetized. Can you offer a new answer with the help of your theory?

If you can, suggest a way of testing your answer to see if the idea is true. Then you should try that test with your own ring.

When theory suggests an answer for the ring, it is helping you to talk about magnets in a way that you couldn't do before. That is theory doing a wonderful job for you by giving a new meaning to the word magnetize, *providing new language for scientific talk.*

Actually, that meaning is very important to electrical engineers, because they use a ring of iron for the core of a transformer; so they are certainly interested in magnetization of this kind.

Progress Questions

MAGNETIC THEORY

1. I think I have magnetized this long thin steel rod. Describe how I can find out with:

a. iron filings,

b. a compass needle,

c. a magnet,

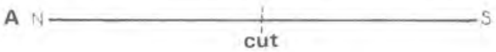
d. anything else you can think of.

2. Suppose you have a magnetized steel rod. Draw sketches to answer these questions.

a. If you snap the rod and drop the pieces in iron filings, what happens?

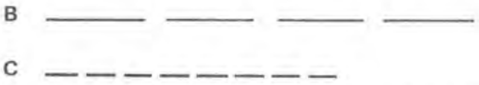
b. If you snap a 'half' rod and drop the quarters in filings, what happens?

3a. Here is a piece of steel wire that has been magnetized (fig. A). It has been cut into two pieces.



Copy this with the two pieces drawn slightly apart and label them N and S.

b. You cut them up again (fig. B), and again (fig. C).

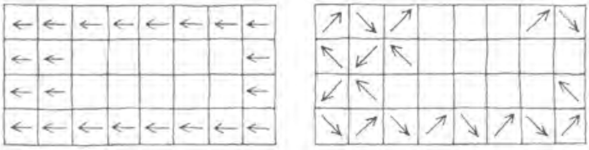


Draw C and D, and label the N and S for each one.

c. Copy and complete. Every time you cut a bar magnet into two, you get two new . . ? . .

4. Scientists put forward a theory that inside a real, big magnet there are lots of tiny magnets, probably too small to see.

a. Copy figs A and B and complete them.



(i) A [/*magnetized*/*unmagnetized*/] piece of steel could be like fig. A.
(ii) A [/*magnetized*/*unmagnetized*/] piece of steel could be like fig. B.

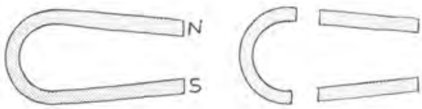
b. Make some drawings to show how this theory fits in with what you find when you cut a magnet in two.

c. You can demagnetize a weak magnet by hammering it. How does this fit in with the theory?

d. You can magnetize a piece of iron wire by putting it inside a long coil of wire, and switching the current on for a moment. Use the theory to explain why this works. (Or what is happening inside the wire.)

5. Can a magnet have just *one* pole, for example only a N pole? Give a reason for your answer.

6. Suppose you could cut a horseshoe magnet into pieces like this:



Copy the diagrams and mark the poles on the cut-up magnet.

7. You are given a ring-shaped piece of steel and told that 'It *is* magnetized'. You drop it in iron filings and cannot find definite poles anywhere.

How could you test whether this ring was really magnetized? (It does not matter if you break the ring up.)

(Your theory of Q.4 should help you. If the steel *is* magnetized then there is some 'lining-up' of basic magnets inside it. Are there ways of lining-up that would not give poles you could find?)

8. *(Have you talked in class about safe storage of magnets? If so, try this question.)*

Fig. A shows a good way to store magnets, so they stay strong.

Use the theory to explain why it works. (You may want to copy the drawing, and draw in some little magnets inside the iron and steel.)

B

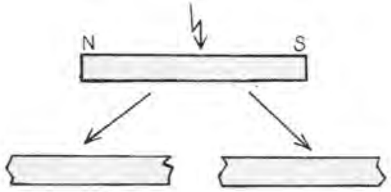
a. How should you store the magnet in fig. B?

b. Why?

Questions

MAGNETIC THEORY

9. A piece of hardened steel rod, or hacksaw blade is magnetized and broken in two, with the result shown in the diagram.

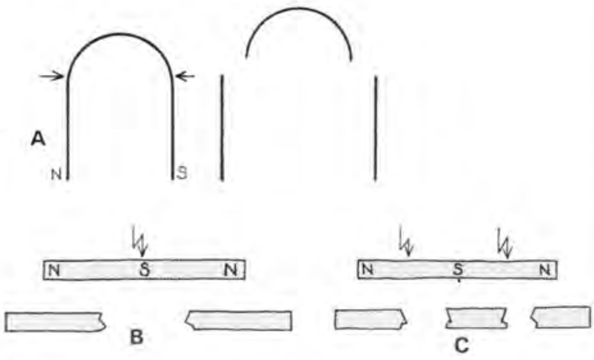


a. How would you show that there are two, and only two, poles on the rod (or hacksaw blade) at the start?

b. Mark the poles you would find on each of the broken pieces.

10. Describe, with diagrams, the theory of 'basic magnets' suggested by what happens in the experiment of Q.9.

11a. Fig. A shows a U-shaped piece of *hardened steel spring* which is magnetized with poles at the ends as shown. It is then cut at places shown by the arrows. Sketch the broken pieces as shown on the right, and mark the poles on your diagram.



b. Fig. B shows a three-pole magnet with one pole in the middle. (It is possible to have such a magnet but the three poles are not equally strong.) That magnet is cut in the middle. Sketch the two parts and show the poles on them.

c. A three-pole magnet is cut into three parts (fig. C). Copy the sketch and label the poles.

12. *(ADVANCED)* Suggest some way of magnetizing a steel bar so that it has poles like those shown in the top part of fig. B of Q.11. There are at least two good ways.

13a. How does the theory you described in Q.10 predict a definite limit to the strength of the strongest bar magnet we can make?

b. If a bar magnet is dipped in iron filings it looks like fig. B, not like fig. A. How does the theory explain this?

c. How does the theory explain the fact that some magnets lose their strength as a result of rough treatment, such as hammering, or heating?

14. A magnet can have two poles, or three, or more. Can it have just *one* pole? Give a reason for your answer.

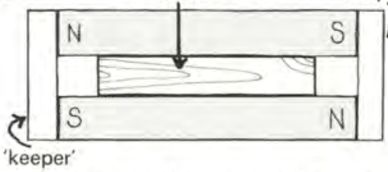
15. Soft iron magnetizes easily, and demagnetizes easily, compared with hardened steel.

a. How can you describe that difference by imagining different behaviour of basic magnets in those two kinds of material?

b. Suppose you placed a sample of *hardened steel* in a coil carrying *alternating* current. The sample would be magnetized, demagnetized, remagnetized, this way . . . that way . . . this way . . . that way . . . etc. It would warm up as the basic magnets changed to-and-fro.
(i) Would you expect a *soft iron* sample to warm up more, less, or the same amount?
(ii) Give a reason for your answer. (HINT. Use your answer to (a).)

16. *(Do not attempt this question unless you have experimented with a ring like this.)*

A ring of thin steel (see the diagram) is stated to be magnetized, but a compass needle placed against it is not deflected at all. Iron filings show nothing.



A

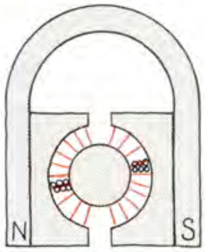
How could you discover whether it was magnetized or not? Answer by saying:
(i) What you would do.
(ii) What would be the result if it were *not* magnetized.
(iii) What would be the result if it were magnetized. Give a diagram for this.

17. *(This asks for a guess from your other physics knowledge.)* How would you magnetize a ring like the one in Q.16?

18. The diagram shows the iron 'shell' of a modern electric motor. The field magnet is an electromagnet. In fact it is the shell itself, with current running in coils C and C′ on the side arms inside. The armature spins in the gap between the side arms.

Copy the sketch. Mark arrows on your copy to show how the basic magnets of the iron must be arranged when the current is flowing in the coils.

19. The diagram shows a horseshoe magnet used in an ammeter. It has soft iron pole-pieces and a central iron core. The moving coil lies in the gap between pole pieces and core.



Copy the sketch. Mark arrows on your copy to show how the basic magnets should be arranged in the pole-pieces and core. (NOTE. The magnetic field in the gap should be radial.)

DOMAINS (OPTIONAL)

20. *(Do not try this question unless you have seen a film of 'magnetic domains' (basic magnets) changing.)*

a. Is each 'basic magnet' of modern magnetic theory a single atom, a molecule, a small group of atoms, a group of a few atoms, a group of many atoms?

b. How does the film enable you to guess the answer to (a)?

DETECTIVES AND THEORY

21. A detective sometimes makes up a 'theory' to guide his work. (Or he may be more modest and call it a 'hunch' or even a 'guess'.)

He does not make up his theory from pure imagination, like a children's story of demons and witches. He draws on clues to suggest his theory and then he uses imagination.

The clues may come from different sources: the detective finds them by crawling along the ground with a magnifying glass; he finds them by noticing something strange about a person, or by overhearing a remark; he reads a rumour in a newspaper; he picks up part of a garbled story from a friend of a bystander; . . .

A good detective then examines his clues and decides whether each is fairly reliable—whether it comes from a fairly trustworthy source. And *then* he makes up his theory.

Even then he is cautious: he checks his theory by looking for new clues and seeing whether they fit with his picture. If new clues fail to fit with it, he changes it, or even throws it away. He tries to use his theory to guide his search. If it grows too complicated and unrealistic to guide him, he throws it away.

Scientists make their theories in much the same way. Look back on the theory of magnetism you have met; and think about it like a detective criticising his own theory.

a. What clues suggested it?

b. How reliable do you think those clues were?

c. What experimental tests checked it or disproved it?

d. *What use is it?*

CHAPTER E
ENERGY AND POWER

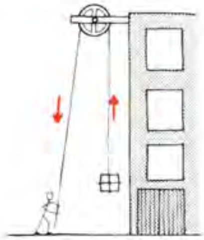
This is an extra chapter, about energy. If you learnt about energy and work in Nuffield Physics Years 1 and 2, or in Combined Science, you need not read this chapter—unless you like it as a reminder. The final section on power is new, but it is 'optional now'.

ENERGY FROM FUEL

Jobs that need fuel Energy is something that is needed for certain useful jobs. Those are the *jobs that use fuel,* such as these:

1. a boy or girl climbing stairs;

2. a builder hauling tiles up to a roof;



3. electric mains lighting lamps or running a heater;

4. a locomotive pulling a train against friction;

5. a car speeding up, then driving against the wind.

All these, and many more, need energy; and they get the energy from fuel.

Fuel. Energy is something *we get from fuel—so we pay for it.* Here are some fuels:

A. COAL OR OIL OR NATURAL GAS. We burn them to make heat and boil water. The boiling water makes steam. The steam drives a steam engine (or turbine).

In a power station the engine drives a dynamo to generate electric power for the mains.

In a factory the engine drives machinery to drill and cut and grind things.

B. FOOD FOR MAN. We call food a fuel, because we get energy from it by burning it—not in a fiery furnace inside us but at body temperature. We get energy for muscles from it; also, heat to keep us warm.

C. FOOD FOR ANIMALS also counts as fuel. In some parts of the World, food enables animals to do mechanical jobs. For example, a horse or a camel may haul up water from a well.

In all parts of the World, food enables animals to grow up and provide 'fuel' for men—milk or meat.

You can think of other things that are fuels, and plenty of things that are not fuels.

Question

1. Which of the following *can* be used as fuel? Wood, bricks, petrol, methylated spirit, sugar, bread, iron nails.

Some things that do not look like fuels can release energy for useful jobs.

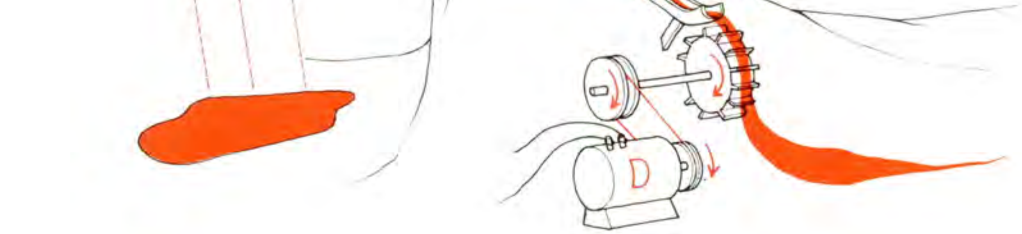
D. WATER IN A HIGH LAKE. That can drive a water wheel or turbine as it runs down to a lower level.

E. WIND. That drives a windmill or the sails of a ship.

Both those energy supplies (D and E) really come from sunshine.

Sunshine warms the earth. The earth warms the air and makes the winds blow.

Sunshine helps water to evaporate from seas and lakes and wet land. Then water vapour is carried up by warm winds to form clouds. And then there is rain which forms rivers and lakes, which may provide water-power.



F. The great supply of energy: sunshine. Sunshine long ago warmed and nourished the living things that produced our stores of coal and oil and natural gas. Sunshine is a great stream of radiation. It enables plants to grow—and thus feeds men and animals.

So we should think of sunshine as original 'free fuel' from the Sun.

How does the Sun get its supply of energy for sunshine?

Inside the Sun, which is a very hot furnace, light atoms are bashed together so violently that their nuclei attract and join up to make heavier atoms.*

In that joining up, which is called *fusion*, a lot of spare 'nuclear energy' is released. That keeps the Sun's furnace hot so that it can pour out a flood of radiation—which *is* sunshine. So, all our benefits from sunshine come from nuclear energy stored in the Sun.

NUCLEAR FUSION

G. Our only other great supply:** Earth's nuclear fuel. We also use nuclear fuel in some power stations. Heavy atoms of uranium (and some others) from rocks release nuclear energy when they break up into lighter atoms. That breaking up is called *fission*.

NUCLEAR FISSION

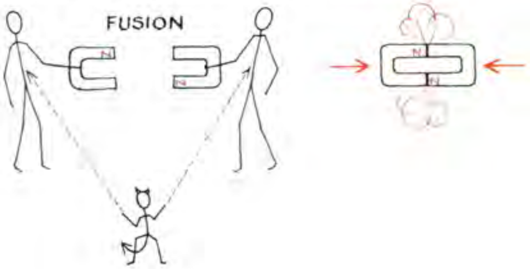
We may also succeed in releasing some nuclear energy by *fusion* of light atoms as in the Sun's supply; but scientists have not yet made a hot enough furnace to keep that going steadily. If they do succeed we can use vast supplies of light atoms from sea-water as nuclear fuel.

But, until then, we have only a few nuclear power plants that use *fission* of uranium etc. Supplies of uranium will run out in a few centuries at most. Meanwhile supplies of coal and oil will only last for a few human generations.

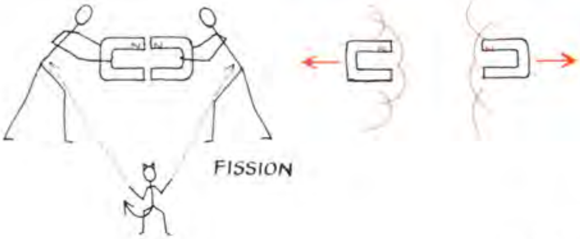
So, if we look into the far future, we see only sunshine from day to day as a steady supply of energy, UNLESS mankind succeeds in using nuclear energy from FUSION.

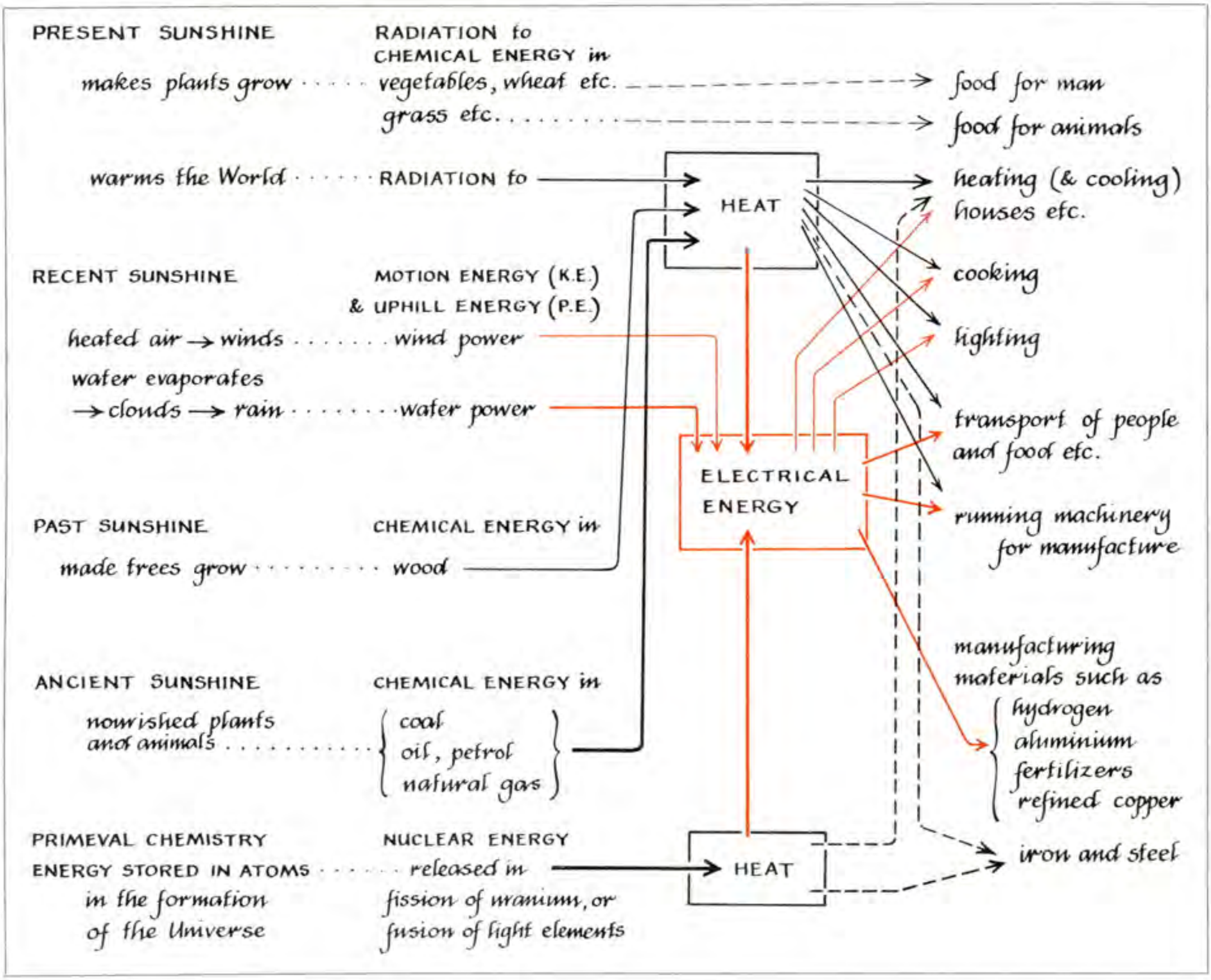
**We also have energy supplies from minerals out of the ground for electric batteries; and from ocean tides, and from volcanic steam. But these are not likely to rank so large.

*As an illustration—though not a proper *nuclear* one—think of two strong magnets placed so that they *attract* each other. Let them pull together with a bang. After that, they are a little warmer. A little of the electromagnetic energy that was locked in the separate magnets' fields has been released as heat.



You could also illustrate *fission* with two large magnets. Think of them, placed so that they *repel*, pushed close together, repelling strongly, and tied together with string. Burn the string, and then let them fly apart, gaining motion energy at the expense of their magnetic fields.





Jobs for Men, Motors, Shelves, Bridges, . . .

Fuel-using jobs are those jobs that *must* use fuel. You cannot haul a load up to the top of a building without using fuel. That fuel may be extra food for a man, oil for a diesel engine, etc.

If you use an electric motor to haul the load up, you don't see any fuel being used. But the motor runs from electric mains; and they are supplied by a power station. Then the power station *must* use some fuel. Its fuel may be coal or oil or water-power; and all those come originally from sunshine.

Stationary jobs Lifting a book from the floor to a shelf needs fuel: it is a fuel-using job. But once the book is on the shelf no more fuel is needed to keep it up there.

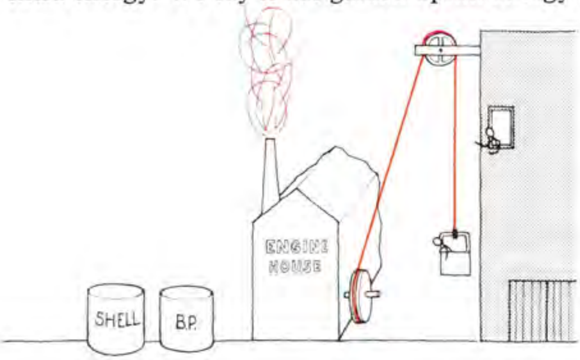
We are glad the shelf does the job of supporting the book; but *the shelf's job does not need a supply of energy.*

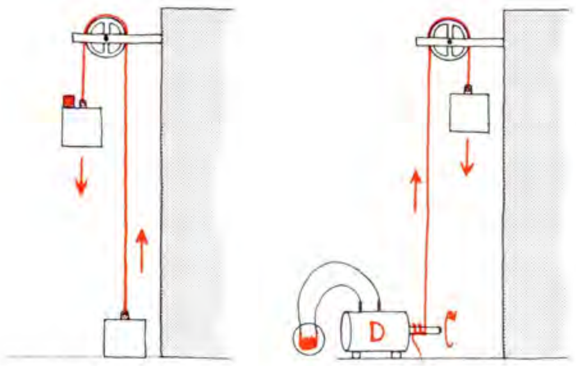
Engineers design machinery to do useful jobs that need fuel, such as car engines, steam engines, electric motors. They also design important things for stationary jobs which do *not* need fuel, things such as shelves, roofs, bridges, towers, concrete buildings. These do not need a supply of energy to keep on doing their stationary job.

Forms of Energy

Let some fuel release some energy. What kind of energy do you gain? What kinds are there?

UP-HILL ENERGY (GRAVITATIONAL POTENTIAL ENERGY). Use fuel to run an engine that raises a load straight up, or drags it up a slope. When it has been raised, the load has somehow stored some extra energy. We say it has gained uphill energy.

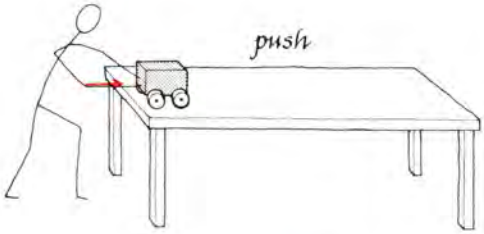


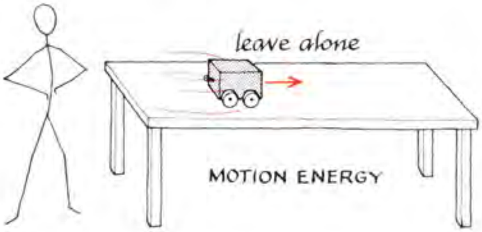


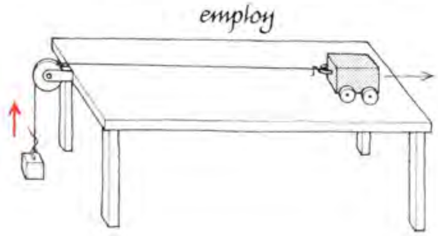
You could get that stored energy back from it by running a cord from it up over a pulley and down to another load which is a little smaller. Let the raised load fall and haul up the other load. Or it could drive a dynamo as it falls.

You yourself gain uphill energy when you walk up stairs or climb a hill.

MOTION ENERGY (KINETIC ENERGY). Use fuel to push or drag a cart and make it go faster. The cart gains motion energy. You could use that motion energy to haul up a load with the help of a rope and a pulley. The cart would slow down and stop, losing its motion energy. The load would be hauled up, gaining uphill energy.

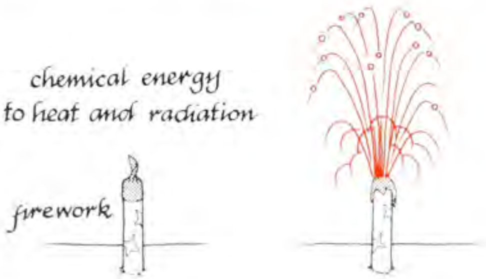




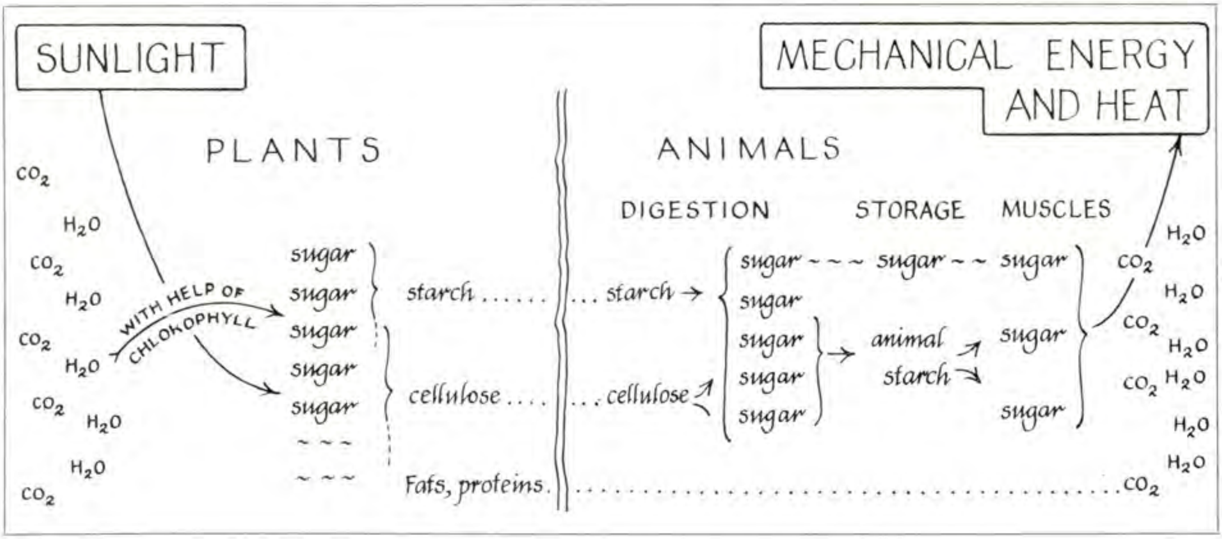


CHEMICAL ENERGY is stored in fuels such as petrol. When petrol explodes in the cylinder of a car engine, it is really burning very rapidly with the help of oxygen from the air. So we ought to say 'petrol & oxygen together' have a store of chemical energy that can be released to produce heat.

Fireworks and explosives contain their own full stock of chemical energy and do not need air.



Chemical energy is also stored in batteries, ready to change to electrical energy. (In a sense, all chemical energy is itself electrical energy, stored in electric fields between atoms and molecules.)



'BREAKFAST ENERGY' is our informal name for the most important chemical energy of all: the energy in your body. It is energy from sunshine: it comes to you in your food. Some of it is held in muscles, ready for use; some is stored as a reserve in fat; some is soon converted to heat to keep you warm.

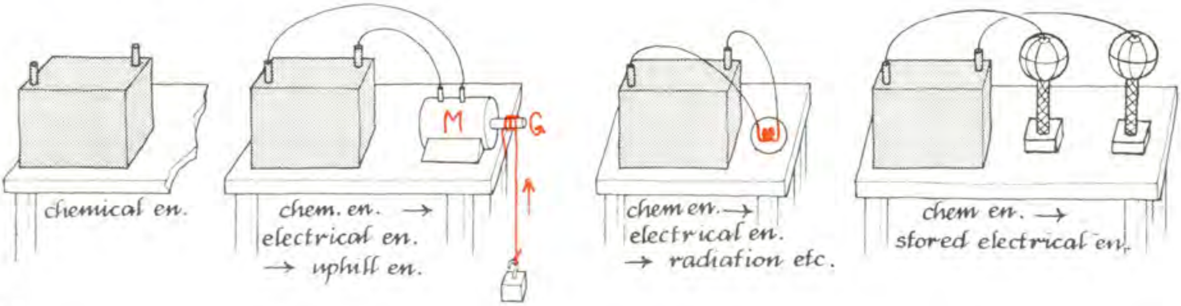
You draw upon 'breakfast energy' when you haul up a load, or climb a staircase, or bicycle against friction and wind resistance.

ELECTRICAL ENERGY is supplied by batteries from chemical energy or by dynamos from mechanical energy. It is carried to all parts of a circuit by electric fields. Or it may be stored by an electric field in a charged capacitor.

HEAT. You will find the full story of HEAT and FORMS OF ENERGY in *Pupils' Text 4*. For now, you should take it for granted that heat is a form of energy. When a fuel burns, its chemical energy is transformed to heat. When a power station uses that heat it goes through several forms *n* molecular energy in steam, mechanical energy in the turbine and *n* electrical energy for the mains.

But when you use some of that electrical energy in your house what form does it end up in?

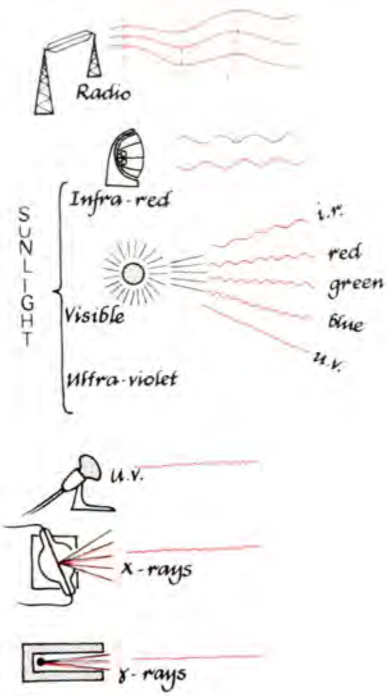
What happens to the 'breakfast energy' you draw upon to walk up a hill and down again? Where has it gone when you have got back?



SPRINGS ENERGY (ELASTIC POTENTIAL ENERGY). When you stretch a spring (or compress it) you store up energy that you can get back. Think of winding a watch or loading a spring gun, an archery bow, a catapult.

RADIATION ENERGY. This is the energy in visible light (so we sometimes call it 'light energy') and in infra-red and ultra-violet radiation.*

(Still farther out in the spectrum, beyond the infra-red radiation we find radio waves which we know are waves in electromagnetic fields. Then we realise that all these forms of radiation are electromagnetic, including those at the other extreme, beyond ultra-violet: X-rays and gamma rays.)



*You may see a demonstration of the energy-flow in different parts of the spectrum of white light. A tiny blackened sensitive thermometer is moved across the spectrum.

MOLECULAR ENERGY. Besides chemical energy, tied up in molecules, energy can be stored when a substance melts or when it evaporates. This energy, sometimes called '*latent heat*', is released when the substance returns to solid or liquid; so its behaviour is simpler than that of chemical energy.

If you want to *feel* this energy, put some crystals of photographic 'hypo' in a test-tube. Add a tiny drop of water. Warm the tube gently till all the crystals have melted. Park the tube with its mouth covered to keep dust out. When it is cool, look at the hypo. If it is still liquid, it is ready to solidify in crystals again, but it needs a start. Drop one small crystal of hypo in. Watch it; and then *feel the tube*.

By accident, you may have felt the molecular energy released when steam condenses to water. A steam burn is far more severe and painful than a boiling-water burn.

NUCLEAR ENERGY. The tiny dense electrically-charged core at the centre of every atom is called the *nucleus*. There is a store of energy associated with the nuclei of the atom, but we cannot usually tap it. A few heavy types of atom are 'radioactive'. Their nuclei are unstable and hurl out tiny chips which fly away with huge motion energy. Those chips are the alpha and beta particles whose tracks you see in a cloud chamber.

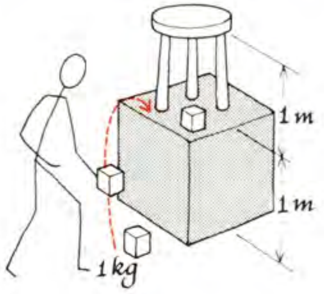
Some atomic nuclei can be made to release some of their energy in 'fission' or in 'fusion'—difficult, violent atomic events over which we now have some control.

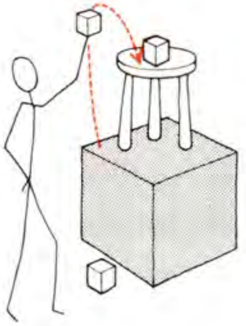
(If you have not seen or done these in an earlier year, you may meet some of them now.)

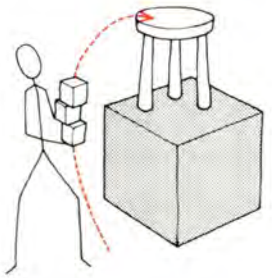
Energy Demonstration E1
Hauling up a Load: a 'Useful Job'

a. Energy transfer FROM chemical energy TO uphill energy

See this done first in six steps, each of 1 kg raised 1 metre; then in a single move of 3 kg raised 2 metres.

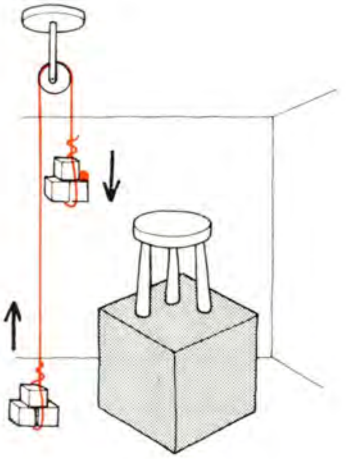






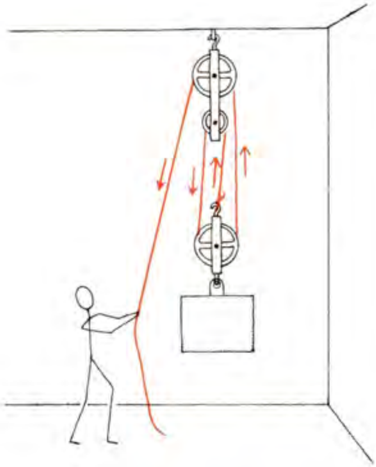
b. Exchanging uphill energy

Let the raised load (3 kg raised 2 metres) haul up another load as it falls. Use a thread and pulley wheel. The 'other load' should be 2 kg; and the raised load must be given a small addition to pay for friction.



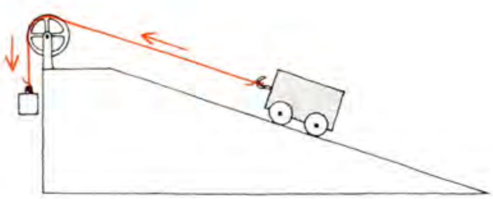
c. Using pulleys

Let a 1-kilogram load pull a cord down to raise a 3-kilogram load with the help of pulleys.



d. Using a ramp

Let a small load haul a larger load up a sloping plank.



In each of the cases (a) (b) (c) (d) think about the energy supplied (the input WORK) and the energy gained (the output WORK).

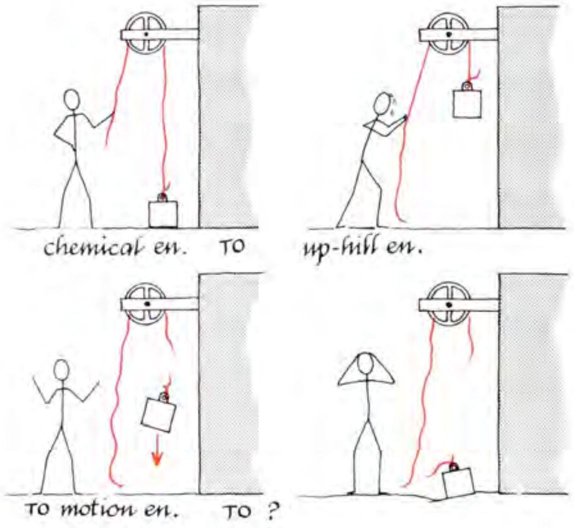
Do you ever get out more energy than you put in?

Energy Experiment E2

a. Losing uphill energy

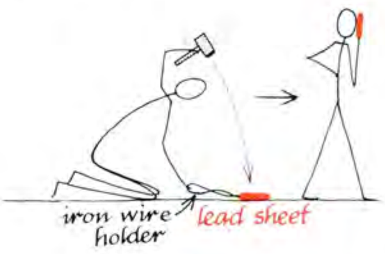
Raise a load high up, so that it has gained uphill energy. Let go. See the uphill energy change to motion energy.

What happens to the motion energy when the load lands on the floor?



b. Hammering lead

Take a *thin* scrap of lead on a wire handle. Put it on a hard floor. Hammer it violently. Then hold it against your cheek.



Transfers of energy You have seen energy change from one form to another. Or sometimes it just moves from one place to another. We call *any* such change a TRANSFER of energy—like a transfer of cash from coins to the same amount in notes, or a transfer of cash from one pocket to another.

Energy 'Circus'

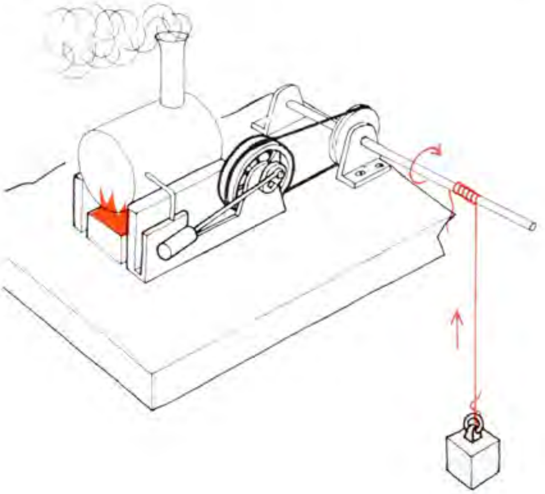
This is a set of experiments to show different energy changes. Some need a steam engine, some need a small dynamo, etc. If you missed them in earlier years, you may be able to have some of them now if the apparatus is available.

Energy Experiments E3
'Circus' of Energy-transfers

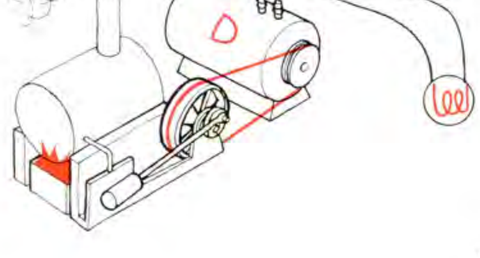
a. Light a match.

b. Run a Bunsen burner. Let it heat a piece of metal red hot so that the metal gives out radiation.

c. Run a model steam engine, and let it haul up a load.



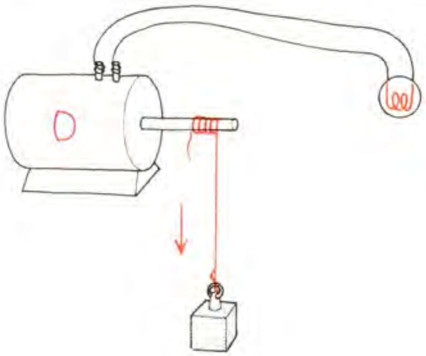
d. Run a model steam engine and let it drive a dynamo which lights a small electric lamp.



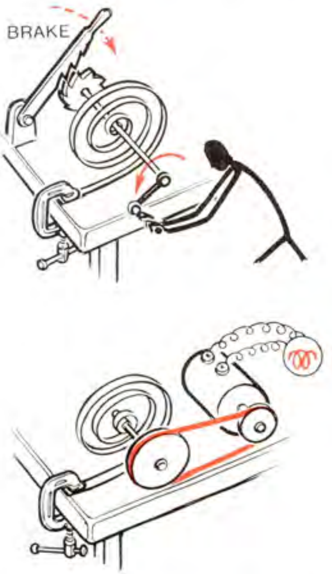
e. Let a battery light a lamp.

f. Let a battery drive a small electric motor which hauls up a load.

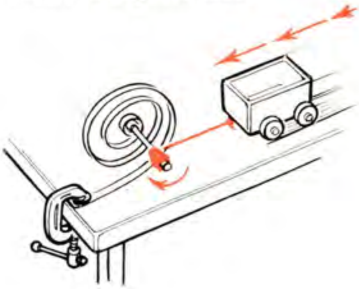
g. Let a falling load drive a dynamo which lights a lamp.



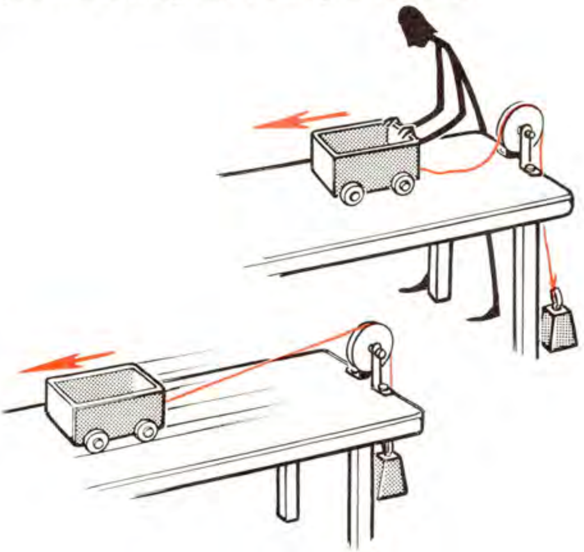
h. Wind up a big clock-spring. Then let it drive a dynamo.



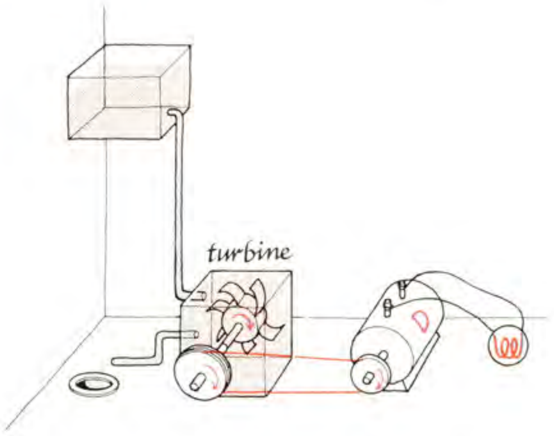
i. Wind up a clock-spring. Then let it pull a cart faster and faster along the table.



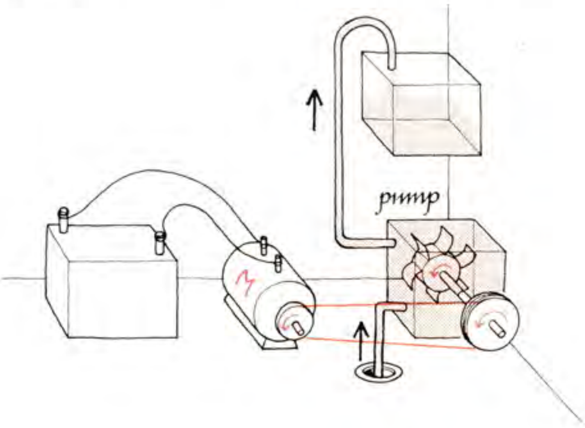
j. Let a moving cart haul up a small load.



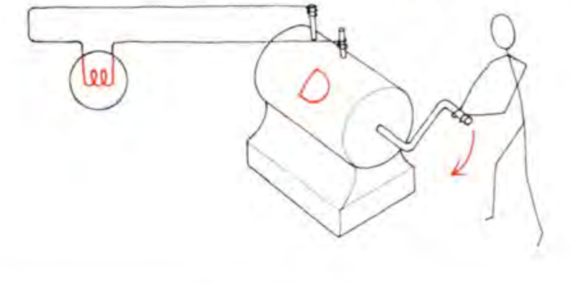
k. Let a water turbine (supplied from a high tank) drive a dynamo.



l. Let an electric motor drive a pump to raise water.



m. Drive a large model dynamo by hand; and feel the effect of making the dynamo supply lamps.



Questions

2. You hammer a small piece of lead, with smashing blows: bang, bang, bang, . . .

a. What kind of energy do *you* lose?

b. What kind of energy does *the lead* gain?

c. How do you know the lead gains that kind of energy?

3. Kick a football. It goes up through the air and just manages to reach a roof, high up. It stops on the roof.

Copy and complete this description of the energy-changes for the ball:

FROM your chemical energy *TO* . . ? . . energy just after the kick; *TO* . . ? . . energy on the roof.

4. You climb three flights of stairs carrying a heavy basket of groceries.

a. Where does the energy to get the basket upstairs come from?

b. What kind of energy supplies that hauling-up?

c. What kind of extra energy does the basket gain?

d. Suppose you stumble at the top of the stairs, and let the basket fall all the way down.

What kind of extra energy does the basket (and its groceries) have instead, *after* the smash?

5. *(Do not try this question unless you saw or did some parts of the 'Energy circus' Experiment E.3.)*

Describe the energy-changes in the experiment of each part of Experiment E.3, that you saw or did. Give descriptions like Examples A, B, C below.

EXAMPLE A. Suppose you set light to a firework, the change would be:

FROM chemical energy in firework *TO* heat and radiation in the flame

EXAMPLE B. Suppose you hold a balloon filled with water just outside a window high above the ground. You let go. You find that the water in the mess on the pavement below is a trifle warmer. Describe the energy-changes of the water.

FROM uphill energy upstairs *TO* motion energy as it falls *TO* heat on the ground

EXAMPLE C. Suppose you used a steam engine run by a Bunsen burner to drive a dynamo, to light a small electric lamp. The changes would form a chain, like this:

FROM chemical energy in the gas and air *TO* heat
[*TO* molecular energy in the steam *TO* mechanical energy in flywheel]
TO electrical energy in dynamo and circuit *TO* heat in lamp
TO radiation from lamp and some heat in air

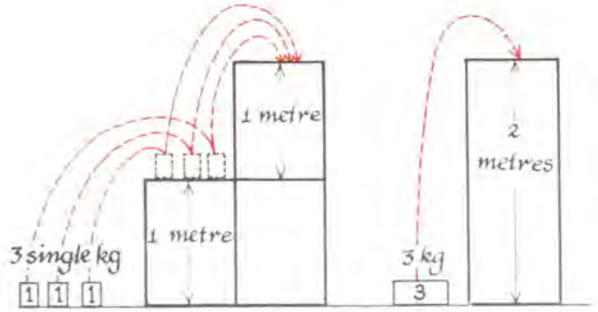
(NOTE. You might leave out the stages in [ ]. MOLECULAR ENERGY in steam may seem rather strange. MECHANICAL ENERGY in the flywheel stays the same. It is constantly being supplied by the engine and taken away by the dynamo.)

The Price of Energy

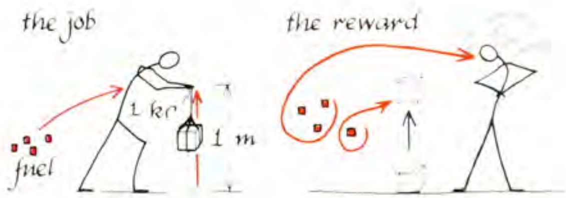
Energy is something you pay for. Suppose you want to haul 3 kilograms up 2 metres. You could do it in separate stages:

(1) haul 1 kg up 1 metre (using some fuel).
(2) haul that kg up 1 metre more (using some fuel).
(3), (4) do the same for the second kilogram.
(5), (6) do the same for the third kilogram.

Each of those six haulage jobs raises a load of 1 kilogram one metre. You could make them all equally easy by using a rope and a pulley.

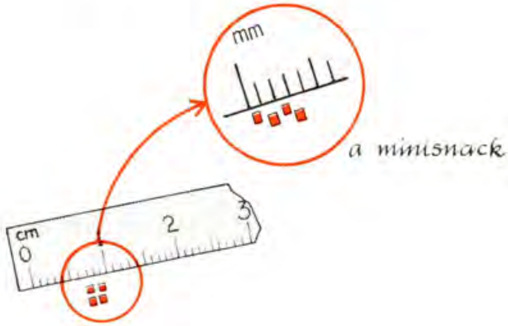


Instead of 6 single haulage jobs, you could reach the same result in one go: haul 3 kg straight up 2 metres. Experiments show that the cost in fuel is the same whether you do the job in 6 stages or all in one go.

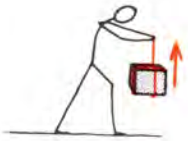


You are 25% efficient Your muscles draw on more chemical energy than they need for the job. At the same time as doing a useful job they let a lot of energy turn into heat. You can't help getting hot when you use your muscles.

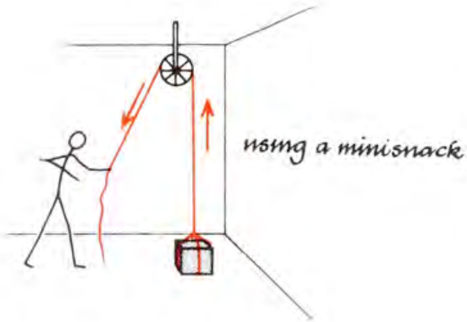
Re-fuelling with a minisnack Suppose you raise 1 kilogram 1 metre and then want to replace the chemical energy your muscles have taken for that. You could re-fuel your body by eating four small crystals of sugar.

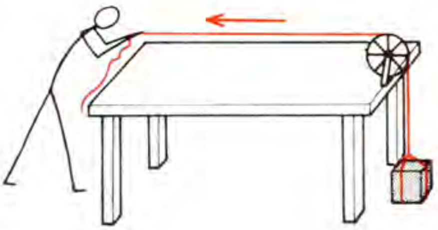


Put a pinch of ordinary granulated sugar on the table. Choose 4 of the smaller crystals and eat them. We call that one mini-snack. That will re-pay you for raising 1 kilogram 1 metre. As you digest them, one crystal will pay for the useful mechanical job, three crystals will pay for the waste heat.



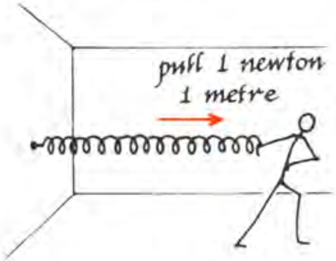
Many ways to spend a minisnack You need not pull *upward*. *You can use a string and a pulley*. Put the kilogram on the floor, attach a string and run the string over a pulley high above it. Then you can pull *downward* and raise the kilogram one metre. That will still cost one minisnack.



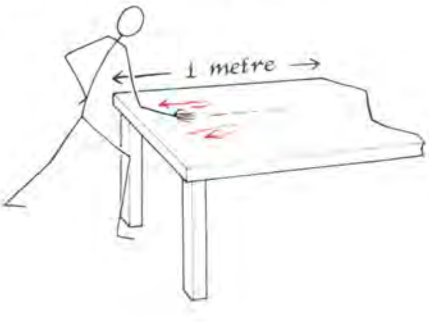


Or you can hold the string out from the pulley and pull horizontally to raise the kilogram; still, one minisnack.

You need not raise a kilogram at all. If you pull with the *same force* for the same distance, one metre, you can stretch a long spring, or drive a small dynamo, or drag a cart along, still at a cost of one minisnack each time.



You could even push your hands for 1 metre along a rough table, so rough that you had to shove with the force you use to lift a kilogram, and it would still cost one minisnack. This time *all* output would go into heat, $\frac{1}{4}$ in your hand and the table, $\frac{3}{4}$ in the rest of your body.



It is the same demand for your body (even if you use different muscles) when you pull with *that force* for *that distance*. It is FORCE × DISTANCE that measures the *useful* output of set energy and a corresponding amount of chemical change in your body measures the supply.

How many minisnacks for a penny? One minisnack is 4 small crystals of sugar. That is about $2\frac{1}{2}$ milligrams, or 0.0000025 kilogram. Find out how much $\frac{1}{2}$ kilogram of sugar costs now. Then calculate how many minisnacks you can buy for a penny.

Example. Suppose $\frac{1}{2}$ kg of sugar costs 20p.

$\frac{1}{2}$ kg is 500 grams. If 20p buy 500 grams, 1p buys $\frac{500}{20}$ grams, or 25 grams.

25 grams for 1p is 25 000 milligrams for 1p.

To calculate how many minisnacks you would get for 1p divide by 2.5 milligrams, which is one minisnack:

$$\frac{25\,000 \text{ milligrams}}{2.5 \text{ milligrams}} = 10\,000$$

At that price, you would get 10 000 minisnacks for 1 penny.

You might buy petrol instead. It could not feed you, but it could run a car. A car engine has about the same efficiency—25% at best. Experiments on burning a sample of petrol show that a minisnack for a car would be a tiny drop of petrol about $1\frac{1}{2}$ millimetres in diameter.

Suppose you buy 9 litres of petrol ($\approx$ 2 gallons). You could calculate how many $1\frac{1}{2}$ millimetre drops there are in 9 litres: the answer is 5 million drops.

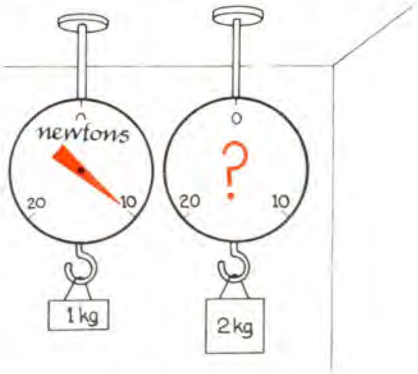
Buy 9 litres of petrol and you have 5 000 000 minisnacks. Find out how much 9 litres ($\approx$ 2 gallons) of petrol cost now, and calculate how many minisnacks the car engine gets for a penny.

Energy Experiment E4
Force in newtons; energy in newton · metres

a. See the size of a newton

Set up a spring balance marked in newtons. The balance measures the force pulling its hook. A newton is the unit in which all forces are measured in science.

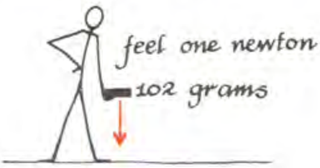
Hang a kilogram on the hook of the balance. See how much that load pulls the hook. That is also the pull of the Earth on the kilogram.



Hang 2 kilograms on the hook. How much does the Earth pull *each* kilogram of those two?

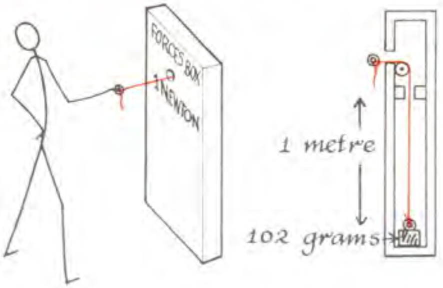
b. Feel a newton

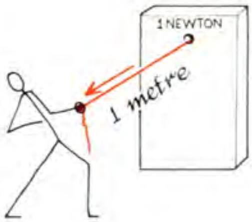
Hold $\frac{1}{10}$ kilogram (100 grams) in your hand. It presses down on your hand with a force of about 1 newton. That is because the Earth pulls it with a force of about 1 newton.

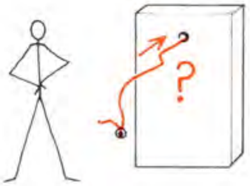


c. Move a force of 1 newton

Look at a *forces box*. It has a ring on a string







which comes out of a hole marked *1 newton*. Pull that ring. You are pulling it out with a force of 1 newton.

d. Make an energy-transfer of 1 newton · metre

Hold the '1 newton' ring of the forces box. Pull it out 1 metre. You have transferred 1 newton · metre of energy *FROM* your 'breakfast energy' *TO* uphill energy of the load which is hidden in the box.

If you let the string go back in gently and slowly, you will get that energy back in your arm. But it will not turn back into chemical energy. It will turn into heat there. If you just let go of the string instead, the load inside falls faster and faster, gaining motion energy; but what happens when the load gets to the bottom?

WORK
FORCE x DISTANCE writes the bill

Adding up the bill You have seen the pull of the Earth on a kilogram measured on a force-meter. It is (almost) 10 newtons. The Earth pulls *each kilogram of ANY material* with a downward force of 10 newtons.

Suppose you haul 1 kilogram up 1 metre (at a cost of 1 minisnack). You pull up with a force of 10 newtons, against the Earth's pull. You pull 10 newtons through a distance 1 metre upward. We multiply 10 newtons by 1 metre and call that WORK. We calculate WORK by this rule:

multiply the FORCE by the DISTANCE THE FORCE MOVES

For hauling 1 kg up 1 metre, the work is:
(10 newtons) × (1 metre) or 10 newton · metres

Suppose you haul 3 kilograms up 2 metres (at a cost of 6 minisnacks). If you do it in 6 stages, each of 1 kg raised 1 metre, the work is:
6 lots of (10 newtons) × (1 metre)
or 60 newton · metres

If you haul 3 kilograms up 2 metres in one go, the work is:
(30 newtons) × (2 metres)
or 60 newton · metres

The WORK is 60 newton · metres, whether you do the job in six stages or all in one go. The separate lots of WORK for stages just add up—and so do the minisnacks for re-fuelling.

The WORK measures *how much the energy you transfer* from one form to another. In this case it is 60 newton · metres *FROM* chemical energy *TO* uphill energy.

Other Examples

(i) Suppose 3 boys and 2 girls push a car along a level road to get it started. They push with a total push of 500 newtons and shove the car along 8 metres. The WORK is an energy-transfer of 4000 newton · metres *FROM* their chemical energy *TO* the car's motion energy (and some waste heat in the wheels). How many minisnacks do the five of them deserve?

(ii) Suppose a man wrecked on a desert island drives an emergency dynamo to make a radio call for help.

He pushes the handle of the dynamo with a force 100 newtons. He pushes it round and round for a toal distance 50 metres. (You must imagine that the round-and-round motion is straightened out into one long line of 50 metres.)

His WORK is 5000 newton · metres. That is the transfer of energy *FROM* his chemical energy *TO* electrical energy (+ some waste heat in the dynamo).

He needs 500 minisnacks of sugar (a very small sugar cube or half a teaspoonful of honey that he finds on the island)—otherwise he will have to draw on his reserve store of fat.

Energy Experiment E5
Climbing Stairs

Before you start, find out how much you weigh in kilograms. Then calculate the pull of the Earth on you, in newtons.

(Remember that the Earth pulls with a force of 10 newtons on each kilogram.)

Estimate the vertical height of the longest staircase you have available.

Walk or run up the staircase.

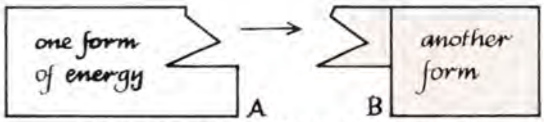
Calculate your *useful* WORK or energy-transfer. That is:
(pull of the Earth on you) × (height of staircase)
in newtons in metres

Add three times that, for unavoidable waste heat, to find your *total* transfer from 'breakfast energy', in newton · metres.

ENERGY NEVER GETS LOST OR CREATED

If you go shopping with coins in your pocket you may give some coins to a shop or to a bus conductor; but you never expect to find some coins *vanish* from your pocket—just disappear to nowhere. Nor do you expect *extra coins to appear* in your pocket from nowhere. Coins don't evaporate; coins don't have kittens.

Energy is like that. It can change from one form to another. It can move from one place to another. But we never find energy disappearing to nowhere, or appearing from nowhere. We can't manufacture energy.* We can only move energy and change its form.



ENERGY ONLY MAKES EXCHANGES

*Beware of trying to 'prove' this by the remark 'You can't get something for nothing.' That would be a swindle, because there are lots of things of which you *can* get something for almost nothing. We can only apply the remark to energy *after* we have decided, with the help of much experimenting, that we cannot change the total of energy. So that is only an 'after remark' like saying 'I always knew he was guilty'—and it would be a wrong to say that before the trial.

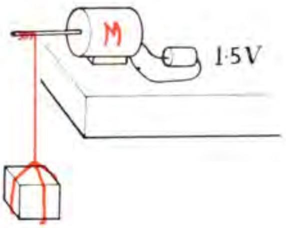
It took scientists a long time to make quite sure of that; and you will find the story of how they did so in *Pupils' Text 4*.

So you should be careful not to say that energy gets lost or made. Say it is *transferred*. Always say WORK is the ENERGY-TRANSFER *FROM* one form *TO* another. And always give the names of the two forms.

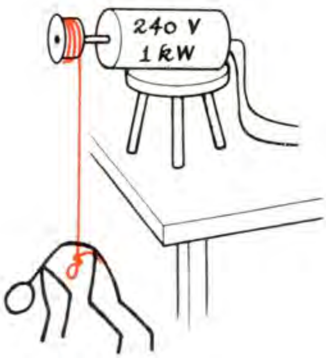
POWER

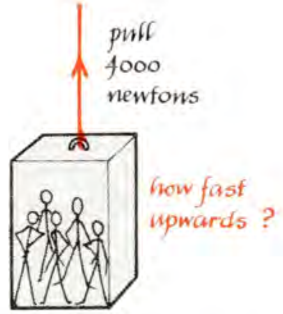
How quickly? You could haul a load of a tonne from floor to ceiling. You would need some pulleys and rope; but you would also need a *a lot of time*.

A toy electric motor, running on one cell, can haul a load of a kilogram up one metre—but it will take at least 20 seconds to do that. It could haul *you* up from floor to table but it would need some worm gear or several pulleys; *and* it would need *a lot of time*—at least a quarter of an hour.



But a large electric motor taking 5 amps from 240-volt mains could haul you up from floor to table in 1 second. (You know that kind of trip is possible because you have made it on a larger scale, in a lift!)





The time the energy-transfer takes is often important. A lift should not take many minutes to haul up its load of people. A ship's propeller must not take a whole day to drive it through the water from England to France. You don't want to take half an hour to walk upstairs.

In all those 'jobs' energy is transferred *FROM* fuel or electric supply *TO* some other form. Given some measurements you could calculate how much energy is transferred, the WORK.

If you yourself are to do the job you could calculate how many minisnacks you would need.

But as well as knowing *how much* energy is transferred we often need to know *how quickly* that is done. We want to know how much energy is transferred *in every second*. That is called POWER.

POWER is *rate of* transfer* or energy

$$\text{or } \frac{\text{energy transferred}}{\text{time taken for the transfer}}$$

It is also FORCE × SPEED.

---

*You meet the idea of 'rate of' in the money a person earns. When you earn your living, you don't just want to know how much money you will be paid, but the rate of pay. You want to know the wage or salary in pounds *per week*. That tells you *how quickly* the money flows into your pocket.

$$\text{RATE OF PAY} = \frac{\text{MONEY YOU EARN}}{\text{TIME TAKEN TO EARN IT}}$$

That is, your wage or salary.

For example: if you earn £100 in 5 weeks, your RATE OF PAY is:

$$\frac{£100}{5 \text{ weeks}} \text{ or } £20 \text{ per week.}$$

If you earned £100 in 50 weeks your RATE OF PAY would be only £2 a week.

Examples

(1) Suppose you use a rope and pulleys to haul a 70-kilogram bucket of water up from a well 10 metres deep. How much is the WORK, the transfer *FROM* your chemical energy *TO* uphill energy of the bucket of water? The Earth pulls the bucket with a force 10 newtons *on each kilogram*, 700 newtons altogether.

The useful WORK is (700 newtons) × (10 metres) transfer of energy *FROM* your chemical energy *TO* uphill energy.

Suppose you take 50 seconds to do that hauling.

$$\text{Your useful POWER} = \frac{\text{ENERGY TRANSFER}}{\text{TIME TAKEN}}$$
$$= \frac{700 \text{ newtons} \times 10 \text{ metres}}{50 \text{ seconds}}$$
$$= \frac{7000 \text{ newton}\cdot\text{metres}}{50 \text{ seconds}}$$
$$= 140 \text{ newton}\cdot\text{metres per second}$$

We give *newton·metre per second* the name *watt*, for short. Then your useful power would be 140 watts. (That is about 0.2 horse-power in the old units for power.)

Your muscles would also generate waste heat at three times that rate. So your TOTAL POWER (total rate of transfer) would be $(140) + (3 \times 140)$ or 560 watts. That would be a rate of transfer of:

140 watts *FROM* chemical energy *TO* useful uphill energy
and 420 watts *FROM* chemical energy *TO* waste heat.

(2) Suppose instead of hauling that huge bucket of water up you haul yourself up by climbing the stairs. Suppose you weigh 70 kilograms (≈ 11 stone). You haul 70 kilograms up 10 metres (3 flights of stairs) in 50 seconds.* Your *useful* power is the same as before:

$$\frac{700 \text{ newtons} \times 10 \text{ metres}}{50 \text{ seconds}} \text{ or } 140 \text{ watts}$$

You must also develop waste heat at three times that rate, 420 watts.

Again, your *total* power is 560 watts.

Power Experiment P1
Climbing stairs

Walk or run up the longest staircase, and let a partner time your climb.

Calculate your useful energy-transfer. Add three times that for waste heat.

Then calculate your total POWER, your total rate of transfer, *FROM* 'breakfast energy' *TO* useful uphill energy and heat.

The traditional horse of one horse-power was supposed to deliver *useful* power at 746 newton·metres per second, or 746 watts. What is *your* HORSE-POWER, during the short time of your climb?)

Power Experiment P2
Power for an Electric Lamp *(OPTIONAL NOW)*

If you know how to use a voltmeter, measure the voltage and current for a small lamp.

Calculate the power for the lamp. That is the rate of energy transfer *FROM* electric energy *TO* heat and light in the lamp. To calculate that POWER, multiply CURRENT through the lamp by VOLTAGE across it.

*Of course you could run up 3 flights of stairs in much less than 50 seconds. Try it if you like—provided your heart is strong and healthy. But you could not keep up a larger power output for long.

If a builder employed you to haul up loads of tiles all day you would not average more than 70 watts of useful power. Even then, for a 8-hour working day you would need 200 000 mini-snacks of extra sugar or some better equivalent. That would be about $\frac{1}{2}$ kilogram of sugar per day—an unsuitable diet, but you would need some form of extra food which would provide that much energy to keep working day after day.

In some parts of the World, where human power is used like that for building, a man's diet is not enough to provide the energy. He cannot go on working all day and every day. He cannot succeed by grim determination, just trying hard. The *output* of useful energy must have the energy-*intake*.

Questions

ENERGY AND POWER

6. You climb three flights of stairs carrying a heavy basket of groceries. How much extra energy does that cost you because you haul the basket up? The staircase is 10 metres high. The basket and its groceries are a load of 10 kilograms. So the Earth pulls the basket with a force 100 newtons.

a. How much energy does the basket gain (in newton · metres)?

b. How many extra minisnacks do you need, *because of the basket?*

7. A 60-kilogram pupil climbs a hill 600 metres high in one hour

a. *(i)* His weight, the pull of the Earth on him, is . . ? . . newtons.
(ii) The 'useful' WORK of his climb is . . ? . . newton · metres.
(iii) For re-fuelling after that he needs . . ? . . minisnacks.
(iv) How many grams of sugar is that? (There are 400 minisnacks in 1 gram of sugar).

b. *(i)* His 'useful' POWER during the climb is . . ? . . newton · metres per second.
(ii) How many *watts* is that?
(iii) How many horse-power is that? (1 horse-power is about 746 watts.)

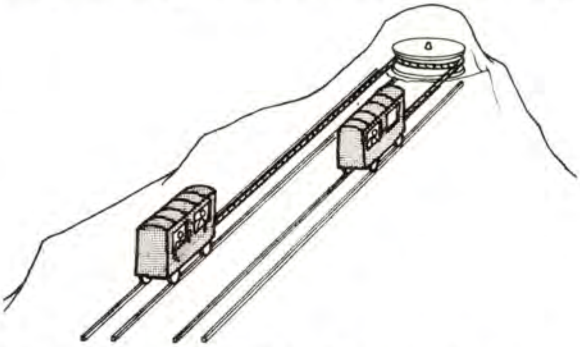
8. Suppose the hill in Q.7 has a giant slide all the way down from top to bottom. The 60-kilogram pupil sits on the slide at the top and coasts down, without gaining much speed.

a. The extra energy that he has at the top is transferred to another form. Describe the transfer. His . . ? . . energy changes to . . ? . . on the way down.

b. The amount of energy he loses is . . ? . . *newton · metres.*

c. Sugar can be burned. How many minisnacks would have to be *burned* to release just as much energy as the pupil loses on the slide?

d. Look back at your answer to a*(iii)* in *Q.7.* If your answer to (c) in *this* question is the same as that, it is wrong. It should be only $\frac{1}{4}$ as big. Why?



9. *(OPTIONAL NOW)* A cable railway takes people up a mountain on steep rails. It has two cars connected by a steel rope which runs round a pulley at the top. One car goes down while the other goes up. They pass at the mid-way point.

On a fine morning, 12 people crowd into the 'up' car and only 2 people take the 'down' car. Each takes some luggage with him, making a total of 100 kilograms for each person and his luggage. The mountain is 1000 metres high and the cars take 500 seconds for the trip. Estimate the POWER of the electric motor.

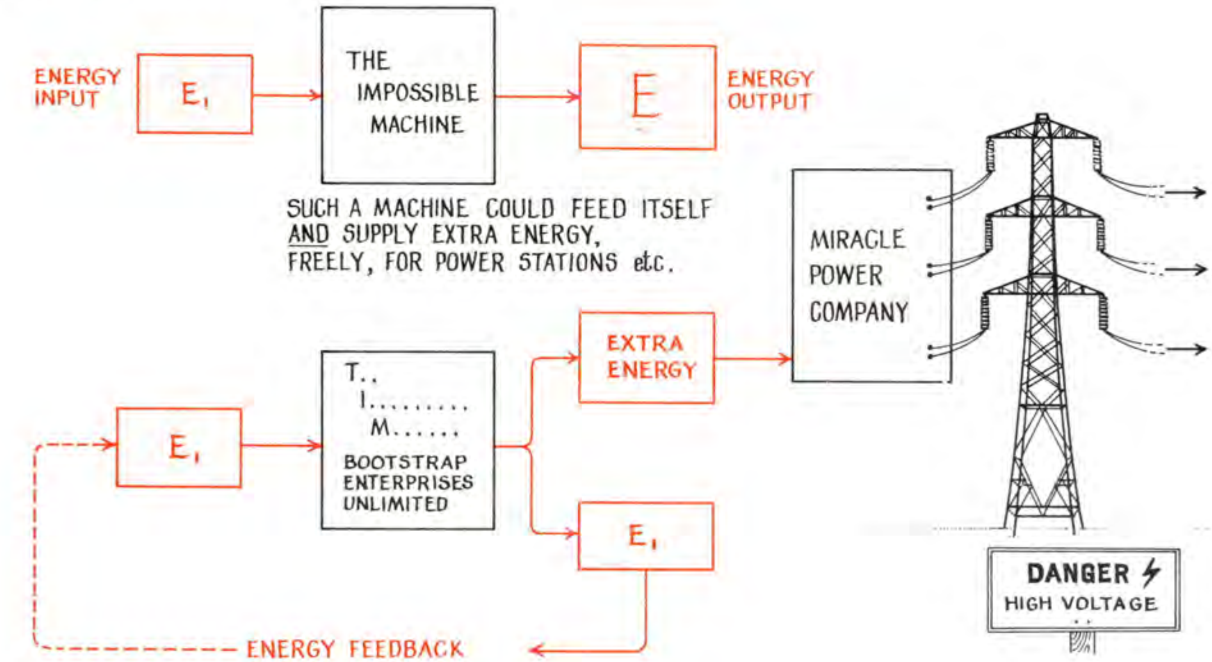
a. Each car weighs 1 tonne (= 1000 kilograms); but *you do not need to know that* for your estimate of power. Why not?

b. Do the 2 'down' passengers *help* the railway, or *hinder it,* or *have no effect?*

c. Altogether the electric motor does a useful job of raising . . ? . . people, through a height of . . ? . . metres? It does that in . . ? . . seconds. The power for that is . . ? . . *newton · metres per second,* or *watts.*

d. The electric motor is likely to be only 60% efficient. And friction of the cable-guides, etc., will bring that down to 50%. Then the power *input* to the electric motor should be . . ? . . *watts.*

e. If the motor runs on a 400-volt supply, it must take . . ? . . *amps* during the trip.



We believe that there is no way of manufacturing energy from nowhere—we can only release energy that is already there in storage.

So we believe that a machine that could put out more energy than it takes in is impossible. (There are still people who hope they can invent one, but we are sure it is hopeless.)

INVENTOR'S HOPE
for perpetual motion

And when energy changes from one form to another, we believe none is ever lost. The *total* of all forms stays the same, whatever happens. Scientists have reached that strong belief after many experiments and many attempts to disprove it. We hope you too will be convinced if you read the chapter in *Pupils' Text 4* which discusses the evidence.

If you are sure of those beliefs, as all scientists are, you should keep them in mind when you think about our present use of energy and the future of mankind. Where are we going with our uses of oil, petrol, gas, and coal, and the electrical energy we derive from those? Is research on nuclear fusion safe, necessary, likely to be successful?

Our beliefs that energy is never created and never destroyed, but only exchanged, form what we call the *First Law of Thermodynamics*.

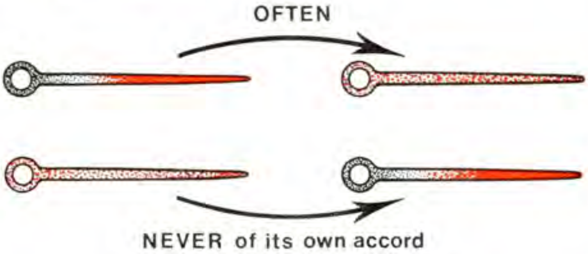
There is one more belief which is just as important and just as firmly held by scientists, but harder to describe or explain. You would have to take it on trust at present. It is called the *Second Law of Thermodynamics*. It can be expressed in several forms. Here are two ways of putting it:

Version A: 'Heat runs downhill' (i) Most of the energy in the World tends to change finally into heat; and *(ii)*, as the heat from hot things spreads, the temperature averages out from high values to lower values: always of its own accord higher to lower—towards a general tepid coolness.

EXAMPLES

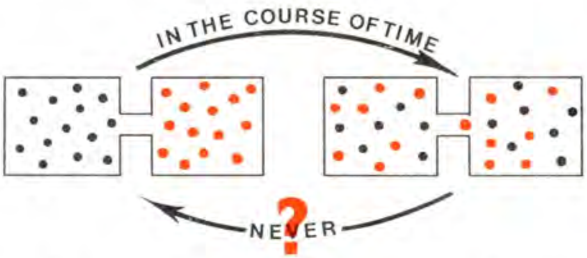
(i) A jet plane flies from London to New York and back to London. Its engines have burned an enormous amount of fuel. That enabled the plane to fly, but where did the fuel's energy end

up? As heat *all of it*—making the air a trifle warmer for the birds. The high-temperature heat of the jet's furnace ends up as low-temperature heat spread out in the air.*



(ii) Heat one end of an iron bar red-hot: a red-hot poker. Then hold it. What happens next? The hot end gets cooler (even if lagged with asbestos) and the cold end gets warmer. Could that be reversed? Have you ever seen an evenly warm poker grow redder-hotter at one end and colder at the other end *of its own accord?* There might still be conservation of energy: heat might just travel from one end to the other. But such travel from cold end to hot end seems very unlikely.

Version B: 'Time runs forwards, not backwards.' Suppose we have two boxes, one full of gas X (say air) and the other full of gas Y (say bromine vapour). We connect the boxes together and wait a long time while the gases mingle (diffuse).



If we wait long enough we expect to find the same mixture in both boxes (X + Y) and (X + Y). Now start from there, with the same mixture in both and wait and wait, hoping that one day, by luck, they will have sorted themselves out into X in one box and Y in the other. Do you think that likely? That would look like time running backwards.

If you make a movie film of the gases mixing, you could make time *seem* to run backwards by running the film backwards through the projector.

X and Y might be the same gas at different temperatures; for example hot air and cold air. Let them mix, what will a thermometer say? After that, are they ever likely to 'un-mix' again—as if time ran backwards?

Question

IMAGINING TIME ... BACKWARDS?

9x. Choose one or two of the following events. Imagine you have made a cinema film of the event. Then show the film RUNNING BACKWARDS.

Write a short description of what people would see as they watched that time-reversed film.

(i) A child holds a raw egg in its hand, and lets go.
(ii) A pupil sits in a barber's chair and has his or her hair trimmed.
(iii) A farmer sees a rabbit run across the field, and shoots it.

(iv) ? (This is your turn. Think of an event that will make an interesting film for reversal. Describe its reverse form.)

It is not obvious that the Second Law will be useful. But it is—very useful. With its help, scientists can do many strange things, such as:

- Find out how to increase the efficiency of locomotives, or jet engines
- Design a marvellous 'heat-pump' to warm houses cheaply
- Learn how to get the best out of nuclear reactors
- Discover a radiation law that tells us the temperature of the Sun
- Predict the melting of ice by pressure
- Understand the speeds of chemical reactions.

*Suppose a rich man gets two £1 notes from the bank, changes them to coins and lets the pupils in your class share the coins. The man could have bought a record, but the pupils can only buy small things like a bar of chocolate.

Of course the pupils might club together and buy a record with their cash; but it is not like that with heat—once distributed, heat can only do small jobs.

Perhaps the most important thing about it for you and everyone is its warning that energy tends to run downhill into heat. That heat is spread out at low temperatures, and of little use—in other words, we *cannot* recycle it to the more usable form of high-temperature heat (as we *can* re-cycle broken glass bottles.)*

This is very important knowledge of the way our world runs—*must* run—in its treatment of energy. But the details are hard to understand unless you are a trained scientist. How far, instead, will you take them on trust? That must depend on your own personal experience of science. That is why we hope you will do a lot of your own experimenting and thinking in school science so that you understand how scientific knowledge is built up. Then you can decide whether you can trust scientific knowledge. Also you may know how in later life to ask scientists for advice, and make wise use of it.

Special Optional Progress Questions

CAR ENGINES AND GASES

10. In your Physics lessons you have met three general Principles about gases:

I A small volume of liquid gives a large volume of gas.

II When you make the volume of a gas smaller, the pressure gets bigger.

III When you make the temperature of a gas higher, the pressure gets bigger.

You can use these pieces of Physics to help you understand how car (internal combustion) engines work.

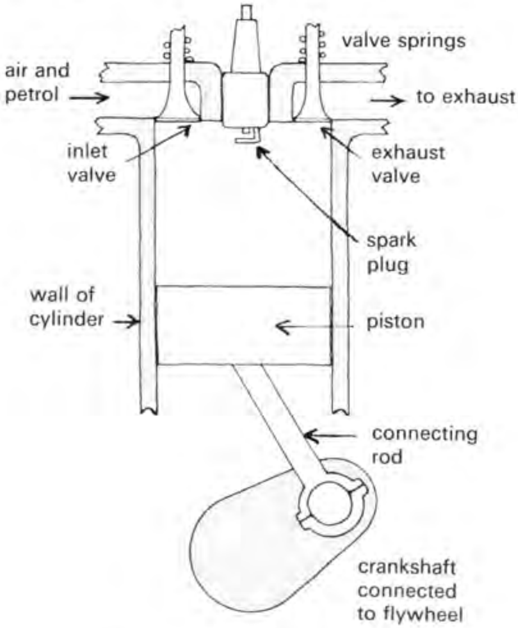
THE FOUR-STROKE INTERNAL COMBUSTION ENGINE

This is what happens inside the cylinder:

1st stroke. The piston moves down. The valve spring on the inlet valve is compressed (by an arm on the camshaft) so the inlet valve is pushed down and opens. A mixture of air and petrol vapour and fine petrol drops comes in. (The camshaft is a rod driven by the machinery. It carries arms which control the valve spring.)

2nd stroke. The piston moves up. Both valves are closed.

3rd stroke. When the piston is at the top, there is a spark between the points of the spark plug. This makes the fuel mixture burn suddenly—it explodes and pushes the piston down.



4th stroke. The piston moves up. The spring on the exhaust valve is compressed (by another arm on the camshaft). So the valve is pushed down and opens. The waste gases go out.

a. Draw four sketches, one for each stroke. Show the valves correctly (open or closed). Put an arrow to show which way the piston is moving (up or down). Write briefly what is happening beside each diagram.

b. During stroke 2, the piston goes up the cylinder.

(i) How does the VOLUME of the gas change?

(ii) How does the PRESSURE of the gas change?

(iii) Copy and complete:

When the piston moves from the bottom of the cylinder to half way up, the volume of the air is

*We burn the wood and eat the food that daily sunshine helps to provide; and petrol engines, diesel engines, and jets all burn the fuels supplied by past sunshine; and the heat produced by *all* these ends up as low temperature heat. Yet we still receive useful available energy from the Sun faster than we squander resources into that almost useless heat.

[/*halved*/*doubled*/] and the pressure is [/*increased*/*decreased*/*unchanged*/].

c. Look at the three general Principles about gases given above. Use them to explain what happens:
(i) during stroke 2.
(ii) when the spark makes the petrol burn and turn to hot gases.

11. Now use the idea of *moving molecules* to give a more detailed picture of:

a. the increase in pressure during stroke 2;

b. the increase in pressure during stroke 3;

c. the changes from liquid petrol to petrol vapour.

ENERGY CHANGES IN CAR ENGINES

12a. Copy and complete:
When the fuel mixture burns, . . ? . . energy of the fuel changes into . . ? . . energy in the gas.

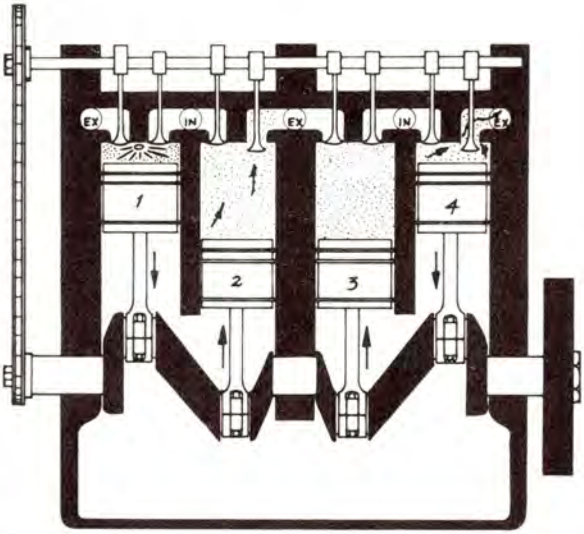
b. Go on and give the next stages in the series of energy changes.

c. Once the flywheel is given energy so that it starts to turn, it goes on turning till it loses the energy. As it turns, it keeps the pistons going up and down.
(i) How does the flywheel lose energy?
(ii) Why is it important to keep the cylinders smooth, and the pistons tight fitting?
(iii) During ONE of the four strokes the cylinder gives the flywheel energy. Which one: 1st, 2nd, 3rd, 4th?

13a. During stroke 1, the inlet valve is open. What makes the air-and-fuel mixture go into the cylinder? (HINT. Think about pressures.)

b. During stroke 4, the outlet valve is open. What makes the waste gases go out of the cylinder?

14. Look at the diagram. It does not show *all* the stages. Write down which stroke each of the four pistons, A, B, C, D, is doing. Which will be the *next* cylinder to fire?



15. *(OPTIONAL EXTRA)* Find out as much as you can about the TWO-stroke engine.

If you like, draw a series of diagrams showing how a two-stroke engine works, and write beside each one what is happening.

Then go on to explain where the three general principles about gases fit in, and try to use the idea of molecules moving too.

Scientists make very careful measurements. They 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 they 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'.

A SPECIMEN ESTIMATE

'How many conkers are there on a horse-chestnut tree?' Two pupils, George and Henry set out to make a guess.

GEORGE I'm thinking about a patch of tree, leaves and conkers. I'm thinking about 1 square metre of tree. I am staring at it from outside, in imagination, and counting conkers. If I divide the square metre into small squares, 10 cm × 10 cm, there are 100 of them in the square metre. Suppose there is one conker is every small square.

HENRY That's too many. The tree would look plastered with conkers.

GEORGE Yes. Then suppose there is one conker in every big square, one in each square metre.

HENRY That's too few: a poor crop. A good guess is somewhere between 1 and 100 in each square metre.

GEORGE If we guess 10 that won't be more than ten times too big.

HENRY Yes. Let's guess 10 conkers in each square metre of foliage.

GEORGE But how many square metres? We don't know anything about the size of the tree.

HENRY We must think about a medium-sized tree. You and I are about $1\frac{1}{2}$ metres tall. If 10 of us made a tower, each standing on the shoulders of the one below, would that do for the height?

GEORGE I don't see how you know that's right.

HENRY Well, only roughly. Try half that: a tower of five of us: that wouldn't be up to the top of a tree. Try twice that: a tower of 20 of us: I think that would be too tall. So I just *guess* somewhere between five of us and twenty of us; and I choose 10 of our height. That may be wrong, but not terribly. It's better than saying we *can't* guess.

GEORGE All right. Ten of us—ten times $1\frac{1}{2}$ metres. That makes 15 metres.

HENRY Horsechestnut trees are wide but not quite as wide as tall. 15 metres tall. Let's guess half the height, say 8 metres. We shan't be too far wrong. Half that, 4 metres would be small; twice that, 16 metres would be huge—ten of us lying in a line on the ground for the tree's width.

GEORGE I agree to 8 metres as a rough guess. We can pretend the tree is square, 8 metres by 8 metres. And 15 metres tall.

HENRY Then the tree is like a box. Four sides 8 metres by 15 metres; and a top 8 metres by 8 metres. That makes altogether:
4 times $8 \times 15 + 8 \times 8$ or $480 + 64$ or
about 550 square metres.

GEORGE Now we know: 550 square metres with 10 conkers in each. We guess 5500 conkers.

HENRY I never expected so many.

GEORGE Well, it's quite a big tree. We can say, fairly safely: 'More than 1000, less than 10 000.'

HENRY That may be safe but can't we narrow the limits? I feel safe in betting it's more than 3000 and less than 8000.

(Their Science Teacher would express that estimate as 5500 ± 2500.)

We often have to make rough estimates like that in science. Try your hand at some of the ones below.

MAKE SOME 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 $\frac{1}{2}$ litre (or 1 pint) containers of milk does a family of two parents and two children take in one year?

What is the distance in *metres* between your home and your school?

What is the speed of a sparrow in flight?

How long would it take you to walk from Land's End to Scotland?

What is the heaviest basket (airline bag, etc.) of books you can comfortably carry to school every day?

What is the average lifetime of a bird?

MORE ESTIMATES

IF YOU DID NOT TRY MAKING ROUGH ESTIMATES LAST YEAR OR THE YEAR BEFORE, CHOOSE ANY TWO OF THE FOLLOWING (FROM PUPILS' TEXTS 1 AND 2). DO THE SAME FOR THEM.

How many grams of stuff in a pair of nylon socks?

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)?

How many hairs are there on your head?

How many eggs do you eat in one year?

How many pencils are there in a kilogram of pencils?

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*If you know about standard form, use that and carry the figures as far as you think wise. Examples: 1320 in standard form is $1.32(0) \times 10^3$; 2 million is 2×10^6; 0.022 is 2.2×10^{-2}

A DICTIONARY OF ELECTRICAL WORDS

These are not definitions to be learnt by heart. They are just descriptions to keep available for reference in case you are not sure of something. (Some names will be much easier to understand later when you have worked with apparatus in the lab. The sign (*) warns you of that.)

Circuit This is a complete ring of metal wire, or such like, that runs from a battery or cell (or a dynamo) to a lamp or other apparatus and on back to the battery. The ring may be round or square or any shape. But there must not be any break in it if you want a current.

Short circuit The electric current takes a short cut through a shorter circuit than was intended. This is usually due to some wires touching by accident, so that part of a longer circuit is left out. Then the short circuit has a low resistance so that the current is much greater.

The current may rise high enough to make the fuse 'blow' (melt)—otherwise, if the heating continued it would be wasteful and possibly dangerous for the apparatus or the building.

Electric current is our name for something that happens in a complete circuit that contains a cell or battery or dynamo. We only know a current by what it *does*. We may see something getting hot in some places, and some magnetic effects, and perhaps some chemical changes.

Though we cannot see or hear anything moving we call that a CURRENT because its behaviour reminds us of a flow of water. When water flows round a closed circuit made up of pipe full of water, the RATE OF FLOW or CURRENT (such as 5 litres per second) is the same at all places in the water circuit. If the pipe divides into two branches, which later rejoin, the currents in the branches add up to the total flow in the rest of the circuit. (2 litres/sec + 3 litres/sec add to 5 litres/sec.) The same is true for currents of water in a river that divides into branches. In early experiments on electric circuits ammeters showed the same kind of story, so scientists started to speak of a *current* of electricity that *flows*, although they could not see it.

Ammeter measures the current passing through it—*which is also the current at all other places round the circuit.* Since we only know a current by the things it does, an ammeter has to measure something a current does. In fact it measures the force exerted by the current's magnetic effect on some standard magnet.

Milli-ammeter measures small currents, a few milliamps (thousandths of an amp).

Micro-ammeter measures very small currents (millionths of an amp).

Galvanometer This is an ancient name, now used for an instrument to measure extremely small currents—often far smaller than microamps. Galvanometers are not always marked in clear units such as microamps; they may be used just to show when there *is* a small current.

Connectors are wires, metal strips, and such like, that we use for joining things together to make a circuit.

Leads When wires lead out to one side of a circuit to connect some special thing, we sometimes call them leads.

Crocodile clips are sometimes attached to connecting wires. They have jaws that snap shut and make it easy to connect to pegs, loose wire ends, etc.

Switch is a device to make a temporary break in a circuit. When the switch is ON the circuit is complete. When the switch is OFF (or 'open') there is a gap and no current flows.

Conductor means any material that will carry current. Metals are conductors; so are carbon, some liquids (but not others), and even gases under harsh treatment. So we could make up a circuit not only with metal wires but with any of those other conductors.

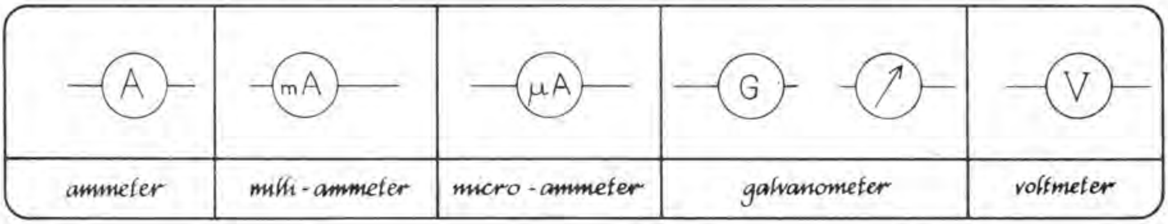
Insulator is a non-conductor. Current will not go through it.

Insulation is a covering of insulator to protect wires etc. It prevents current running across from one wire to another where they happen to touch (short circuiting). It may be silk, plastic, rubber, ordinary air, or a thin layer of varnish (usually called enamel).

Direct current, d.c., is current that continues running the same way, like traffic in a one-way street. All cells and batteries give d.c.

Alternating current, a.c.runs first one way then the opposite way to-and-fro 50 times a second. (Like traffic being directed through a road-block northward for 2 minutes, southward for 2 minutes, northward . . .) The mains that light your house supply a.c.

Cell A cell uses chemical changes to drive an electric current. On a single $1\frac{1}{2}$-volt cell the positive terminal is usually the knob at one end; the negative terminal is the flat metal base at the other end.



Battery Several cells connected in series, 'head-to-tail', the positive of one joined to the negative of the next.

Positive and negative Any cell or battery has two terminals. The terminals are not the same as each other. So we need two different names for them. Later on, you will see that you can get 'electric charge' from either—not the same kind of charges from both, but + from one and − from the other.

Two centuries ago Benjamin Franklin—who got electric charges from the sky with a kite in a thunderstorm—used the names positive and negative and we have used them ever since.

See the pictures here of signs that engineers and scientists use in sketching electric circuits. The sign for a cell is a pair of upright lines: a tall thin line for positive, and a short fat line for negative. (An easy way to remember which is which: the long line has enough line in it to make a plus sign; the short line *is* a minus.)

To sketch a battery of cells in series, draw several such pairs of lines, one after the other. The joining lines between one pair and the next are usually left out.

Accumulator A type of cell or battery that can be recharged by driving a current backwards through it.

Those cells use lead and chemical compounds of lead, and sulphuric acid, for their energy supply.

A 12-volt car battery is a group of 6 accumulator cells in series.

Power supply or Power pack is an appliance to take the place of a battery. It is often a box that takes in a.c. and uses a rectifier to make d.c. It may also change the voltage to much higher or much lower than the mains, according to the use it is designed for. Such a device is often cheaper or more convenient than batteries because it runs from the mains which are constantly available.

Rectifier A valve that lets current through one way and not the opposite way.

When we try to drive a forward-and-backward alternating current through a rectifier, it lets forward current through but stops any backward current. So what gets through is a series of bumps of current all in the same direction: bumpy d.c.

In a good power supply the bumps are then smoothed out to make a steady direct current.

Diode One form of rectifier is called a *diode*.

Dynamo is a machine that will drive an electric current when it is itself driven by a steam engine (or by your hand or a bicycle). A dynamo takes the place of a battery, drawing on mechanical energy to provide its electrical output, instead of chemical energy which a battery uses.

Generator is a more modern name for a dynamo. We still use 'dynamo' for a small machine, but the large ones in power stations are called generators or alternators.

Alternator is an a.c. generator.

Terminal A knob where the current comes out or goes in.

A cell or a battery has two terminals, one marked + for positive (sometimes painted red), the other marked − for negative.

Switches, resistors, etc. have terminals if they are mounted on bases for use in the lab. Then you can connect those things quickly in a circuit by clamping a wire tightly under each terminal.

Terminals must be made of metal where they grip the wires; but they often have a head of plastic insulator.

Plugs and sockets are a special kind of terminal. Connecting wires with metal rods *(plugs)* on their ends are easy to put into a circuit. But the things they connect to must have terminals with holes of the right size. We call those receiving terminals sockets.

Wall plugs for lamps etc. in your house are really a pair of metal plugs to join the lamp's wires to the two wires that come to the wall socket from the power station. (Modern wall plugs have a third wire to make an earth connection for safety. See Chapter 6.)

Ammeters usually have one terminal marked +. That does not mean the ammeter is actively positive there, like a battery. It only tells you which way round to connect the ammeter in a circuit so that the pointer will swing forward. The rule that manufacturers follow in marking ammeters is: *the wire that started from the + terminal of the battery must go to the terminal of the ammeter marked +.*

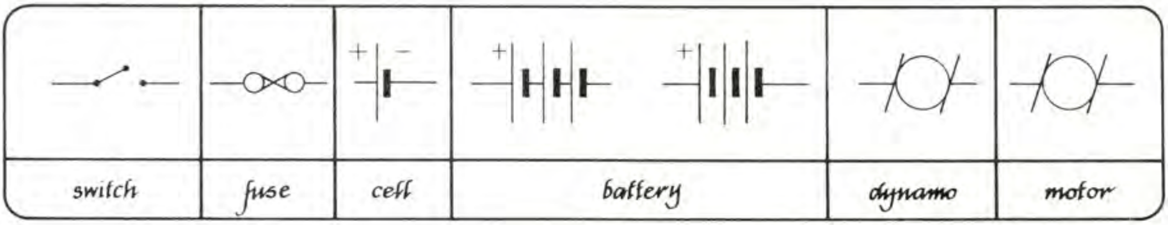
'In series' When things are joined up in series they are connected head to tail in a line, one after the other. The current has to go through each in turn.

'In parallel' When a circuit splits into two branches, we say the branches are in parallel. The current divides and part goes through one branch, the rest through the other.

(If two locomotives pull the same train they are in series. If two horses side by side pull the same cart, they are in parallel.)

Resistance of a piece of apparatus tells you how difficult it is to drive current through the apparatus—how many volts are needed for every amp you wish to drive.

Resistor is a device that has large resistance compared with a short bit of copper wire. It may be a long thin wire coiled up and packed in a cover; or it may be a thin sheet of carbon (leadpencil graphite) with terminals.



Rheostat is a **Variable Resistor** It is usually a long wire of suitable metal wound in a coil with a sliding contact so that you can put any amount of the wire, from none to all, in your circuit.

Voltage The electrical driving force that seems to make currents flow (*).

Potential difference, p.d., is the official name for voltage. This is rather like electrical pressure that drives a current round a circuit (*).

Voltmeter measures voltage or p.d. It tells us energy-transfer (in joules) for every coulomb (*).

(*NOTE.* Voltmeters and the things they measure will be much easier to understand when you have worked with them in the lab. And clear useful definitions are developed in Year 4.)

e.m.f. (electro-motive force) is the full driving voltage of any cell or battery or dynamo. The e.m.f. is the energy-transfer FROM chemical or mechanical form TO electrical energy for each coulomb driven round the whole circuit (*).

Alternating voltage (a.c. voltage) pushes forward round the circuit, then backward, then forward, . . . and so on.

A Cycle of alternating current or voltage is one complete round of changes forward-and-then-backward.

Frequency tells us how many complete cycles an alternating current makes in one second. So frequency is measured in *cycles per second,* now called *hertz* or Hz for short.

The a.c. mains in Britain and Europe have a frequency of 50 hertz. The mains in U.S.A. run at 60 Hz.

The B.B.C. broadcasts electric waves that switch to and fro at many thousands of hertz, or even millions.

Fuse is an automatic switch, for safety, a piece of wire that will melt if some accident makes a short circuit in which the current grows too great for safety.

Fuses used to be thin wires of tin or lead; now they are usually very thin copper. In older fuse boxes the wire is gripped by screws in an insulating holder. The modern custom is to place the fuse wire inside a little insulated tube with metal ends that is called a cartridge and pushes into spring clips.

Whatever the type of fuse, TURN OFF THE MAIN SWITCH before you put in a new fuse.

Circuit breaker is a safety device to take the place of a fuse. It is a trip switch operated by an electromagnet to switch the supply off if the current grows too large by some accident.

Live wire ('Line'), Neutral wire, Earth wire These names are used in wiring houses for lights and appliances. See the note in Chapter 6 on earthing and safety.

Turns (of wire) Suppose you wind wire round an iron bar to make a magnet, or wind wire into a hollow coil. Each time your hand goes once round we call that a *turn.* In a hoop coil of 10 turns the wire goes 10 times round the hoop.

Hoop coil is just a coil of wire shaped in a circle, like a toy hoop.

Capacitor is a device for storing electric charges. It is a sandwich: two large sheets of metal separated by a slice of insulator. A battery can drive charges, + and −, on to the metal sheets (*).

Oscilloscope (or Cathode Ray Oscilloscope, C.R.O.) is an electronic graph-plotter. A stream of electrons flies through a long glass tube with a vacuum in it and makes a tiny bright spot on the end of the tube—like a primitive TV picture tube. The spot can be moved up-and-down and to-and-fro electrically to draw pictures or plot graphs (*).

Units

1 amp (A) (full name ampere), is the unit of CURRENT. When we say 'the current is *3 amps*' it is like saying 'the length is 10 *centimetres*' or 'the volume is 5 *litres*'. *One amp* is the same as a flow of *one coulomb per second.*

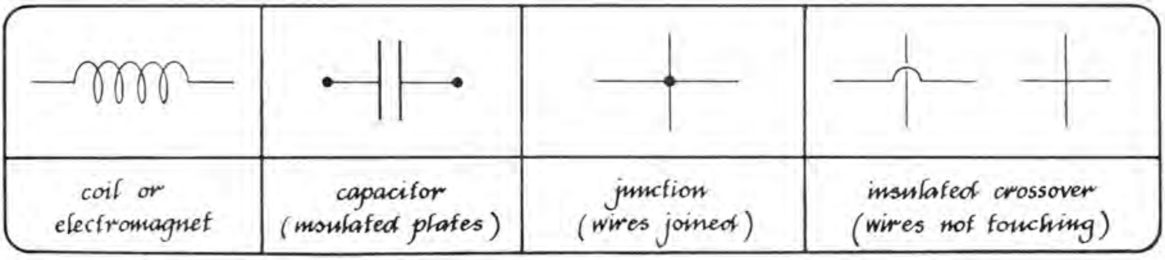
1 milliamp, (mA), is $\frac{1}{1000}$ amp (just as 1 millimetre is $\frac{1}{1000}$ of a metre. We use this unit for small currents. (A few milliamps would just give you a noticeable shock.)

1 microamp (μA) is one-millionth of an amp.

1 watt, (W), is the unit of POWER, rate of energy-transfer from one form to another. *One watt* is a short name for *one newton·metre per second* or *one joule per second.*

746 watts makes the old-fashioned unit, 1 horse-power. (One watt is about one rat-power.)

1 kilowatt, (kW), is 1000 *watts.*



1 kilowatt·hour, (kWh), is 1000 watts running for 1 hour. It is a unit of ENERGY, often used in electric light bills. It is 3 600 000 *joules*.

1 joule, (J), is the unit of ENERGY TRANSFER. It is also used for any kind of ENERGY. *One joule* is a short name for *one newton·metre*.

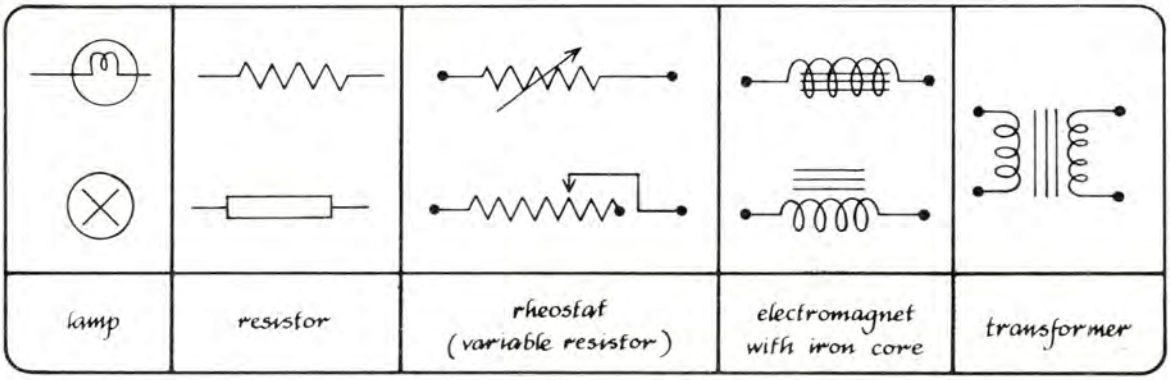
1 ohm, (Ω), is the unit of RESISTANCE. *One ohm* is a short name for *one volt per amp*.

1 volt, (V), is the unit of p.d., POTENTIAL DIFFERENCE or VOLTAGE. *One volt* is a short name for one *joule per coulomb*.

1 kilovolt, (kV), is 1000 volts.

1 coulomb is a unit of ELECTRIC CHARGE. In experiments with charges at rest on balloons etc., the charges are tiny fractions of a coulomb—a millionth or less. A whole coulomb all by itself would be an enormous charge—it would exert a vast force on another coulomb nearby. But, in a wire, coulombs of negative charge move along easily among positive charges.

A current of *one amp* is the same as a flow of *one coulomb per second*.



This volume contains the material for pupils for the third year of Revised Nuffield Physics. The main titles of the sections are 'Waves', 'Optics', 'Light and colour', 'Motion and force', 'Gases', 'Electromagnetism', 'Voltage and power', 'Electrostatics', and 'A fruitful theory' (a simple theory of magnets), together with a chapter on 'Energy and power' for pupils who have not followed this material in earlier years of the Nuffield programme.

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Published by
Longman Group Limited

ISBN 0 582 04673 4