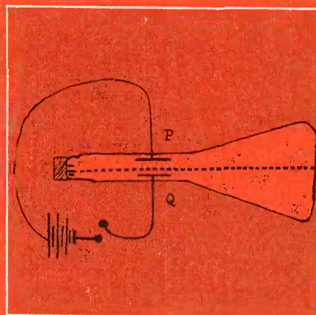
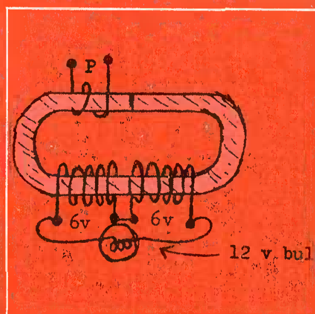
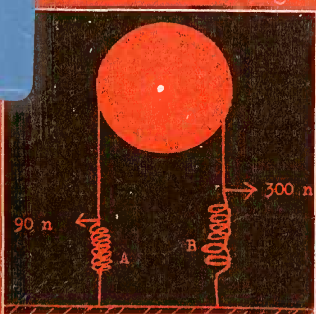
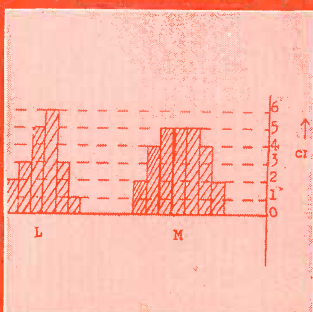
PHYSICS

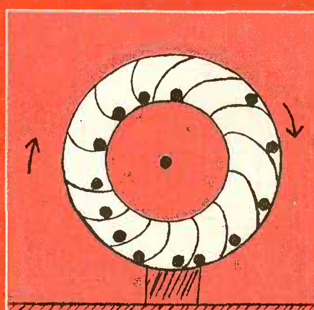
Questions book IV











Nuffield Physics
Questions Book IV

PQB 04204

Nuffield Physics
Questions Book IV

Published for the Nuffield Foundation by
Longman/Penguin Books.

First published 1966
Reprinted with corrections 1967
This reprint 1971

The Longman Group, London and Harlow
Penguin Books Ltd, Harmondsworth, Middlesex

Made and printed in Great Britain by
Richard Clay (The Chaucer Press) Ltd,
Bungay, Suffolk

Set in Monotype Plantin

Designed by Ivan and Robin Dodd

FOREWORD

This volume is one of the first to be produced by the Nuffield Science Teaching Project, whose work began early in 1962. At that time many individual schoolteachers and a number of organizations in Britain (among whom the Scottish Education Department and the Association for Science Education, as it now is, were conspicuous) had drawn attention to the need for a renewal of the science curriculum and for a wider study of imaginative ways of teaching scientific subjects. The Trustees of the Nuffield Foundation considered that there were great opportunities here. They therefore set up a science teaching project and allocated large resources to its work.

The first problems to be tackled were concerned with the teaching of O-Level physics, chemistry, and biology in secondary schools. The programme has since been extended to the teaching of science in sixth forms, in primary schools, and in secondary school classes which are not studying for O-Level examinations. In all these programmes the principal aim is to develop materials that will help teachers to present science in a lively, exciting and intelligible way. Since the work has been done by teachers, this volume and its companions belong to the teaching profession as a whole.

The production of the materials would not have been possible without the wholehearted and unstinting collaboration of the team members (mostly teachers on secondment from schools); the consultative committees who helped to give the work direction and purpose; the teachers in the 170 schools who participated in the trials of these and other materials; the headmasters, local authorities, and boards of governors who agreed that their schools should accept extra burdens in order to further the work of the project; and the many other people and organizations that have contributed good advice, practical assistance, or generous gifts of material and money.

To the extent that this initiative in curriculum development is already the common property of the science teaching profession, it is important that the current volumes should be thought of as contributions to a continuing process. The revision and renewal that will be necessary in the future, will be greatly helped by the interest and the comments of those who use the full Nuffield programme and of those who follow only some of its suggestions. By their interest in the project, the trustees of the Nuffield Foundation have sought to demonstrate that the continuing renewal of the curriculum – in all subjects – should be a major educational objective.

Brian Young
Director of the Nuffield Foundation

List of Contents

To those on whom these problems are inflicted

First of all, don't worry.

You will probably be able to answer some of the problems. Others you will find too difficult. Some, you will find, have no simple answer: this is intentional, but see what you can do. And some problems are simply meant to start discussion – they ask, 'What do you think?'

Some problems will involve things you have already covered in your physics. Others will bring in new topics. And some problems will be concerned with things which are unfamiliar but which are linked with what you have already heard about. Some questions are just problems to test your ingenuity. A good scientist tests what he can, and what he has time for, but he cannot test everything, he cannot find all the answers. All the same, he enjoys speculating about – wondering about – a lot of other things.

Altogether there are far too many problems for you to be able to tackle all of them. You will have to pick and choose. Some problems will be more interesting, or provoking, than others. Do them. With luck, you will enjoy them.

Above all, don't worry.

In some places you will come across Uncle George and Freddie Jones. Most of you will think they are awful nuisances. Some of you will think that they ought not to be introduced into anything so solemn as physics questions. They have their uses!

Uncle George is intelligent and interested, and has time to spare, but he knows very little physics. He certainly didn't do any physics at school; he was on the classics side, and when he was a boy the classics side did no science. So, you see, he is *not* an examiner who knows all the answers and is waiting to trip you up. He understands what you say if you tell him simply and shortly, and don't lead him astray with 'red herrings'. He is also quite willing – perhaps rather too willing! – to suggest new ideas of his own, sometimes rather 'off-beat'.

Freddie is your own age. He is ingenious and moderately sensible, though you will often be able to put him right about things. He also is liable to have off-beat ideas.

1 Multiflash pictures

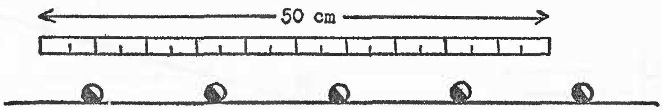


Figure 1

1 Figure 1 represents a 'multi-flash' photograph of a ball rolling along a flat surface. The rate of flashing was 1500 per minute.

a. What sort of motion did the ball have? Can you tell which way it was moving?
b. What was its speed?

2 *a.* You will probably guess that figure 2 represents a ball falling from position 1 to position 11, but could you really be sure of this from the diagram? Could it not be going upwards from 11 to 1? Explain your answer.
b. Assuming the ball *is* falling from 1 to 11, what can you say about its motion?

3 Referring still to figure 2 and assuming that the flashing rate is 1500 per minute, find:

a. the average speed between the time of picture 6 and the time of 7 (cm per sec);
b. the average speed between 10 and 11 (cm per sec);
c. the time interval between 6 and 10, or between 7 and 11 (sec);
d. the increase of speed (cm/sec) in this time interval;
e. the acceleration in cm/sec per sec;
f. the acceleration in metres/sec per sec.

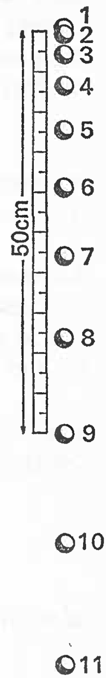


Figure 2

4 Suppose that, for figure 2, the rate of flashing had been 300 per minute instead of 1500 per minute. Suppose that the first flash comes as the ball is released, in position 1.

Draw a diagram to the same scale showing what the picture would now look like.

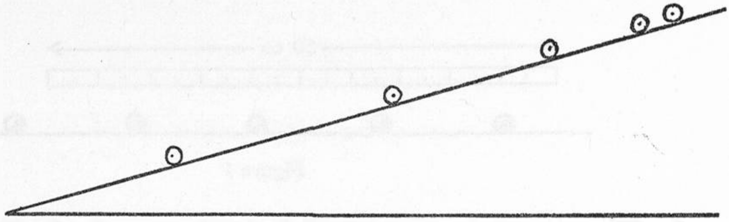


Figure 5

5 For figure 5, a ball rolling down an inclined plane, the flasher was set for 150 a minute, that is, one-tenth of what it was for the ball falling vertically in figure 2. By using the inclined plane we have 'diluted gravity' to only a fraction of its 'freely falling' value. We call the acceleration of gravity 'g'; let us call the number representing the fraction 'f'. So the acceleration for the ball rolling down the inclined plane in figure 5 is 'fg'.

By comparing figure 2 with figure 5, and knowing the rate of flashing in both cases, find the fraction 'f'. Explain how you got your result.

2 Revision of vibrators and ticker-tape

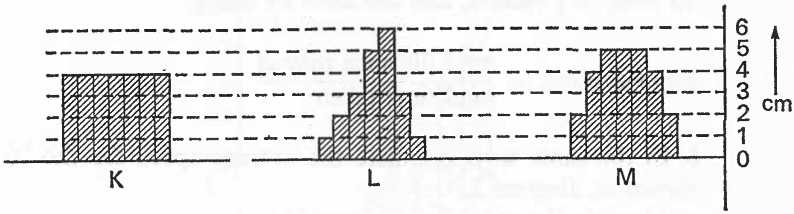


Figure 6

6 Diagrams K,L,M, show successive ten-tick pieces of ticker-tape cut off and pasted side by side. In each case there are seven pieces, and the heights are shown in centimetres. The dots at the start and the end were too close to count properly, so only the middle sets of ten ticks (70 in all) are shown.

a. Describe briefly the kind of motion followed by the person or object pulling the tape through if the result is *(i)* like K, *(ii)* like L, *(iii)* like M.
b. So far as you can tell from the diagrams, which tape reached the fastest speed, and what was that speed *(i)* in cm per ten-tick (remember that each length of tape corresponds to a time of ten ticks) *(ii)* in cm per second, if the vibrator used tapped out 50 dots in one second?
c. Actually it seems likely that the fastest speed reached was more than that calculated in (*b*), though for a shorter time than ten ticks. Why is this?

7 Look again at diagrams K,L,M of question 6.

a. How far did the object attached to the tape move in 70 ticks ($\frac{7}{5}$ seconds) for the motion shown in K?
b. How far for the motion shown in L?
c. How far for the motion shown in M?

8 *a*. Calculate the *average speed* for the 70 ticks shown in diagram K, question 6. To do this, use answer 7 (*a*); remember that the time is 70 ticks $= \frac{7}{5}$ second, and calculate by using:

$$\text{average speed} = \frac{\text{total distance moved}}{\text{total time taken}}$$

b. In the same way, calculate the average speed for the 70 ticks shown in diagram L.
c. Then do the same for diagram M.
d. The average speed you found in (*a*) is, of course, the actual speed of tape K throughout the time of 70 ticks. This is *not* true for tape L. Did tape L *ever* have the actual speed you found in (*b*)? If so, how many times did it have that speed?

Note: The same question could be asked about tape M, and the answer would be the same.

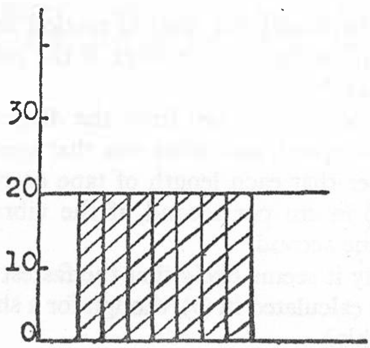


Figure 9

9 *a*. What is the value of the constant velocity represented by figure 9? Give the answer in *cm per ten-tick*.
b. If the paper strips, diagram 9, had been for 50 ticks instead of 10, how tall would they have been for the same velocity?
c. If 50 ticks take 1 second, what is the value of the constant velocity represented by diagram in *cm per second*? What is the value of this velocity in metres per second?

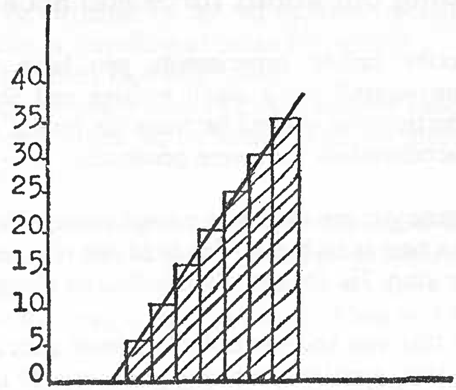


Figure 10

10 *a.* Figure 10: by how much does the velocity increase in every ten-tick interval of time? Give the answer in cm per ten-tick.
b. How much is this increase of velocity in cm per second? (50 ticks = 1 second)
c. Answer (*b*) is the *acceleration* in cm per second in every ten-tick. What is the acceleration in cm per second in every second?

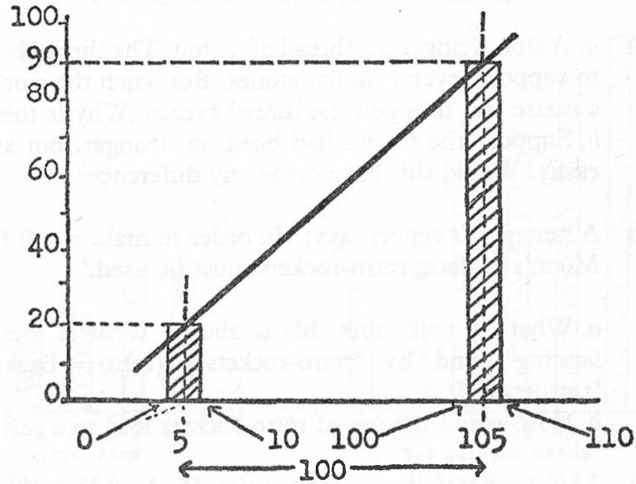


Figure 11

11 Figure 11 shows two lengths of tape. One includes dots 0 to 10, then we count on another 90 dots, and cut off a length of tape including dots 100 to 110. So these tapes are '100 dots apart'. And 100 dots = 2 seconds. Find the acceleration in (*a*) cm per 10 dots per second, and (*b*) cm per second per second.

3 Finding out about force and acceleration

12 Describe briefly experiments you have tried *without making measurements,** using small trolleys and elastic cords. Say what connection you noticed between the pull of the forces exerted and the accelerations that were produced.

13 Imagine you are sitting on a large trolley. You have a piece of rope with a ring at each end. You hold one ring; another pupil holds the other ring. He (or she) then pulls you along,

a. so that you and the trolley move at a steady speed,
b. so that, starting from rest, you cover 10 metres in 6 seconds,
c. so that, starting from rest, you cover 10 metres in 3 seconds.

What sort of pull in your arms would you feel in (*a*), (*b*), and (*c*) above?

d. Next, a third pupil sits behind you on the trolley. You notice that this does not make much difference to the pull you feel for (*a*), the steady speed. What difference does it make to (*b*) and (*c*)?

14 *a.* A stone hangs on a thread of cotton. The thread is strong enough to support several similar stones. But when the stone is lifted half a metre and dropped the thread breaks. Why is this?
b. Suppose the thread had been no stronger, but stretched more easily. Would this have made any difference?

15 A newspaper report says; 'In order to make a soft landing on the Moon's surface, retro-rockets must be used.'

a. What do you think this is about? What is meant by a 'soft landing', and by 'retro-rockets'? (retro = backwards, as in 'retrogress')
b. How would the use of retro-rockets lead to a soft landing?

16 *This question follows from question 15.* Answer each part below by saying 'increased', 'decreased', or 'unchanged'.

How would the force the retro-rockets have to exert in order to ensure a soft landing be altered if:

* You may count the number of trolleys!

a. they are to be switched on for ten minutes instead of five?
b. the space-ship is travelling at twice the speed?
c. it contains two men instead of one?
d. the space-ship is made with twice the volume simply by having more room inside – that is, no more metal, no more equipment, no more men?

17 You have done acceleration experiments with small trolleys pulled by elastic. First you had to pull a trolley along with a steady force F, unchanging over most of the trolley's run from start to stop. This was done by using a piece of elastic. Then you pulled it with a force of $2F$, then, perhaps, $3F$.

a. How did you make sure that a *steady* force F was being exerted? (Give details of exactly how you did this.)
b. How did you get forces of $2F$ and $3F$?
c. You also inclined the trolley board slightly in order to compensate for friction – how did you find the correct angle of inclination?

18 Two pupils did a trolley and tape experiment in which they pulled the trolley, first with one elastic cord, and then with two elastic cords kept extended to the same extent as before.

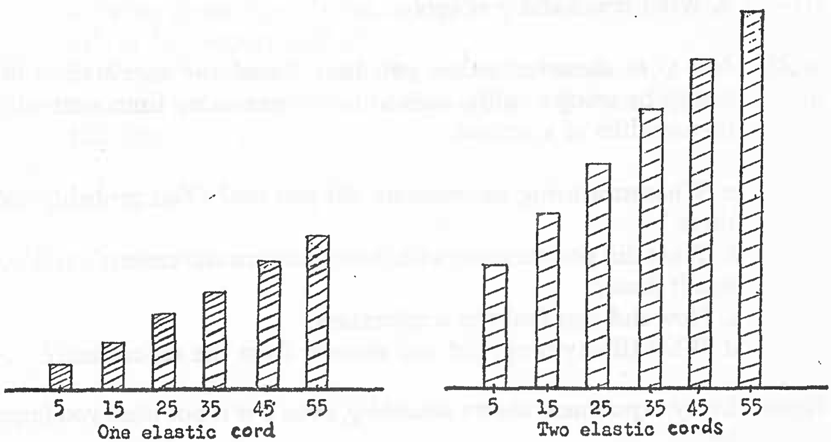


Figure 18 (*i*) Figure 18 (*ii*)

They took the first tape and cut the middle part of it into six ten-tick lengths, 0–10, 10–20, 20–30, 30–40, 40–50, and 50–60. These were pasted at regular intervals on graph paper, with the result shown, one-quarter real size, in figure 18 (*i*). They then did the same thing with the second tape, result as in figure 18 (*ii*), also one-quarter actual size.

a. Do these graphs show 'steady force, steady acceleration'? How do you know?
b. Do these graphs show 'twice the pull, then twice the acceleration?' How do you show this from the graphs given?
c. The first strip in figure 18 (*ii*) is more than twice the length of the first strip in figure 18 (*i*). Similarly for the last strips. How do you explain this?

19 In the experiment, question 18, how could you simplify and speed up the working of 18 (*b*) by assuming 18 (*a*) is true, that a steady force gives a steady acceleration?
How could you further speed up the work by *not* using scissors and paste?

20 *Not to be answered* unless you have done an experiment with a carbon dioxide puck pulled with an elastic cord.

a. What is a carbon dioxide puck? What is the advantage of using it?
b. How was a steady force applied to the puck?
c. How was the acceleration measured?
d. What result did you get?

21 *Not to be answered* unless you have found the acceleration of a trolley by using a 'millisecond timer', measuring time intervals in thousandths of a second.

a. What measuring instruments did you use? (You probably used three.)
b. What did you measure with them (four measurements), and how was it done?
c. How did you find the acceleration?
d. What (if anything) did you *discover* from the experiment?

Note: Every experiment shows *something*, even if it is not what you hoped for!

22 *a*. How could you arrange to pull one trolley with a force F, then two trolleys with $2F$, then three trolleys with $3F$? Say briefly how you would measure the accelerations.
b. What would you expect to notice about the results for the accelerations?

23 This is the same as 22, except that 'puck' is substituted for 'trolley'.

a. How would you arrange to pull one carbon dioxide puck with a force F, then two with $2F$, then three with $3F$? Say briefly how you would measure the accelerations.
b. What would you expect to notice about the results for the accelerations?

24 If one trolley requires a force F to give it an acceleration, a;

a. what force is required to give three trolleys, piled on top of each other, an acceleration of $2a$?
b. what force is required to give four trolleys an acceleration of $2{\cdot}5a$?

25 You answered 24 by common sense, backed up by the results of experiments like those referred to in questions 17–23. You can now bring together all these results in one relation between: force; acceleration; number of trolleys.

a. Write down this relation, using the symbol $\propto$ for 'varies directly as', or 'is proportional to'.
b. Write the relation, using the symbols F for force, a for acceleration and m for number of trolleys. (Why m? – you will hear about this later.)

4 Things move with constant velocity unless . . .

26 Suppose that each of the following objects is seen to be moving with a constant speed and is not changing direction, that is, its *velocity* is constant:

a. a *chair* being pushed across a level floor,
b. a *barge* being pulled along by a tug-boat,
c. a *cycle* going downhill, rider freewheeling,
d. a carbon dioxide *puck* moving over a glass surface,
e. a *spoon* dropping slowly through syrup,
f. a *man* descending on a parachute,
g. a *locomotive* pulling a train up a gradient,
h. a *spaceship* far away from other bodies,
i. a *girder* being raised at a steady speed by a crane.

(*i*) Write down, for each of (*a*) to (*i*) above, the forces acting on the object underlined – or, alternatively, say that *no* forces at all are acting on it. If there *are* forces acting, what can we say about these forces?
(*ii*) An object at rest is a special case of an object having constant velocity, that is, its constant velocity is zero. What can we say about the forces acting on an object which is not moving?

27 If a body moves with constant velocity (including being at rest), then there are no forces acting on it, or the forces acting on it are *balanced*. That is to say, there is *no resultant force*. Suppose, however, that the body is *not* moving with constant velocity, then a resultant force must be acting on it. It might be:

a. accelerating,
b. decelerating (slowing down),
c. moving in a curve,
d. (*a*) and (*c*) together,
e. (*b*) and (*c*) together.

Give one example of each of (*a*) to (*e*) above, and say in what direction the resultant force is acting. Give diagrams.

Questions (*a*) and (*b*) are easy; (*c*), (*d*), and (*e*) are difficult.

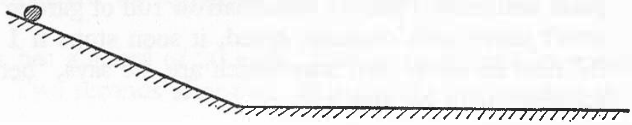


Figure 28

28 Figure 28 shows a hill down which a ball rolls on to a flat horizontal surface which goes on as far as you like.

a. What happens to a real ball on a real surface?
b. What would happen if there were no friction or air resistance at all?

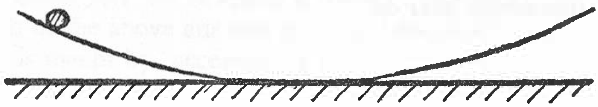


Figure 29 (*a*)

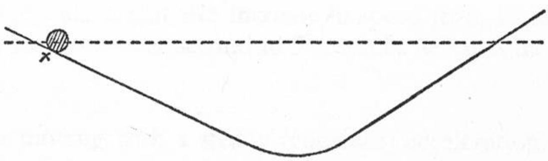


Figure 29 (*b*)

29 *a.* Figure 29 (*a*) shows a curved glass surface – a large 'watch-glass' from the chemistry lab, or a large curved mirror. It is placed on the bench and a small steel ball is held as shown, and is then released. What happens to the steel ball?
b. Figure 29 (*b*) shows a length of curtain rail, bent as shown. A ball is placed at position x and is let go. How far does it go up the other side? What happens then?

30 Newton's First Law (write it out if you haven't already written it) states:

'Every object continues to move with constant speed in a straight line, or to remain at rest, unless some unbalanced (resultant) force acts on it.'

Your Uncle George sees this law written in your book. 'Apart from *unbalanced* force which I don't understand,' he says, 'this is plain nonsense. Here's a wheelbarrow full of garden rubbish; this won't move with constant speed, it soon stops if I stop pushing it.' And he states two laws which are, he says, 'better and more sensible' than Newton's.

Uncle George's laws of motion.

1. Everything slows down and stops unless someone pushes it (on the flat, he means).

2. Everything that goes up comes down again – or tries to.

Write a page or so in answer to this, *or* jot down a few notes for a discussion later on.

5 Arithmetic to algebra via geometry

31 A car has a speed of 20 mph. Two seconds later its speed is 23 mph. Two seconds after that, 26 mph. We can tabulate this:

time, seconds	0	2	4
speed, mph.	20	23	26

a. If it continues to accelerate like this, what is its speed at time 6 seconds? 7 seconds? 10 seconds?
b. What could you think its speed was at time -2 seconds, that is, 2 seconds *before* its speed was 20 mph?
c. How much increase of speed is there in 2 seconds?
d. How much increase of speed is there in 1 second?
e. Which of the above answers is the *acceleration*?
f. What is meant by 'acceleration'?

32 *a.* A train increases its speed steadily from 40 km per hour to 50 km per hour in 5 seconds. What acceleration is this?
b. The same train might also increase in speed from 12 metres per second to 15 metres per second in 5 seconds. What is its acceleration?

33 A body is moving with a steady (constant) acceleration. It has a velocity v at the instant the clock starts and, after accelerating steadily with an acceleration a for time t, its velocity is v. We can say,

$$a = \frac{v - u}{t}$$

a. Define 'acceleration', and show how the above equation comes from your definition.
b. Write in an intermediate stage between the equation above and the equation below:

$$v = u + at$$

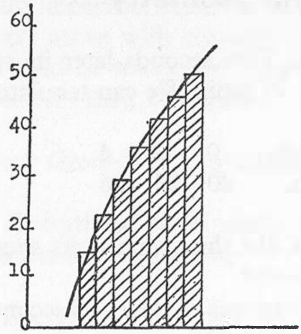


Figure 34 (*i*)

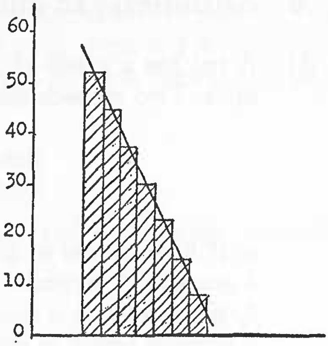


Figure 34 (*ii*)

34 Figure 34 shows two paper tape diagrams. Two other paper tape diagrams are shown in figures 9 and 10. As usual, the tape is attached to the moving object and is dragged through the vibrator.

Strips of paper, seven in each case, are cut off between dots 0 and 10, 10 and 20 and so on, up to 60 to 70. The strips are stuck side by side.

a. What kind of motion is represented by figure 9?
b. What kind of motion is represented by figure 10?
c. What kind of motion is represented by figure 34 (i)?
d. What kind of motion is represented by figure 34 (ii)?
e. How far has the object in figure 9 moved between ticks 0 and 70?
f. How far has the object in figure 10 moved between ticks 0 and 70?
g. How far has the object in figure 34 (*i*) moved between ticks 0 and 70?
h. How far has the object in figure 34 (*ii*) moved between ticks 0 and 70?

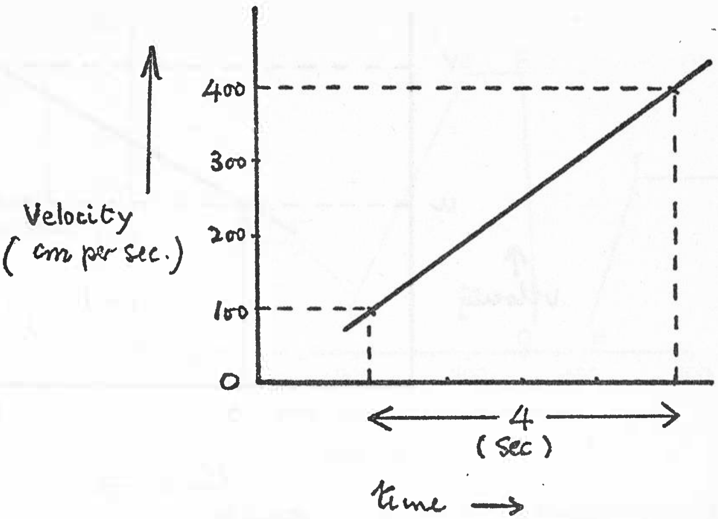


Figure 35

35 Figure 35 is a graph of the motion of an object whose speed is increased from 100 cm per sec to 400 cm per second.

a. What is it, in this graph, that represents the distance the object moved in 4 seconds?
b. Find the distance moved. (Divide the diagram into a rectangle and a triangle, and remember that the area of a triangle is $\frac{1}{2}$ base $\times$ height.)

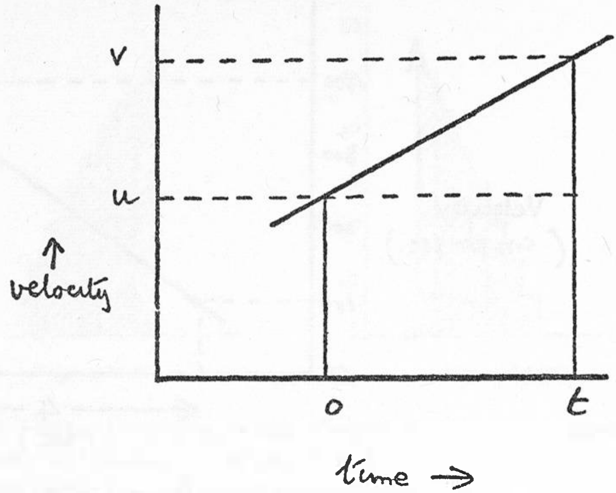


Figure 36

36 An object has a velocity u at the instant the clock starts and, after time t, reaches a final velocity v. Its speed has increased at a constant rate, shown by the straight line in figure 36. We shall use the symbol 's' for the distance covered in time t. Then

$$s = ut + \frac{v-u}{2} \cdot t$$

a. How is this equation obtained from figure 36?
b. In terms of the acceleration a,

$$s = ut + \tfrac{1}{2}\, at^2$$

How is this obtained from the previous equation?

37 This is an alternative, and entirely algebraical, method of obtaining the last equation $s = ut + \frac{1}{2}\, at^2$. We use the symbols u, v, t, a, s with the same meanings as before, and the acceleration a is constant.

a. The average velocity during time t is $\frac{v+u}{2}$, why?

b. Therefore $s = \left[\frac{v+u}{2}\right] \cdot t$, why?

c. Finish the proof by using, from question 33, the equation

$$v = u + at, \text{ so getting}$$
$$s = ut + \tfrac{1}{2}\, at^2$$

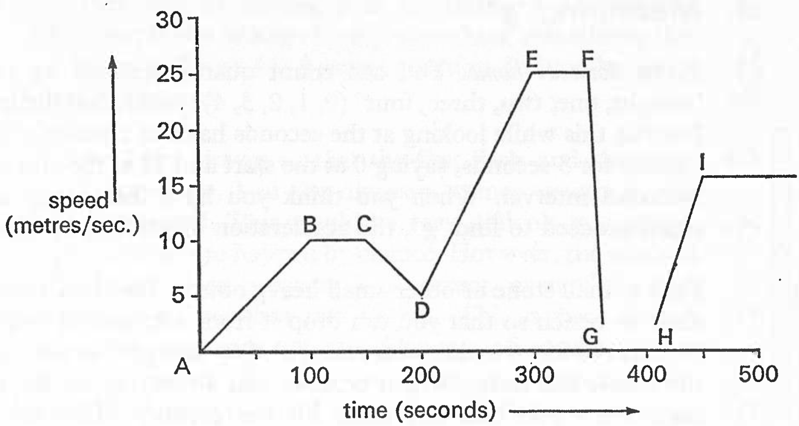


Figure 38

38 Figure 38 is a graph of the motion of a car which travelled from the centre of a town to a nearby village. Speed in metres per second is plotted upwards, and time along.

From the information obtained *by looking at* the graph, write an account of the journey. Do not make any measurements or calculations.

39 Find the acceleration the car had during the time intervals represented by (*a*) A to B, (*b*) B to C, (*c*) C to D, (*d*) D to E, in figure 38.

40 Find, in two ways, the distance covered by the car during the time interval represented by D to E in figure 38. Check that the two answers are the same,

a. by measurement of two areas on the graph,
b. by using $s = ut + \frac{1}{2}at^2$.

6 Measuring '*g*'

41 *To be done at home.* You can count quarter-seconds by saying 'nought, one, two, three, four' (0, 1, 2, 3, 4) quickly but distinctly. Practise this while looking at the seconds hand of a watch or clock – count for 3 seconds, saying 0 at the start and 12 at the end of the 3-second interval. When you think you have the timing about right, proceed to find 'g', the acceleration of gravity, as follows.

Find a small stone or other small heavy object. Stand on a stool or chair or bench so that you can drop it from a measured height of 2 metres (6 feet 6 inches near enough). Say 'nought' as you release the stone, and notice which number you are saying, or have just said, when you hear the stone hit the ground. Make the best estimate you can of time taken – make a guess to the nearest tenth of a second.

a. Find 'g' from $s = \frac{1}{2}gt^2$.
b. How do we get $s = \frac{1}{2}gt^2$ from the general equation

$$s = ut + \tfrac{1}{2}at^2?$$

c. Why is this a highly inaccurate experiment?
d. Why doesn't it matter much about measuring the 2 metres exactly?

42 You have seen a determination of g which was a great improvement on the rough experiment in question 41. Time was measured in milliseconds instead of quarter-seconds.

a. Draw a diagram of the arrangement for releasing the ball. How did this start the timer counting?
b. Explain how the timer was stopped by the ball at the end of its fall. Give a diagram.
c. How did you calculate g?

43 A ball takes 450 milliseconds to fall 1·0 metre.

a. What value does this give for g? ($s = \frac{1}{2}gt^2$).
b. How long would it take to fall 25 cm?
c. If it continued with the same acceleration, how long would it take in falling from a cliff 100 metres high?
d. In fact, it would *not* continue with the same acceleration for 100 metres, why not?

44 Another way of finding g is by taking a 'multiflash' photograph of a falling object; something resembling this is shown in figure 44. Answer question 3 if you have not already done so.

Figure 2 was drawn so that the first flash and therefore the first picture, 1 in the diagram, comes exactly as the ball is released. This would be very difficult to arrange, and is unlikely to happen by chance. However, the method of calculation in question 3 is correct, even if the ball was released between two flashes. This is because the calculation depends on the *difference* of speeds at two instants. Figure 44 shows 9 positions at $\frac{1}{25}$ second intervals (1500 per minute) of the same ball. Pictures previous to 1 are missing. We shall get *three* values of g from this diagram, and then we can average the results. Proceed as follows:

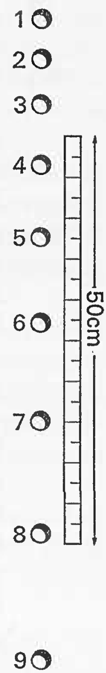


Figure 44

a. Find the average velocity between 1 and 2, and the average velocity between 6 and 7. The time interval between these is $\frac{5}{25}$ sec.

$$g = \frac{\text{increase of velocity}}{\text{time interval}}$$

b. Repeat for the $\frac{5}{25}$ second between 2 and 3, and 7 and 8.
c. Repeat for 3 and 4, and 8 and 9.
d. Average the three values for g found in (*a*), (*b*), and (*c*).

7 On being pushed around

45 Consider the following:

a. a *tin-can*, which could be filled with sand, swinging on a long string attached to the ceiling,
b. a *piece of wood*, or anything that could have small loads put in or on it, floating on water,
c. carbon dioxide pucks on horizontal glass,
d. flat, heavy *pieces of metal* – weights perhaps – resting on ball bearings on a smooth surface,
e. friction-compensated *trolleys*, that is, compensated by sloping the plane slightly.

What have all these in common? Answer, they are attempts to get rid of effects due to gravity and friction, so that we can test how things behave when these confusing forces are not acting – that is, they are attempts to simplify things. Of course they are not very successful attempts; at best we only get rid of gravity and friction for things moving in one plane, and that must be horizontal or nearly horizontal. There are other snags, for example, (*a*) works only as long as the can moves just a *small* distance, otherwise the weight of the can becomes very important. And (*e*) works only in one direction; if we try to push the trolley any way except *down* the plane we have large forces due to weight and friction acting. Nevertheless, they are the best we can do, short of a voyage in a space craft!

You have tried pushing the can, the wood, the puck, the trolley, etc., with one finger, or pulling with cotton. Describe what you feel, when

(*i*) you give '*it*' (the thing in italics in (*a*) to (*e*) above) a sudden increase of speed, and when you give it a slow increase of speed or stop it slowly – that is the difference in feel for large and small accelerations,
(*ii*) when you try different quantities of matter, e.g. two pucks or two trolleys on top of each other, as compared with one; or the can filled with sand compared with the can empty.

Yes, the answers to these questions seem too easy, but they are important. They show the property of matter we call *inertia*. Inertia is a short way of saying 'amount of difficultness in getting into motion', or 'amount of sluggishness', or 'amount of unshovability', or 'amount of difficultness in being accelerated'. Two trolleys have twice the inertia that one has. Two trolleys are twice as massive; they have twice the mass. Exactly how to measure mass is something we shall see later.

Notice that inertia works both ways. The greater the difficulty in getting moving, the greater the difficulty in stopping. Compared with a car, a ten-ton lorry has a more powerful engine and more powerful brakes. If the brakes won't stop the lorry, something else will – and then we have a nasty accident.

What about *force*? Force is what must be exerted to give matter an acceleration. The bigger the acceleration (or deceleration), the bigger the force required. The bigger the mass, the bigger the force required for the same acceleration. In fact, you have already discovered the relation between force, mass, and acceleration – see question 25.

(*iii*) Write down the relation between force (F), acceleration (a), and mass (m). Use '$\propto$' to mean 'is proportional to' or 'varies directly as'.

46 *Difficult.* Having read question 45, do your best to explain 'in your own words' what is meant by, (*a*) inertia, (*b*) mass, (*c*) force.

This is *not* an invitation to write out definitions to be learnt by heart; you will *not* be asked this in an examination. It is an 'Uncle George' question: explain to Uncle George what these three words mean. You can assume he understands 'acceleration'. In each answer, give him an actual example of what you are talking about; most of us find real things easier to understand than generalities.

47 *a.* An egg stands on a piece of metal tubing which stands on cardboard which stands on a tumbler which contains water. The cardboard is then jerked out. What happens to the egg, and why? What *two* reasons are there for having water in the tumbler?

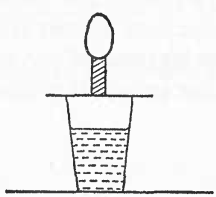


Figure 47

b. Several other 'parlour tricks' with coins, weights, books, etc., depend on inertia. Describe and explain *one* such trick.

48 *a.* Uncle George has wax-polished his car so that water stands on it in large drops, without wetting it. The car is left out in heavy rain. The rain stops. Then Uncle George gets in and drives off. He comes to a traffic light, which changes to red, and he stops rather quickly. A 'swoosh' of water comes over his windscreen. Explain what inertia has to do with this.
b. Uncle George and Freddie, who are inexperienced sailors, hire a motor-cruiser on the Norfolk Broads. They set off down the river in fine style. Then they want to stop for the night. Uncle George, who is steering, sees a nice piece of bank ahead. 'I'll drive alongside there,' he says, 'and when I say "jump", I'll switch off the engine while you jump ashore with the stern anchor and stick it in the bank.' They do this, and Freddie, who bravely hangs on to the anchor, gets very wet. Later, Uncle George, who has heard about inertia, says it is 'inertia's fault that you got wet'. Explain how inertia made Freddie wet, and say what Uncle George ought to have done.

49 In question 30 there is a statement of Newton's First Law of Motion. What connection is there, do you think, between inertia and Newton's First Law?

50 You have used a thing called a 'wig-wag machine' or an 'inertia balance'. Its 'rate of waggle' depends on the inertia, or mass, of an object put on it, and not at all on the weight of the object. It works in just the same way in the laboratory and in a space-ship

a. How would you show, without taking it out of the laboratory, that it does compare *masses* of objects, and not *weights*?
b. If you put a larger lump on it, it waggles more slowly. Give a reason why this happens – that is, a reason in terms of inertia and force ('The larger lump has the larger inertia, therefore . . .')
c. What else do you think has a main, controlling effect on its rate of waggle? (Choose your answer from: resistance of the air, weight of the springs, springiness of the springs, tightness of fastening to the bench, whether or not it is exactly level.)

51 You have masses of $\frac{1}{2}$ kg, 1 kg, and 2 kg. How would you use a wig-wag machine to find the mass of a lump which is 'somewhere about $1\frac{1}{2}$ kg'? (Remember that the time for one waggle is *not* directly proportional to the mass you put on the platform; in fact, you do not know how time varies with mass. *Hint:* Graph paper might be needed.)

52 Trolleys and ticker-tape can be used to compare masses, Section 3. The answer to question 25 was,

$$\text{force} \propto [\text{number of trolleys}] \times [\text{acceleration}]$$

If we increase the number of trolleys, or load things on to a trolley, we increase the total *volume*, *mass* (Inertia), *weight*, and other properties as well.

a. On what does the force needed for a given acceleration depend: volume, weight, mass of the trolleys, or something else?
b. 'Force $\propto$ [. . . .] $\times$ [acceleration]'

Write out the above relation, and fill in the blank with *one* word that is more useful than the previous 'number of trolleys'.

Note 1 : 'Number of trolleys' did not really mean a number, it meant 'the amount of whatever-it-is possessed by the number of trolleys we used'. Now we know the proper name for the 'whatever-it-is'.

Note 2 : And that name is 'mass', so force is proportional to mass $\times$ acceleration. This is the same as saying,

$$\text{force} = K \text{ mass} \times \text{acceleration}$$

where K is the same number for all forces, masses, accelerations; but K *does* depend on the units we use. Later, in Section 8, we shall see that, if we use sensible units, which means using the *newton* as the unit of force, then $K = 1$, so

$$\text{force} = \text{mass} \times \text{acceleration, or } F = ma$$

8 Using gravity to compare masses. Kilograms – weight and newtons

Remember, mass is what is measured by comparing accelerations produced by the *same* force on different masses – the bigger the acceleration, the less the mass. This can be done directly by means of trolleys and ticker-tape, or more quickly by finding rates of waggle of wig-wag machines. Neither is very accurate nor speedy, but a much easier and more accurate way of comparing masses is ready to hand.

53 *a.* How can you quickly compare the masses of two objects by comparing their weights?
b. Describe briefly a method of comparing weights which is *different* from (*a*).

54 The two methods of comparing masses you mentioned in question 53 can be correct *only* if the weight of an object is directly proportional to its mass, so that comparing weight is the same as comparing mass.

Briefly describe the kind of experiment that convinces us (and which convinced Galileo) that weight is directly proportional to mass. (The reason why this 'convinces us' is given by question 55.)

55 The *weight* of a body is the pull (force) of the Earth on it. Let w = the pull of the Earth on a body of mass m. If it is allowed to fall freely, then this force w, its weight, gives it the acceleration we call 'g'.

a. Use the equation at the end of Section 7,

$$F = ma$$

to show that, for a freely falling body,

$$w = mg$$

b. This is the same as saying $g = \frac{w}{m}$. Now explain why the experiment in question 54 convinces us that we can compare masses by comparing weights on a beam balance or spring balance, as you said in question 53.

56 *Difficult.* We still haven't explained what looked like a trick at the end of Section 7, when we jumped from $F = K\,ma$ to $F = ma$, by saying that it all depended on using 'sensible units'.

We have been measuring force (thought of as a push or a pull) in kg-wt. 1 kg-wt is the force of the Earth pulling on a mass of 1 kilogram. Also you have found by experiment that the acceleration of gravity, g, is about 9·8 metres per second per second. Put this in the $F = K\,ma$ (or $w = K\,mg$) equation. Then,

$$1 \text{ kg-wt} = K \times 1 \text{ kg} \times 9{\cdot}8 \text{ metres per second per second}$$

a. What is the nasty number that represents the value of K in $F = K\,ma$, if we use kg-wt as unit of force?

Let us therefore forget about gravity and gravitational units of force (weights), and invent a new unit of force, namely a force which gives unit mass *unit* acceleration (1, not 9·8 . . .). We call it the *newton*. Then,

$$1 \text{ newton} = K \times 1 \text{ kg} \times 1 \text{ metre per second per second}$$

b. So what now is the value of K? And what is the definition of a *newton* which gives this value of K? ('1 newton is that force which . . .')

57 *Difficult.* There is another very good reason, besides that of simplifying an equation, which makes us use the newton as a unit of force, rather than the pull of gravity on a mass of 1 kilogram, which we call a kilogram-weight.

What is that other 'good reason'? (*Hint: it has to do with the value of K at different places.*)

58 The Earth gives a mass of 1 kilogram an acceleration of 9·8 metres per second per second. 1 newton gives a mass of 1 kilogram an acceleration of 1 metre per second per second.

a. What is the pull of the Earth, measured in newtons, on a mass of 1 kilogram?
b. What is the pull of the Earth on 2 kg? On X kg?
c. What is the pull of the Earth on unit mass of any lump of matter, measured in newtons per kilogram?

d. 'Gravitational field' is measured as 'force per unit mass'. What, then, is the gravitational field strength of the Earth? (Remember to give the units.)

59 The value you give in 58 (*d*) for the Earth's gravitational field strength is the value at sea-level. Will the value up a mountain be more or less or the same?

Give the reasons for your answer.

60 An 80-kg man goes from England, where he was in a gravitational field of 9·81 newtons per kilogram, to the equator, where he is in a gravitational field of 9·78 newtons per kilogram. By how much does the force of gravity acting on him change (answer in newtons)?

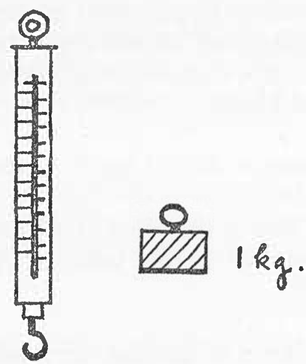


Figure 61

61 Figure 61 shows a spring-balance marked in newtons. The manufacturer did *not* get this marked by using a trolley and ticker-tape.

a. How do you think he did get it marked in newtons?
b. Suppose you had a trolley with a mass of *exactly* 1 kilogram. How would you use it, together with the usual ticker-tape and vibrator, to test whether the 1 newton mark is correct? (Give just a brief outline of the method.)

62 *a*. How would a spaceman use the apparatus of figure 61 to find g on the Moon or on Mars?
b. How would he find g on a planet where g is more than 10 newtons per kg? (He has a 100-gm mass, as well as the 1 kg.)

63 A spaceman, in his space suit, weighs 882 newtons on Earth, where the gravitational field is 9·8 newtons per kilogram. What would he weigh,

a. on a smaller planet, where the field is 1·4 newtons per kg?
b. on a larger planet, where the field is 15 newtons per kg?

9 Problems on $F = ma$

(You may also require: $v = u + at$; $s = ut + \frac{1}{2}at^2$.)

64 A boy pulls a 5-kg cart loaded with 95 kg of bricks. He pulls with a force of 200 newtons. Neglect friction.

a. Find the acceleration of the cart.
b. How far, starting from rest, does he pull the cart in 2 seconds?
c. If this went on, how far would he pull the cart, from rest, in 10 seconds? How fast would it then be moving?
d. The answers in (*c*) are not possible. Why not? (Don't just say 'because of friction'. There are other reasons – look at the numbers.)

65 Repeat the calculations (*a*), (*b*), (*c*) of question 64, assuming this time that friction drags the cart back with a constant force of 50 newtons.

66 A 20,000-kilogram wagon is on a slightly inclined railway, with just enough downhill slope to compensate for friction. A child pushes the wagon downhill with a force of 2 kg-wt, and continues to push for 5 minutes.

a. Express the force in newtons.
b. What speed does the wagon acquire after 5 minutes?
c. How far does the child walk?

(Note, assume that a small extra push was given at the start, sufficient to overcome 'static friction'. You can take $g = 10$ newtons per kg.)

67 A 1500-kg car travelling at 12 metres per second (about 27 mph) crashes into a wall and is stopped in 0·10 second. Find the average collision-force stopping the car during that time.

To get some feeling for the size of the force, convert your answer into tons-weight by using the relation: 1 ton-wt (British) = 10,000 newtons, approximately.

68 A 60-kilogram boy jumps from a window-ledge 1·25 metres above a hard floor. Estimate the force exerted on him by the floor while he is stopping, by answering the questions below. Suppose that he foolishly forgets to bend his knees while landing so that the total 'give' of his feet, etc., is only 0·025 metre (1 inch), in compression of floor, shoes, feet, ankles, spine, etc., during the stopping process.

a. Show that his time of fall is 0·5 second (use $g = 10$ metres per second per second).
b. Find the speed of the boy at the end of his fall, just before landing. To calculate the time taken by the landing process we must find the boy's average speed during the landing process. Write down his speed just before he lands and his speed when he has finished landing, take the average.
c. Use that average speed to find how long he takes for the process of landing, that is, how long he takes to travel 0·025 metre.
d. You know his speed before landing and his speed after landing, so you know his change of speed; and you also now know how long he took to make that change of speed. Calculate his acceleration (negative) during landing.
e. Using $F = ma$, calculate the force the floor exerted on him during landing.
f. Express this force in tons-wt, using 1 ton-wt = 10,000 newtons.

69 A 70-kilogram sprinter starts from rest and reaches a speed of 8 metres per second in 2 seconds.

a. What is his average acceleration during those 2 seconds?
b. What is his weight (pull of the Earth on him) in newtons?
c. What force is required to give him this acceleration?
d. Express this force as a fraction of his *weight* (take $g = 10$ newtons per kilogram).

70 A hammer, with a light handle and a 1·2-kilogram head, moving with a speed of 5 metres per second, strikes a horizontal nail in a piece of wood without any rebound. The nail is driven 1 millimetre into the wood.

a. Find the average deceleration of the hammer.
b. Find the average force acting on the nail.
c. What difference, if any, do you think it would make if the hammer *did* rebound? Give the reason for your answer.

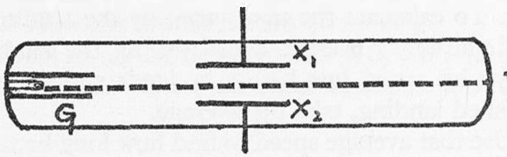


Figure 71

71 Electrons are shot from an electron gun G at high speed in a vacuum tube, and travel down the tube to the point P. On the way they pass between two horizontal plates X_1 and X_2 which are 0·02 metres long.

a. what is the general effect on the electrons of connecting X_1 to the positive plate of a battery and X_2 to the negative plate?
b. How does an electron move when it has passed beyond the plates?
c. Difficult. How long does an electron spend between the plates if its velocity is 3×10^7 metres per sec?
d. Difficult. If the vertical force on an electron, while it is between the plates, is 10^{-15} newtons, and the mass of the electron is 9×10^{-31} kg, what is its vertical acceleration?
e. Difficult. What is its vertical displacement while between the plates?
f. Difficult. If the distance from the centre of the plates to P is 0·2 metre, roughly how far from P would the electron strike the end of the tube while X_1 and X_2 are connected to the battery?

10 Impulse and momentum-change. Newton's second law

This Section does three things. First, and least important, there is an easier way of doing questions such as 66, 67 and 69. Second, this leads to an important new idea: *momentum*. Third, this brings us to a statement of Newton's Second Law of motion (which we do *not* have to learn by heart) and another way of writing $F = ma$.

Question 69 is a good one to take first. The sprinter, of mass m (70 kg), pushes against the ground with a force F, which means that the ground pushes back against him with a force F; that is why he gets moving. It takes a time t (2 seconds) for him to reach a speed v (8 metres per second). By using $v = u + at$, and $F = ma$, you should have obtained the answer in 69 (c), that $F = 280$ newtons.

A good measure of what the ground has been doing (pushing him with a force F for time t) is the product Ft, which we call the *impulse*. A good measure of what the man has gained is the product mv, mass $\times$ velocity, which is called *momentum* (remember he started from rest).

Now, *impulse* $= Ft =$ [280 newtons] $\times$ [2 sec] $=$ 560 newtons · seconds, and *momentum* $= mv =$ [70 kilograms] $\times$ [8 metres/sec] $=$ 560 kilogram · metres/second.

We already know, from $F = ma$, that

1 newton = 1 kilogram · metre per second per second
so 1 newton · second = 1 kilogram · metre/second.
560 newton · second = 560 kilogram · metres/second.

Therefore, for the sprinter in our problem,
impulse = *momentum gained* from that impulse.
$Ft = mv$

This is right for something starting from rest, $u = 0$. But if it started with velocity u, which increased to v, the *gain* of velocity is $(v - u)$, so it is better for us to write

$Ft = m(v - u) = mv - mu$
impulse = *momentum gained*

72 Now work out 69 (c) directly from $Ft = mv$, remembering that $u = 0$. Write $F = \frac{mv}{t}$. You know the values of m, v, and t. Remember that 'kilogram · metres per second' is the same as 'newtons'.

73 Work out 66 (b) from $Ft = mv$.

74 Work out 67 from $Ft = mv$.

75 Work out 71 from $Ft = mv$. First find (c) as before, then use $Ft = mv$ to find v. Omit (d). Then work out (e), by remembering that the initial *vertical* velocity was 0, so that the average vertical velocity while it is between the plates is $\frac{v}{2}$, and the vertical displacement is $\frac{vt}{2}$. Then (f) as before.

76 Of course we can easily get *impulse* = *momentum gained* by two lines of algebra, as well as from one particular example. Start by writing $F = ma$. Then:

a. The acceleration a is the increase of speed from u to v in time t. What can we substitute for a?
b. Multiply both sides of the equation by t and what do we get?

77 *Important question for those who will be doing calculations about molecules later on.*

A toy machine-gun shoots ball bearings weighing 2 gm (0·002 kg) each at the rate of 3 per second at a vertical steel plate, with a horizontal velocity of 11 metres per second. The balls rebound from the plate with practically the same speed with which they hit it.

a. What is the momentum of a ball on impact?
b. What is the momentum of a ball as it rebounds? (Remember the velocity is reversed, so mv is changed from $+\,mv$ to $-\,mv$.)
c. What is the *change of momentum* of *one* ball on impact?
d. What is the *change of momentum* of all the balls meeting the plate in *one second* (namely 3 per second).
e. Use $F = \frac{\textit{Change of momentum}}{\text{time (1 second)}}$ to find the average force on the plate.

78 A small hose shoots water at the rate of 6 gm (0·006 kg) per second at a vertical steel plate with a horizontal velocity of 11 metres per second. The water rebounds with practically the same speed with which it hit the plate. Find the force exerted on the plate.

This is the same as 77, and the answer is the same. The only difference is that, instead of 3 balls, we take '1 second's worth' of water (0·006 kg), and go straight to answer (*d*).

Newton's Second Law

Newton's First law was stated at the end of Section 4.

Law 1. 'Every object continues to move with constant speed in a straight line, or to remain at rest, unless some unbalanced (resultant) force acts on it.'

Now we can go on to Law 2, which says what happens when a resultant force does act.

Law 2. 'When an unbalanced (resultant) force acts on an object the gain of momentum produced is proportional to the force multiplied by the time for which the force acts.'

Instead of 'is proportional to' we can put 'equals', *provided* we measure the quantities concerned in a proper and consistent system of units. One such system is the one we have been using, based on metres, seconds, kilograms, newtons, etc. Newton's law 2, expressed as an equation is:

$$F = \frac{mv - mu}{t}, \text{ or } Ft = mv - mu$$

$$\textit{impulse} = \textit{momentum gained}$$

Another way of writing this is to put $\frac{v-u}{t} = a$, the acceleration, and then we get:

$$F = ma,$$

which was the equation we first got from the trolley and ticker-tape experiments.

11 $F = ma$ applied to flow of liquids and gases

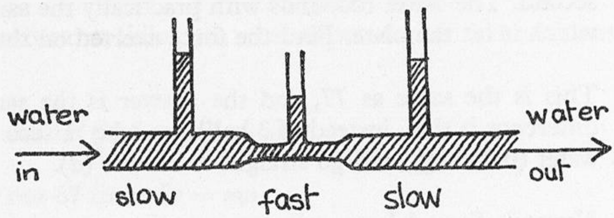


Figure 79

79 Figure 79 illustrates an experiment you have performed or seen performed. Describe the experiment and say what happened.

80 Newton's Second Law, $F = ma$, shows that anything having mass, including liquids, and gases as well as solids, needs force to accelerate it. Also, pressure is force per unit area. Now use figure 79, to explain why 'pressure is smaller where flow is faster'. It will help if you imagine a little submarine (an oblong piece of wood of the same density as the water) moving along with the water. Start your answer as follows.

'In the wide part, A, the submarine is moving along fairly slowly with the water. It is not changing its motion. In the narrow part, B, the submarine is moving much faster, but is not changing its motion. At C, where the tube is narrowing, the water has to change from slow flow to faster flow and the little submarine must change speed too.' Now go on to say what you can about the forces acting on the front end, and on the stern, of the submarine. In which part of the tube, A or B, is the pressure smaller?

Then tell the story about the submarine when it reaches the position D.

81 Tear off two strips of paper about 13 inches long (foolscap) and 2 inches wide. Stand upright, but bend your neck so that your face is towards the ground. Hold one strip in one hand so that it hangs vertically with the top end touching the tip of your nose. Hold the other strip in the other hand with its top end touching your chin. Blow. What happens? And why?

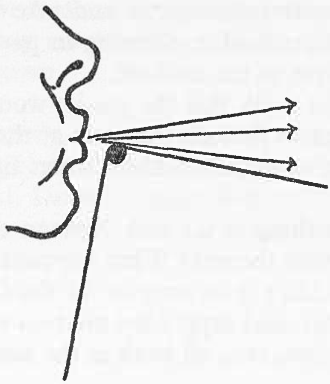


Figure 82

82 Now fold one of the paper strips of the previous question in the middle, so that the two parts are at about 90° with each other. With a finger and thumb of each hand, hold the strip so that the bend is touching, or close to, your lower lip (figure 82). Blow. What happens? And why?

83 Apparatus: cotton reel (with or without cotton) having a clear central hole. Postcard, preferably the $4\frac{1}{2}'' \times 3\frac{1}{2}''$ size. Pin. Draw the diagonals of the postcard and so find its centre. Stick the pin through the centre.

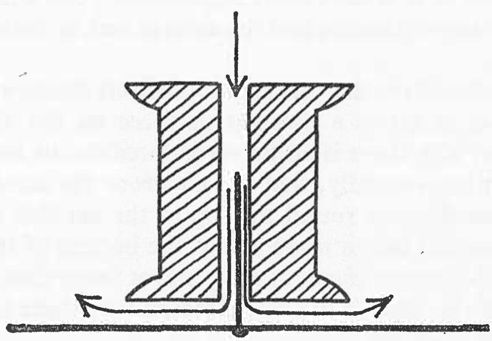


Figure 83

Hold the reel in one hand and the card in the other, so that they are in the position of figure 83, but touching each other. Blow hard down the hole, and at the instant you start to blow, let go of the postcard. What happens? How do you explain it?

84 *a.* Look at a Bunsen burner and take it to pieces. Then draw a sectional diagram of it, showing in particular the position of the gas-jet relative to the air-hole.
b. You might think that the gas-jet would push air and gas *out* of the hole, but in fact air comes *in* at the hole, mixes with the gas and is burnt at the top of the burner. Explain why air comes in at the hole.
c. This is nothing to do with Newton or Bernoulli, but why has air mixed with the gas? What happens when the Bunsen 'lights back'? Wouldn't it be simpler for the Gas Board to mix in air at the gasometer, and supply the mixture all ready for burning? (Gas stoves, gas fires, etc., all work in the same way as a Bunsen.)

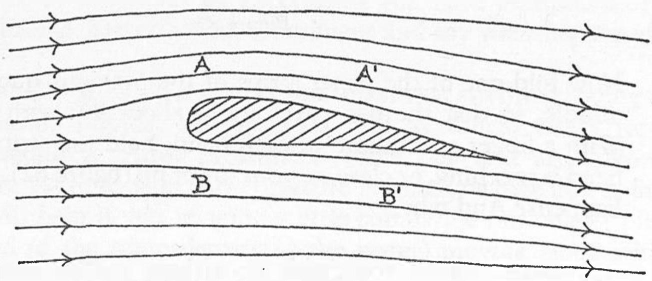


Figure 85

85 Figure 85 shows an 'aerofoil' section, such as the section of the wing of an aircraft. The arrows indicate air moving past a stationary aerofoil as in wind-tunnel experiments; but it makes no difference if the aerofoil moves and the air is at rest, as for an aircraft in flight.

a. Notice, first, that the aerofoil deflects the air stream downwards, that is, it exerts a downwards force on the air. So what is *one* reason why there is an upwards force on the aerofoil?
b. Notice, secondly, that the air *above* the aerofoil has to move a greater distance round the top of the aerofoil than the air *under* the aerofoil has to move round the bottom of the aerofoil. Therefore the stream *above*, at AA′, moves faster than the stream below, at BB′. So what is the *second* reason why there is an upwards force on the aerofoil?

(Now you have explained why an aircraft flies.)

86 Two ships attempt to steam on parallel courses, close together. If they do this they are likely to collide. Why? Illustrate your answer with a diagram.

87 Examine a scent-spray, fly-spray, hair-spray, paint-spray or any simple type that sprays when air is blown over the top of a tube dipping into liquid. Draw a simple diagram and explain why the spray works.

12 More about momentum. The Third Law*

88 A body A exerts a force F for a time t on a body B, that is, A gives B an impulse Ft. Equally, B will exert a force F on A, but in the opposite direction, so we call it $-F$. This means that B gives an impulse $-Ft$ to A.

a. Mention (one sentence for each) four examples of 'a body A exerting a force on a body B', while B exerts an opposite force on A.

Let $m_B v_B$ be the *change* of momentum A produces in B, and let $m_A v_A$ be the *change* of momentum B produces in A.

b. What do m_A, m_B, v_A, v_B stand for?
c. Prove that,

$$m_A v_A + m_B v_B = 0.$$

89 *a.* Express in words what equation 88 (*c*) tells us about *change of momentum* when bodies exert forces on each other.
b. Express in words what can be said about the *total momentum* of a 'closed system' of bodies.
c. What do you think is meant by a 'closed system'?

90 You have probably verified the principle called 'conservation of momentum' in several different ways, though it is unlikely you have done all those mentioned below! Choose any *one* of these – the one you consider most interesting – and describe how you used it to verify *numerically* the conservation of momentum principle.

Trolley experiments:

a. Collision between moving trolley and trolley at rest, with the trolleys not sticking together.
b. A collision with the trolleys sticking together after contact.
c. A lump of something dropped on to a moving trolley.
d. Two trolleys 'exploding'.
e. Trolleys 'imploding', that is, pulled together by, for example, a stretched elastic band.
f. Trolleys 'colliding' without coming into contact, because they carry magnets. (*g*, *h*, *i*, *j*, see next page.)

* Questions 88 and 89 are difficult and might be omitted altogether or postponed until after Question 92.

g. Carbon dioxide *puck* collision experiments.
h. *Pendulum* collision experiments.
i. Collision experiments between *rolling balls*.
j. Collision experiments with *coins*.

91 Two identical cars A and B stand on a horizontal road bumper to bumper. John stands on the bumper of A with his hands resting on B and pushes hard until he falls off because the two cars have got too far apart. Ignoring the effects of friction, what can you say about the velocities of the two cars:

a. at the moment (time t) John falls off?
b. at any earlier moment than t?
c. at any moment after t?
d. How are the answers to (*a*), (*b*), and (*c*) affected if both cars are subject to small equal frictional forces?
e. What effect would it have had if, instead of falling off, John had managed to remain standing on the bumper of A?

92 The experiment of the previous question is repeated, but car A now carries passengers while car B remains empty. The effect of this is to give car A a mass equal to $1\frac{1}{2}$ times that of car B. John pushes the cars apart as before until he falls off. Ignoring the effects of friction, what can you say about the velocities of the two cars:

a. at the moment (time t) John falls off?
b. at any earlier moment than t?
c. at any moment after t?

93 A bullet of mass m_B, having a high velocity v_B, is fired into a lump of matter of mass m_L. The bullet does not emerge, and the lump acquires a velocity v_L.

a. Use the conservation of momentum principle to show that,

$$v_B = \frac{(m_L + m_B)v_L}{m_B}$$

b. Usually it is quite sufficiently accurate to simplify this to
$v_B = \dfrac{m_L v_L}{m_B}$ Why?
c. Describe briefly an experiment in which you have found the velocity of an air-gun bullet by this method.

94 Figure 94 (i) is the outline of a plan of a cloud chamber. It is set up so as to show tracks of α-particles.

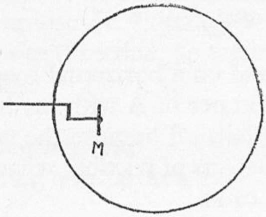


Figure 94 (*i*)

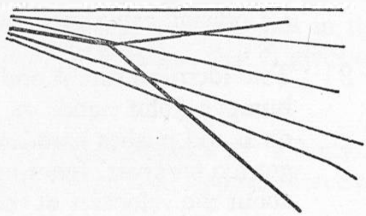


Figure 94 (*ii*)

a. What is there on the metal plate M?
b. Copy the diagrams and draw in two or three possible tracks, as you might see them at one instant.
c. What do the tracks consist of?
d. A thumb-print is not a thumb, but it shows where a thumb has been. What do the tracks show?
e. A very large majority of the tracks are straight, and there is no visible evidence of violent collisions. What does this suggest about atoms?
f. Sometimes a track does show a sudden split into two tracks, figure 94 (ii). How do you explain this?

95 *a. Continuing from question 94.* If the gas in the cloud chamber is helium, instead of air, then the angle between the two branches of a split track is always 90°. What does this tell us about α-particles?
b. How would you use two pendulums, or two heavy ball-bearings, to demonstrate to Uncle George that your answer (*a*) is true?
c. A better demonstration might be given by using two ping-pong balls hung on long nylon threads. The balls have been coated with carbon to make them conducting. How would you give this demonstration of 90° paths after collision?
d. In one way, (*c*) is more realistic than (*b*) as a demonstration of something similar to an α-particle collision in helium. Why is it more realistic?

13 Fuels: work and energy: revision

(The questions in this section are taken from Years I and II.)

96 Here is a list of ten 'jobs' done by living and non-living things. Which of these is a 'fuel-using' job, and which requires no fuel?

a. A man hoisting a sack of potatoes off the ground on to his back.
b. Pillars holding up a roof.
c. Air molecules in motion.
d. A piston moving in and compressing gas.
e. A man winding a clock spring.
f. A clamp tightly holding a piece of wood.
g. A refrigerator keeping things cold on a hot day.
h. Water keeping a boat afloat.
i. A bus moving along a horizontal road on a windy day.
j. A man or a computer doing sums.

97 An engine pumps water from a lake to a high reservoir. To raise 200 gallons of water 300 feet above the lake the engine uses up (burns) 1 pint of diesel oil.

a. How many pints of oil would be required to pump 400 gallons to a height of 300 feet?
b. How many pints to pump 200 gallons to 600 feet?
c. How many pints to pump 400 gallons to 600 feet?
d. How many pints to pump 600 gallons to 450 feet?
e. If 1 gallon of water weighs 10 lb, how many foot-pounds of energy does the engine provide when it uses 1 pint of fuel?
f. Not *all* the energy of the fuel goes into raising water. Suggest two or three ways in which energy is 'wasted'.
g. In what form does wasted energy finally appear?

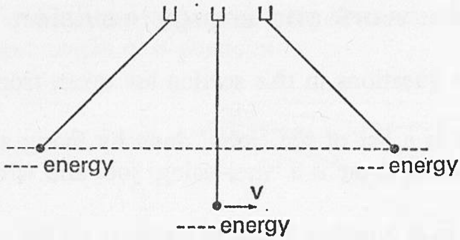


Figure 98

98 The figures show three positions of a swinging pendulum bob, the two extreme positions on either side, and the central position where it is moving with the maximum speed v. Each figure is drawn to represent either kinetic energy or potential energy. Copy the figures and write in the correct word in each case.

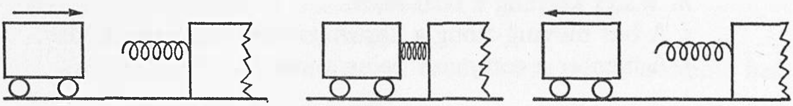


Figure 99

99 Similarly copy each of the three figures above and label it either 'kinetic energy' or 'strain energy'. Then write two or three sentences telling what energy changes take place when 'truck hits buffers'.

100 Copy out (*a*) to (*g*) below, completing (*b*), etc., in the same way as (*a*). See next page for (*e*), (*f*), (*g*).
(*Note*: Energy from man or animals, derived from food, is chemical energy.)

a. Child spins top, top hums and finally comes to rest. Energy changes: chemical → kinetic energy → heat
↘ sound ↗

b. Car generator charges accumulator, which, later on, lights headlamps.
Energy changes: . . .

c. Wind turns 'windmill' sails of a windpump, windpump raises water out of ditch into a river at a high level.
Energy changes: . . .

d. Water in high-reservoir runs down large pipes and turns blades of turbine wheel at the bottom, turbine drives electric generator; generator supplies current to electric fire in your room.
Energy changes: . . .

e. Bullet placed in rifle, trigger pulled, hot gases formed in gun-barrel, bullet shot out, hits wall.
Energy changes: . . .

f. Nuclear reactor makes high pressure steam which turns a steam turbine which drives a generator which makes electricity.
Energy changes: . . .

g. Radium atom emits fast alpha-particle which hits a fluorescent screen and makes a faint 'splash' of light.
Energy changes: . . .

101 A brick having weight equal to 25 newtons is lying on the ground. A man picks it up and raises it to 1·6 metres above the ground. He then allows it to fall.

a. What is the energy-transfer, or work (joules) when the man lifts the brick?
b. What is the increase of potential energy of the brick when it is lifted 1·6 metres above the ground?
c. What is its kinetic energy just before it hits the ground?
d. What happens to this energy after it hits the ground?

102 Suppose, in the last question, that the brick, instead of hitting the ground, had fallen into a hole 0·4 metres deep.

a. What is its kinetic energy just before it hits the bottom of the hole?
b. How do you account for the fact that it seems to have acquired more kinetic energy than is equivalent to the work?

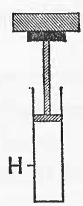


Figure 103

103 A brick is put on top of a piston that encloses air in a cylinder (like a bicycle pump – with the end closed). The piston descends, oscillates up and down two or three times, and comes to rest 4 inches lower down than it was before. The gas is compressed when the piston moves down. The brick and piston together weigh 7 lb.

a. How much potential energy was lost as the piston fell 4 inches?
b. Why did the piston fall, at first, more than 4 inches?
c. Why did it come up again?
d. Why did it finally come to rest?
e. What could have happened if there had been a very small hole in the top of the piston?
f. Suppose the piston was airtight, but there was a very small hole at the point H in the diagram. Which of the following statements is correct? Give the reason for your answer.

(*i*) The piston stops at H.
(*ii*) The piston falls to the bottom of the pump.
(*iii*) The piston stops above H.
(*iv*) The piston stops below H.

104 Remember that we have explained gas pressure by saying that it is caused by the motion of the molecules of the gas. A bicycle pump is held with the handle at the top, *and the lower end is open*. The handle (and piston) is pushed down.

a. What change in the motion of the air molecules in the pump occurs as the piston moves down?
b. How does this change take place? That is, how does it happen?
c. What happens to the air?

Now think of the pump *with the lower end tightly closed*.
Again the piston is pushed down: let us say, half-way along the pump barrel.

d. Does the change you mentioned in (*a*) still take place? If you say *it does not*, give the reason for your answer. If you say it *does*, then answer (*e*) below.
e. The air cannot now get out of the pump. Yet the piston pushed the molecules downwards (you have agreed). What has happened to this downward motion of the molecules? And what can you say about the temperature of the air in the pump?

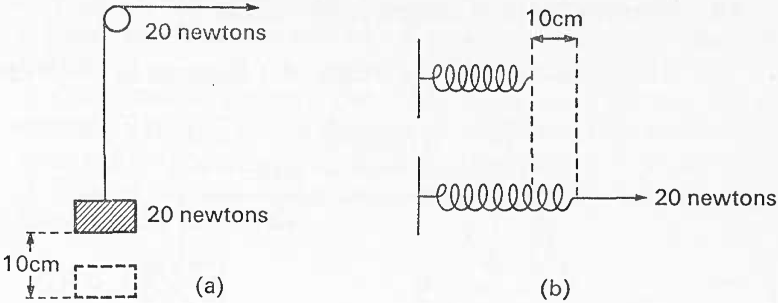


Figure 105

105 *a.* A man lifts a 20-newton load through a height of 0·1 metre (10 cm). How much gravitation potential energy is thereby given to the load?
b. A man extends a spring through a distance of 10 cm (0·1 metre). The force he finally needs to hold the spring in position is 20 newtons. All the time he is stretching the spring he uses no more force than is necessary to stretch it, that is, the first bit of stretch is accomplished with a force that is practically zero, and only at the end does he have to exert 20 newtons. Why, in doing this, does he store less potential energy in the spring than was stored in the load (question (*a*)) when it was lifted 0·1 metre?
c. Make a guess at the actual amount of potential energy likely to be stored in the spring in question (*b*). (The obvious answer is the correct answer, provided that the spring obeys Hooke's law.)

106 It is possible to convert heat into other forms of energy, or at any rate, to convert some of it. The essential thing in any machine that converts heat into some other form is that there must be a difference of temperature that the machine can use.

a. Give the name of some form of heat conversion machine and say how the necessary high temperature is obtained.
b. Conversely, if we have a number of things all at the same temperature (all at room temperature for example) we cannot continuously maintain a difference of temperature without supplying energy from outside. Very likely you have in your home, or have seen somewhere, a machine which, starting with everything at room temperature, makes some things hotter and other things colder. What is it called? And, in the one you are thinking about, in what form does it get its supply of outside energy?

14 Machines and energy. Friction

(In this section take the weight of 1 kilogram to be 10 newtons.)

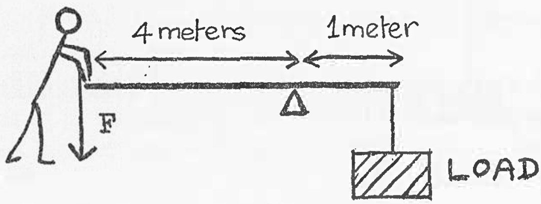


Figure 107

107 A man uses a long plank to lift a heavy load. He arranges the plank across a pivot as shown in the diagram. By pushing downwards with an effort, F, he can just lift a 100-kg load.

a. What is the pull of the Earth on the load?
b. How big must the effort F be?
c. How many times bigger than the effort is the load?
d. If the plank swings on the pivot so that the effort moves down, how much energy is transferred from the man to the plank?
e. How far is the load raised?
f. How much energy is transferred from the plank to the load?
g. Is there any gain or loss in energy corresponding to the gain in force found in (*c*)?

108 If the pivot of the plank in question 107 were in the form of a rather rusty steel rod fixed to the plank and running in holes in two rusty steel plates, what difference would it make to the above answers? Take each answer in turn and guess some suitable figures. What is now your answer to (*g*)?

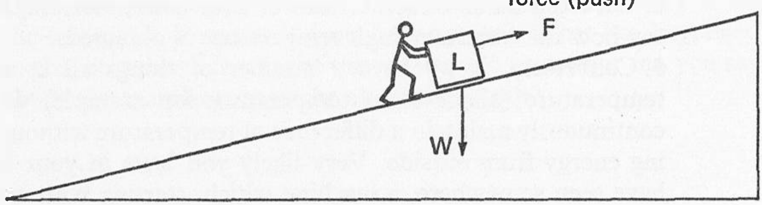


Figure 109

109 A man pushes a 30-kilogram load a distance of 12 metres up a smooth frictionless slope of 1 in 4.

a. Through what *vertical* height does the load rise?
b. Find, in joules, the amount of potential energy the load has gained.
c. This potential energy is due solely to the work the man did in exerting a force F over a distance of 12 metres. Equate the work done and the energy gained, and so find the value of F (in newtons).
d. What is the ratio of the force the man exerts to the pull of the Earth on the load?

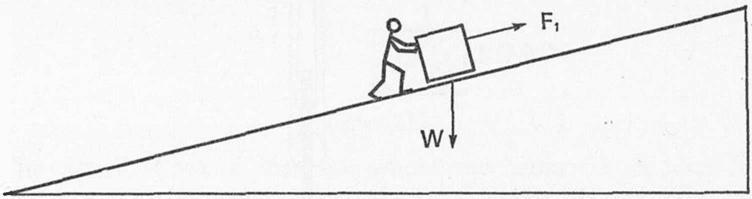


Figure 110

110 A frictionless slope like that of question 109 is, of course, unobtainable in practice. Figure 110 shows a *rough* slope and now the man exerts a force, F_1, pushing a 30-kg load up the slope.

a. Is F_1 bigger or smaller than F (question 109)? Why?
b. If $F_1 = 125$ newtons, how much work does the man do in pushing the load 12 metres?
c. How much potential energy is gained?
d. How much of the energy the man provided has *not* been transferred to potential energy?
e. What has happened to it?
f. How much is the frictional force that the man has to overcome when he pushes the load up the rough slope? Whereabouts does this frictional force act?

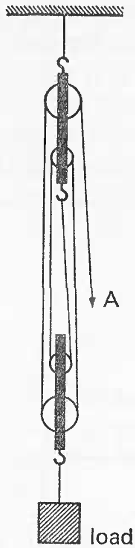


Figure 111

111 The figure shows a set of four pulleys being used for raising a 12-kilogram load.

a. If the load is to be raised 1 metre, how far must the rope at A be pulled? (Think of the length of 'slack' produced when the load is raised.)
b. The *least* value of the effort required to keep the load moving upwards is 40 newtons, *not* 30 newtons. Give two reasons why this is so.
c. How much energy is transferred by the effort in raising the load 1 metre?
d. How much potential energy is transferred to the load?
e. The 'efficiency' of a machine may be defined as the percentage,

$$\frac{\text{energy transferred from machine to load}}{\text{energy transferred from effort to machine}} \times 100\%$$

What is the efficiency of this pulley system?

Note : Figure 111 is drawn as it is in order to make the pulley arrangement quite clear. In fact, the pulleys in each block would be on the same axle, next to each other, though free to turn separately.

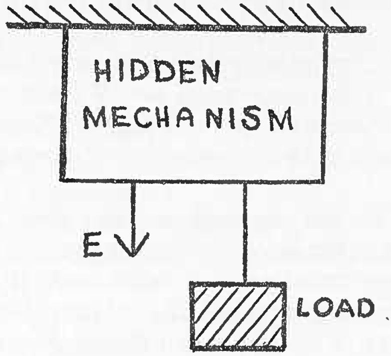


Figure 112

112 The figure shows a machine whose mechanism is hidden (it might be a set of gears). When the rope labelled E, for effort, is pulled down 7 metres the load rises 1 metre.

a. If the effort is 20 newtons, and the machine is entirely frictionless, what is the maximum load that can be raised?
b. What can you say about energy input and energy output under these conditions?
c. In fact, the machine is not frictionless, and it is found that an effort of 25 newtons is required to keep a load of 140 newtons moving steadily upwards. What do you think would be the *least* effort required to hold a load of 140 newtons so that it is just prevented from falling?
d. What happens when the effort rope is let go so that there is no force on it?
e. The machine is left in a damp shed and gets a little rusty. An effort of 45 newtons is now required to raise the 140 newtons load. What happens now when the effort rope is let go? Why?

113 *a.* A 'screwjack' is used for lifting a car when a wheel has to be changed. All such screwjacks are so inefficient that more than half of the effort exerted is used in overcoming friction in the jack. This inefficiency is, however, of considerable usefulness to the user; why?
b. A machine like that in (*a*) is said to 'overhaul'. Suggest why this term is used (think of an inefficient pulley system).

15 Work done in producing kinetic energy

At the beginning of Section 10 we multiplied *force* by *time*, Ft, and equated it to momentum, mv. We arrived at a new method of solving problems, a new statement of Newton's Second Law, and a new principle, the conservation of momentum.

In this Section we shall multiply *force* F by *distance* s, in the direction of the force, getting the product Fs. This is a measure of the energy-transfer and is called *work*. If the energy goes entirely into increasing the speed of an object, then we can put Fs equal to the energy of motion, called *Kinetic Energy*, gained by the object.

In Section 10 we took the simplest possible meaning for momentum, the product mv, and discovered that it was equal to Ft. Kinetic energy obviously cannot be the same as momentum, otherwise Fs would be equal to Ft, which would be silly. Kinetic energy must be represented by some other expression containing m and v. What expression? It is easy to show that kinetic energy $= \frac{1}{2}mv^2$ (see question 115). However, this proof applies only to cases of *constant force*. The expression $\frac{1}{2}mv^2$ is correct whether or not the force is constant, and the rather more difficult geometrical proof, question 114, does not need the assumption of constant force. (You will not be asked to remember these proofs for examinations.)

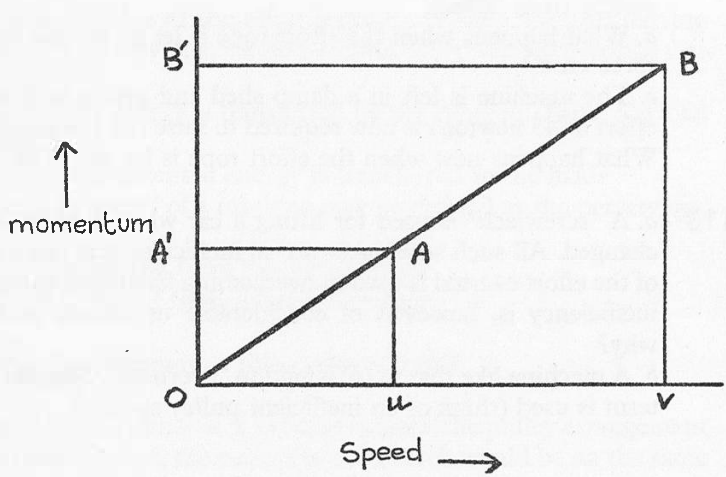


Figure 114

114 Figure 114 is a graph of the momentum of a moving object plotted against speed. The object accelerates from a speed u to a speed v, not neccessarily with a constant acceleration.

a. What does A′A represent?
b. Explain why the area OA′A represents $\frac{1}{2}mu^2$.
c. What does B′B represent?
d. What does the area OB′B represent?
e. Explain why the area A′A BB′ represents $(\frac{1}{2}mv^2 - \frac{1}{2}mu^2)$.

These questions (*a*) to (*e*) are easy, and you should have no difficulty in answering them. The last part, (*f*), is difficult, and you should not attempt it unless you have already heard about it.

f. Prove that the area A′A BB′ is the increase of kinetic energy, Fs, which occurs when the speed of the moving object increases from u to v.

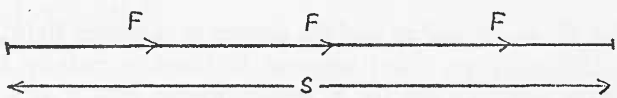


Figure 115

115 A steady force F acts on an object of mass m and increases its speed from u to v while it moves a distance s. The energy-transfer (work) is equal to Fs. We are going to show that $Fs = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$, which is the increase of kinetic energy. Of course, if the object was at rest to start with, then $u = 0$, and $Fs = \frac{1}{2}mv^2$.

Line (*a*) $Fs = F \,.\, \dfrac{u+v}{2} \,.\, t$

Line (*b*) $Fs = ma \,.\, \dfrac{u+v}{2} \,.\, t$

Line (*c*) $Fs = m \,.\, \dfrac{v-u}{t} \,.\, \dfrac{v+u}{2} \,.\, t$

Line (*d*) $Fs = \frac{1}{2}m\,(v-u)\,.\,(v+u)$

Line (*e*) $Fs = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

a. What do u and v mean, and where does $\dfrac{u+v}{2} \,.\, t$ come from?

b. Where does this come from?
c. What have we done here?

Lines (*d*) and (*e*) are just rearranging the symbols and putting $(v - u) \, . \, (v + u) = v^2 - u^2$. Also,

f. In which of the five lines, (*a*) to (*e*), have we made use of the fact that F is a force having a steady constant value?

116 Use $Fs = \frac{1}{2} mv^2$ to solve the following problem.

A long train of goods wagons has a total mass of 800,000 kg. The train is accelerated from rest to a speed of 15 metres per second by a locomotive which exerts a steady pull of 100,000 newtons. Show that the distance covered in reaching this speed is 900 metres.

(As a matter of interest we can quickly turn these figures into British units, approximately. 800,000 kg = 800 tons; 100,000 newtons = a force of 10 tons weight; 15 metres per second = 33 mph. Is 900 metres more or less than $\frac{1}{2}$ mile?)

117 Use $Fs = -\frac{1}{2} mu^2$ to find the answer to question 70 (*b*), Section 9. In this question, $v = 0$ because the hammer ends up at rest. The minus sign you get for F merely means that F is a 'stopping' force, acting in a direction opposite to the direction in which s is measured.

118 Use $Fs = -\frac{1}{2} mu^2$ to solve question 68, Section 9. You still have to work parts (*a*) and (*b*), to find the boy's speed. Then go straight to part (*e*).

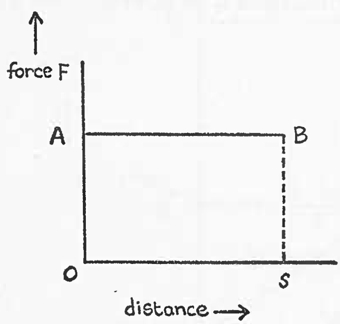


Figure 119 (*a*)

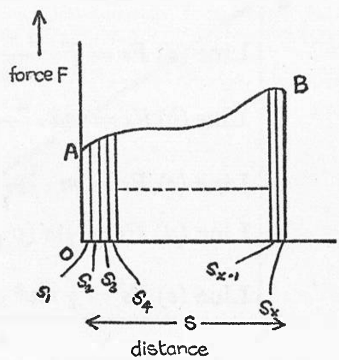


Figure 119 (*b*)

119 Figure 119 (*a*) shows force plotted against distance for a constant force F, e.g. a steady pull in an elastic thread used to accelerate

a trolley. Figure 119 (*b*) shows a force which varies with distance, e.g. a changing or jerking pull in the elastic thread, or, to take quite a different example, the force exerted on a bullet in a rifle barrel as the bullet moves down towards the muzzle of the rifle.

a. What, in 119 (*a*) represents the *work*, *Fs*, when the constant force F moves the distance s? Why?
b. What do you guess, in figure 119 (*b*), represents the total work when the varying force F moves the distance s?
c. Prove that your answer to (*b*) is correct. The distance s has been divided for you into portions $s_1, s_2 \ldots s_x$. You can suppose that the force is F_1 over s_1, F_2 over s_2 and so on.

120 Give a *brief outline* of an experiment in which you measured $\frac{1}{2}mv^2$, the kinetic energy gained by a trolley from a catapult – steel strip, rubber band, or spring – and also measured the strain energy released from the catapult. Give *full details* of how you measured (*i*) $\frac{1}{2}mv^2$, (*ii*) *Fs*.

121 What is Galileo's 'pin and pendulum' experiment, and why did Galileo think it important?

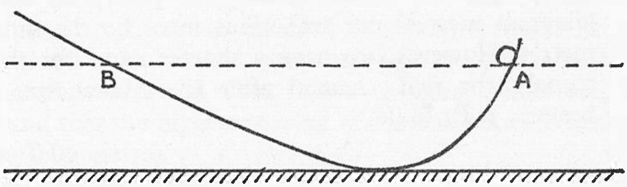


Figure 122

122 (*Difficult*) Freddie Jones bent some curtain rail in the shape shown, figure 122, and held a steel ball at A. He then released it, but it did not reach B, at the same level as the other side. Close observation showed that it skidded without rolling over the first few centimetres at A, where the slope is steep, then it started to roll. *Question*. Why didn't it reach B? *Answer*. Friction. But where was the high frictional loss, and why didn't it occur in other parts of the ball's travel?

123 A pendulum bob is given potential energy (position energy) by being lifted with the string kept taut. It is then released. It swings for a long time, but finally stops. Explain the energy changes that occur, and say what you think has happened to the original energy when the pendulum has stopped swinging.

16 Problems on momentum and kinetic energy

In all problems in this section where g is required, put,

$g = 10$ newtons per kg (gravitational field strength) or,
$g = 10$ metres/second per second (acceleration).

These are, of course, two ways of saying the same thing. The number, 10, is a close enough approximation.

Equations that may be useful.

$v = u + at$
$s = ut + \frac{1}{2}at^2$ It is often quicker to use commonsense!
$F = ma = \dfrac{mv - mu}{t}$
$Fs = \frac{1}{2}\,mv^2 - \frac{1}{2}\,mu^2$ $Ft = mv - mu$

Units. Work = force × distance, Fs, which is measured in newton · metres. Putting $Fs = mas$, we see work could also be measured in 'kilogram · metres/sec per sec · metres', or 'kilogram metres^2 per sec^2'. Kinetic energy $= \frac{1}{2}\,mv^2$, and also has the units kilogram metres^2 per sec^2. This must be the same as newton · metres. However, we have a shorter name for the energy unit, namely the *joule*, named after the Manchester physicist and brewer, J. P. Joule.

1 joule = 1 newton · metre

Definition: 1 joule is the work done, or energy produced, by a force of 1 newton moving a distance of 1 metre in the direction of the force.

124 Taking the value for g, 10 newtons per kilogram, find how far you have to raise a 1 kg-weight in order to give it an extra joule of potential energy.

125 A 0·1-kilogram ball falls vertically from a height of 3 metres on to a horizontal steel plate and rebounds to a height of 2·5 metres. (*d* and *e* on next page.)

a. What is the potential energy of the ball before the fall?
b. What is its kinetic energy as it strikes the plate?
c. What is its kinetic energy as it leaves the plate on rebound?

d. What happens to the energy which represents the difference between (*b*) and (*c*)?
e. In order to calculate (*b*) you had to ignore something – what was it?

126 A falling load of 5·0 gm is arranged to accelerate a 1·0-kg trolley down a friction compensated track. The load falls 1 metre before hitting the floor. After the load has hit the floor the trolley is timed over a distance of 1 metre.

a. What is the potential energy transferred from the falling load?
b. Assuming all the potential energy is transferred to kinetic energy of the trolley, how fast will the trolley be moving? How long will it take to travel the 1 metre distance over which it was timed?
c. The assumption made in (*b*) is not *quite* correct: a little bit of potential energy is transferred to some other form than kinetic energy of the trolley. To what form is it transferred?
d. If we took account of the little bit of energy in (*c*), would the answer to the first question in (*b*) be the same, or greater, or less?

127 A heavy pendulum had a 0·2-kg bob on a thread 1·0 metre long. A multiflash picture was taken as it swung through its central position, with 50 flashes every second. A horizontal scale of centimetres was placed close to the swinging pendulum, and it was found that the biggest spacing of the bob between flashes was 6·0 cm (0·06 metre).

a. Find the maximum velocity of the bob.
b. Find its maximum kinetic energy.
c. Find the height to which the bob rises in its extreme position.
d. *Either* by scale drawing, *or* by trigonometry, find the angle of swing of the pendulum, i.e. the angle between the central and the extreme positions.

128 A 0·03-kg bullet travelling horizontally at 600 metres per second enters a bank of earth. It penetrates the bank to a depth of 3 metres.

a. What is the kinetic energy of the bullet before impact?
b. Find the average force of retardation acting on the bullet.

129 A 0·02-kg bullet is fired at 400 metres per second into a block of wood fixed to a trolley running on a friction-compensated track. The trolley, plus wood, plus bullet weigh 2·0 kg. The bullet embeds itself in the block of wood, and the trolley, wood, and bullet move down the track. Calculate:

a. the speed of the trolley after the impact (remember to use the principle of Conservation of Momentum),
b. the kinetic energy of the bullet before impact,
c. the kinetic energy of trolley, wood, and bullet after impact,
d. the kinetic energy lost during the impact.
e. Express (*d*) as a percentage of (*b*).
f. Into what forms is the lost K.E. transferred?

130 A car's brakes can exert a retarding *force* equal to one-half the *weight* (= pull of the Earth) of the car. The brakes are applied when the car is travelling at 30 metres per second (about 66 mph).

a. If $m =$ mass of the car, what is its weight in newtons?
b. What is the retarding force of the brakes in newtons?
c. Use $Fs = \frac{1}{2}\, mv^2$ (or more correctly, $Fs = -\frac{1}{2}\, mu^2$) to find the stopping distance of the car.
d. How long does the car take to stop?
e. Comment on the likely results of 60 mph travel in misty or foggy conditions on a motorway.

131 A 1000-kg gun fires a 30-kg shell horizontally with a velocity of 500 metres per second.

a. Find the velocity of recoil of the gun.
b. Calculate the initial kinetic energies of the gun and of the shell.
c. What fraction of the *total* kinetic energy does the shell carry?
d. Find the constant force necessary to absorb the recoil of the gun in a distance of 40 cm (0·4 metre).

132 Turn back to question 114 and copy the diagram, figure 114. Now draw on your diagram, in dotted lines, similar graphs for:

a. a moving object having one-half the mass,
b. a moving object having twice the mass.

17 Revision of kinetic theory. (Introduction for those who missed Years I and II)

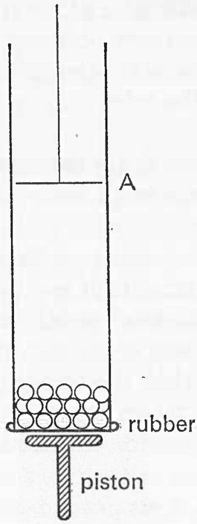


Figure 133

133 The diagram shows a wide glass tube with a base made of sheet rubber. The rubber can be kept in up-and-down motion by a piston fixed to a vibrating rod. A number of small balls are dropped into the tube. They are then enclosed by a light disc which is supported at the position A by the impacts of the balls.

a. Draw a sketch showing what the apparatus looks like when the piston and balls are in motion.
b. Write a few sentences pointing out the resemblance in behaviour between air molecules and the balls in the tube (including the way in which the disc is supported).
c. When a small load is placed on the disc, the disc
(*i*) falls a little way, and
(*ii*) comes to a new equilibrium position. Why does it behave in this way?
d. In order to keep the balls in motion, energy has constantly to be fed in by the piston. But no energy has to be supplied to air molecules in a room to keep them in constant motion. Why is there this difference?
e. If we raise the temperature of the air, we believe the molecules move faster. How can we 'raise the temperature' of the balls in the tube?

134 *a.* How could we make the apparatus of figure 133 resemble the whole of the atmosphere vertically above us, instead of a sample stopping at the ceiling?
b. Write a few sentences pointing out resemblances to and differences between the real atmosphere above us and the imitation 'atmosphere' in the tube.

135 You have seen, through a microscope, the 'Brownian motion' of smoke particles in a small box.

a. Describe the motion the smoke particles had and illustrate, with a sketch, the movements of one particle.
b. Explain why the motion of the smoke particles suggests that air molecules are also in motion, with much greater speeds.
c. Particles larger than the smoke particles would be easier to see. What *two* disadvantages would there be in using larger particles for the Brownian motion experiment?

136 A ping-pong ball is suspended on a fine thread in a closed, and entirely draught-free, room. Would the ball be completely at rest? Write a sentence or two in explanation.

137 *a.* Draw a diagram of, and explain briefly, one experiment you have seen which shows diffusion occurring in liquids, and,
b. one experiment which shows diffusion in gases. (If you haven't seen or heard of these experiments, leave this unanswered.)

138 Explain the difference between the processes by which
(*i*) air heated by an electric fire warms a room by convection, and
(*ii*) a layer of carbon dioxide gas beneath air diffuses into the air.

139 Robert Boyle, who lived in the seventeenth century, carried out many experiments on the pressure of gases, and discovered a famous law that bears his name. In 1661 he read a paper to the Royal Society of London entitled, 'Touching the Spring of Air'.

He supposed that air consists of particles in contact with each other and furnished all round with springs – perhaps nowadays we might think of 'particles' made of sponge rubber.

a. How, on this theory, would Boyle explain the pressure of a gas, and the fact that a gas resists compression?

Boyle's observations, and his law, were firmly based on experimental fact, but his theory was not found useful, and we now have a different theory, which explains pressure by means of particles in motion.
b. How does the motion theory of gas particles explain the fact that gases can exert pressure?

140 Even the best of toy balloons 'go down'. A few days after they have been blown up, there is no pressure inside, and most of the gas has escaped ('no pressure' means that the pressure is not above atmospheric pressure). This is because they have tiny pores through which the gas escapes. Even if the balloon has been blown up with air, it still goes down. Why does not air from outside diffuse in as fast as air from inside diffuses out, thereby keeping the balloon blown up?

141 *a.* Unless a gas is kept in a closed container it diffuses out until it occupies (mixed perhaps with other gases) all the space available to it – this is a fact of common observation. There is no container round the Earth's atmosphere, and yet the atmosphere remains without any apparent diminution of pressure from one year to the next – fortunately for ourselves. How do you explain this?
b. Some astronomers believe that, many millions of years ago, the Earth had an atmosphere consisting mainly of hydrogen. Most of this has gone. Where has it gone? Why would the Earth lose an atmosphere of hydrogen much more quickly than one made up of, for example, nitrogen?

142 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. How does the distance between the molecules in the tube compare with the distance between the molecules in the air outside?

The picture is made by a stream of 'electrons' which shoot across the tube and fall on the coated screen, thus making it luminous. Explain what would happen if the pressure in the tube were not very low.

143 This is not a numerical question; answer (*a*) to (*h*) below by writing 'greater', or 'less', or 'the same'. (Part (*i*) cannot be answered so easily.)

A motor-car tyre is pumped up to a pressure of 30 p.s.i.* at midday, when the temperature is 15° C. That night the temperature falls to 5° C. The tyre *does not leak*, and *its volume remains the same*. What happens to:

a. the number of molecules in the tyre,
b. the average speed at which a molecule moves,
c. the average distance a molecule moves between one collision and the next,
d. the average time between one collision and the next,
e. the pressure in the tyre?

The motorist pumps up the tyre to 30 lb per sq. in. again, the temperature still being 5° C. Compared with the original condition (when the pressure was 30 p.s.i. at 15° C), what happens to:

f. the number of molecules in the tyre,
g. the average speed at which a molecule moves,
h. the average distance a molecule moves between one collision and the next,
i. the average time between one collision and the next? Give your ideas about this in not more than three sentences.

* *p.s.i.* stands for 'pounds-weight per square inch', which is how a garage mechanic measures pressure. One p.s.i. is approximately equal to 7,000 newtons per square metre, but in this question you do not need that information.

18 Kinetic theory applied to Boyle's Law

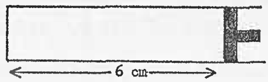


Figure 144 (*i*)

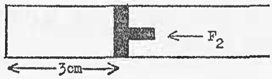


Figure 144 (*ii*)

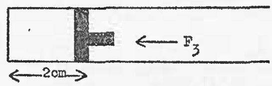


Figure 144 (*iii*)

144 Answer questions (*a*) to (*j*) by writing 'twice', 'half', 'three times', 'the same', etc., whichever you think to be the correct answer. Figure 144 (*i*) shows air enclosed in a cylinder fitted with an air-tight piston; inside and outside the cylinder the pressure is atmospheric, and, with no extra force applied, the piston stays where it is.

In figure 144 (*ii*) the piston has been pushed in so that the enclosed air occupies half the length of the cylinder that it previously occupied. Any heat produced has been allowed to leak away, and the temperature is the same as before. A force F_2 is now required to hold the piston in place. Similarly in figure 144 (*iii*), the air occupies one-third of the length and a larger force F_3 must be exerted.

First we compare figure 144 (*ii*) with figure 144 (*i*). What can we say about:

a. the total number of molecules enclosed? (Is it the same, twice, one-third or what?)
b. the volume of air in the cylinder?
c. the number of molecules per cubic centimetre?
d. the average speed of a molecule?
e. the pressure exerted by the air in the cylinder?

Now compare *figure 144* (*iii*) with *figure 144* (*i*); what can we say about:

f. the total number of molecules enclosed?
g. the volume of the air in the cylinder?

h. the number of molecules per cubic centimetre?
i. the average speed of a molecule?
j. the pressure exerted by the air in the cylinder?

Lastly,

k. Which *two* of the following equations correctly express the changes that take place?

$$\frac{p_1}{v_1} = \frac{p_2}{v_2}; \quad \frac{p_1}{p_2} = \frac{v_2}{v_1}; \quad \frac{p_1}{p_2} = \frac{v_1}{v_2}; \quad p_1v_1 = p_2v_2$$

(p_1 and v_1 are the pressure and volume in figure 144 (*i*), p_2 and v_2 are the pressure and volume in figure 144 (*ii*), or figure 144 (*iii*), or after any similar change.)

145 Look at your answer to part (*f*), question 144 and write one (or at most, two) sentences giving the reason for your answer. Now do the same for answers (*g*) to (*j*).

Lastly, show that your answer to (*k*) agrees with, first, your answers to (*b*) and (*e*), and second, your answers to (*g*) and (*j*).

146 If the force F_2 in figure 144 (*ii*) is 6 kg-wt, what is F_3 in figure 144 (*iii*), and why?

147 The average distance between the centres of two air molecules, at normal atmospheric pressure, is about 10 times the 'diameter' of a molecule (see figure 147).

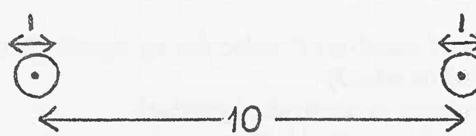


Figure 147

a. What difference would it make to your answers to (*f*) to (*k*) of question 144 if, instead of air, we had in the cylinder a gas whose molecules are twice the size of air molecules?
b. What difference would it make to the force needed to push in the piston in question 144 if the molecules were 5 times as big in diameter?

148 *Difficult.* Suppose air molecules attract each other with a force which is greater the closer they are together. Suppose that, when two molecules are 10 molecular diameters apart (as they are, on average, in air at atmospheric pressure) the force is quite negligible. When they are 2 molecular diameters apart the force is appreciable.

A measured volume of air at atmospheric pressure is compressed so much that the molecules are less than 2 diameters apart, and the new volume is measured. The temperature is the same as before. We now calculate what the new pressure should be according to Boyle's law, and then we measure the actual pressure. Would you expect the actual pressure to be more, or less, or the same as the calculated pressure? Give a reason for your answer. (Consider only the effect of attractions between molecules, and do not worry about any effect due to the *size* of the molecules.)

149 *Difficult. a.* If a real gas, such as air or hydrogen, is cooled to a low enough temperature it becomes a liquid. How is this explained by a molecular theory of gases?
b. A gas in which there was no attraction at all between the molecules would be very peculiar. Mention one peculiar property it would have. (Actually there is no such gas.)

150 A cylinder of oxygen contains $2\frac{1}{2}$ litres at a pressure of 20 atmospheres. What volume of oxygen will it provide to assist a hospital patient's breathing?

Note: One can make up a large number of simple numerical questions on Boyle's law, but it is not worth spending much time on them. Incidentally, there is a slight catch in this question!

19 Kinetic theory. Molecular velocity by 'uniform density' atmosphere

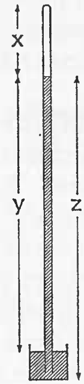


Figure 151

151 The diagram shows a simple barometer.

a. What does it measure?
b. Which height does one measure *x*, *y*, or *z*?
c. Why use mercury in it (not more than two reasons)?
d. What is there in the tube above the mercury?
e. Does the temperature *of the barometer* make any difference to its reading? Explain briefly.
f. If mercury were used which was still damp with water after a previous experiment: would that make any difference?

152 Normal barometric height = 0·76 metre of mercury; mercury is 13·6 times denser than water; 1 cubic metre of water weighs 1000 kg; 1 cubic metre of air weighs 1·2 kg.

a. If the atmosphere consisted entirely of mercury, the pressure at the bottom being the same as it is now, how high would this 'mercury atmosphere' be?
b. How high would a 'water atmosphere' be?
c. How high, then, is an air atmosphere? (Answer to nearest whole kilometre.)
d. In fact, atmospheric air extends much higher than the height calculated in (*c*). Why is this?

153 Write a brief account, with diagrams if necessary, describing the experiments by which you would find (*a*) the density of mercury, (*b*) the density of air at room pressure.

154 *Given:* height of a 'constant density' atmosphere (one in which the density of the air is everywhere the same as at the Earth's surface) = 8·0 kilometres; acceleration of gravity, g = 10 metres/second per second.

a. Use the equation $v^2 = 2gs$ to find the speed, v, at which an object would hit the ground if it fell freely (in a vacuum) from a height, s, of 8 kilometres.

This result is the same whether the object is a brick or a molecule, provided it falls in a vacuum. But, in falling through the atmosphere a brick does not fall through a vacuum; it falls through air.

b. What would in fact happen to a *brick* released at the top of the 'constant density' atmosphere?
c. What would happen to an *air molecule* if, at some instant, it is at rest at the top of the 'constant density' atmosphere, and starts to fall under gravity?
d. So long as it falls, it loses potential energy and gains kinetic energy. What happens to the kinetic energy gained in falling?

155 Of course, the 'constant density' atmosphere of 1·2 kg per cubic metre is a fiction. The density of our *real* atmosphere gets less as we go upwards, and the atmosphere still exists (though very 'thin') at heights of several hundred miles.

a. What would be the speed reached by a molecule that fell to the Earth's surface from a height of 32 kilometres? *Note:* The correct answer to question 154 (*a*) is 400 metres/sec, which is calculated for a height of 8 kilometres. You need not go through all the working again to get the new answer – but it is *not* 1600 metres/sec!
b. What would be the speed of a molecule falling from a height of 2 kilometres?
c. Complete the following sentences: 'Air molecules at different heights in the atmosphere possess different amounts of . . . energy. Similarly air molecules at the same height possess different amounts of . . . energy.'

20 Kinetic theory: proof of $PV = \frac{1}{3} Nmv^2$

Note: In this work you will make further use of an important equation you have used earlier, namely,

force $\times$ time = change of momentum, that is,

$$Ft = mv$$

F is the force which must be exerted during a time interval t in order to change the momentum of a body by mv. In all the problems we have here, the mass m of the body remains the same all the time, so F is the force needed, during a time interval t, in order to change the velocity of a body of mass m by an amount v.

156 A ball of mass 0·3 kg, travelling with a horizontal velocity of 20 metres/sec hits a movable trolley. After hitting, the ball drops vertically, figure 156 (*a*).

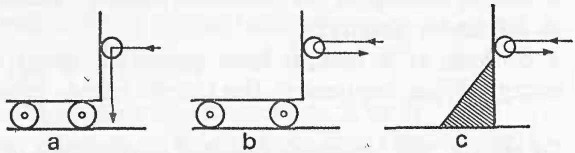


Figure 156

a. (*i*) How much momentum does the ball lose? (*ii*) How much momentum does the trolley gain?

In figure 156 (*b*) the ball rebounds horizontally with the same speed of 20 metres/sec, but, of course, in the opposite direction.
b. (*i*) How much momentum does the ball lose? (*ii*) How much momentum does the trolley gain?

In figure 156 (*c*) there is no trolley; the ball hits a wall rigidly fixed to the Earth. The ball rebounds as in (*b*).
c. (*i*) How much momentum does the ball lose? (*ii*) What gains the momentum, now that there is no trolley to move back?

157 We refer still to figure 156 (*c*). Supposing 100 balls are travelling at 20 metres/sec, and all rebound with the same speed.

a. How much total momentum do the balls lose?
b. How much momentum is gained by the wall, and the Earth to which it is attached?

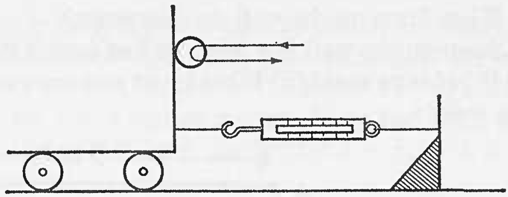


Figure 158

158 Suppose now that the balls of question 157 hit a 'wall' attached to a trolley which is held in place by a spring-balance, figure 158. Suppose, too, that the balls do not reach the wall at once, but at regular intervals, that is, there is a constant stream of balls.

a. The stream is very slow – say 1 ball every quarter-minute. What would you notice on the spring-balance?
b. The stream increases to one ball every 2 seconds. What about the spring-balance reading now?
c. It increases further to two balls a second. What now?
d. If balls of mass 0·3 kg arrive at the rate of two a second, each moving at 20 metres/sec and rebounding with the same speed:

(*i*) how much change of momentum does each ball have? This answer is the same as question 156 (*b*).
(*ii*) What is the change of momentum *per second*?
(*iii*) What is the force exerted on the wall by the rebounding balls?

Of course, the force is the same if the wall is fixed and not on a spring, provided always that the balls rebound in the same way. The spring was put in the diagram simply to show the force being exerted. And so long as the stream of balls continues, the force continues. A stream of water from a hose would have the same effect.

e. What mass of water, per second, arriving at the wall with a speed of 20 metres/sec and rebounding, would have the same effect as two 0·3 kg balls a second? (Yes – very simple!)

159 Let us take a problem with some different figures, just for practice – a wall which is hit by balls, each of mass 0·2 kg, each moving at 30 metres/sec, hitting head on, and rebounding in the opposite direction at 30 metres/sec. The balls arrive at the rate of 10 balls per second.

a. What force on the wall do they exert?
b. Suppose the wall is a large wall of area 3 metres × 4 metres. (*i*) What is its area? (*ii*) What is the *pressure* exerted by the balls on the wall?

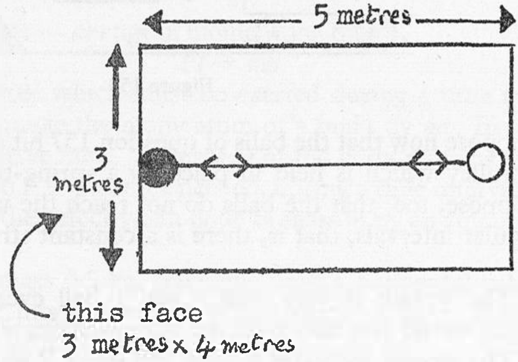


Figure 160

160 Imagine now a closed box (see diagram) 5 metres long between opposite faces, which are 3 metres × 4 metres as in question 159 (4 metres not shown). The ball travels to and fro between the faces, rebounding without any energy loss. Its mass is 0·2 kg. and it travels at 30 metres/sec.

a. How far does it travel between successive collisions with *one* face?
b. How long does it take to travel that distance?
c. How many times does it hit the *same face* per second?
d. What is the change of momentum per second at one face?
e. What is the force exerted by this ball on *one* face?
f. Suppose that, instead of *one* ball, there were 100 balls moving backwards and forwards in the same way – what would be the force on one face then?
g. Suppose, instead of 100 balls moving horizontally, as in the diagram, they were moving in *all possible directions*, that is, between all three pairs of faces for the box, then only one-third are effectively available for hitting one particular pair of opposite faces. So the force on one face (the 3 metres × 4 metres face) is only one-third of that calculated in (*f*), that is, it is – what?
h. This face has area 3 × 4 square metres. What is the pressure exerted on it?

161 *Referring still to the problems of question 160.* If the balls are moving, as we supposed in 160 (*g*), in all directions, then the pressure on all six faces of the box should be the same. Yet we ended part (*h*) by dividing by 3 × 4 square metres. If we had been considering another face we would have divided by 3 × 5, or 4 × 5, for this particular box.

Is the pressure the same for all the faces? If so, say why the result calculated in 160 would work out the same whichever face we chose. If you cannot see the reason, work through question 160 for balls moving 4 metres between the 3 × 5 faces. If you still cannot see the reason why the calculation ends with the same answer for part (*h*), then go on to question 163 – algebra shows this more clearly than arithmetic does.

162 We next go on, in question 163, to molecules in a box instead of balls, and to algebra instead of arithmetic. In question 160 we have supposed something that cannot really happen, namely, balls moving backwards and forwards in all directions for ever.

a. Explain, giving *two* reasons, why balls in a box cannot rebound for ever. (One reason has to do with gravity, and the other with the elastic properties of balls and walls.)
b. This is a difficult question, but you ought to think about it: why do neither of the two reasons you give in (*a*) apply to molecules in a box?

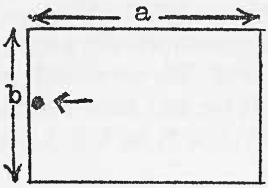


Figure 163 (*i*)

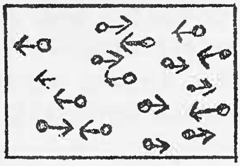


Figure 163 (*ii*)

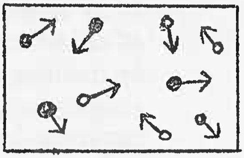


Figure 163 (*iii*)

163 Now we come to molecules in a box. Consider first one molecule in the box, figure 163 (*i*), hitting one face of area $b \times c$, travelling a distance a before hitting the other $b \times c$ face, and then back again, with a constant speed v. The mass of the molecule is m. (And where do you think c is?)

a. What is the change of momentum at each collision?
b. How long does the molecule take to travel the distance $2a$ between successive collisions with *one* face? (This is the time interval between collisions with one face.)
c. What is the *rate* of change of momentum at one face (i.e. change of momentum divided by time interval between collision at one face?)
d. What, then, is the force exerted by one molecule on one face? (Force = rate of change of momentum.)
e. Suppose there are N molecules in the box, figure 163 (*ii*), *all* moving horizontally backwards and forwards like the one molecule shown in figure 163 (*i*), what is the force on one face now?
f. But, to take the actual case, the molecules are moving in all directions, as in figure 163 (*iii*). Only one-third of them can be assumed to be hitting one of the three pairs of faces of the box. So what is the force on one face?
g. The area of the face we are considering is $b \times c$. So what is the pressure on this face?
h. You should now have a quantity abc at the bottom of your expression for (g). We write $abc = V$. What is V?
i. Write down the final expression in the form,

$$PV = \ldots.$$

21 Kinetic theory. Calculations of molecular velocity and mean free path

164 The equation of Section 20, $PV = \frac{1}{3} Nmv^2$, can be written:

$$PV = \tfrac{2}{3} \cdot N \cdot \tfrac{1}{2} mv^2$$

a. What is N, and what is $\frac{1}{2} mv^2$?
b. If N remains constant, so does the *mass* of the gas. Why?
c. Why is it reasonable to suppose that $\frac{1}{2}mv^2$ is associated with the *temperature* of the gas?

165 *a.* Boyle's law states: 'The product, PV, of the pressure and the volume of a given . . . of gas is constant, *provided* that the . . . of the gas remains constant.' Copy this sentence, filling in the two blanks.
b. What connection is there between Boyle's law, stated above, and the equation

$$PV = \tfrac{2}{3} \cdot N \cdot \tfrac{1}{2} mv^2?$$

Note: The answers to question 164 need not be repeated here; carry on from that point.

166 In question 168 you will calculate the average velocity of air molecules in ordinary atmospheric air. For this purpose we use the equation,

$$v^2 = \frac{3PV}{Nm}$$

a. What equation is this the same as?

We can most conveniently consider 1 cubic metre of air, which means $V = 1$ cubic metre. We know from earlier measurements that the density of air at ordinary atmospheric pressure is 1·2 kg per cubic metre.

b. If $V = 1$ cubic metre and the pressure is atmospheric, what is (Nm) equal to?
c. Why does it have this value? (See next page for *d.*)

The only remaining quantity we need, in order to be able to calculate v, is P, which is, of course, atmospheric pressure.

d. V is in cubic metres; (Nm) is in kg. In what units must P be measured?

167 We know:

(*i*) Normal atmospheric pressure = a height of 0·76 metre of mercury,
(*ii*) Mercury is 13·6 times as dense as water,
(*iii*) A cubic metre of water weighs 1000 kg-wt.
(*iv*) $g = 10$ newtons per kg approximately.

We now have to find P in newtons per square metre.

a. What is the weight of a cubic metre of mercury in kg-wt?
b. What is this weight in newtons?
c. What is the pressure P in newtons per square metre, of an 'atmosphere' of mercury 0·76 cm high? (Write down the figures but do not work it out.)
d. $0{\cdot}76 \times 136 = 103$. Because of the various approximations we are making, we will take this as being 100 (anyhow a more correct figure is 101 rather than 103, because g is more nearly equal to 9·8 newtons per kg). What value for P do we now have?

168 All we have to do now is to substitute known values in the equation,

$$v^2 = \frac{3PV}{Nm}$$

We have $P = 100{,}000$ newtons per square metre, from 167 (*d*),

$V = 1$ cubic metre,
$Nm = 1{\cdot}2$ kg, from question 166.

Find v^2, and lastly v.

169 Referring to question 168:

a. If we did this calculation for 2 cubic metres instead of 1, V would be twice as big. Yet we should get the same result for v. Why?
b. If we did the calculation for 2 atmospheres pressure instead of

one atmosphere, P would be twice as big. Yet we should still get the same result for v. Why?
c. More difficult. If we did the calculation for a different *temperature*, we should get a different result. Why?
d. That makes us think: what temperature were we using in question 168?

170 The correct answer to question 168 is 500 metres per second. This is for ordinary atmospheric air having a mass, Nm, of 1·2 kg for each cubic metre.

a. Suppose a heavier gas had a mass of 4·8 kg for each cubic metre. What would be the value of v for molecules of this gas? (Answer is *not* 125 metres/sec.)
b. A lighter gas has a mass 0·3 kg for each cubic metre. What value of v does this give? (Answer is *not* 2000 metres/sec.)

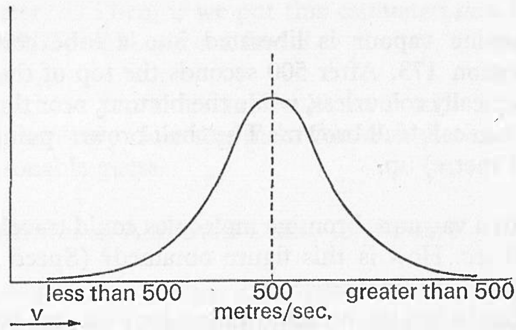


Figure 171

171 Use the graph drawn in figure 171 to explain something important about the velocities of molecules in a cubic metre of atmospheric air. (500 metre/sec is the answer to question 168.)

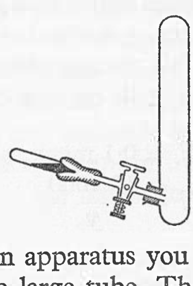


Figure 172

172 *a.* The diagram shows an apparatus you have seen used. Air has been pumped out of the large tube. The nozzle of the ampoule containing liquid bromine is broken off inside the rubber connection. The liquid bromine is set free into the vacuum by opening

the stop cock. Draw the large tube and, by means of shading, show what it looks like 1 second after the stopcock has been turned.
b. Suppose, in part (*a*), we had said '$\frac{1}{100}$ second' instead of 1 second, this would make no difference to your sketch. Why? (Bromine vapour molecules have a speed of about 200 metres per second.)
c. But suppose we said draw a 'snapshot' picture after only $\frac{1}{1000}$ second – would the picture be different now? Explain. (The large tube is about 40 cm tall.)

173 *a.* Draw another large tube, as in question 172, but this time, instead of a vacuum inside, let it contain air. By means of shading, show what the large tube looks like 10 minutes after the stopcock has been turned on.
b. Explain why the bromine has 'diffused' so slowly in (*a*) above, but moved so rapidly throughout the tube in question 172.

174 Bromine vapour is liberated into a tube containing air, as in question 173. After 500 seconds the top of the large tube is still practically colourless, while the bottom, near the side tube, is what we can call 'full brown'. The 'half brown' point is 10 centimetres (0·1 metre) up.

a. In a vacuum, bromine molecules could travel 100,000 metres in 500 sec. How is this figure obtained? (Speed of bromine molecules = 200 metres/sec.)
b. But in fact the bromine molecules went, not 100,000 metres, but, on average, only 0·1 metre. This is because they keep hitting air molecules, and bouncing off in all directions. If y = the length of the average step between collisions, how many collisions does a bromine molecule make in 500 seconds? (We call this number N.)
c. We have a formula which tells us that in N steps, each of length y between collisions, a molecule travels on average $y\sqrt{N}$ from its starting-point. This average distance, the 'half-brown' distance mentioned above, is 10 cm, which is 0·1 metre. Knowing that,

$$y\sqrt{N} = 0{\cdot}1 \text{ metre, and, from part } (b),$$
$$N = \frac{100{,}000}{y},$$

find y.

This is the distance a bromine molecule moves, on average, between collisions.

22 How big is a molecule?

175 *First Method.* A cubic metre of ordinary air from the room in which you are sitting weighs 1·2 kilograms. A cubic metre of liquid air weighs 900 kilograms.

a. Therefore in each unit volume of liquid air there are 750 times as many molecules as there are in ordinary air. How does this statement arise from the previous two statements?
b. Calculations like those in Section 21 show that the length of the mean free path in ordinary air is about 10^{-7} metre, or 1000 A.U. (Angström Units), 1 A.U. being 10^{-10} metre. What is meant by 'mean free path'?
c. It follows from (*a*) and (*b*) that the mean free path in liquid air is 1000/750 A.U. Why?
d. We must now estimate the mean free path of a molecule in terms of its diameter, *d*. Then, if we put this estimated mean free path equal to 1000/750 A.U. we can find *d*.

How far apart do you think molecules in liquid air would be? Clearly they are very close together. One diameter? $\frac{1}{2}d$? $\frac{1}{3}d$? $\frac{1}{10}d$? Make a reasonable guess.

e. Find *d*. Answer in Angstrom Units, 10^{-10} metre.

176 *Second Method. a.* Air, like any other gas at room temperature and pressure, consists of molecules having a mean free path which is large compared with the diameter of a molecule. When two molecules collide, what is the distance between their centres? Yes, twice the radius, which is the diameter *d*.
b. The *area* swept out by a molecule as it moves is actually πr^2, where r is its radius. Why? Illustrate with a diagram.
c. But lots of molecules are each sweeping out an area πr^2. This is an idea which is too difficult for us to use. Instead, we think of *one* molecule having *twice* the radius, and all the rest being nothing but points. So far as that one molecule is concerned, the number of collisions per second, and the mean free path, is just the same as in the actual case. This one molecule sweeps through an area πd^2. Why?
d. The volume it sweeps through between collisions is
πd^2 (10^{-7} metre). Explain where this comes from. (See next page for *e*.)

e. In liquid air the molecules are packed closely together and each molecule effectively occupies a volume of about d^3. The density of liquid air is 900 kilograms per cubic metre, and the density of ordinary air is 1·2 kilograms per cubic metre. Show that the volume in which you would find one molecule in ordinary air is $750d^3$.
f. $750d^3$ is also the volume in which our double-size molecule, in (*c*) above, would find one point molecule with which it would collide. Therefore we can equate $750d^3$ to πd^2 (10^{-7} metre). Do this, and show that

$d = 4 \times 10^{-10}$ metre, or 4 Angström Units.

177 *Difficult. Read the whole question first.* What do you think is meant by the size, or diameter, of a molecule? Do not just say 'the distance measured across it' – the distance measured where? across what? and most important, measured how?

Illustrate the difficulty of answering this question by considering what is meant by the 'size' of a rather limp sausage-shaped balloon, whose 'size' is measured by some method involving collisions with the balloon. Or, if you like, consider the difficulty of saying what is meant by the 'size' of a jelly fish which is constantly moving beneath the surface of the sea. Then go on to consider the molecule by writing a paragraph beginning 'In the same way . . .'

178 *a*. If the diameter of an air molecule is 4×10^{-10} metre, what is the volume (cubic metres) of the space which contains 1 molecule in liquid air? (i.e. the volume of the cubical box that holds 1 molecule.)
b. If the density of liquid air is 900 kg per cubic metre, and the density of 'room' air is 1·2 kg per cubic metre, what is the volume of the space that contains 1 molecule of air in the room in which you are sitting?
c. Estimate in metres the length, breadth and width of the room, and calculate the number of air molecules it contains.

179 *a.* In question 178 (*b*) you should find that the volume which contains one molecule of ordinary air is $750 \times (4 \times 10^{-10})^3$ cubic metres. How many molecules are there in a room 4 metres $\times$ 3 metres $\times$ 2 metres, that is 24 cubic metres?

b. An important quantity for the chemist is the 'Avogadro number', that is, the number of molecules in 22·4 litres, at 0° C, of a gas. (The number of molecules in a given *volume* of a gas is the same for all gases, including air.) 22·4 litres at 0° C is about 24 litres at room temperature. 1 cubic metre = 1000 litres. You have found in (*a*) the number of molecules in 24 cubic metres. How many in 24 litres?

This is the 'Avogadro number'.

180 Complete the following table, which gives approximate values for air at room temperature.

Size of molecule	=	$3{\cdot}5 \times 10^{-10}$ metre
Distance between molecules	=	35×10^{-10} metre
Mean free path	=	10^{-7} metre
Speed of molecules	=	500 metres per second
Mass of molecule	=	
Number in 24 cubic metres	=	
Number in 24 litres	=	
Number in laboratory	=	

23 Kinetic theory: kinetic energy and heat

This section may well be omitted if time is short. However, anyone who has completed most or all of the previous section will find it quite easy.

We can now calculate a value for the *increase of kinetic energy* of the molecules of a gas when heated from 0° to 100° C (or any other range). This calculated value can then be compared with the known heat, in kilocalories, required to *raise the temperature* from 0° to 100° C. Will these values, we shall ask, be equal when measured in the same units?

At present we can consider only the kinetic energies which molecules possess because of their motions in straight lines from one collision to the next. Molecules may have energy because of movements in other ways, e.g. spinning round each other; this we cannot deal with as yet. However, we can learn something by comparing 'straight line' kinetic energy with heat.

Data will be given for two gases, both constituents of the atmosphere, viz. argon and oxygen. Oxygen has two atoms in the molecule, chemical formula, O_2. Argon atoms do not unite with each other, so the chemical formula is simply, A.

The two equations we need are,

kinetic energy $= \frac{1}{2}Mv^2$ and

$$PV = \tfrac{1}{3}Mv^2$$

where M is the mass of the gas considered.

181 *a.* What do v and P stand for in the equation $PV = \frac{1}{3}Mv^2$?
b. If $M = 1$ kilogram, what does V mean?

182 *a.* Which of the following gases would you say are
(*i*) 'like argon', or
(*ii*) 'like oxygen', or
(*iii*) have three atoms in the molecule?
Nitrogen, N_2; Helium, He; Carbon dioxide, CO_2; Ozone, O_3; Neon, Ne; Carbon monoxide, CO; Steam, H_2O; Mercury vapour, Hg; Hydrogen, H_2.
b. Air consists, by weight, of 75·5% nitrogen, 23·2% oxygen, 1·3% argon. Under which heading in (*a*) would you classify air?

183 We will now find the increase of kinetic energy of the molecules of 1 kilogram of argon gas when it is heated from 0° to 100° C. We start by writing

$$\text{K.E.} = \tfrac{1}{2}\,Mv^2 = \frac{3}{2}\,(\tfrac{1}{3}Mv^2) = \frac{3}{2}\,PV$$

If P = atmospheric pressure, then P = 100,000 newtons per square metre.
Also,

V for 1 kilogram of argon *at* 0° C = 0·56 cubic metre.
V for 1 kilogram of argon *at 100°* C = 0·77 cubic metre
(These values are obtained from the known density of argon.)

Now find the kinetic energy of the molecules of 1 kilogram of argon, first at 0° C and then at 100° C, and find by subtraction, the increase of kinetic energy.

184 Measurement of the 'specific heat' of argon, kept at constant volume, shows that 0·074 kilocalorie is required to heat 1 kilogram through 1° C.

a. How many kilocalories are required to heat 1 kilogram from 0° to 100° C?
b. Is answer (*a*) identical with the answer to question 183? Obviously not, because one is in kilocalories and the other in joules. But let us equate the two answers and find how many joules go to 1 kilocalorie.
c. Quite different measurements on the heating of water (measurements we shall hear about later) show that 1 kilocalorie = 4180 joules (approximately). Does this agree with your value in (*b*)?
d. What assumption do we make when, in (*b*), we equate answer 183 and answer 184 (*a*)?

185 Repeat question 183 for *oxygen*, given that

V for 1 kilogram of oxygen at 0° C = 0·70 cubic metre
V for 1 kilogram of oxygen at 100° C = 0·95 cubic metre

186 Experiment shows that 0·17 kilocalorie is required to heat 1 kilogram of oxygen through 1° C when its volume is kept constant.

a. How many kilocalories are required to heat 1 kilogram of oxygen from 0° to 100° C?
b. How many joules is this, if 1 kilocalorie = 4180 joules?
c. Does answer (*b*) agree with the answer to question 185?

187 Consider your answers to the four questions 183–186.

a. Does it seem that when argon gas is heated at constant volume all the heat supplied is used in increasing the 'straight line' kinetic energy of the molecules?
b. What do you think happens to the heat supplied to oxygen when its temperature is raised and the volume stays the same?
c. Would you expect your answer to (*a*) to be equally true for other gases which, like argon, have only one atom in the molecule? Give the reason for your answer.
d. Would your answer (*b*) also apply to other gases which, like oxygen, have two atoms in the molecule? Give the reason for your answer.

24 Perpetual movement and perpetual motion

Perpetual Movement means something *going on moving* forever without any supply of energy.

Perpetual Motion means something – a machine of some sort – *providing a continuous output of energy* in excess of what is put into it.

188 *a.* Give an example of 'almost perpetual movement' that you might see in a laboratory, or in everyday life outside the laboratory. *b.* Why only 'almost'?

189 *Difficult.* You told Uncle George that two good examples of perpetual movement are:

the movement of the Earth round the Sun, and the movement of molecules in a gas.

Now he asks:

a. Why the Earth does not slow down and stop? and
b. Why the molecules do not slow down and stop?

Do your best to explain (*a*) and (*b*) to him in about three sentences for each.

190 After your chat with Uncle George about perpetual movement, you and he talk about perpetual motion, and you tell him, with one or two examples, that perpetual-motion machines are impossible. He says, 'I remember reading about a perpetual-motion machine some time ago. As far as I remember, it consisted of an electric generator joined by wires to an electric motor, which is coupled by a pulley and band to the generator. The generator provides current which drives the motor, which rotates the generator, which gives current for the motor and so on. Wasn't that a perpetual-motion machine?'

a. Write a few sentences of your subsequent conversation with Uncle George.
b. He then says, 'All right, I agree that the generator–motor machine would not provide a continuous supply of energy. But my grandfather – your great grandfather – he was clever, he had a

perpetual-motion machine. It was a windmill; it ground corn. If you had seen the large wheels and shafts rotating inside, and the rotating grindstone, you would have had no doubt that it had plenty of energy. Yet he paid nothing for coal, gas, electricity or anything of the sort.'

What do you reply to this?

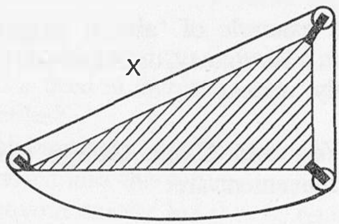


Figure 191 (*a*)

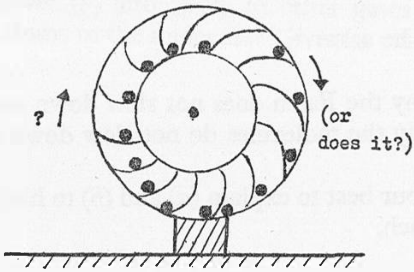


Figure 191 (*b*)

191 *Difficult*. Here are two 'perpetual-motion machines'. You have to say why they do not work. In (*a*) a loop of rope hangs over pulleys on an inclined plane as shown. The length at X is greater than the length at Y, therefore it is heavier. Therefore X goes down and Y goes up, continuously. What do you say?
b. As the wheel rotates the balls on the right run out farther from the centre, so that they exert a clockwise turning effect which is greater than the anti-clockwise turning effect of the balls on the left. Therefore the wheel continuously rotates in a clockwise direction. What do you say?

In question 191 the 'machines' have friction which would impede motion, but this is *not* the real reason why they do not work. Anyhow, you can suppose the friction is very small.

25 The belief that energy is indestructible

Experience shows that perpetual-motion machines, defined as in Section 24, are impossible. Energy cannot be created.

Energy may seem to be destroyed, e.g. when a rider of a bicycle, on a level road, stops pedalling and the bicycle slowly comes to a stop. However, we often notice that when mechanical energy disappears, something else – heat, sound, light, electricity, etc. – may appear. Naturally, we begin to think that these are other forms of energy.

First, however, we shall consider 'conservation of mechanical energy', that is, kinetic energy and potential energy.

192 A 5-kilogram load, situated in the Earth's gravitational field (whose value may be taken as 10 newtons per kilogram), is raised a vertical height of 3 metres.

a. What is the energy-transfer in joules?
b. How much potential energy (in joules) is gained?
c. The load is then allowed to fall back through the distance of 3 metres. How much kinetic energy (in joules) does it gain?

Formulae: kinetic energy $= \frac{1}{2} mv^2$; $v^2 = u^2 + 2as$,
where u will be zero, since the load starts from rest, and $a = g$, the gravitational acceleration of 10 metres/second per second, which is the same thing as the gravitational field strength, 10 newtons per kilogram.

d. In (*c*) potential energy has been transferred to kinetic. Does the P.E. lost equal the K.E. gained?

193 Repeat question 192, using, instead of the figures given, a mass m, gravitational field g and height h. Thus, you will show that in all similar cases, and not just that of 192, kinetic energy gained = potential energy lost.

194 Freddie Jones is much impressed with this easy proof of 'conservation of mechanical energy' (question 193). You say, 'It couldn't have been otherwise. We made it like this ourselves.' Briefly explain to Freddie (one sentence would do) why it could not 'have been otherwise'.

195 *a.* Describe two examples (different from those of questions 196 and 197) of mechanical energy disappearing and heat appearing.
b. Mention also (no description of mechanism required) one means whereby some heat disappears and some mechanical energy appears in its place.

196 You attempt to drill a hole through a small steel plate, using a drill and a rather blunt bit. Result: a squealing noise, a rise in temperature and a few small pieces of metal – the mass of the plate plus metal pieces being equal to the mass of the plate before the hole was made.

a. What energy changes have taken place?
b. Freddie Jones says that the energy has finally ended up as kinetic energy. Is he right? What do you think?

197 A bullet is fired from a rifle and hits a wall. After it hits, it is so hot that it nearly reaches melting point; this means that its molecules have increased kinetic energy. But before it hit the wall the bullet – which means the molecules of which it is composed – had a great deal of kinetic energy. 'So', says Freddie, 'there is no change; kinetic energy is still kinetic energy.'

You agree with this, but there is a difference you would like to point out. What difference?

198 *Difficult.* In question 197 we carefully said 'nearly reaches melting point'. Suppose the bullet has so much energy that it melts when it is stopped. Is it now true that its energy is entirely in the form of molecular kinetic energy? Or is some of it now potential energy? What do you think, and for what reason?

199 Joules of mechanical energy disappear and calories of heat appear. Also, in some special cases – a motor cycle for example – calories disappear and joules appear. However, we cannot assume without further experiment that for every calorie that appears the same number of joules disappear, though we may well think that this proposition – which we may briefly call 'conservation of energy' – is likely to be true.

What sort of experiments would convince us that 'conservation of energy' is true for heat and mechanical energy? (Do not describe the actual apparatus; questions on this are matters for Section 26.)

26 Conservation of energy: equivalence of heat and mechanical energy

200 Many experiments have been done in which a measured quantity of mechanical energy (joules) has been transferred to heat energy which has also been measured (kilocalories). Different quantities, large and small, of heat energy have been transferred, and the transference has taken place in many different ways. The ratio,

$$\frac{\text{heat energy produced (kilocalories)}}{\text{mechanical energy lost (joules)}} = \mathrm{J}$$

is found to be very nearly the same in every case (i.e. it is the same within the accepted errors of the experiments). This ratio is called the 'mechanical equivalent of heat' and is denoted by the symbol 'J'. For example, here are the names of six experimenters, with dates, methods used and result obtained (measured in *thousands* of joules per kilocalorie).

1847 Joule (England)	Falling weights turned paddle wheel which churned water	4·21
1850 Joule (England)	Ditto . . . churning mercury	4·16
1861 Hirn (France)	Heat to mechanical energy by steam engine	4·17
1879 Rowlands (U.S.A.)	Water churning by paddle wheel driven by steam engine	4·179
1899 Callender & Barnes (England)	Electrical heating of water	4·183
1927 Laby & Hercus (Australia)	Water churning	4·180

One reason for these experiments is, of course, that scientists and engineers need to know an accurate value for 'J'. What is another reason for wishing to know that *all* these experiments give the same result? (If you are not sure of the answer question 199 provides a clue.)

201 In an experiment performed by the French scientist Hirn, a hammer weighing 400 kg moving at 5 metres per second crashed into a 3-kg block of lead held against a heavy anvil. The lead was crushed and its temperature rose by 7° C. (To raise the temperature of 1 kg of lead by 1° C requires 0·03 kilocalorie.)

a. What was the kinetic energy of the hammer (joules)?
b. How much heat (kilocalories) is produced in the lead?
c. Assuming that *all* the K.E. was converted into heat in the lead, calculate how many joules are equivalent to 1 kilocalorie.
d. Give two reasons why the assumption in (*c*) is not fully justified. Will these errors tend to make the result too large or too small?

202 A meteorite of mass 10 kilograms enters the Earth's atmosphere. In consequence of air resistance its speed is rapidly reduced from 400 metres per second to 100 metres per second.

a How much heat energy (kilocalories) is generated as a result of this change of speed? (K.E. $= \frac{1}{2}mv^2$; take the ratio, J, of heat produced to kinetic energy lost to be 4200 joules per kilocalorie.)
b. What do you think is likely to happen to this meteorite?
c. Why is the hazard from meteorites much greater for a space traveller than for people on the Earth's surface?

203 A straight tube 1 metre long is closed at both ends, and contains 2 kg of lead shot. It is inverted 50 times. The lead shot absorbs 60% of the heat generated. $g = 10$ newtons per kilogram. J = 4200 joules per kilocalorie.

a. Calculate the rise in temperature of the lead.
b. Which piece of information, given above, was not necessary for the calculation (*a*)? Why was it unnecessary?

204 This question refers to one of the experiments by which Joule found the ratio of heat produced to mechanical energy lost (now called 'J').

A mass of metal totalling 26·3 kg fell through a height of 1·6 metres, and turned paddles immersed in water in a calorimeter so that the potential energy lost was changed to heat energy. This was done 20 times, and the water and calorimeter rose in temperature by 0·31° C. The calorimeter and water together may be taken to be equivalent to 6·3 kg of water.

a. Calculate a value for J. ($g = 10$ newtons per kilogram.)
b. Joule made corrections for a number of errors in this experiment. In your calculation (*a*) you cannot make allowances for these because you are not given the necessary data. Mention *two* errors that you think Joule would have allowed for.

27 Power

205 Two pumps A and B are each capable of pumping water up a height of 30 metres vertically. Pump A takes 2 hours to pump up 600 kg of water. Pump B raises the same amount in 20 minutes.

a. Which pump is the more powerful?
b. How much potential energy (joules) is gained when 600 kg is raised 30 metres? (take $g = 10$ newtons per kg)
c. What is the rate of working, in joules per second,
(*i*) of A,
(*ii*) of B?
d. What is the power of each pump in watts?
e. What is the power of each pump in kilowatts?

206 A boy weighing 110 lb races up a flight of 60 steps, each 8 inches high, in 10 seconds.

a. Find the rate at which he transfers food energy to potential energy,
(*i*) in ft . lb wt . per second,
(*ii*) in horse-power (1 hp = 550 ft . lb wt . per second)
b. If his muscles are only 25% efficient, at what rate (in hp) is he actually transferring food energy?
c. What happens to the other 75% of food energy?

207 *a*. Rework question 206 (*a*) in kilowatts, taking as suitable equivalents, 2·2 lb = 1 kg, and 4 inches = 10 cm. Also, $g = 10$ newtons per kilogram.
b. Compare your answers to 206 (*a*) and 207 (*a*). What fraction of a kilowatt equals 1 hp?

208 You are given a small 6-volt electric motor, and a 6-volt accumulator. The motor has an axle on which string can be wound. How would you find by experiment the power output of the motor in watts?

209 *a*. An electric lamp is marked '40 watts'. Say exactly what this means.
b. Electricity costs $1\frac{1}{2}d$ per kilowatt . hour. How many hours could the 40-watt lamp be used, for one shilling?

210 *a.* Joule, watt, kilowatt, kilowatt . hour. Which two of these are units of energy, and which two are units of power?
b. If a kilowatt . hour costs $1\frac{1}{2}d$, how many joules can you buy for a penny?

211 Freddie Jones has to live in lodgings for a few weeks, while his parents are abroad. Each time he has a hot bath, the landlady charges him one shilling. Is she swindling him?

Data you will need:
Average hot bath takes 20 gallons.
1 gallon = 4·5 litres (approx.)
1 litre of water weighs 1 kilogram
The water has to be heated from 10° to 50° C.
1 kilocalorie = 4200 joules
3,600,000 joules = 1 kilowatt . hour
1 kilowatt . hour costs $1\frac{1}{2}d$.

212 Uncle George has a car with 2 sidelamps, 2 rearlamps, and a lamp to illuminate the rear number plate. Each of these lamps has a power of 6 watts. In addition, there are two headlamps of 36 watts each.

a. How many watts altogether?
b. Uncle George sees your answer to (*a*). 'Good gracious,' he says, 'if the engine has to supply all those watts, then at night time the car's speed will be much reduced and I cannot climb any very steep hills.'

Do you think he is right about this? The maker says that the engine's maximum power output is 60 hp, and we may take 1 hp to be $\frac{3}{4}$ kilowatt. (Don't say that the power comes from the battery, not the engine. The engine drives a generator which is capable of charging the battery with a small current even when all the lights are on.)

213 A crew of 8 men are rowing in an 'eight' (a light racing craft with four oars each side). We are going to calculate the horsepower supplied to the boat. We estimate that they make 30 strokes per minute, and that the length of the pull at each stroke is 4 feet. The strength of the pull is 80 lb-wt.

a. How much work does one man do in one stroke?
b. How much work does he do per second?
c. How much work does the crew do per second?
d. What is the horse-power of the crew?
(1 hp = 550 ft . lb wt . per second)

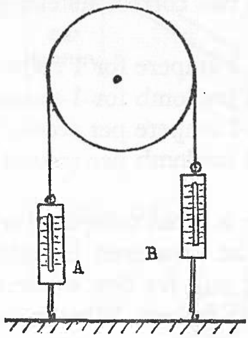


Figure 214

214 Figure 214 shows a band-brake round a flywheel. The flywheel is rotated by an engine or electric motor whose power output is to be measured. The brake is attached to two spring-balances A and B.

a. What can you say about the readings of A and B *before* the wheel starts to rotate?
b. What happens when the wheel starts to rotate and increases speed to a final steady speed?
c. Which way, clockwise or anticlockwise, is the wheel in figure 214 rotating?
In an actual case the reading of A is 90 newtons, and the reading of B is 300 newtons. The radius of the wheel is 0·2 metre, and it makes 3000 revolutions per second.
d. What is the effective drag on the band, in newtons?
e. What is the circumference of the wheel?
f. How much energy is transferred to heat, in the wheel and band, in one revolution of the wheel?
g. How much energy is transferred per second?
h. What is the power of the engine in kilowatts?

28 Electric currents and charges

215 What is it that is measured in coulombs? And what is measured in amperes?

Two of the four statements below are false, and two are correct. Write out the two correct statements.

1 coulomb = 1 ampere for 1 second
1 ampere = 1 coulomb for 1 second
1 coulomb = 1 ampere per second
1 ampere = 1 coulomb per second

216 Flow of water is often compared with flow of electricity. Flow of water might be measured in gallons per second. What is the corresponding unit for flow of electricity? The water itself might be measured in gallons. What is the corresponding unit for electricity?

The next question is taken from Year II.

If you have already answered it, read it through again, and then write down the important property of electricity (flowing in wired circuits) which the answers to this problem demonstrate.

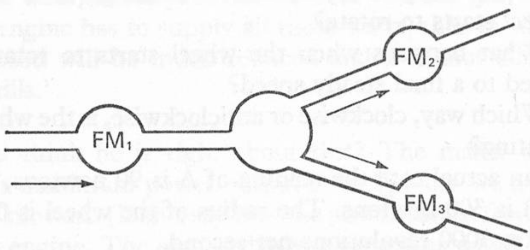


Figure 217 (*a*)

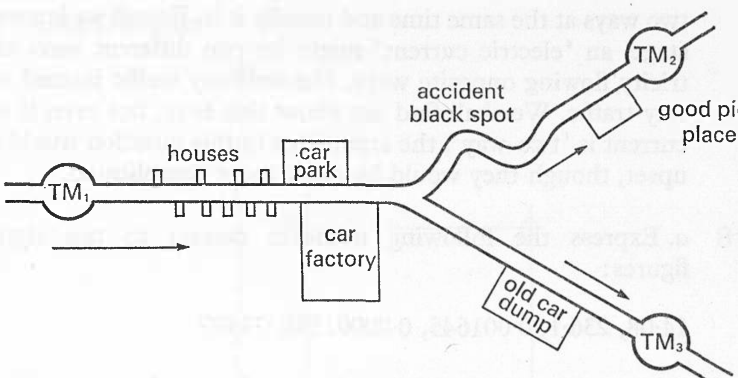


Figure 217 (*b*)

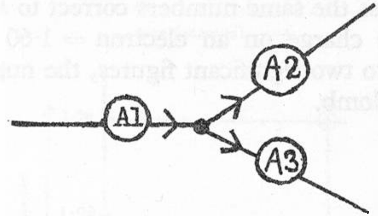


Figure 217 (*c*)

217 The three diagrams of figure 217 show (*a*) flow of water with water-flow meters, (*b*) flow of traffic, with three persons counting the cars per hour passing on each road, or with some automatic traffic-flow-meter, and (*c*) wires carrying electric currents, with ammeters.

a. Figure 217 (*a*): we expect that the reading of flow-meter 1 equals that of the other two together, i.e.

$$FM_1 = FM_2 + FM_3$$

What common-sense assumptions do we make about water, which leads us to expect this result?

b. Figure 217 (*b*): is it true that TM1 = TM2 + TM3? Answer 'yes' or 'no', and write a sentence or two in explanation.
c. Figure 217 (*c*): does this resemble the water in (*a*) or the traffic in (*b*)? What, then, do we assume about electricity in circuits of the kind you have used so far?

Note: We have supposed that the water, the cars, and the electricity go one way only. This must be true for the water; but traffic can be two ways at the same time and usually it is. For all we know at this stage, an 'electric current' might be two different sorts of electricity flowing opposite ways, like ordinary traffic instead of one-way traffic. We shall find out about this later, but even if electric current is 'two-way', the arguments in this question would not be upset, though they would be made more complicated.

218 *a.* Express the following numbers correct to *two* significant figures:

14·08, 236·1, 0·001645, 0·00001556, 73497

Note: For ——5 to ——9 add 1 to the next figure when approximating; for ——0 to ——4 do not add 1.

b. Express the same numbers correct to *three* significant figures.

c. If the charge on an electron = $1{\cdot}60 \times 10^{-19}$ coulomb, find, correct to two significant figures, the number of electron charges in 1 coulomb.

29 Electrolysis

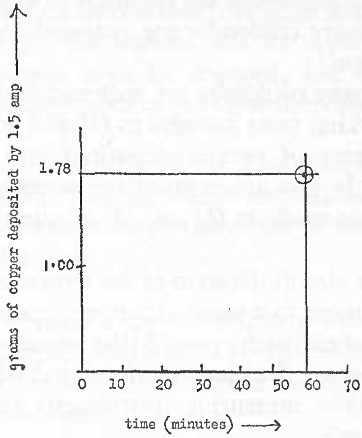


Figure 219
(*i*)

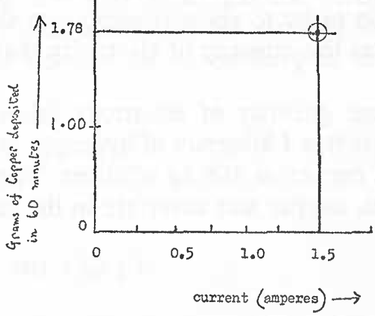


Figure 219
(*ii*)

219 A current of 1·5 amperes is passed for 1 hour through a solution of copper sulphate and, at the end of that time, it is found that 1·78 gm of copper has been deposited. This result gives one point on each of two graphs, figure 219 (*i*) and (*ii*), drawn on the left.

a. Copy figure 219 (*i*) and draw a line showing how the mass of copper deposited by 1·5 ampere increases with time. How long will it take for 1·0 gram to be deposited by 1·5 ampere?
b. What assumption about mass deposited and time elapsed have you made in drawing the graph?
c. Copy figure 219 (*ii*) and draw a line showing how the mass deposited in 1 hour increases with the current. How much current is needed to deposit 1·0 gram in 1 hour?
d. What assumption about mass deposited and current passed have you made in drawing the graph?

220 *a.* Find from the figures given in the first sentence of question 219, how many coulombs are required to deposit 1·78 gm of copper.
b. How many coulombs are required to deposit half that much, i.e. 0·89 gm?
c. How many coulombs are required to deposit 1·0 gm of copper?
d. In working your answers to (*b*) and (*c*), what are you assuming about grams of copper deposited and coulombs of electricity passed? Is this assumption the same as, or different from, the assumption made in (*b*) and (*d*) of question 219? Explain.

221 *a.* Draw a circuit diagram of the apparatus you would use to show by experiment that mass of copper deposited is proportional to the quantity of electricity passed (the assumption you made in question 220). What are the plates made of, and what liquid would you use?
b. What *three* measuring instruments are needed to perform the experiment?
c. What readings would you take, and what would you do with the results, in order to show convincingly that mass deposited varies directly as the quantity of electricity that has passed?

222 The same quantity of electricity (about 96 million coulombs) which sets free 1 kilogram of hydrogen in electrolysis also sets free 32 kg of copper or 108 kg of silver. The weights of the atoms of hydrogen, copper and silver are in the ratio,

$$1 : 64 : 108$$

a. What do these figures suggest about the electric charges carried by one atom of hydrogen and one atom of silver in electrolysis?
b. What do they suggest about the charge carried by one atom of copper compared with the charge carried by a single atom of hydrogen or a single atom of silver?

Note: The deductions you make here are simple but important. This is the first piece of evidence for the existence of a 'least possible' quantity of electricity, namely, the quantity carried by a single hydrogen or silver atom, or some other atoms, in electrolysis. We never find an atom carrying, for example, half as much charge as the hydrogen atom carries.

Charged atoms are called *ions* to distinguish them from ordinary uncharged atoms.

223 *a.* When electricity is passed through copper sulphate solution copper is deposited on the *cathode* (the plate joined to the negative end of the battery). We explain this by saying that the copper atoms in the solution must be charged. Are they charged with positive charge or negative charge? Give the reason for your answer.

b. Yes, the answer to (*a*) is 'positive'. Does this mean that we must have positive charge flowing from the cathode to the battery through the wire connecting them? Or is there an alternative explanation? – if so, say what it is.

224 *a.* The current through a copper sulphate solution is carried, at least in part, by copper atoms with a positive charge (question 223). Are negative charges also being carried through the *solution*? Give a reason for your answer.
b. If the current in the solution is carried by both positive and negative charges, does this mean that the wires joined from the battery to the plates must also be carrying both positive and negative charges? Explain the reason for your answer.

30 Potential difference, voltmeters

225 A mains electric-light bulb is marked '100 watts'. This figure is correct, we may assume, when the bulb is connected to a supply at the proper voltage.

a. How many joules of electrical energy are converted *per second* by this bulb?
b. What other forms of energy is the electrical energy converted to?
c. If *all* the energy finally ends as heat energy how many kilo-calories of heat appear in 7 minutes? (1 kilocalorie = 4200 joules)

226 A current of 0·5 ampere is required to light a certain mains type bulb to its proper brightness.

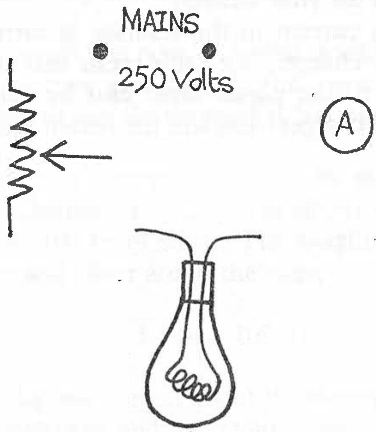


Figure 226

a. Given the necessary apparatus (mains supply, ammeter, rheostat, the bulb – see figure 226), draw a circuit diagram showing how you would connect these items in order to measure the current and to light the bulb correctly.
b. Without the rheostat, the current would be more than $\frac{1}{2}$ amp. How would you adjust to get a current of exactly 0·5 ampere?
c. Given a tin can large enough for the bulb to go into (and a waterproof connection to the bulb), water, a measuring cylinder, and a thermometer, how would you find the power in watts consumed by the bulb when the current is 0·5 amp, without using a voltmeter?
d. Why is a tin can rather better than a glass beaker for experiment (*c*)? Give any one good reason.

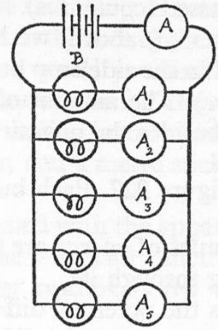


Figure 227

227 Figure 227 shows five sidelamp bulbs joined in parallel to a battery which lights them with normal brilliance. Each bulb is correctly marked '3 watts'. Each of the ammeters A to A_5 reads 0·5 ampere.

a. If all the ammeters are accurate, what does ammeter A read?
b. How many joules of electrical energy are used in each second by each 3-watt bulb?
c. How many joules are used in each second by all five bulbs?
d. How many coulombs pass in one second through each bulb?
e. How many coulombs pass in one second through all five bulbs together?
f. What can we say about the way in which quantity of electrical energy converted into other forms varies with quantity of electricity passed?

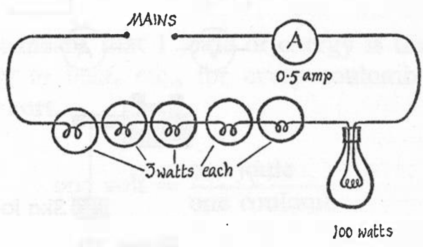


Figure 228

228 *a.* How many coulombs pass through each small lamp (figure 228) in 1 second? How many per second through the large lamp?
b. How many joules of electric energy are used by each small lamp in 1 second?
c. How many joules are used by the mains bulb in 1 second?
d. We know that the energy converted (joules) varies directly as

the electricity passed (coulombs). But now, for the *same* number of coulombs (answer (*a*) above) we have very different numbers of joules converted in the sidelamp bulb and the mains bulb (answers (*b*) and (*c*) *above*). The amount of energy converted depends on something else besides the quantity of electricity – what else?

229 Refer back to figure 227. Each bulb takes '3 watts, 0·5 ampere'.

a. How many joules of energy are 'delivered' in each bulb by each coulomb passing through it?
b. What, then, is the potential difference ('voltage') of battery B?
c. What is meant by 'potential difference'?
d. And what is meant by a 'potential difference of 1 volt'?

230 Refer now to figure 228. A current of 0·5 amp. goes through each bulb. Each small bulb is '3 watts', and the mains bulb is '100 watts'.

a. How much energy does one coulomb transfer to heat and light in each small bulb?
b. How much energy does one coulomb transfer to heat and light in the mains bulb?
c. What is the p.d. across the *five* small bulbs?
d. What is the p.d. across the mains bulb?
e. What is the p.d. of the mains?

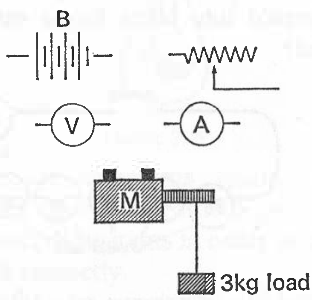


Figure 231

231 In figure 231 M is a small electric motor that runs on a 6-volt supply, B is an 8-volt battery, R is a rheostat, A is an ammeter and V is a voltmeter.

a. Draw a diagram showing these items joined in a suitable circuit. Include the ammeter to measure the current when the p.d. across the motor is 6 volts.

b. How would you ensure that the p.d. across the motor is 6 volts?
c. A 3-kg load is attached to the axle of the motor and can be raised as the motor turns. How would you find the joules of electrical energy supplied to the motor during the time the load is raised 1 meter? What other measuring instrument do you require besides a voltmeter, an ammeter, and a metre stick?

232 In an experiment performed with the apparatus of figure 231, the motor is found to raise the 3-kg load 1 metre in 8·0 seconds. At the same time, the voltmeter reading is 6·0 volts and the ammeter reads 2·5 ampere.

a. How much mechanical work is done in raising the 3-kg load through 1 metre? ($g = 10$ newtons per kilogram)
b. How many coulombs flow through the motor in 8 seconds, if the ammeter reading is 2·5 amp.?
c. What does '6 volts' mean in joules and coulombs? How many joules of electrical energy are used up when the load is raised 1 metre?
d. The 'efficiency' of a motor can be written:

$$\text{efficiency} = \frac{\text{output of mechanical energy}}{\text{input of electrical energy}} \times 100\%$$

What is the efficiency of this motor?
e. What has happened to the rest of the electrical energy, which did not appear as mechanical energy?

233 A p.d. of 1 volt means that 1 joule of energy is transferred *from* electrical energy to heat, etc., for every coulomb of electricity flowing, or, in short,

$$\text{one volt} = \frac{\text{one joule}}{\text{one coulomb}}$$

By definition, 1 watt means a rate of energy transfer of 1 joule per second. Also, 1 ampere means 1 coulomb per second.

Use these three definitions, of volt, watt and coulomb, to show that

$$1 \text{ volt} \times 1 \text{ ampere} = 1 \text{ watt}.$$

234 *a.* How much current is taken from 240-volt mains by a 60-watt bulb?
b. A rheostat is marked '10 amp, 200 watts'. This means that 200 watts is the maximum rate at which it can safely dissipate energy (i.e. lose in the form of heat), and that the current is then 10 amperes. What is the largest p.d. that can safely be put across the terminals of this rheostat?
c. When a p.d. of 12 volts is joined across an electric lamp, it takes 3 amperes of current. How much power does it use?

235 Explain 'Ohm's Law' and say under what circumstances it is likely to be useful.

236 *a.* What is meant by *electrical resistance*?
b. Why is it that the idea of electrical resistance becomes somewhat simpler if applied to a conductor that 'obeys Ohm's law'.
c. What is meant by saying that a conductor has a resistance of 1 ohm?

237 *a.* What current does a 6-volt battery supply when joined to a 2-ohm resistance?
b. When a 200-ohm resistance is joined to the mains, the current is 1·15 amps. What is the mains voltage?
c. A 2-volt accumulator is joined to a resistor and an ammeter which reads 0·25 amp. What is the resistance of the circuit?

238 What current would a 2-volt accumulator supply when joined to resistances of 4 and 6 ohms in series? If the resistors were joined in parallel, what current would then be supplied?

239 What is the resistance of a 12-volt 36-watt car headlamp bulb? If you determined the resistance with a 1·5-volt cell and a milliammeter, would you expect to get this result? Explain.

240 A battery produces a current of 0·6 amp when the external resistance is 2 ohms, and 0·2 amp when the external resistance is 12 ohms. Find

a. the internal resistance;
b. the e.m.f. of the battery.

31 Transformers

(This section could be postponed to Year V.)

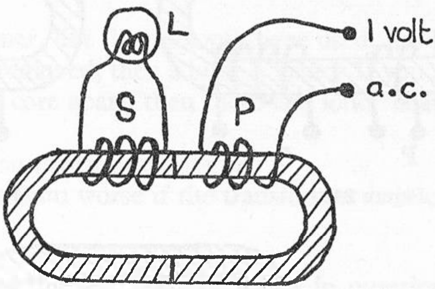


Figure 241

241 P is a primary coil of 20 turns, joined to a 1 volt a.c. supply. S is a secondary of 50 turns joined to a small 2·5-volt lamp, which lights with what we may call 'normal brightness'. These facts are expressed in the top line of the following table. Use the knowledge you have gained in experiments with a similar transformer to fill in the remaining spaces of the table. For the third column, write N if the lamp is normally bright, D for dim or not alight, B for brighter than normal (including 'burnt-out').

Number of turns on primary, P	Number of turns on secondary, S	Brightness of lamp	Secondary volts
20	50	N	2·5
50	20		
20	30		
40	100		
20	80		

242 *a.* Your experiments show (as in question 241) that you can get 2·5 volts from the secondary of a transformer by supplying 1 volt to the primary. This, however, is not thought to contradict the 'conservation of energy' principle. Why not?
b. In fact, you cannot get out quite as much energy from the secondary as you put into the primary. Suggest one or two ways in which energy may be wasted in the transformer, by being converted into heat.

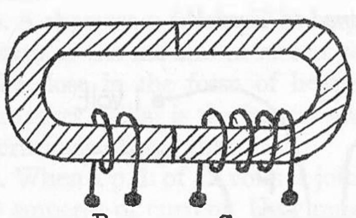


Figure 243 (*a*)

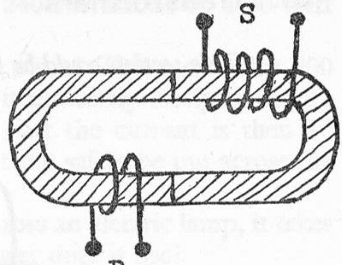


Figure 243 (*b*)

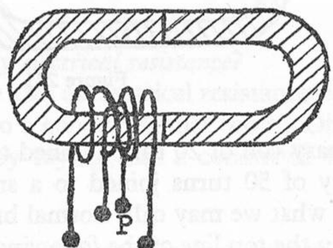


Figure 243 (*c*)

243 Figure 243 (*a*), (*b*) and (*c*) show different arrangements of the same transformer. P is a primary coil of 20 turns, always connected to a one-volt a.c. supply. S is a secondary coil of 50 turns, joined to a 2·5-volt bulb. In (*c*) the secondary is wound on top of the primary. (*i*) There seems to be no difference between the three arrangements: in every case the bulb lights normally although the secondary is in different places. How do you explain this?

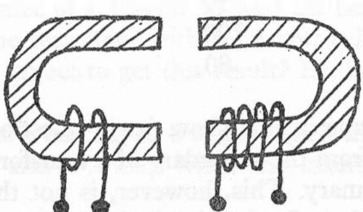


Figure 243 (*d*)

(*ii*) Figure 243 (*d*) shows arrangement (*a*) with the iron cores slightly separated. This gives a different result; this time the bulb lights only very dimly. Why is it that separating the two parts of the iron core of a transformer causes it to work much less efficiently? (*iii*) Arrangement (*c*), when the iron cores are slightly separated as in (*d*) does not give any better result. Would you have expected this? Give the reason for your answer.

244 If a transformer, like the ones you have used, has loose parts, e.g. if the clip is removed, then a hum is heard. If you start to pull the halves of the core apart, then there is a loud 'chatter'.

a. How do you explain this noise?
b. Why is the hum worse if the transformer is in contact with the bench?

245 Look again at the first three diagrams in question 243. Suppose that all the three secondaries in 243 (*a*), 243 (*b*) and 243 (*c*) are placed on *one* transformer core with *one* primary. Each secondary is joined to a bulb, and all *three* bulbs are found to light normally.

a. How do you explain this result?
b. How would you expect the primary current in this case to compare with the primary current when there is one secondary with one bulb?

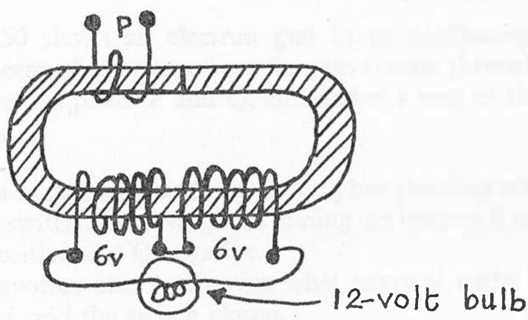


Figure 246

246 A transformer has two secondaries, each of which is used to light a 6-volt 12-watt bulb.

a. How would you use this transformer to light one 12-volt 24-watt bulb?
b. In an attempt to light the 12-volt bulb, a boy joined the transformer coils, wound as in figure 246, in the manner shown. The bulb did not light at all. Why not?
c. What connections should have been made in this case?

247 A new laboratory in a school is to be equipped with a low-voltage d.c. supply and a higher voltage a.c. supply. The mains input to the laboratory is at 240 volts, but it was decided that this was dangerously high for a bench supply, and that 100 volts would be better. A large step-down transformer was used, and the design was such that 4 turns of wire on the coils were required for each volt input to the primary.

a. How many turns were required on the primary, and how many on the secondary?
b. The secondary had a centre-tapping, 'which' said the physics master concerned, 'we will "earth" on to a metal water pipe for the sake of safety'. Why is it safer to earth the centre-tapping, rather than one end or the other of the secondary coil?

248 What is the chief advantage of alternating current over direct current for the purpose of supplying power?

Alternating current generated at a power station usually has a voltage of about 10,000. Why is this voltage:
a. stepped down to 240 volts for domestic use,
b. stepped up to 132,000 volts for transmission over long distances?

32 Cathode-ray oscilloscope, used with d.c. and a.c.

249 *a.* Do electrons (e.g. electrons coming from an 'electron gun') themselves glow so that you can see them? (Yes or No.)
b. If 'No', what enables you to see where an electron stream goes:
(*i*) in a 'cathode-ray oscillograph'?
(*ii*) in a 'fine-beam tube'? (If you have never seen one do not answer this.)

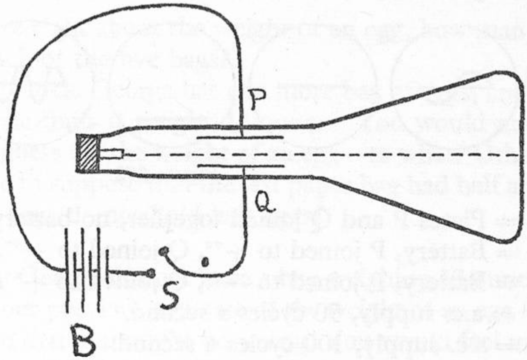


Figure 250

250 Figure 250 shows an electron gun in an oscilloscope tube. A narrow beam of electrons from the gun travels through the tube, passes the two plates P and Q, and makes a spot at the centre of the screen.

a. Draw a sketch, similar to figure 250, but showing what happens when the switch S is closed, thus joining the battery B to the plates, with P positive and Q negative.
b. Draw another sketch showing what happens when the battery is *reversed*, and the switch closed.

251 Battery B in figure 250 consists of three cells, which, when joined to a 6-volt bulb, light the bulb normally. This battery is removed and, in its place, the secondary terminals of an a.c. transformer are joined to P and Q. This transformer also lights a 6-volt bulb normally.

a. What happens to the electron beam now?
b. What is the appearance on the screen at the end of the tube? (Draw a diagram showing the end of the tube.)

252 We now apply to the oscilloscope tube in figure 250 a 'time base' which causes the spot to move across the screen from left to right at a steady speed. The spot then travels back again from right to left very quickly in almost no time at all. It does this 500 times a second.

Various things (A to E below) are joined to the plates P and Q. Each time we draw a sketch (five in all) showing what the screen looks like. Unfortunately we forget to label the sketches (figure 252). Copy the sketches, putting them in the right order and with the right label, A, B, C, D, E, under each.

Figure 252

A = Plates P and Q joined together, no battery or a.c. supply.
B = Battery, P joined to $+^{ve}$, Q joined to $-^{ve}$.
C = Battery, P joined to $-^{ve}$, Q joined to $+^{ve}$.
D = a.c. supply, 50 cycles a second.
E = a.c. supply, 100 cycles a second.

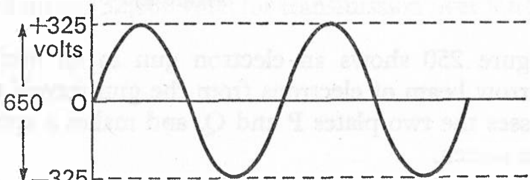


Figure 253

253 The supply of electricity to houses in a certain city is stated by the local Electricity Board to be '230 volts a.c.'. When this supply is applied, in a suitable manner, to a cathode-ray oscilloscope, the voltage is found to swing from + 325 volts to – 325 volts (figure 253).

a. Is the Electricity Board wrong in calling this 230 volts a.c.?
b. If the Board is not wrong, what do they mean by calling this '230 volts'?
c. What is the *peak* voltage of the supply shown in figure 253? What is the *average* voltage?
What is the R.M.S. (root mean square) voltage?
(Choose your answers from the three values, 0 volt, 230 volts, 325 volts.)

33 Millikan's experiment (or: 'the atomic nature of eggs and electricity')

254 *a*. Uncle George has several paper bags of eggs, and he does not know how many eggs there are in any of the bags. To find out, he weighs each bag of eggs on a spring-balance. One bag weighs 14 ounces, another 12 ounces, others weigh 18 ounces, 8 ounces, 10 ounces. What do you guess each one of the eggs weighs, taking it for granted that the eggs are all the same? How did you get your answer?
b. If you are right about the weight of an egg, how many eggs are there in each of the five bags?
c. Suppose Uncle George has one more bag of eggs, and, when he weighs it, he finds it weighs 13 ounces. You would now have to alter your guess for the weight of an egg – to what? Otherwise you would have to suppose that the last paper bag had half an egg in it, and paper bags do not hold half eggs!

(But Uncle George did not have a bag weighing 13 ounces, so you can keep your previous estimate of the weight of an egg – realizing all the time that you might be wrong. You would feel much more certain about it if he weighed many more bags and never found anything different from 0, 2, 4, 6, 8 . . . ounces.)

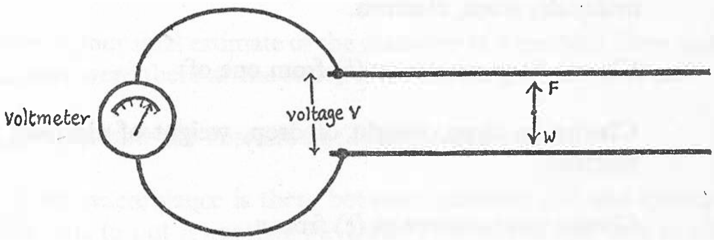


Figure 255

255 Figure 255 represents an oil-drop between two parallel plates. The oil-drop is charged, and a potential difference (voltage) is maintained between the plates so that the drop is pulled upwards. Its own weight, W, pulls it down. The voltage V is adjusted so that the drop remains still. The 'electric force' F pulls it up, and its weight W pulls it down.

a. If the drop stays still, what can we say about F and W?
b. Suppose the charge (we will call it q) on the drop changes, but we also change the voltage V to correspond, so that the drop re-

mains stationary. Then, although q changes, qV remains the same – how do we know this?
c. We do not know q, but V can be read off on a voltmeter. If the charge q varies in steps – that is, whole numbers of electrons – what happens to $1/V$? Why is it $1/V$ that matters, and not V?
d. If, however, the charge q varies not in steps but continuously so that it can take any value whatever, what happens to $1/V$ now?
e. What do we find (about $1/V$) in the actual experiment?
f. What do we deduce about electric charge?

256 Look back at the 'Uncle George' egg question, 254, and also at the 'Millikan' oil-drop question, 255.

a. What is it in the oil-drop question that corresponds to an egg in the egg question? (Don't say 'oil-drops' – the oil-drops are more like the paper bags.)
b. What is it in the oil-drop question that corresponds to the *weight* of an egg?
c. What is it in the oil-drop question that corresponds to the *reading* of the *spring-balance* in the egg question?

Note: Choose your answer to (*a*) from *one* of the following:

molecule, atom, electron.

Choose your answer to (*b*) from one of:

Charge on drop, weight of drop, weight of electron, charge on electron.

Choose your answer to (*c*) from:

voltmeter reading, $\dfrac{1}{\text{voltmeter reading}}$.

257 If you can, give some details about the apparatus used for the Millikan experiment, question 255, and say how the apparatus was used.

258 A number of marbles lie touching each other, inside a tube. You cannot count them, but you can measure the length of the row of marbles, which is 15·6 cm. Someone takes *one or more* of the marbles out. Now, when you measure the length of the row, it is 13·0 cm.

a. If you assume all the marbles have the same diameter, what is the *largest* diameter this could be?
b. Some marbles are added and the length of the row is 20·8 cm. Does this alter your estimate of the largest possible diameter for a marble? Explain the reason for your answer.
c. Some marbles are taken away, and the length of the row is now 16·9 cm. Does this cause you to change your estimate of the largest possible diameter? Explain.
d. You are now beginning to think that the 'largest possible diameter' is in fact the actual diameter. To test this idea further, the experiment is done four more times. The eight readings for the length of the row, including the first four, are:

15·6 cm	11·7 cm
13·0 cm	13·0 cm
20·8 cm	19·5 cm
16·9 cm	18·2 cm

What is your final estimate of the diameter of a marble? How many marbles were there at the start, when the length was 15·6 cm?

e. Explain how the answers in (*d*) *might* be wrong.

259 *a.* What resemblance is there between question 258 and question 255? (Or, to put it another way, why is question 258 here at all?)
b. What, in question 258, corresponds to an electron in the oil-drop question?
c. What, in question 258, corresponds to the charge on an electron?
d. What, in question 258, corresponds to $\dfrac{1}{\text{voltmeter reading}}$?

Organizer Professor E M Rogers

Associate organizers J L Lewis E J Wenham

Assistant organizer D W Harding

This book has been prepared by
Dr H F Boulind

Other Nuffield Physics publications

Teachers' guide I
Teachers' guide II
Teachers' guide III
Teachers' guide IV
Teachers' guide V

Guide to experiments I
Guide to experiments II
Guide to experiments III
Guide to experiments IV
Guide to experiments V

Questions book I
Questions book II
Questions book III
Questions book V