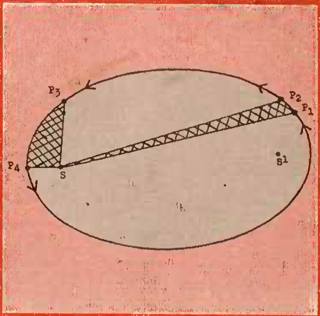
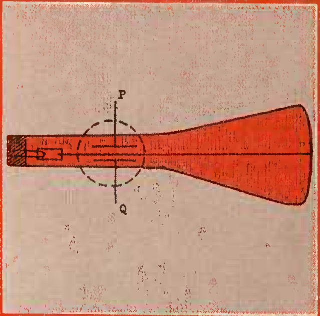
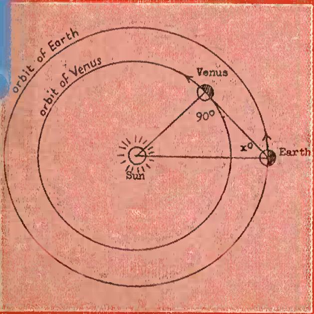
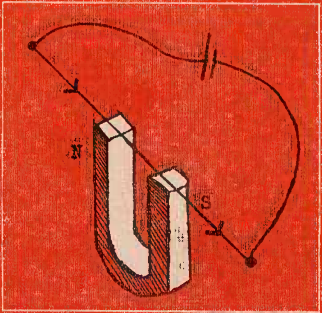
PHYSICS

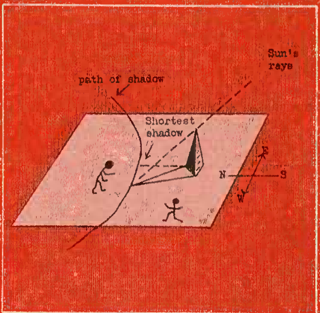
Questions book V











Nuffield Physics
Questions Book V

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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

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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.

1 Introduction to circular motion

1 A circular hoop is placed on a flat floor and a large ballbearing (or heavy marble), B, is set rolling round the inside of the hoop. So long as it is moving the ballbearing presses against the inside of the hoop – try it and see. You will probably have to hold the hoop in position.

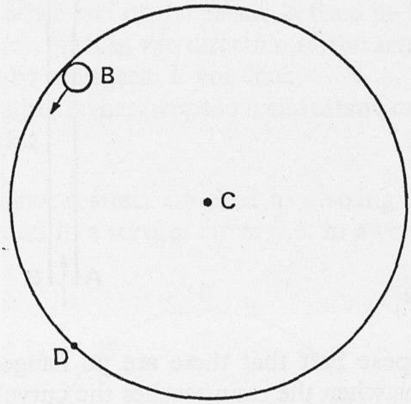


Figure 1

a. Which way is the force exerted by the hoop on the ball – towards the centre C, or away from it? Which way is the force exerted on the hoop by the ball?
b. When the ball has reached the position D the hoop is suddenly lifted off the floor. What happens to the ball? Draw a diagram to illustrate your answer.

2 AA′ and BB′ are the two rails of a single flat railway track. A train proceeds from the straight portion at AB towards the left-hand curve at A′B′.

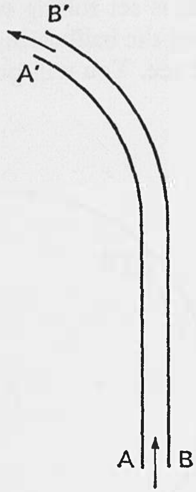


Figure 2

a. Suppose first that there are no flanges on the wheels. What happens when the train reaches the curve?
b. But of course there are flanges on the wheels, and these flanges fit inside the rails. When the train rounds the curve, which rail presses against the wheel flanges? Is it the inner rail, AA′, or the outer, BB′? Give a common-sense reason for your answer, using the word 'momentum'.

3 *Difficult.* In question 2 we thought about the horizontal forces between rails and train. Now let us think about the *vertical* forces. When the train is on the straight portion AB, its weight is equally supported by each rail.

a. When the train is moving round the curve, are the rails still exerting equal upward forces? Or if not, which rail exerts the greater force?
b. What happens if the train goes round 'too fast'? (Think of a toy train if you like; the answers are the same for a toy train and a real train. Saying 'it comes off the rails' is not enough.)
c. Give the reasons for your answers to (*a*) and (*b*).
d. On both toy tracks and real tracks, curves are usually 'banked'. Which way are they banked, with AA′ lower or BB′ lower? Give the reason for the kind of banking you suggest.

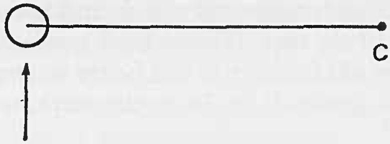


Figure 4

4 *a.* A nearly frictionless object, e.g. a 'carbon dioxide puck' is placed on a smooth table, and a length of elastic is fixed to it (figure 4). The other end of the elastic is fixed at C. The puck is then given a quick push in the direction of the arrow. What happens? Illustrate by a diagram if you like.
b. Show on a diagram what happens if the elastic cannot stand the strain, and breaks.

5 The diagram shows a stone attached to a string held at O, and being swung round in a *vertical* circle (i.e. in a vertical plane).

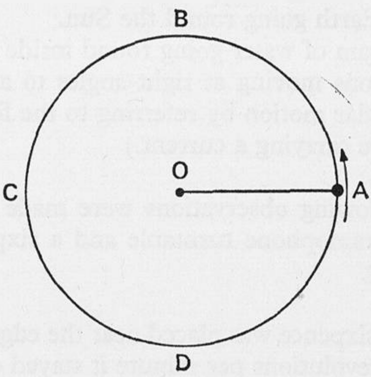


Figure 5

a. What force is keeping the stone moving in a circle when it is at A, or at C?
b. What *two* forces are keeping the stone moving in a circle when it is at B?
c. If the string is weak it is most likely to break when the stone is near D. Why is this?
d. Draw a diagram showing the path of the stone if the string breaks at D. You may suppose that ground level is at a distance equal to BD, below D.
e. Draw a diagram showing the path of the stone if, in the portion AB, it is 'not moving fast enough'.

6 Fill a pail with water and turn it upside down, *keeping the water in the pail all the time*. (If you have not sufficient confidence in the principles of physics you had better wear a macintosh – or a bathing suit – and do it in the garden anyhow!)

a. How did you do it?
b. Why did the water stay in the pail? (This is quite difficult to answer – if you answer it properly you really do understand motion in a circle.)

7 By now you are probably reasonably convinced that a 'centripetal' force (force towards the centre) is needed whenever a body moves in a circle. What is it that provides the centripetal force in the following cases of circular motion?

a. A coin placed on a rotating gramophone turntable.
b. A car going round a bend.
c. The Moon going round the Earth.
d. The Earth going round the Sun.
e. A stream of water going round inside a bent pipe.
f. Electrons moving at right-angles to a magnetic field. (Explain the circular motion by referring to the force exerted by a magnet on a wire carrying a current.)

8 The following observations were made in 'experiments' with a rough gramophone turntable and a sixpence (try for yourself if you like).

(*i*) The sixpence was placed near the edge of the turntable. At $33\frac{1}{3}$ and 45 revolutions per minute it stayed on. At 78 revolutions per minute it came off.
(*ii*) At 78 revolutions per minute the sixpence stayed on, provided that its centre was less than 9·5 cm from the centre of the turntable, but came off if its centre was more than 9·5 cm from the turntable centre.
(*iii*) A record was placed on the turntable, and the sixpence was placed on the record. At 78 revolutions per minute the sixpence now came off if it was 7·5 cm (or more) from the turntable centre.

What can be deduced from these observations:

a. About centripetal force and rate of revolution?
b. About centripetal force and speed of movement in a circle?

c. About centripetal force and radius of revolution, when the rate of revolution is constant?
d. See note below.
e. About friction between sixpences and turntable baize, and friction between sixpences and record material?

Note: The answer to (*c*) is that the greater the radius, the *greater* the centripetal force necessary to keep the object moving in a circle – provided it is the *rate of revolution* which is constant. Question (*d*) should be 'About centripetal force and radius when the *speed of movement in a circle is constant*'. Unfortunately it would be difficult to get any information about this from experiments with a gramophone turntable (though not impossible). We shall see later that the answer to (*d*) is that the greater the radius, the *less* the centripetal force when the speed of movement is constant.

2 Satellites

9 Isaac Newton recorded in a letter how he noticed an apple falling in an orchard, and conceived the idea that the same force that caused the apple to fall also held the Moon in orbit. Perhaps he started to think in this way: 'There is no wind and the apple falls vertically. If the wind blows? If a boy up the tree throws the apple? If, instead of an apple, it is a cannon-ball fired from a gun? Suppose it travels so fast that it passes beyond the horizon before reaching the ground?'

Write a story on these lines, linking the apple and the Moon, and including a diagram showing what happens to the apple when it is projected horizontally with varying speeds. (Newton did in fact draw such a diagram.)

10 An artificial satellite is orbiting 200 kilometres above the Earth's surface, and the radius of the Earth can be taken as 6400 kilometres. Acceleration of gravity, g, may be taken as 10 metres per second per second.

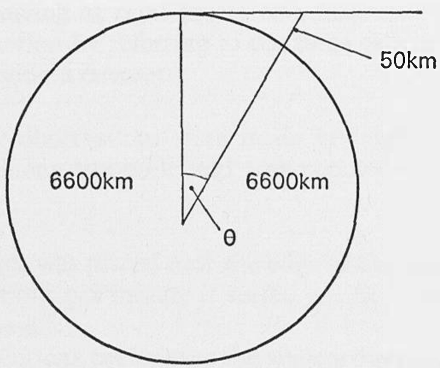


Figure 10

a. Show that, under this acceleration, the satellite 'falls' 50 km in 100 seconds (use $s = \frac{1}{2}gt^2$).
b. The radius of the orbit is $6400 + 200 = 6600$ km. In 100 seconds the satellite has turned in its orbit through an angle θ (see figure 10). If you know some trigonometry, then you can find θ because you see that cosine $\theta = \dfrac{6600}{6650}$ and so you can find θ from tables. If you do not know trigonometry you must accept the answer, $\theta = 7°$ (or more exactly 7·1°). (continued on next page)

c. If 7° of orbit is covered in 100 seconds, how long does it take to make one complete orbit of 360°? (My answer is 86 minutes; do you agree?)

11 We shall now repeat question 10 for the Moon instead of an artificial satellite close to the Earth. Instead of 6600 km, we have the distance from Earth to Moon, about 400,000 km. Since we are dealing with greater distances, we had better work with a greater time of fall; 1000 sec instead of 100 sec.

a. Use the same value of g as before, and show that the Moon 'falls' 5000 km in 1000 seconds, starting from rest.
b. The 'new' angle θ (figure 10) is 9°. If you can use trigonometry to find this, show that 9° is correct.
c. Show that, if 9° of the whole orbit of 360° is correct in 1000 seconds, then the time of one complete orbit of the Moon round the Earth is about 11 hours.

12 The answer to question 11 (*c*) is ridiculous: the Moon does not circle the Earth in 11 hours; it actually takes about 27 days.

a. Where did we go wrong?
b. What do we deduce about gravitational acceleration (due to the Earth) at the distance of the Moon, and near to the Earth's surface?

13 *a.* A satellite just above the Earth would have to circle the Earth in 86 minutes in order to stay up. How fast would it have to travel in miles per second? (Radius of the Earth = 4000 miles, circumference = $2\pi \times$ radius.)
b. What would happen to a satellite travelling within the Earth's atmosphere with this speed?

14 Read the first sentence of question 13 (*a*) and then answer the following question: What would happen near the equator if, instead of rotating once every 24 hours, the Earth rotated once every hour?

3 Derivation of $\frac{v^2}{R}$ (centripetal acceleration) and $\frac{mv^2}{R}$ (centripetal force)

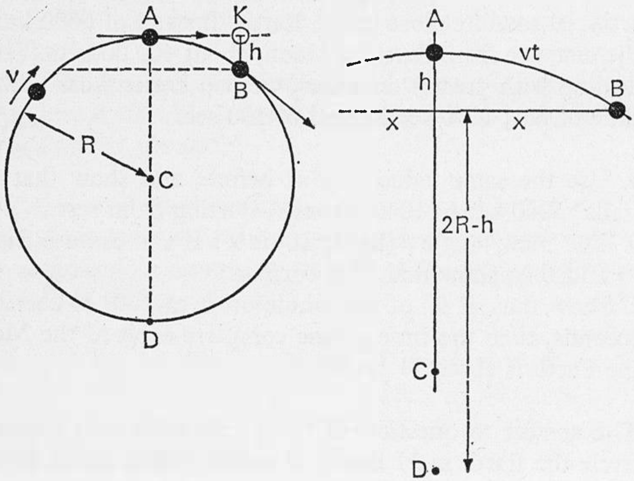


Figure 15

15 *First proof of* $\frac{v^2}{R}$. An object is moving in a circular path (or orbit) with a constant speed represented by v. v is really the velocity of the object, always changing in direction but constant in magnitude. At one instant it is at A and its velocity, tangential to the circle is shown by the arrow at A. A short time t later it is at B, and its velocity is represented by the second arrow. The radius of the circle is R and the distance between A and B is x. A chord is drawn from B at right angles to AC. Since the time t, and therefore AB, is supposed to be very small, the length of the chord is, for all practical purposes, equal to $2x$.

If the object had not been pulled round in a circle it would have travelled from A to K. Because of the force pulling it, it has fallen, in time t, through the distance KB, which we will call h. An equal distance h is marked off from A, towards C. As a first step towards obtaining the expression $\frac{v^2}{R}$ we write:

$$h(2R - h) = x^2 \qquad . \quad . \quad . \quad (1)$$

a. Explain (as if to another pupil) why equation (1) is correct.

We can write this,

$$h = \frac{x^2}{2R - h}$$

and then, quite correctly, we can leave out the h from $2R - h$ and write

$$h = \frac{x^2}{2R} \qquad . \quad . \quad . \quad . \quad . \quad (2)$$

b. Explain why we can leave out the h in $2R - h$.

Since the object travels from A to B in time t with speed v, therefore $x = vt$, and we write

$$h = \frac{(vt)^2}{2R} = \tfrac{1}{2}\left(\frac{v^2}{R}\right)t^2 \qquad . \quad . \quad . \quad (3)$$

Now, h is the distance fallen towards the centre, and there was no initial velocity at A in that direction. There must have been an acceleration a towards the centre, and by using

$$s = ut + \tfrac{1}{2}at^2 \qquad . \quad . \quad . \quad (4)$$

We see that,

$$a = \frac{v^2}{R} \qquad . \quad . \quad . \quad . \quad . \quad (5)$$

where a is the *centripetal acceleration.*
c. Explain how equation (3) and equation (4) together lead to equation (5).

16 This question is *not essential*, and you do *not* have to learn this proof for an examination. However, if you have worked through question 15, you can now:
Copy figure 15 and write out a proper proof, with sufficient explanation, but not too much, of:

$$\text{centripetal acceleration} = \frac{v^2}{R},$$

for a body moving in a circular orbit.

17 *Alternative proof of* $\frac{v^2}{R}$ *for centripetal acceleration*

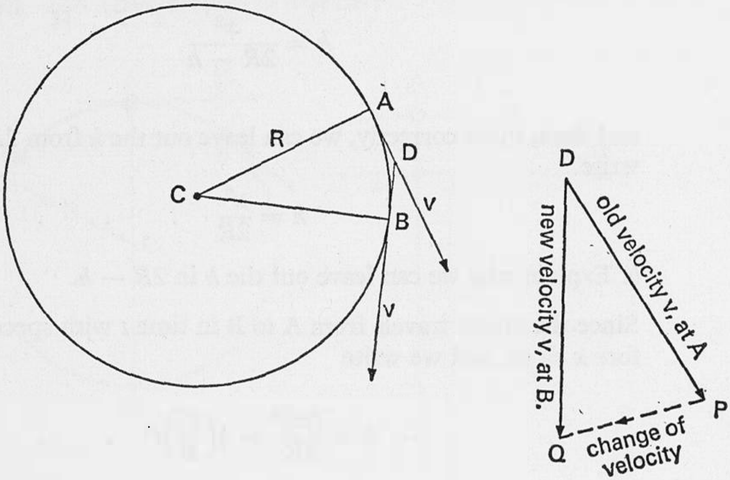


Figure 17

An object is moving with a constant speed v in a circular path. At one instant it is at A and its velocity, tangential to the circle, is shown by the arrow. A short time, t, later it is at B and its velocity is represented by the second arrow. The radius of the circle is R. The velocity line at B is produced backwards to meet that from A at D. On the right, a second diagram is drawn, also from D, but the circle part of the diagram is left out, so as to make it look simpler. DP represents the velocity at A. DQ, of equal length, represents the velocity at B. The triangles PQD and ABC are similar.

a. Why is PQ labelled 'change of velocity'?
b. Why are PQD and ABC similar triangles?
We then say,

$$\frac{\text{change of velocity}}{v} = \frac{\text{AB}}{R} \quad . \quad . \quad (1)$$

or, change of velocity $= \dfrac{\text{AB}.v}{R}$

c. Why is equation (1) true?
We remember that $t =$ time taken, A to B, and write

$$\frac{\text{change of velocity}}{t} = \frac{\text{AB}.v}{t\ R} \quad . \quad . \quad (2)$$

which is simply dividing both sides by t. So we get,

$$\text{acceleration} = v.\frac{v}{R} = \frac{v^2}{R} \quad . \quad . \quad . \quad (3)$$

d. Explain how equation (3) follows from equation (2).
e. How do you know, from the right-hand diagram, that the acceleration is directed towards the centre?

18 This question is *not essential*, and you do *not* have to learn this proof for an examination. However, if you have worked through question 17, you can now:
Copy figure 17 and write out a proper proof, with sufficient explanation, but not too much, of:

$$\text{centripetal acceleration} = \frac{v^2}{R},$$

for a body moving in a circular orbit.

19 *Difficult*. Whether we have used the first method of proving $\frac{v^2}{R}$ for centripetal acceleration or the alternative method of question 17 we have had to make approximations, or use phrases such as 'for practical purposes'. Yet the final equation,

$$a = \frac{v^2}{R}$$

is not an approximation; mathematically it is completely correct. Explain (as if to Uncle George) why this is so.

20 *a.* If a body moving in a circle has a centripetal acceleration, then there must exist a centripetal force producing that acceleration. Mention *three* examples of an object moving in a circular path, and say in each case what provides the centripetal force.
b. The acceleration is v^2/R, so the force must be mv^2/R. Why?
c. In the expression v^2/R, where did the v^2 come from? (Or why v^2 rather than v or $\frac{1}{v}$ or v^3, etc.?) (continued)

d. In the expression v^2/R, where did the $\frac{1}{R}$ come from? (Or why $\frac{1}{R}$ rather than R or R^2 or $\frac{1}{R^2}$, etc.?)

21 A heavy ball rolls round inside a hoop resting on the floor, as in question 1. The mass of the ball is 0·25 kg, the radius of the hoop is 0·4 metre, and the ball rotates through a full circle once in every second.

a. What is the speed, v, of the ball?
b. What force does the hoop exert on the ball, keeping it on a circular path (i.e. what is the centripetal force)? Note, π^2 is very nearly equal to 10, and you may take $\pi^2 = 10$.
c. Work out (*a*) and (*b*) again, this time for a hoop of radius 0·3 metre.
d. Your answers to (*b*) and (*c*) should be 4 newtons and 3 newtons. How do you account for the fact that the smaller circle requires the *smaller* force, although, from $\frac{mv^2}{R}$, you might think that, since R is in the denominator, the smaller circle would require the *larger* force?

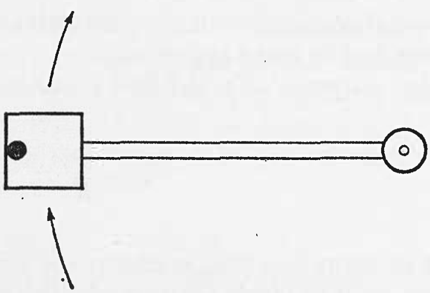


Figure 22

22 You are inside a cage which is being rapidly rotated as in figure 22 – the sort of thing you might pay to have done to you at a fair. Afterwards you tell a friend that 'Centrifugal force flung me against the outer wall and kept me pressed there'. 'Rubbish,' he says, 'there is no centrifugal force; it was only that you tried to go straight on, like Newton said.' Explain what happened to you from your friend's point of view, that is, in terms of centripetal force.

23 *a. Difficult.* Explain using centripetal force (*not* centrifugal) how it is that a spin-dryer can extract water from wet clothes, so that they are as dry as they would be if they had been put through a mangle.
b. Easy. A spin-dryer has a tub which is 0·25 metre in radius. It makes 5 revolutions per second. What is the value of the centripetal acceleration (v^2/R) at the rim of the tub?
c. Your answer to (*b*) should be in metres per seconds per seconds. The acceleration of gravity, g, is 10 metres per seconds per seconds. How many times gravitational acceleration might your mother be using to dry clothes in her kitchen?

Experimental tests

In answering questions 24, 25, 26:

(*i*) draw a diagram of the apparatus you use (but of course one diagram will do for all three questions, if you use the same apparatus);
(*ii*) say what measurements you take and how you take them;
(*iii*) say how you would use the measurements to arrive at the result you are asked to obtain.

24 How would you show that the centripetal force, required to keep an object moving in a circular path, varies as the *square* of the speed of the object (v^2)?

25 *Difficult.* How would you show by an experiment that centripetal force varies *inversely* with the radius of the circular path $\left(\frac{1}{R}\right)$?

Note: This is not quite straightforward. The question means that centripetal force varies as $\frac{1}{R}$ *if the velocity for different radii is the same.* You can probably keep the revolutions per *second* the same, but that is not the same thing as keeping the velocity the same. What do you suggest?

26 How would you show that the expression for centripetal force,

$$F = \frac{mv^2}{R},$$

is correct in any one particular case?

4 Electrons travelling in straight lines and circles

27 *a.* Make a sketch showing the electrodes (filament and anode) of a 'hot cathode' discharge tube, and add to your sketch the items which are connected externally.
b. State the uses of (*i*) the filament, (*ii*) the anode, (*iii*) the specially treated screen, of a cathode-ray discharge tube.

28 The 'fine-beam' tube does not have a fluorescent screen, but the beam is visible *inside* the tube. An ordinary cathode-ray tube does not have a visible beam. How is the beam inside the 'fine-beam' tube made visible?

29 *a.* Make a sketch of a 'Maltese cross' tube.
b. What particular property of cathode rays does it show us?
c. For what historical reason do manufacturers usually use a Maltese cross as an obstacle?

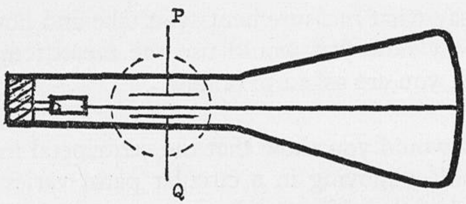


Figure 30

30 *a.* The diagram above is a rough sketch of a cathode-ray tube with a beam going straight through the tube and forming a bright spot on the screen. Draw a similar but larger sketch showing the path of the beam when a potential difference is established between P and Q with P positive and Q negative. Omit the dotted circle.
b. Draw a second sketch, omitting P and Q, but showing what happens when the beam passes through a magnetic field which covers the space shown by the dotted circle. The *direction* of the magnetic field is such that a wire carrying a positive electric current going from left to right would be deflected towards the top of the paper.

31 The two experiments you have illustrated in question 30 are usually said to show that cathode rays are *negatively* charged. Someone says: 'These experiments do not show that at all; the result would be just the same if the rays are *positively* charged and going in the opposite direction.'

What arguments could you put forward to suggest that it is exceedingly unlikely that, in this apparatus, the rays could be 'going in the opposite direction'? (Confine the discussion to the deflexion experiments themselves; do not bring in other information.)

32 Discuss briefly whether the experiments considered in this section (cathode-ray oscilloscope tubes, Maltese cross tube, fine beam tube) give us any evidence about the particle nature of cathode rays – that is, about whether the rays are particles (electrons) or a continuous form of something we might call 'juice'.

5 Measurement of *e/m* for electrons

We shall now talk about 'electrons', and forget about the 'juice' possibility (question 32). The fact that we determine 'e/m for electrons' does not in itself mean that electrons exist; it could be that a mass m is always associated with a charge in a 'continuous something' that we call cathode rays, so that e/m is constant for any part of the rays. However, there is convincing evidence for electrons (e.g. Millikan's experiment), and it would now be unrealistic to pretend that we do not know whether or not they exist.

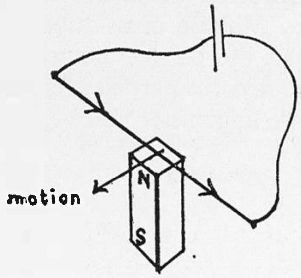


Figure 33 (*a*)

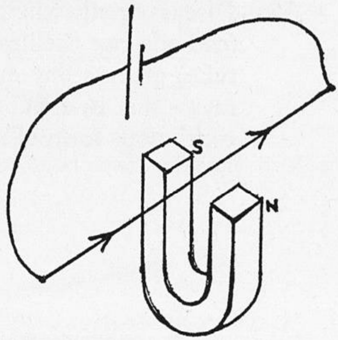


Figure 33 (*b*)

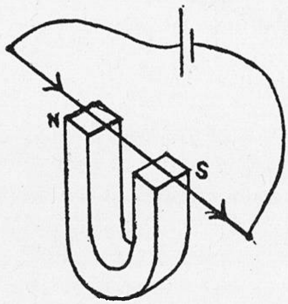


Figure 33 (*c*)

33 *a.* In figure (*a*) the wire jumps off the magnet to the *left*, as shown.
(*i*) Which way will the wire move if the magnet is turned the other way up (S-pole at top)?
(*ii*) Which way will the wire move if the current is reversed, but the magnet is as in figure (*a*)?
(*iii*) Which way will the wire move if, compared with figure (*a*), the current is reversed *and* the magnet is placed S-pole uppermost?
b. What happens to the wire in figure (*b*)?
c. What *two* things, one after the other, happen to the wire in figure (*c*)?

34 Figure 34 shows a piece of wire of length l, carrying a current i, and placed in a magnetic field. The current enters the wire by two leads x and y coming from a battery well outside the magnetic field.

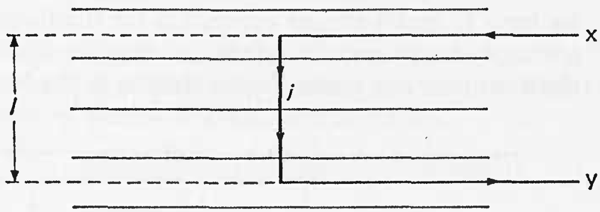


Figure 34

a. In what direction is the force on the piece of wire?
b. Why is there no force acting on the leads x and y?
c. The force on the piece of wire varies directly as its length l and the current i. On what else, besides i and l, would you expect the force to depend?
d. If B = the force on a wire of unit length carrying unit current (or, more correctly, B = force per unit length per unit current), what is the force F on a wire of length l carrying current i? (Write $F = \ldots$ something in terms of B, i, and l.)

35 In an experiment to determine B for a pair of Helmholtz coils (which will later be used with a 'fine-beam' tube) a 'test-wire' 20 cm (0·20 metre) long was placed in the magnetic field of the coils, and a current of 20 amperes was passed through it. An extra load on the wire of 0·5 gm (0·0005 kg) had to be attached to the wire to keep it in place. The weight of this load balances the force of the magnetic field.

a. Use the equation $F = Bil$ (question 34 (*d*)) to find B from these figures. (First write $B = \frac{F}{il}$, then substitute. You need to remember that $g = 10$ newtons per kg. Give your answer to B in units of 'newtons per ampere-metre'.)
b. Draw a rough sketch of the apparatus you have used (or seen used) to determine B in this way. You need not draw the coils; just indicate the magnetic field direction.

36 We now imagine an electron beam in the magnetic field in place of the wire carrying a current. Instead of:

$$F = Bil$$

we have to find a similar expression for the force on an electron having a charge e and a velocity v. Suppose that, in a time t, N electrons pass any place, Y for example, in the beam.

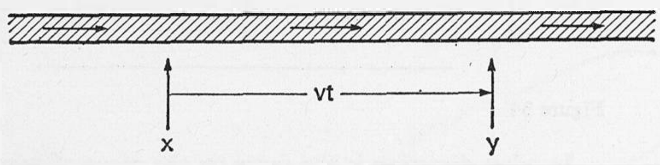


Figure 36

a. What is the charge passing Y in time t?
b. What is the current i (charge per second) at Y?
c. If the speed is v, what length l, of beam passes Y in time t? (*Hint.* Suppose a length XY of the beam will pass Y in time t. How long is XY?)
d. Use $F = Bil$ and substitute in it the value of i from (*b*) and of l from (*c*). What do you get for the force on N electrons?
e. What is the force on a single electron?
(Now check your answers with the answers at the end of this section.)

37 *a.* With no magnetic field, the electron beam in a fine-beam tube follows a straight path. How would you describe the path when a magnetic field is switched on?
b. If the path is circular, it is because a centripetal force is exerted on the electrons, given by

$$F = Bev$$

But we can also write an expression for the centripetal force needed by a particle of mass m if it is to move with a speed v in a circular path of radius R. What is this other expression?
c. Write an equation putting Bev equal to the second expression you wrote in (*b*). Check your answer with those at the end of this section.

38 The equation of 37 (*c*) contains an unknown quantity v, the speed of the electrons, as well as e/m. To find v and e/m separately we must have another equation as well. We get this by measuring the potential difference, V, between the cathode and the anode of the 'electron gun' from which the electrons come.

a. What does 'potential difference' mean? And what does '1 volt' mean (in terms of coulombs and joules)? Look it up in Year IV notes or answers to questions if you have forgotten.

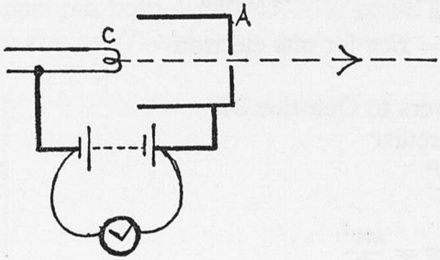


Figure 38 (*b*)

(*b*) Figure 38 is a simplified diagram of the connections to the cathode, C, and anode, A, of an electron gun. If the charge on an electron is e and the potential difference between cathode and anode is v, how much energy does each electron acquire by the time it reaches A?
c. This energy is in the form of *kinetic energy of motion* of an electron. Write down the usual expression for the kinetic energy of a particle of mass m having velocity v.
d. Write an equation putting the two expressions for energy, from (*b*) and (*c*) equal to each other. Check your answers with those at the end of this section.

39 Write down again the answer you obtained (after checking its correctness) to question 37 (*c*), and the answer to 38 (*d*).

a. Find from these two equations an expression for the velocity, v, of the electrons.
b. Now find an expression for e/m, the ratio of charge to mass, for the electrons.
c. If we know the value of the electron charge, e (from Millikan's experiments for example), how do we find the mass m of an electron?

Answer to Question 35 (*a*): $B = 0{\cdot}00125$ newtons per ampere metre. (*Note:* This is the arithmetical result of the calculation, written to more figures than the given values justify.)

Answers to Question 36

a. Ne

b. $i = \dfrac{Ne}{t}$

c. $l = vt$

d. $F = \dfrac{B.Ne.vt}{t} = BNev$

e. $F = Bev$ for one electron

Answers to Question 37

a. Circular

b. $\dfrac{mv^2}{R}$

c. $Bev = \dfrac{mv^2}{R}$

Answers to Question 38

a. The potential difference between two points (or two places in a circuit) is the energy transferred *from* electrical energy *to* some other form when unit charge passes from one point to the other. 1 volt is the p.d. when 1 joule of electrical energy is changed to another form when 1 coulomb (or 1 ampere for 1 second) passes between the two points. V volts means V joule/coulomb

b. eV

c. $\frac{1}{2}mv^2$

d. $eV = \frac{1}{2}mv^2$

6 Electrolysis. Electrons, ions, protons

Note: Questions 40 to 45 are the same as questions in Year IV. If they have previously been worked through, or if, as suggested, electrolysis is largely left to Chemistry, they can now be passed with a casual glance, except for question 45, which should be studied carefully.

40 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, (*i*) and (*ii*), drawn below.

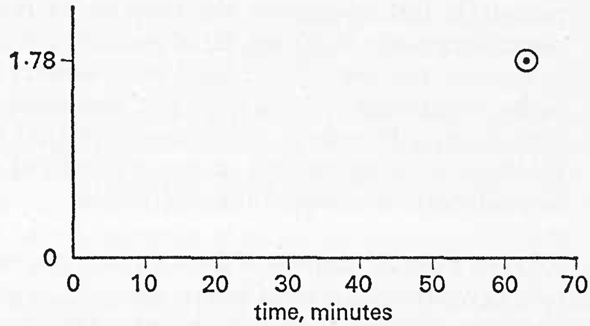


Figure 40 (*i*)

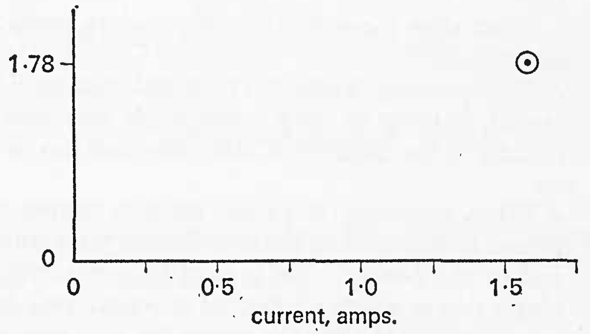


Figure 40 (*ii*)

a. Copy and complete graph (*i*), drawing a line showing how the mass of copper deposited by 1·5 ampere increases with time. How long will it take for 1·0 gm to be deposited by 1·5 ampere?
b. What assumption about mass deposited and time elapsed have you made in drawing your graph?

c. Copy and complete graph (*ii*), drawing a line showing how the mass deposited in 1 hour increases with the current. How much current is needed to deposit 1·0 gm in 1 hour?
d. What assumption about mass deposited and current passed have you made in drawing your graph?

41 *a.* Find from the figures given in the first sentence of question 6·1, 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 40? Explain.
e. Suppose you wished to extend your answers to very tiny deposits. What would you do to predict how many coulombs would deposit one-millionth of 1·78 grams of copper? Can you see any objection to extending this to one-millionth of one-millionth of one-millionth of one-millionth of 1·78 gm?

42 *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 41). 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?

43 *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: 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.

44 *a.* The current through a copper sulphate solution is carried, at least in part, by copper atoms with a positive charge (question 43). 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.

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

$$1:64:108$$

a. What do these figures suggest about the 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: Charged atoms are called IONS to distinguish them from ordinary uncharged atoms. A hydrogen ion (which is just a hydrogen nucleus) is called a PROTON.

46 The ratio $\frac{\text{charge}}{\text{mass}}$ for electrons is, approximately,

$$\frac{e}{m} = 1{\cdot}76 \times 10^{11} \text{ coulombs per kg}$$

The ratio $\frac{\text{charge}}{\text{mass}}$ for hydrogen ions in electrolysis $\frac{e}{M}$ is, approximately, $9{\cdot}6 \times 10^{7}$ coulombs per kg
a much smaller value.

a. This could mean,
(*i*) that e is larger for electrons, or
(*ii*) that m is smaller, or
(*iii*) a bit of both, viz. e larger and m smaller.
Which of these alternatives do you think is most likely to be correct, and why? (continued)

b. Assuming that e is the same for electrons and hydrogen ions, we have,

$$\frac{e}{m} = 1{\cdot}76 \times 10^{11} \text{ coulombs per kg (electrons).}$$

$$\frac{e}{M} = 9{\cdot}6 \times 10^{7} \text{ coulombs per kg (protons).}$$

Find the ratio $\frac{m}{M}$ of electron mass to proton mass, by dividing the second equation by the first.

47 The value for e found by Millikan's experiment is

$$e = 1{\cdot}6 \times 10^{-19} \text{ coulomb}$$

From this, and from the values of $\frac{e}{m}$ and $\frac{e}{M}$ in question 46 (*b*), find:

a. the mass of an electron
b. the mass of a proton
c. the number of hydrogen *atoms* in 1 kg of hydrogen.

7 Positive rays and isotopes

48 Place a penny, or better, a larger round object such as a beaker or a cup or a saucer, on a sheet of paper and draw round it. Mark one point on the circle, then shift the penny slightly, so that you can draw a slightly displaced circle through the same point. Draw one or two more circles, not greatly displaced from the original circle. Imagine that the original point was the starting-point for a stream of ions splaying out in slightly different directions, and that the ions were bent into circular orbits by a magnetic field, all with the same radius. What does your sketch show you about these orbits?

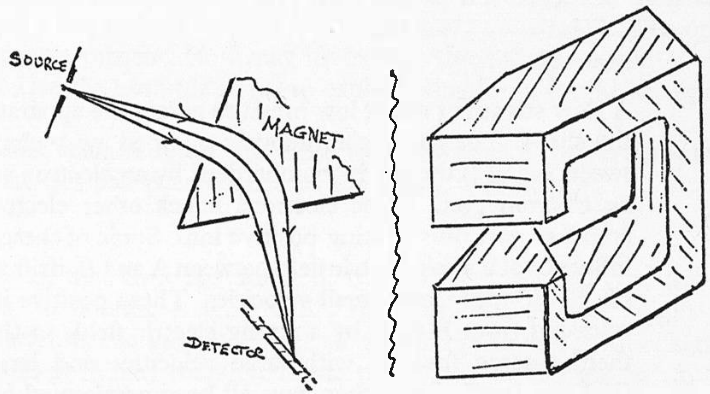


Figure 49

49 Here is a diagram, figure 49, of a type of magnet used in the 'modern mass spectrometer' described in question 50. It focuses streams of ions that have been deflected only 60°, instead of 180° as in question 48.

Give in a sentence or two a reason why a magnet like this would focus the stream after a deflexion which is much smaller than 180°.

50 Here is a diagram which shows the basic idea of a modern 60-degree mass spectrometer.

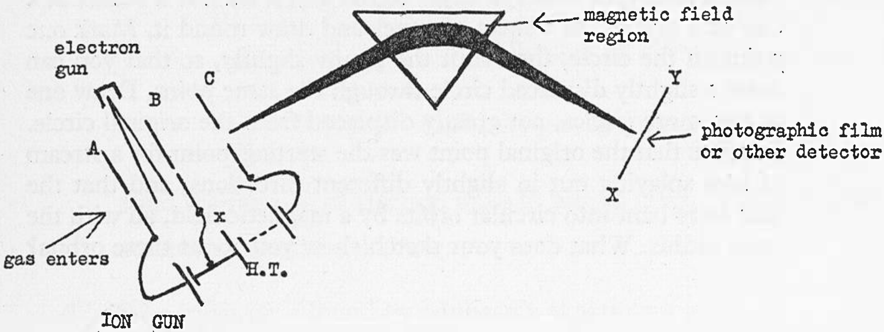


Figure 50

A slow stream of gas at low pressure enters the apparatus through the slit A. The gas is continuously pumped away elsewhere. Between A and B the gas is 'bombarded' by an electron stream from an electron gun. These electrons knock other electrons off the atoms of gas, thus making positive ions. Some of these, under the influence of a weak electric field between A and B, drift through the slit B with only very small velocities. These positive ions are accelerated from B to C by a strong electric field, so that some of them emerge from C with large velocities and large energies (K.E. = $\frac{1}{2}mv^2$). Since they have all been accelerated by the same field between B and C, they all have very nearly the same kinetic energy. Even though a fine slit is used at C, the ion beam splays out through a small angle, and it is focused on a photographic film XY, or some other detector, by a magnetic field whose direction is perpendicular to the paper.

a. Why is it necessary to have ions coming through C all with the same energy? What would be the disadvantage if this were not the case?
b. Why is it necessary to have B negative with respect to A, but only slightly negative?
c. Suppose the gas contains a mixture of atoms of two different masses, m_1 and m_2, m_2 being greater than m_1. Suppose also that *all* the gas ions formed carry an equal positive charge (i.e. all have lost the same number – one or more – of electrons). What is going to happen when the ion beam has been focused by the magnetic field? Will the m_2 ions be focused on the film nearer to X, or nearer to Y, than the m_1 ions are?

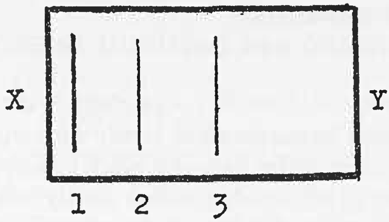


Figure 51

51 *a.* Neon gas, under low pressure, is fed into the mass spectrometer apparatus of question 50. When the film at XY is developed it shows *three* traces, a very dark one, at 1, a very faint trace at 2, and a not so faint trace at 3. The gas was pure neon, and no other gas was present. How may we explain these three traces?
b. Use the example in (*a*) to explain what is meant by 'isotopes'.

52 Look again at figure 50. What would happen if, by mistake, both batteries had been connected the wrong way round?

53 A mass spectrometer shows that chlorine gas contains two isotopes, that is, it has atoms of two different masses. One isotope has an atomic weight of 35, the other has atomic weight 37. Roughly, the atomic weight of chlorine as found by the chemist is 35·5. What, roughly, is the proportion of '35 atoms' to '37 atoms' in chlorine?

54 Uranium contains two isotopes, U_{235} (i.e. uranium atoms of atomic weight 235) which is 'fissionable' in a nuclear reactor or in an atomic bomb, and U_{238}, which is stable. In natural uranium, only 1 atom in 140 is U_{235}; the other 139 are U_{238} atoms. A problem arises: how to separate the 235 isotope from the 238.

a. How might this be done on a very small scale, that is, how might you collect a very small quantity of U_{235} in a small metal container?
b. Suggest two possible ways of separating U_{235} and U_{238} on a larger scale, or at any rate, of obtaining a specimen of uranium containing more than 1 atom of U_{235} in 140. (Just make two suggestions; do not trouble about whether or not your ideas are known to be used in practice.)

8 The heavens: what do we see (without telescopes)?

55 On a clear cloudless day – or night – the sky above us looks like an inverted hemispherical bowl, with ourselves at the centre: a bright blue bowl by day, or a black bowl by night. Inside this bowl but above us we see objects that clearly belong to the Earth – clouds, and man-made things such as aircraft. Obviously farther away, part of the bowl perhaps, are the Sun, the Moon and the stars, including the very interesting objects we call planets.

a. Certainly to us, on Earth, the Sun is the most important and necessary of these objects – why?
b. Moonlight may be useful at night, but the most important thing to us here about the Moon is that it produces *tides*: what evidence is there that the Moon, rather than the Sun or stars, is chiefly associated with oceanic rise and fall?
c. Have the stars any practical usefulness to us at all? If so, what?

56 Which looks the larger, the Sun or the Moon? What evidence is there – evidence which men could have known 3,000 years ago – that the Sun is farther away than the Moon?

57 *a.* How far away from you must you hold a penny so that it looks the same size as the moon? (Diameter of the moon makes an angle of $\frac{1}{2}°$ at our eyes. Diameter of a penny = 3 cm. Answer to nearest centimetre.)
b. If the Moon is 400,000 kilometres away, what is its diameter?

58 Look at the diagram on the next page.

a. Is this in the northern or the southern hemisphere? Or can't you be sure? Explain.
b. Is it morning or afternoon? How do you know?
c. Suppose figure 58 refers to England in winter time. What time (nearest hour) would you expect a clock to show when the shadow is shortest?
d. But suppose it is England in summer time, what time would you expect a clock to show? Why?

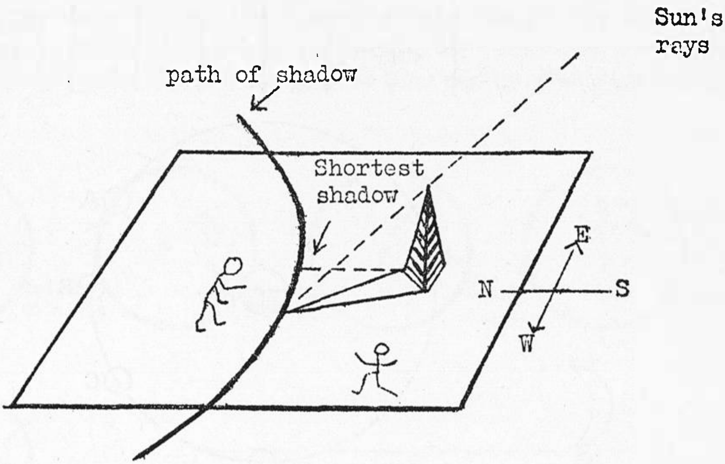


Figure 58

59 Suppose now that figure 58 is a correct picture at a certain place in March. What would the picture be like (*a*) in December, (*b*) in June? (Answer by drawing two sketches. You may suppose that at this place the Sun never comes directly overhead.)

60 *a*. What if the Sun did go directly overhead? Draw a sketch, like figure 58, but referring to a place and a date for which the Sun passes overhead.
b. When does the Sun pass overhead at the equator? – or does it pass overhead on every day?

61 The Sun, like the Moon, makes an angle of about $\frac{1}{2}°$ at your eye. If the Sun is 150 million kilometres away, what is its diameter?

62 You know what the Moon looks like when seen at 'full Moon' on a clear night. What would the Earth look like to a space-man standing on the Moon and looking at the Earth? (Write a brief account comparing what he would see of the earth with what you see of the Moon.)

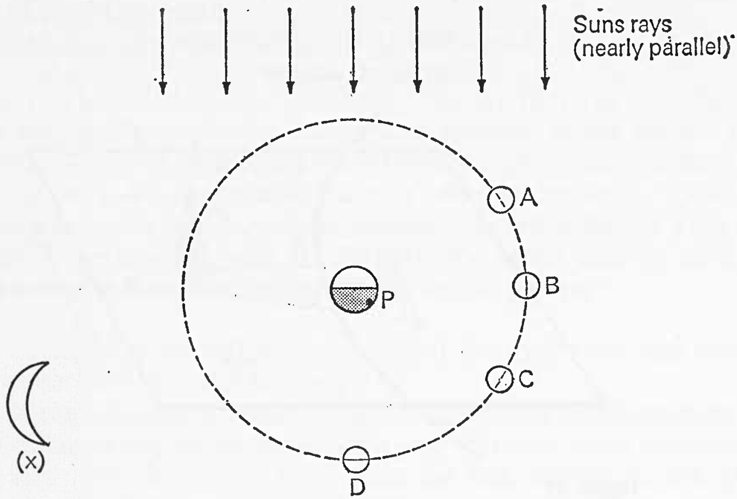


Figure 63

63 An observer at P, in the 'night-time' portion of the Earth (figure 63), looks at the Moon. Draw diagrams to show what the shape of the Moon is, as he sees it, when it is (*a*) at A, (*b*) at B, (*c*) at C, (*d*) at D. (Draw little diagrams like the one at *x*. The others will have different shapes. Label them correctly, (*a*), etc. You may assume that, even for position D, Sun, Earth and Moon are not exactly in line.)

Whereabouts, on the diagram, would the Moon be if no Moon is visible anywhere on Earth?

64 *a*. Write a few sentences describing the appearance of the sky on a clear moonless night.
b. Describe the gradual changes in the appearance of the sky as night turns into day (or day into night if you prefer!).
c. Why is the townsman much less conscious of the existence of the stars than is the countryman?

65 *a*. Why is the Pole Star important to us?
b. Draw a sketch of the constellation called the Plough and show how it helps in finding the Pole Star.
c. The Sun, the Moon and most of the stars rise in the east, move westwards across the sky, and set in the west. But some stars can be seen moving *eastwards* across the sky. How do you explain this? Whereabouts are they, with respect to the Pole Star?

66 Draw some constellation other than the Plough; say where you saw it in the sky (north, north-east, etc.; near the horizon, or nearly overhead); and say at what time and on what date you saw it.

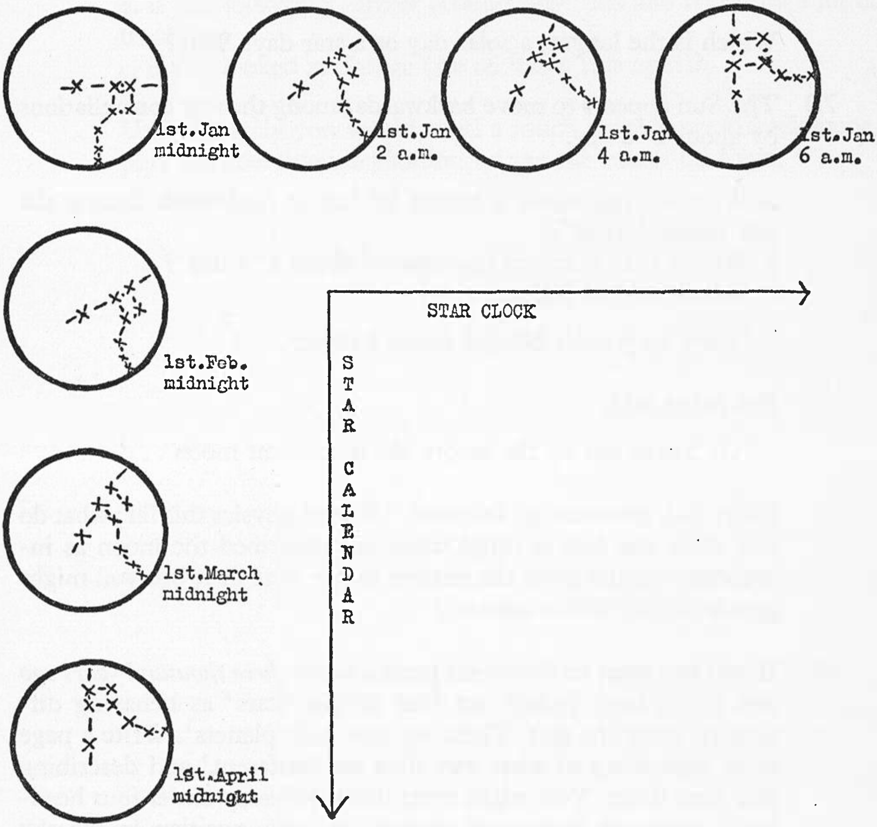


Figure 67

67 Use the diagram, figure 67, to explain what happens to the star pattern in the sky,
a. hour by hour on the same night;

b. month by month at the same hour.

68 Explain why the star pattern, seen at the same hour, revolves, approximately, 15° every hour in the same night, and 30° every month.

69 At noon the Sun crosses the zenith, which is an imaginary vertical north-south plane. The solar day is the time interval (24 hours) between two successive passages of the Sun across the zenith. The star day is the time interval between two successive passages of any one particular star across the zenith.

Which is the longer, a solar day or a star day? Why?

70 The Sun appears to move backwards among the star constellations by about 1° a day.

a. What do you think is meant by 'move backwards among the star constellations'?
b. Why is the backward movement 'about 1° a day'?
c. Romeo said to Juliet,

> 'Lady by yonder blessed moon I swear . . .'

But Juliet said,

> 'O! Swear not by the moon, the inconstant moon . . .'

Juliet had, presumably, followed 'O' level physics this far; what do you think she had in mind when she described the moon as inconstant? (Juliet gives the answer in her next line, but you might give a slightly better answer.)

71 If you had been an observant person *living three thousand years ago* you might have picked out four of the 'stars' as behaving differently from the rest. These we now call 'planets'. Write a page or so explaining in what way they are 'different' and describing how they differ. You might write this brief essay under four headings: Apparent movement among the stars, position in the sky where seen, brightness, colour. Those planets are, of course, Venus, Mars, Jupiter, Saturn.

72 Supposing you look through any small telescope such as an amateur astronomer might use, what is there especially striking you would notice,

a. if you looked at Venus (at different times during the year);
b. if you looked at Jupiter (Galileo saw this and it caused a lot of trouble);
c. if you looked at Saturn (we all know this one!)?

Unfortunately you would need a much more powerful telescope, plus considerable imagination, to see the canals on Mars.

9 Greek astronomical theories

'What is truth? said jesting Pilate; and would not stay for an answer' (Francis Bacon).

Must a theory be true, if it is to be useful? This is a question we shall be better able to answer, or to reword, at the end of this section.

73 If you live near London, look at the Underground map of London Transport. Compare that with the London Transport map of bus routes (which also shows Underground railways). Which is right? Which would you rather use? Why?

Which picture of atoms or molecules is the right one to use in thinking out a simple kinetic theory of gases? In discussing electron bombardment making ions . . .?

74 What evidence is there for believing the Earth is round?

a. Give three reasons that might have been known to, or discovered by, the Greeks two thousand years ago. Illustrate your answers by diagrams where necessary.
b. Mention, if you can, some further reasons belonging to the twentieth century.

75 Suppose you could meet and talk with a young Greek man or woman of your own age, living in the year 500 B.C. What reasons might he or she give for supposing that the Earth is stationary, immovable in space? And what might you reply?

Questions 76–79 are based on the diagram labelled figure 76. You can answer them from common sense and common everyday knowledge, even if you have never before seen anything like figure 76. The black blob at the centre of the main diagram is the Earth, supposed stationary in space. The little man standing on it (he is only a few thousand miles high!) is supposed to be at latitude $52\frac{1}{2}°$; he might be at Birmingham for example. On the outside of the diagram you see the rotating sphere that contains the stars studded into it. The 'equator plane' and 'horizon plane' are imaginary planes, although useful mathematically. The Sun is set in a crystal sphere inside the sphere of the stars. This sphere rotates on an axis which makes an angle of $23\frac{1}{2}°$ with the axis of the starry sphere; this makes the Sun go round the Earth, not in the plane of the equator, but in the 'ecliptic' plane. Outside the sphere of the stars you can put what you like: the Abode of the Blessed perhaps, and the celestial machinery for turning everything round.

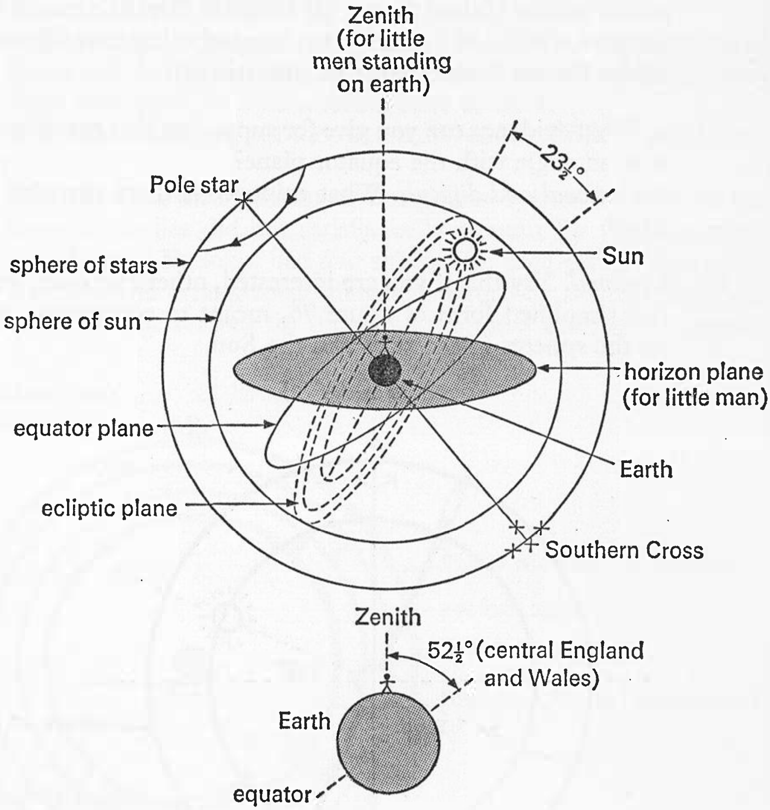


Figure 76
stationary Earth, rotating stars and Sun

76 Why are the pole star and the southern cross put where they are on the diagram? How would you define the 'equator plane'? (This is the *celestial* equator. The Earth's equator is contained in that equator plane, of course.)

77 Do the stars *appear* to move in the direction of the arrow at the top of the diagram, or in the opposite direction? Give the reason for your answer by quoting your everyday (or rather, 'everynight') experience. (continued on next page)

78 What do you think is meant by the 'zenith', and what is meant by the 'horizon plane'? (This is the *celestial* horizon of course.) What is the angle between the zenith direction and the horizon plane?

Could the horizon plane be the same as it is in figure 76 for a person in (*a*) the United States, (*b*) Canada? Give the reason for your answers. (*Note.* No catch here; remembering that Alaska is one of the United States makes no difference!)

79 *a.* What evidence can you give for supposing that the ecliptic plane is at an angle with the equator plane?
b. Optional and difficult. What evidence is there that this angle is $23\frac{1}{2}°$?

80 *Optional.* Try this if you are interested, otherwise omit. Figure 80 is a simplified form of figure 76, meant to concentrate attention on the spheres of the stars and the Sun.

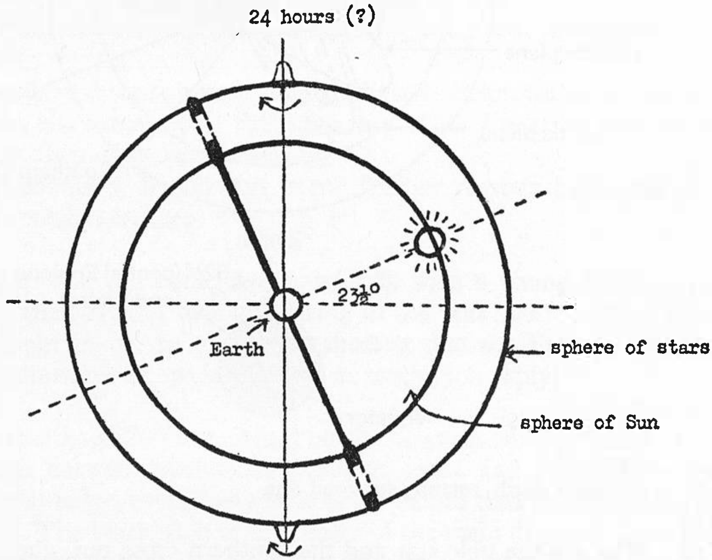


Figure 80
spheres of stars and Sun (Pythagoras)

a. Does the sphere of the stars rotate once in *exactly* 24 hours? Think carefully, and give the reason for your answer.
b. Suppose first that the sphere of the Sun is entirely independent of the sphere of the stars, at what rate does it rotate? And in which direction?

(continued on next page)

c. But suppose instead that the Sun's sphere has its axle embedded in the sphere of the stars, as shown by the dotted lines so that they rotated together. What independent rotation (rate and direction) would the Sun's sphere have to have?

81 *Optional.* Try this if you are interested, otherwise omit.
a. Where would you put the sphere of the Moon in the scheme of figure 80? If this also is given the rotation of the starry spheres, what rotation of its own would it have to have?
b. Where would you put the sphere of Venus? of Mars? of Jupiter?

82 *Optional.* The arrangement of one crystal sphere for each of the heavenly bodies did not satisfactorily account for their observed motions, and Eudoxus had *four* spheres for each planet (figure 82). Describe the arrangement shown in figure 82, saying what you can about the reasons for including the third and fourth spheres.

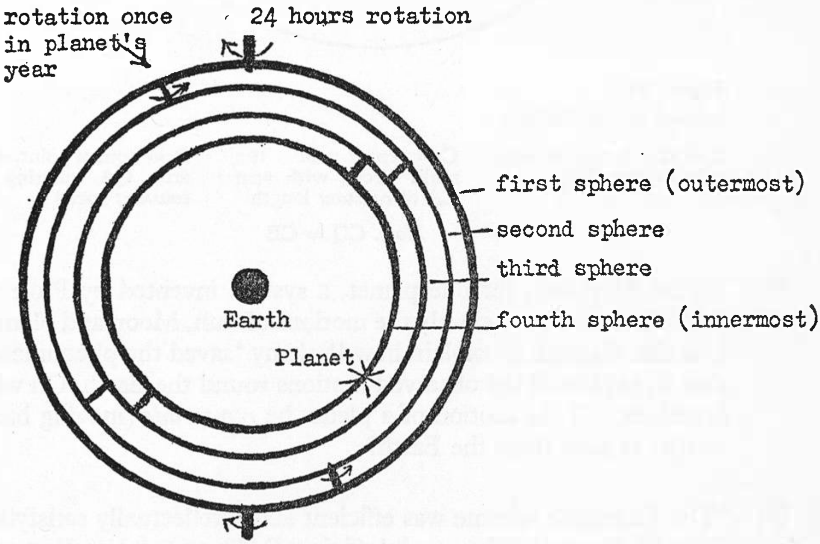


Figure 82
four crystal spheres for each planet (Eudoxus)

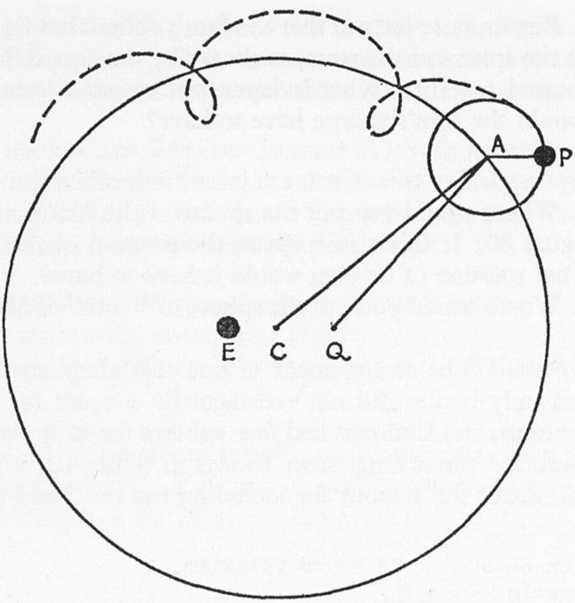


Figure 83
scheme due to Ptolemy

E = the Earth which is in *fixed* position

C = centre of the main circle, with arm CA of *constant* length

Q = equant point, with arm QA rotating at *constant* speed

Note. CQ = CE

83 Figure 83 shows, for one planet, a system invented by Ptolemy, which imitated very closely the motions of Sun, Moon and planets. Use this diagram to explain how Ptolemy 'saved the phenomena', that is, explained the observed motions round the Earth. On what occasions will the motion of a planet be *retrograde* (moving backwards) as seen from the Earth?

84 'The Ptolemaic scheme was efficient and intellectually satisfying' (Eric M. Rogers). Why was it 'efficient'? Why was it 'intellectually satisfying'? Suppose that an Alexandrian of the second century says that the Ptolemaic theory is 'true', what would you say in reply?

85 Professor Herbert Butterfield says of Ptolemy that he is '... one of those individual makers of world systems ... who astonish us by the power which they showed in producing a synthesis so mythical ... that we should regard their work as a matter for aesthetic judgement alone' (*The Origins of Modern Science*).

Is Butterfield being fair to Ptolemy? Write a few sentences of discussion. (Mythical = purely fictitious; aesthetic = in accordance with good artistic taste, or with beauty.)

86 *Difficult.* Compare and contrast the Ptolemaic theory of the motions of heavenly bodies with the kinetic theory of motions of molecules, by considering whether either theory is true, useful and satisfying, and whether it links up with knowledge in quite different fields. You need not describe either theory; assume that your reader *understands the mathematics and physics of both*, but has not considered the 'philosophical implications'.

10 The search for simplicity or for 'truth': orbits replace crystal spheres

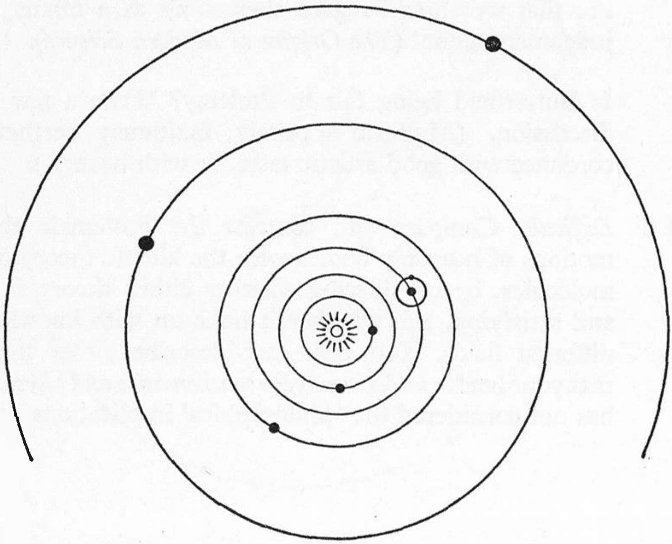


Figure 87
the Copernican system

87 *a*. Copy figure 87 and mark on your diagram S (for Sun), M (Mercury), V (Venus), E (Earth), m (Moon), Mars, Jupiter and Saturn. (Exact radii do not matter, but make the diagram look something like figure 87.)
b. What did Copernicus know about the *speeds* of the planets – that is, on his model, are they moving *faster* farther from the Sun, or all at the same speed, or more slowly the greater the distance?
c. Where would you put Uranus, Neptune, Pluto on this scheme? What might you put round the outside dot in figure 87? Where would you put the asteroids (little planets)? (All these were unknown to Copernicus.)

88 What do you think are the main differences between the Copernican system, figure 87, and those shown in the diagrams of section 9 (Pythagorus, Eudoxus, Ptolemy)? How did Copernicus explain the apparent 24-hourly rotation of the fixed stars?

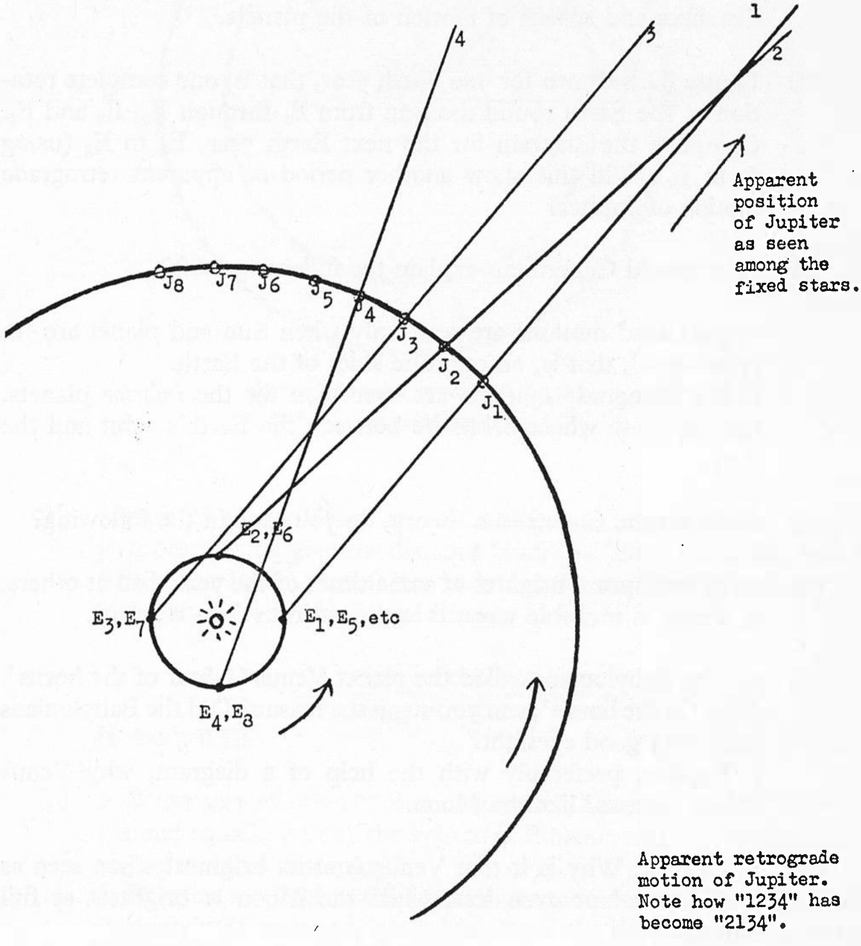


Figure 89

89 Copy figure 89 on a larger sheet of paper so that you have plenty of space to continue the sight lines such as E_2J_2 farther out to a 'sphere of fixed stars' far out at the edge. Continue the sight lines and mark the apparent positions of Jupiter among the fixed

stars. Use your diagram to explain the fact that Jupiter sometimes appears to move backwards (retrograde) against the background of the fixed stars.

Note: This diagram has been drawn roughly to scale both as regards distances and speeds of motion of the planets.

90 Figure 89 is drawn for one Earth year, that is, one complete rotation of the Earth round the Sun from E, through E_2, E_3 and E_4. Complete the diagram for the next Earth year, E_5 to E_8 (using J_5 to J_8). Will this show another period of apparent retrograde motion of Jupiter?

91 How would Copernicus explain the following facts?

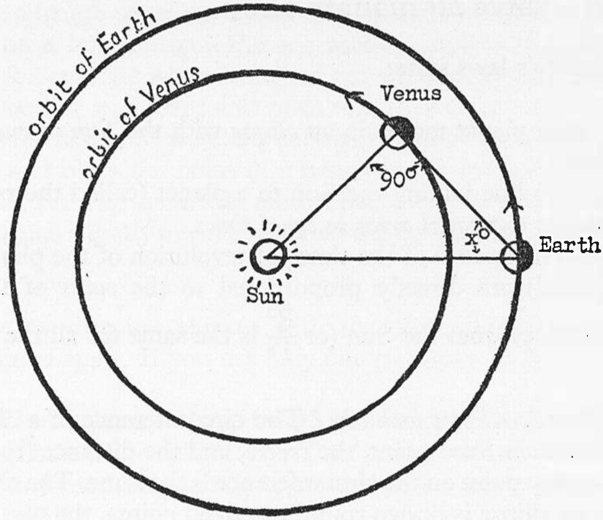
a. Backward motions are seen only when Sun and planet are 'in opposition', that is, on opposite sides of the Earth.
b. No retrograde motions are ever seen for the *inferior* planets, that is, those whose orbits lie between the Earth's orbit and the Sun.

92 How, on the Copernican theory, do you explain the following?

a. Mars appears brighter at some times of the year than at others.
b. Venus is invisible when it is closest to us (two reasons).

93 *a.* The Babylonians called the planet Venus 'Ishtar of the horns'. Why 'of the horns'; can you suggest a reason? Did the Babylonians have very good eyesight?
b. Explain, preferably with the help of a diagram, why Venus shows 'phases' like the Moon.

94 *a. Difficult.* Why is it that Venus is at its brightest when seen as 'half-Venus' or even less, while the Moon is brightest at full Moon?
b. Why do we see no phases of Mars or Jupiter? (Use a sketch to answer.)



Venus seen at greatest angle, x, from the Sun.
x = 45°, or more nearly 46°

Figure 95

95 Figure 95 shows Venus at a time when, as seen from the Earth, it appears at its greatest distance from the Sun, that is the angle SEV (Sun Earth Venus) has its largest value. This largest angle, x in figure 95, is 46°. Show that the ratio,

$$\frac{\text{radius of orbit of Venus}}{\text{radius of orbit of Earth}}$$

is about 0·72.

96 *a.* What sort of observations concerning heavenly bodies are explained equally well by the system of Ptolemy and that of Copernicus (give some examples)?
b. In what respects is the Copernican system superior to that of Ptolemy? (If stumped, get a hint from the previous seven questions.)

97 Why were people in the sixteenth century (when Copernicus's book was published) not very eager to accept his ideas? (There are a number of reasons of different kinds, not all directly concerned with physics.)

11 Laws all planets obey

Kepler's laws state:

I Each planet moves in an *ellipse* with the *Sun at one focus* of the ellipse.
II The line joining the Sun to a planet (called the radius vector) sweeps out *equal areas in equal times.*
III The *squares* of the times of revolution of the planets (planets' 'years') are directly proportional to the *cubes* of their average distances from the Sun (or $\frac{R^3}{T^2}$ is the same for all the planets).

What do ellipses look like? The circumference of a *circle* is drawn round *one* fixed point, the *centre*, and the distance from the centre to every point on the circumference is the same. The circumference of an ellipse is drawn round *two* fixed points, the two *foci*, and the *sum* of the distances from each focus to every point on the circumference is the same. In the ellipse drawn in figure 98, S and S^1 are the two foci, and P is any point on the ellipse. Then, wherever P may be, SP + S^1P always has the same value.

Draw some ellipses and see what they look like. All circles have the same shape! Not so ellipses; they can be long and thin, right down to being nothing but a straight line. Or they can be round, right up to being circles. Or they can have shapes which are in between these two extremes.

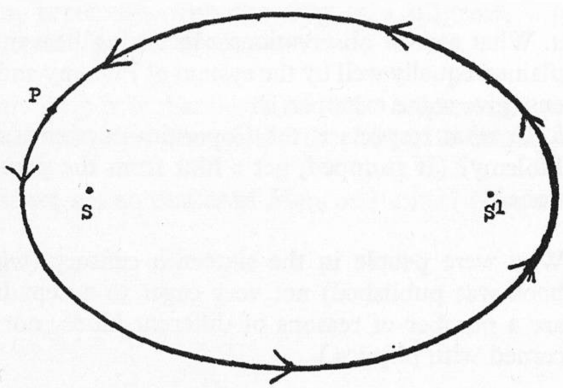


Figure 98

98 Take a length of strong cotton or thread not more than 20 cm long and tie it into a loop – the one used for figure 98 ended up as a loop 9·2 cm long when stretched out straight. Put a piece of paper on wood or wallboard and push into it two drawing pins – those used for figure 98 were 8·0 cm apart. Loop the cotton round the pins and place the point of a pencil in the loop. Push the pencil round, keeping the thread taut. A little practice is necessary. Slope the pencil slightly outwards so that the thread does not slide underneath.

Now try drawing ellipses with the pins (the foci) at different distances apart. If you use only one pin what do you get?

If $SS^1 = 8{\cdot}0$ cm and the length all round the cotton loop is 18·4 cm, what is $SP + S^1P$? Why? The 'major' axis of the ellipse is the 'big diameter' through SS^1; prove that the major axis also equals $SP + S^1P$.

99 Draw an ellipse carefully, on a piece of paper. Draw a line from one focus to some point on the ellipse and a line from the other focus to that point. Do that for several different points. Now suppose a small lamp at one focus sends out rays of light along the lines you have drawn. Look at the angles in your drawing. Can you say where those rays would go after they met the ellipse if the ellipse were a wall of polished metal acting as a mirror. Try making some measurements to check your guess.

Suppose waves (e.g. water ripples) started out from one focus, where would a reflected ripple arrive, all parts arriving at the same instant?

100 Use figure 98 to explain to Uncle George the meaning of Kepler's Law I.

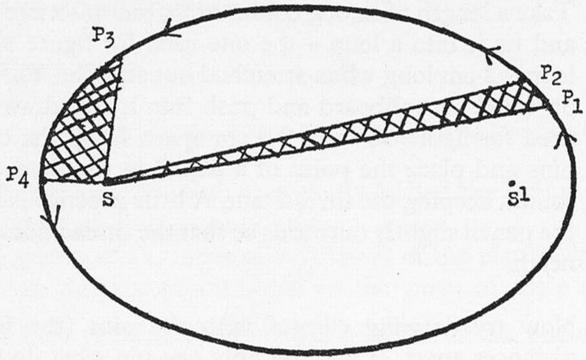


Figure 101
Kepler's second law

101 Use figure 101 to explain to Uncle George the meaning of Kepler's Law II.

102

Planet	Orbit radius R (miles)	Orbit period T (days)	R^3 (miles)^3	T^2 (days)^2	R^3/T^2 (miles)^3/ (days)^2
Venus	$6{\cdot}7 \times 10^7$	220	300×10^{21}	50×10^3	$6{\cdot}0 \times 10^{18}$
Earth	$9{\cdot}3 \times 10^7$	365	800×10^{21}	134×10^3	?
Mars	$14{\cdot}0 \times 10^7$	690	2800×10^{21}	470×10^3	?
Jupiter	$48{\cdot}0 \times 10^7$	4300	?	?	?
Saturn	$89{\cdot}0 \times 10^7$	10800	?	?	?

Complete Table 102 so as to show Uncle George that Kepler's Law III is correct for the five planets mentioned. (*Note.* The numbers are known much more exactly than is shown in the table, but approximations are used here so as to avoid lengthy arithmetic. Do not work to more than two, or at the most, three, significant figures.)

103 Figure 103 is drawn to show the very small 'eccentricity' of the Earth's orbit – only 4·0006 cm at 'maximum' radius, compared with 4·0000 cm at 'minimum' radius.

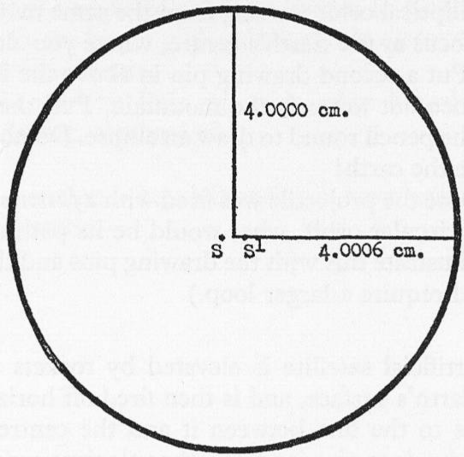


Figure 103

Eccentricity of the Earth's orbit. This is, of course, drawn simply as a circle, because 0·0006 cm is much less than the thickness of a pencil line

a. The actual radius of the Earth's orbit is about 150 million kilometres. How big a difference is there between the smallest and the largest value of the Sun-to-Earth distance?
b. What do S and S^1 represent in figure 103? Actually, *both* points are *inside* the Sun; where exactly is *one* of them?

104 Suppose you could fire a projectile straight out, horizontally from the top of a very high mountain. If you chose the right speed it would go right round the Earth in a circular orbit – and it would continue to go round, if it were not for the effect of air-resistance. If you fired it a little more slowly it would not follow a circle, but an ellipse, a 'Kepler ellipse'. If you like, here is how you could draw some Kepler ellipses for such an 'Earth satellite'.
Draw a circle, about 2 in. radius, to represent the Earth. Sketch a mountain $\frac{1}{2}$ in. high at one place on that Earth's surface. Sketch a circular orbit through the mountain-top, a circle $2\frac{1}{2}$ in. in radius (1000 miles). You can draw that orbit with a loop of thread just 5 in. total length. Put a drawing pin through the centre of the Earth, place the loop over the drawing pin and pull the thread taut. Run the pencil round to draw the circular orbit.

(continued)

An elliptical orbit starting from the same mountain-top must have one focus at the Earth's centre, where you already have a drawing pin. Put a second drawing pin in above the Earth's centre a short distance out towards the mountain. Pull the same loop taut and run the pencil round to draw an ellipse. Do not continue the ellipse inside the earth!
Suppose the projectile was fired with a *faster* speed than is required for a circular orbit, what would be its path now, and how would you illustrate this with the drawing pins and the cotton? (Hint, you would require a larger loop.)

105 An artificial satellite is elevated by rockets to 2000 miles above the Earth's surface, and is then fired off horizontally (i.e. at right-angles to the line between it and the centre of the Earth). The intention is to give it exactly the velocity needed to make it follow a perfectly circular orbit. But, as a result of a miscalculation, although it is fired horizontally, it is given *too big* a velocity.

a. Draw a diagram with the Earth represented by a circle about the size of a penny, and sketch in an orbit like that you think it might possibly follow – make sure, at any rate, that it is an orbit which Kepler would not consider impossible.
b. Write a few sentences discussing the various things that might happen if the satellite were given *too small* a horizontal velocity.

Note: Assume that, when fired horizontally, it has no vertical velocity.

106 Kepler is principally remembered for *two* theories of planetary motion. One is the elliptical orbits theory, with which the previous questions of this section have been concerned. The other is an earlier scheme of placing the planets by means of the five regular solids.

Describe Kepler's 'five regular solids' theory very briefly. Give rough sketches if you like, but do not spend a long time drawing anything complicated.

107 (Following from 106.) Write about two pages of discussion, explaining why one of Kepler's theories is interesting but of no present value, while the other is regarded as completely successful. Your brief essay can be written under three headings:

(*i*) which theory best fitted the facts known to Kepler;
(*ii*) which deals the better with subsequently discovered facts, e.g. newly discovered planets;
(*iii*) which theory best links up with other knowledge in quite different fields, e.g. mechanics?

Note : Perhaps this question is best left until you have learnt a little about Galileo and Newton.

12 Galileo and Newton

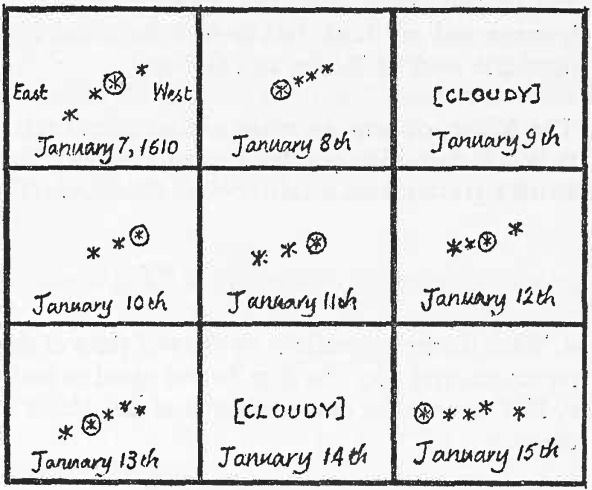
Galileo heard that a Dutchman had made an optical instrument which would make distant things look closer – a 'tele-scope' as Galileo named it. So Galileo made one himself, then he looked through it at objects in the heavens.

108 Sometimes scientists use instruments in order to provide senses with which the human body is not equipped, e.g. apparatus for detecting and measuring radio waves. More often instruments are used to extend in some way the range and sensitivity of the senses we already possess. The *telescope* is one of the second kind of instrument.

a. Obviously a telescope is useful because it makes distant things look bigger and we see greater detail. What other useful function does a telescope perform besides making things look bigger? (*Note.* The name 'tele-scope' seems to refer more to this second function than to the first.)
b. How can it perform this second function? (*Hint.* Think of the size of a telescope lens and the size of the human eye.)
c. You have convex lenses of about 30 cm and 5 cm focal length, and a means of mounting them and sliding them up and down on a metal rod. You also have a piece of tissue paper. To make a telescope,
(*i*) which lens would you take first, and whereabouts on the rod would you mount it?
(*ii*) what would you do with the tissue paper?
(*iii*) where would you put the second lens?
(*iv*) at what position would you expect to have your eye when looking through the telescope – up against the lens? – 25 cm from the lens? – or where?

109 *a.* Galileo's telescope was not quite like the one in (*c*) above. What lenses did he use? What is the name of an optical instrument in use today which has Galileo's telescopic arrangement of lenses?
b. If you can, obtain a long-focus convex lens and a short-focus concave lens, and make a Galileo telescope, even if you only hold the lenses in your two hands. What advantages has it over the 'two-convex' telescope in 108? (It also has disadvantages, and is not much used for astronomical purposes.)

110 'Galileo looked through his telescope at the planet Jupiter and saw some small stars near it. Next night the star pattern had changed. Waiting impatiently through a cloudy night, Galileo saw one night, later still, that the pattern had again changed.'



Galileo's observations of Jupiter's moons

These sketches are copied from Galileo's handwritten record. The orbits of the moons are nearly in a plane containing our line of sight from Earth to Jupiter; so the moons are often in front of Jupiter or behind, and they are often eclipsed by moving into Jupiter's shadow. They move quickly round their orbits. That is why the pattern changes so quickly and why, often, less than four moons are visible. (For a copy of Galileo's written record, see *Galileo*, by J. J. Fahie.)

Figure 110

'It was clear that the small stars were moons (satellites) moving round Jupiter. Delighted with this, Galileo published a full description and claimed Jupiter and the Jovian moons as strong support for Copernicus's idea of the solar system.'

a. How did the discovery of these satellites support the Copernican view as against that of Ptolemy?
b. Why did the discovery bring Galileo into trouble with the Church authorities?
c. Mention two other things besides the satellites of Jupiter that Galileo saw through his telescope and which were 'disturbing to the traditional view'.

Galileo, like Copernicus, considered that the Earth was just one member of the solar system and that there was no evidence that it was any more important or distinguished than the others. He also developed and taught, though in an unfinished form, a new view of force and motion. But a precise statement of the laws of motion, and of gravitation, and their application to bodies both in the heavens and on Earth had to wait for Isaac Newton, who built upon the work of Kepler and Galileo.

111 The Moon, of mass m, rotates in an orbit round the Earth with radius R. Let v be its orbital speed, and let g be the value of the Earth's gravitational acceleration at the Moon. Then we can write

$$\frac{mv^2}{R} = mg$$

a. What do the expressions on the two sides of the above equation represent, and why can they be put equal to each other?
b. If $T =$ time for one revolution of the Moon round the Earth, then,

$$T = \frac{2\pi R}{v}$$

Why is this?
c. Show by algebra that,

$$T^2 = \frac{4\pi^2 R}{g}$$

112 *a.* Use the last equation (111 (*c*)) to calculate T for the Moon, taking,

$g =$ 10 metres per second per second.
$R =$ 400,000 kilometres.

b. Did you get the result $\frac{100}{9}$, or about 11, hours? Could this be a correct value for the period of one revolution of the Moon round the Earth?

113 *a.* The answer to 112 (*b*) is incorrect because we have assumed that g is the same whatever the distance from the Earth. Clearly g must diminish with distance. The simplest assumption was that g is *inversely proportional* to distance. If $g =$ 10 metres per second

per second at the Earth's surface, what is g at the Moon, 60 times as far from the centre of the Earth?
b. Use this value of g to calculate T for the Moon. Does this result agree with observation?

114 *a.* The answer to 113 (*b*) does not fit the facts either. Let us follow Newton and use an *inverse square* law.

What value does this give for g at the Moon which is 60 times as far from the Earth's centre as the surface of the Earth?
b. Now return to the previous question and calculate T for the Moon. *This* value should be correct, within the approximations we have made.

115 Newton's law of gravitation can be represented by the equation,

$$F = \frac{GMm}{r^2}$$

where F is the gravitational attraction between two masses M and m at a distance r apart.

a. In this equation, why does r^2 appear in the denominator?
b. What experiments show us that F is proportional to m, that is, what experiments show that the force exerted by one body (which may be the Earth) on another depends on the mass of the other?
c. By what argument did Newton decide that F is proportional to m *and* M, that is, Mm?
d. Why is G called a 'universal constant'?
e. How do you know, from common observation, that G, when measured in our metre-kilogram-second units, must have a very small value?

(*Hint*. Think about two masses each of 1 kg placed 1 metre apart.)

116 Remembering that the weight of an object of mass m at the Earth's surface can be written mg, where g is gravitational acceleration at the surface, show that

$$g = G\frac{M}{R^2}, \text{ or } G = g\frac{R^2}{M}$$

where R = radius, and M = mass, of the Earth.

117 In earlier work we have seen that 'gravitational acceleration', represented by g and measured in metres per second per second, may equally be called 'gravitational field strength', and be measured in newtons per kilogram.

Show that,
1 metre per second per second = 1 newton per kilogram.

(*Hint*. Use $F = ma$.)

118 You might think we could use the equation $G = g\frac{R^2}{M}$ (question 116) to calculate G, but of course we do not know M, the mass of the Earth. In fact, we have to determine G in the laboratory, or outside, and then use the equation to find M.

By what sort of experiment (in principle, not in detail) could we, in the laboratory, find the value of G?

119 *a.* Jack and Jill are attracted to each other, and tend to come together. Could any appreciable portion of this attraction be gravitational? Calculate the gravitational attraction they have for each other when they are 2 metres apart, given that,

$$\text{the mass of Jack} = 70 \text{ kg}$$
$$\text{the mass of Jill} = 60 \text{ kg}$$
$$G = 6{\cdot}6 \times 10^{-11} \text{ newton-metres}^2 \text{ per kilogram}^2$$

Express your answer in newtons. Make a rough estimate of how this answer compares with the weight of the tiniest piece of paper you could tear off. (*Note.* This question is not entirely silly. It shows the difficulty of measuring gravitational forces between objects in the laboratory, even if they are 'bodies' denser than those of Jack and Jill, lumps of lead or platinum, for example.)
b. Where did the 'newton-metres^2 per kilogram^2' come from?
c. Taking this question more seriously than it deserves, and remembering the shape and size of Jack and Jill, what exactly do you think is meant by saying they are '2 metres apart'?

13 Applying Newton's laws of motion and of gravitation

The gravitational law may be stated as an equation (see question 115),

$$F = G.\frac{Mm}{r^2}$$

The laws of motion may be stated,

I Any object remains at rest, or continues to move with constant speed in a straight line, if it is left alone; that is, if there is no resultant (unbalanced) force acting on it.
II A force acting on an object makes it accelerate in the direction of the force. The acceleration is given by,

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

We may also write,

$$\text{Force} \times \text{time} = \text{change of momentum, or,}$$
$$\text{Ft} = \text{change of } mv.$$

III When one object pushes or pulls another, the other always exerts an equal and opposite push or pull. This is true whether the objects are at rest, moving with constant velocity, or accelerating.

Using these laws as starting-points, Newton 'derived' or 'explained' or 'predicted' the following:

1 *The Moon's motion* round the Earth, controlled by inverse-square-law gravity (Newton's original test).
2 *Kepler's Law I.* Planets' orbits are ellipses with Sun in one focus.
3 *Kepler's Law II.* Arm from Sun to planet sweeps out equal areas in equal times (shown to be true for *any* 'central' force pulling a planet straight towards the sun).
4 *Kepler's Law III.* (Orbit radius)^3/(Planet's year)^2 same for all planets of the solar system.
5 *Planet's moons:* same rule applies to all the satellites of a planet, but with different value of constant (e.g. Jupiter's moons and now Earth's satellites).

6 *Comets*, until then lawless and mysterious, follow elliptical orbits according to Kepler's Law I, as members of solar system. Times of comets' returns predicted successfully.
7 *Relative masses* of Earth and Sun, Earth and Jupiter, etc., estimated through Kepler's Law III (estimate can be made for any two bodies which own satellites).
8 *Shape of Earth* must be oblate spheroid: proportion of radii estimated.
9 *Small differences of g* predicted: due to shape of Earth and due to Earth's spin: both make measured *g* slightly smaller at equator.
10 *Ocean tides*, due to differences of Moon's attraction. (Two tides in 24 hours predicted.)

Similar tides due to Sun are smaller; added to Moon's tides, they make spring tides, subtracted they make neap tides. (Relation with phases of Moon also predicted.)

11 *Mass of Moon* estimated by treating our ocean tide as a satellite of the Moon.
12 *Precession of the equinoxes:* shown to be consequence of gravitational pulls of Sun and Moon acting on the equatorial bulge of the spinning Earth. The 26,000-year period predicted roughly.
13 *Irregularities of the Moon's motion.* The elliptical orbit changes its ellipticity and moves round in its own plane; the plane of the orbit slews round slowly; and the Moon shows small extra monthly and yearly accelerations. All are symptoms of small differences of Sun's gravitational pull. Newton predicted several, tested some of them.
14 *Perturbation of planetary orbits.* Each planet is affected slightly by the gravitational pulls of other planets. Newton started the prediction of these small perturbations.

Discovery of Neptune. Long after Newton's death, when the planet Uranus had been discovered, it showed small residual perturbations from its expected orbit in addition to the effects of known planets. From these, Adams and Leverrier independently predicted the location and size and orbit of an unknown planet that could produce these tiny perturbations by inverse-square-law gravitation. Then the planet was seen: a triumph of Newtonian theory.

120 Questions 111 and 114 dealt in a simple fashion with the first of Newton's 'predictions', listed above. The second, Kepler's Law I, is mathematically difficult. The third, Kepler's Law II, does not depend on inverse square gravitation. The fourth, Law III, is the subject of question 122.

Take any *one* of the others, 5 to 14, say what it means and give as much as you can of Newton's explanation.

121 *a.* 'Prediction 3' above, Kepler's Law II. Draw a diagram of a planet moving in an ellipse round the Sun, and use your diagram to help you to explain what is meant by 'Arm from Sun to Planet sweeps out equal areas in equal times'.

b. Describe some simple demonstration of Kepler's Law II, for spinning bodies, that you have seen. Say what was done, and what happened.

122 'Prediction 4', Kepler's Law III. If you turn back to question 102 you will see how the Law III can be verified *from observations and measurements* for five planets of the solar system. We can also test this Law for other satellite systems, e.g. the 'Jovian System', for which figures are given below. We could, of course, convert the figures for R into metres by multiplying by the diameter of Jupiter in metres, but that is not necessary in order to test Law III.

Jupiter's satellites and Kepler's Third Law

Satellite	Orbit radius in Jovian diameters (R)	Time of revolution in hours	R^3	T^2	R^3/T^2
Io	3·0	42	27	18×10^2	$1{\cdot}5 \times 10^2$
Europa	4·8	85	110	72×10^2	
Ganymede	7·7	172			
Callisto	13·5	400			

Complete the above table.

123 Read the passage on the next page headed *De Mundi Systemate*. You need read only the English. The diagram is from Newton's book, together with his own latin, and dates from 1726. The translation was made a year or so later. Copy the diagram and write a brief description of what it illustrates, in good twentieth-century English!

DE MUNDI SYSTEMATE

non amplius in terram caderet. Designet AFB superficien Terrae; e centrum ejus; & VD, VE, VF, lineas curvas, quas projectile de montis praealti vertice v, secundum lineas horizonti parallelas, auctis cum velocitatis gradibus, successive emissum describat. Et ne aëris resistentia, qua motus coelestes vix retardantur, in computum veniat, fingamus hunc omnem tolli, vel saltem nil resistere. Et eadem ra-

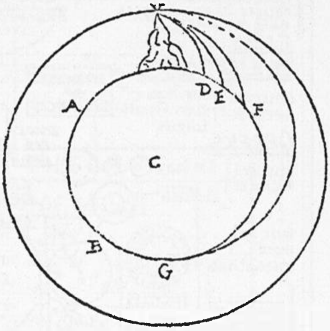


Figure 123

NEWTON'S SYSTEM OF THE WORLD

'3. The action of centripetal forces.

That by means of centripetal forces the planets may be retained in certain orbits, we may easily understand, if we consider the motions of projectiles . . .; for a stone that is projected is by the pressure of its own weight forced out of the rectilinear path, which by the initial projection alone it should have pursued, and made to describe a curved line in the air; and through that crooked way is at last brought down to the ground; and the greater the velocity is with which it is projected, the farther it goes before it falls to the earth . . .

Let AFB represent the surface of the earth, C its centre, VD, VE, VF the curved lines which a body would describe, if projected in an horizontal direction from the top of an high mountain successively with more and more velocity . . . let us suppose either that there is no air about the earth, or at least that it is endowed with little or no power of resisting; and for the same reason that the body projected with a less velocity describes the lesser arc VD, and with a greater velocity the greater arc VE, and, augmenting the velocity, it goes farther and farther to F and G, if the velocity was still more and more augmented, it would reach at last quite beyond the circumference of the earth, and return to the mountain from which it was projected.'

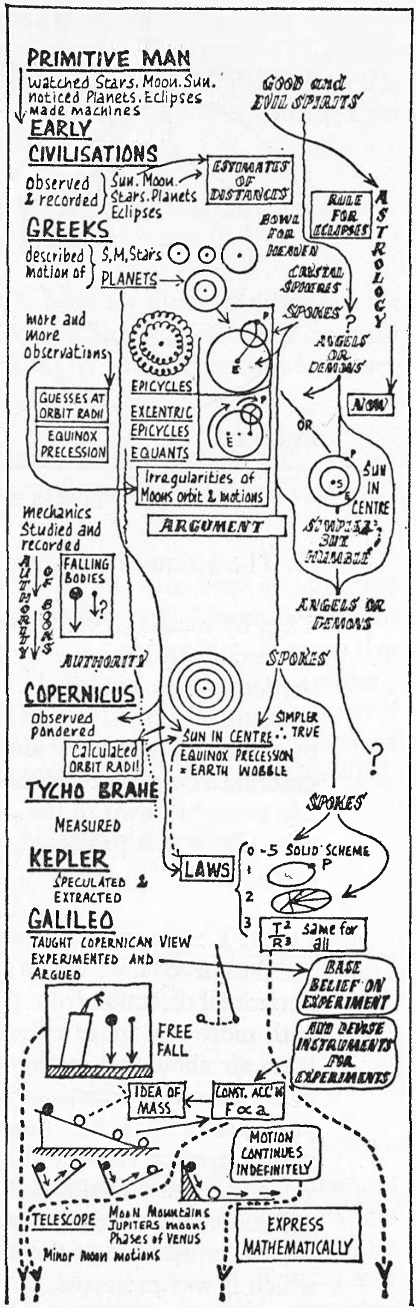

PRIMITIVE MAN
watched Stars. Moon. Sun.
noticed Planets. Eclipses
made machines
EARLY CIVILISATIONS
observed & recorded
Sun. Moon. Stars. Planets Eclipses
ESTIMATES OF DISTANCES
GOOD and EVIL SPIRITS
ASTROLOGY
RULE FOR ECLIPSES
BOWL FOR HEAVEN
GREEKS
described motion of
S, M, Stars
PLANETS
CRYSTAL SPHERES
SPOKES?
ANGELS OR DEMONS
more and more observations
GUESSES AT ORBIT RADII
EQUINOX PRECESSION
EPICYCLES
EXCENTRIC EPICYCLES
EQUANTS
NOW
OR
SUN IN CENTRE
SIMPLER BUT HUMBLE
Irregularities of Moons orbit & motions
ARGUMENT
Mechanics Studied and recorded
AUTHORITY OF BOOKS
FALLING BODIES
ANGELS OR DEMONS
AUTHORITY
SPOKES
COPERNICUS
observed pondered
Calculated ORBIT RADII
SUN IN CENTRE
SIMPLER ∴ TRUE
EQUINOX PRECESSION = EARTH WOBBLE
TYCHO BRAHE
MEASURED
SPOKES
KEPLER
SPECULATED & EXTRACTED
LAWS
0 - 5 SOLID SCHEME
1
2
3
T²/R³ same for all
GALILEO
TAUGHT COPERNICAN VIEW
EXPERIMENTED AND ARGUED
BASE BELIEF ON EXPERIMENT
AND DEVISE INSTRUMENTS FOR EXPERIMENTS
FREE FALL
IDEA OF MASS
CONST. ACC'N F ∝ a
MOTION CONTINUES INDEFINITELY
TELESCOPE
Moon Mountains
Jupiters moons
Phases of Venus
Minor moon motions
EXPRESS MATHEMATICALLY

Figure 125

NEWTON

THINKING
CODIFYING
USING

GUESSING
DEFINING
REASONING (MATHS)

SEARCH FOR SIMPLICITY AND COMPLETENESS

THEORY

LAWS OF MOTION

I Every body ....

II $F \propto Ma$ or $F\Delta t \propto \Delta(mv)$

III Action = − Reaction

MOTION IN A CIRCLE

Has central accel. $\frac{V^2}{R}$

& this needs force $\frac{Mv^2}{R}$

UNIVERSAL GRAVITATION

every body attracts every other body with force which

$\propto \frac{1}{\text{distance}^2}$

$\propto$ attracted mass M_1

$\propto$ attracting mass M_2

$$F = G\frac{M_1 M_2}{d^2}$$

ASSUME THESE APPLY TO CELESTIAL BODIES

REASONING and Mathematics

DEDUCTIONS
PREDICTIONS
EXPLANATIONS
& EXP'TL TESTS

MOON'S ACC" diluted 'g'

$m\frac{v^2}{R} \stackrel{?}{=} mg\left(\frac{r_{\text{earth}}}{R_{\text{moon orbit}}}\right)^2$ | $g\left(\frac{r}{R}\right)^2 = 0.0089$ ft/sec²; $\frac{v^2}{R} = 0.0089$ ft/sec²

PLANETARY MOTION

No force needed to keep planet moving

Inward force needed to maintain orbit

" " provided by gravitation

→ with inv. sq. law → ELLIPSE ✓ KEPLER I
SUN IN FOCUS

NO SPOKES NO ANGELS OR DEMONS

any CENTRAL attract. → EQUAL AREA LAW ✓ KEPLER II

$\frac{mv^2}{R} = G\frac{Mm}{R^2} \longrightarrow \frac{T^2}{R^3}$ SAME FOR ALL ✓ KEPLER III

also holds for JUPITER'S moons

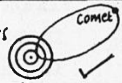
MASSES OF SUN, JUPITER

& any planet having satellite can be calculated in terms of Earths' mass.

? No check yet
No alternative method of estimating ?

COMETS – Solar system Visitors (elliptical orbits)

return on time. ✓



TIDES due to differences of Moons attraction on ocean.

∴ 2 tides per 24 hrs. ✓

Sun also causes (smaller) tides

spring tides due to M+S neap tides due to M−S

Connection with Moon long suspected (Galileo laughed)

MASS OF MOON

Estimate by comparing its tide to Sun's tide and using Sun's mass and distance

No check yet but density reasonable

TIDES CAN NOW BE PREDICTED YEARS AHEAD

MOON'S MOTION IRREGULARITIES has many { orbit changes, eccentricity, tilt etc. speed changes

Moon's speed in orbit changes during month and during year. Orbit precesses, changes its eccentricity, its tilt etc. Newton showed these changes are due to differences of Sun's pull. He predicted a number of these succesfully.

BULGE OF EARTH

Assuming earlier pasty earth Newton calculated shape {Pole Vs equator}

and effect orig'of bulge and centrifugal force.

Too small to measure then LATER GEODESY VERIFIED

PRECESSION OF EQUINOXES

Due to pulls of Sun and Moon on Earth's extra bulges making it wobble like a spinning top.

Newton calculated time of wobble – 26,000 yrs ✓

agreed with astronomical estimates

PERTURBATIONS OF PLANETS. Planet not held in orbit by Sun alone but also pulled slightly by other planets. These small extra pulls change orbit slightly.

[Not directed to Sun ∴ Kepler II x x]

Newton Started this investigation

Lagrange
Laplace
{ contined it and showed it does account for observed changes of orbit

Adams
Leverrier
used $F = G\frac{M_1 M_2}{d^2}$ to discover NEPTUNE from its tiny effects on orbit of Uranus ✓

BUT

A minute residual change of Mercury's orbit was not explained until EINSTEIN modified NEWTON'S gravitation law slightly

124 Take another of the 'predictions', 5 to 14, *not* the one you chose for your answer to question 120, say what it means, and give as much as you can of Newton's explanation.

125 Look at the chart on pages 60–61, which runs from 'primitive man' to Einstein. You may have seen a larger version of this with the three pieces put together into a single 'tall chart'.

Study this for about ten minutes – you are sure to find something of interest in it. Now choose some small part of it and write for a quarter of an hour about that, or about some thoughts it suggests to you.

126 Look again at the chart. It would not be sensible to try to copy out that huge diagram – it is just a picture that someone drew to remind you of the growth of knowledge. Copying it out or trying to learn it by heart would not be learning science. But you could develop your knowledge of science if you developed your own version of such a chart. Try drawing your chart of some part of the story, not trying to copy it from this one but starting afresh, thinking and reading and then making your own sketch.

127 Turn back to section 9, and look at questions 82 and 83, the planetary schemes of Eudoxus and of Ptolemy. Think also of Newton's planetary scheme of elliptical orbits under inverse square law forces.

a. The schemes of Eudoxus and Ptolemy are very good '*models*'. Why?
b. But the Newtonian scheme is a much better kind of model. Why?

14 Things moving backwards and forwards. Experiments with a pendulum

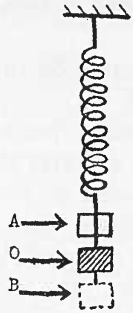


Figure 128

128 Look at any kind of to-and-fro motion that is smooth and not jerky, e.g. a pendulum or a trolley attached to two horizontal springs (figure 129) or a mass on the end of a vertical spring (figure 128). Let O be the rest position or centre position of the motion, A one extreme position and B the extreme position in the opposite direction. A and B are the positions where 'displacement' of the mass from its rest position is a maximum. Copy and complete the following table. If you choose a horizontal motion you can say 'left' and 'right' instead of 'up' and 'down'.

position	*displacement*	*velocity*	*acceleration*
A	maximum upwards	zero	maximum downwards
O		maximum	
B		up OR down	

Explain why there are *two* answers for velocity at O.

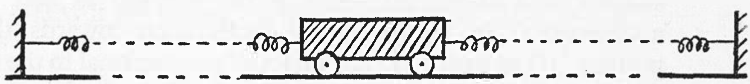


Figure 129

129 Figure 129 shows a trolley attached to two springs stretched horizontally. The mass of the trolley can be increased by loading it with pieces of anything suitable or even a second similar trolley placed upside down on top of it, thus doubling the mass. (Anything placed on the trolley must be firmly attached so that it does not

slide about when the trolley moves.) The 'stiffness', or 'spring factor', may be altered by using stronger springs or by using four similar springs instead of two, thus doubling the 'spring factor'.

a. What kind of motion do you see when you displace the trolley and then release it?
b. Why does it do this; that is, why doesn't it simply come back to the rest position and stay there?
c. If masses are loaded on to the trolley, what do you expect to happen to the trolley's 'time of oscillation' (the time it takes to move to and fro or one complete cycle)? Why does this happen?
d. If four springs are used instead of two, what do you expect to happen to the time of oscillation? Why does this happen?
e. What would you do experimentally to find out whether doubling the *mass* factor has the same effect on the time of oscillation as halving the spring factor? (*Hint*. As well as the straightforward obvious tests, there is an ingenious one. Can you think of it?)

130 Question 128 was about displacements, velocities and acceleration of particles moving with a to-and-fro motion. Question 129 was concerned with mass and 'springiness'. In your own investigations in the laboratory, did you find out anything that is not included under the first two questions? If so, what? (Say what you did and what happened, and, if possible, give an explanation.)

SIMPLE HARMONIC MOTION: what meanings do these three words have? *Motion* is easy; first we have had motion in a straight line, then circular motion and now to-and-fro motion. These are kinds of motion that occur naturally, and which can fairly easily be expressed mathematically.
Why '*simple*'? Of the many kinds of to-and-fro motion, only one kind is called 'simple'. Simple harmonic motion (SHM) is a to-and-fro kind of motion which is the simplest to deal with by mathematics. In an SHM the acceleration towards the 'rest position' (O in figure 128) is 'directly' proportional to the distance from the rest position. At 2 cm distance from the 'rest' or 'zero displacement' position the acceleration is twice as much as it is at 1 cm distance. This makes the mathematics simple, but even so, you will not have to worry with the maths during the present year.
Harmonic motion refers to 'the kind of motion that produces musical notes'; in other words, it is another name for to-and-fro motion, because that is the kind of motion (provided it is fast

enough) that produces a musical sound. (*Simple* harmonic motion produces a single '*pure*' musical note.)

131 *a.* How would you show, to your own satisfaction, that objects that produce sound are vibrating?
b. What is meant by 'frequency' of vibration? What relation is there between frequency of vibration and the pitch of the note produced?

Experiments to try at home

132 1 Make a flat soap film (a soap bubble on a wire frame, or between thumb and finger held to make a circle). Whistle through the film and watch it. What do you see? Can you give a scientific explanation?
2 Make a tiny tambourine by pasting a piece of tissue paper across a small metal or cardboard ring. Put a few grains of sand on it and sing or whistle to it.
3 Get a large fork from the kitchen. Hit its prongs and listen, holding it close to your ear. Then try dipping the tips of the prongs in water just after you have hit them: watch.
4 Drive two nails in a piece of wood about 6 in. apart. Stretch a rubber band between them. Stick a tiny piece of mirror (from a broken powder-compact mirror) across the two rubber strips, near the centre, using a little rubber cement. Shine a beam of light on the mirror (sunlight does well) and watch the reflection on a wall when you twang the rubber band.

133 *a.* If the acceleration of an object towards a fixed point – the 'rest position' – is proportional to its displacement from that point, then the object moves with SHM (that is the definition of SHM). It follows that the *force* tending to return the object to the rest position must be proportional to its displacement: why does this follow?
b. A mass on a spring, when displaced and released, vibrates with SHM if the spring 'obeys Hooke's law'. Why is this?

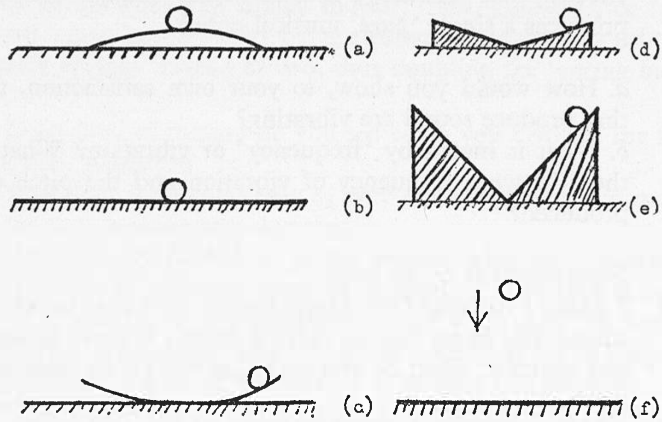


Figure 134

134 Diagrams (*a*) to (*f*) above show a small ball-bearing ball which can move on six different surfaces. In (*a*) and (*b*) the ball is given a small push. In the others the ball is held in place and then released.

(*i*) In some of the cases the ball will not oscillate at all. Which?
(*ii*) In some cases the ball will oscillate, but not with SHM. Which?
(*iii*) In one case the ball may very well oscillate with SHM. Which one?

Write a few sentences about positions (*e*) and (*f*).

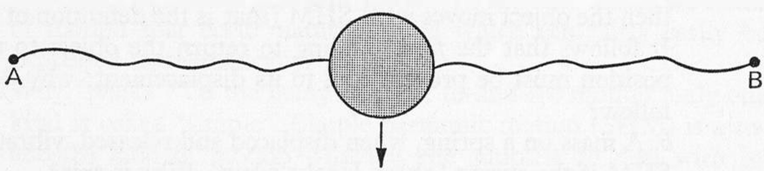


Figure 135

135 Figure 135 shows a carbon dioxide puck resting on a smooth horizontal surface – a bird's eye view, seen from above. It is tied to two fixed pins A and B by two equal lengths of elastic, both 'slack', as shown. The puck is moved at right angles to AB, so that the elastic threads become taut and stretched. It is then released. Do you think its motion will be simple harmonic? Give a reason for your answer.

136 *a.* An experiment to be tried at home, or rather, outside your home! You need a path of asphalt or concrete or anything that shows up a water trace. You also need an empty fruit can with the top taken off, a hammer and a medium-size nail.

Use the nail and hammer to bang four holes, equally spaced, under the top rim of the can. Put a piece of string through the holes so that you have two loops you can hold in your hand, and on which you can allow the can to swing. Knock a small hole in the bottom of the can.

Now fill the can with water and let it swing steadily to and fro across the path while you walk forward at a steady rate (best practise this over grass or gravel first, if the supply of path is limited.) The water makes a trace on the path; sketch the general shape of the trace you get. What is the mathematical name for a smooth curve of this type?
b. (*still more messy*) Bang the exit-hole in the *side* of the can near the bottom, instead of in the bottom. Hang the can from a strong spring, so that it can bounce up and down, with SHM. Hold it near a wall, or a vertical sheet of cardboard, which catches the spouting water. Make the can bounce up and down and watch the water mark on the wall. Then give the can a *twist* as well, so that the water mark also moves horizontally. If you add a piece of string above the spring this horizontal motion can be practically uniform, as the string twists.
c. With the same can on a string, with no spring, try making the can swing to and fro as a pendulum, while the water spouts out horizontally and hits a vertical sheet of cardboard. Then draw the cardboard quickly, smoothly, upward, to obtain a time graph of pendulum motion.

137 Describe a demonstration you have seen of an SHM, produced as a 'projection' of a circular motion. Draw a diagram, and say what you observed.

138 *a.* What is meant by the 'amplitude' of a vibration or oscillation?
b. What is meant by the 'period'? In what units is it measured?
c. What is meant by the 'frequency'? In what units is it measured?
d. A very short pendulum makes two complete swings to and fro per second. What is its period?
e. What is the period of '50-cycle alternating current'?

139 *a.* By what experiments would you find whether the period of a pendulum depends on its amplitude? What result would you expect?
b. What experiments would you perform in order to discover whether the period of a pendulum depends on the mass of the bob? What result would you expect?

140 In order to find how the period of a pendulum depends on its length, you 'timed' the pendulum for various lengths, and then, by dividing by the number of swings you counted, you found the period, T, for each length, l. You then plotted T against l and then T^2 against l.

a. Why is it more useful to plot T^2 against l?
b. Figure 140 (*b*) shows a pendulum with the top end of its string clamped between two pieces of wood. Copy the diagram and show on it exactly what length you would measure in order to find l, the 'length of the pendulum'.

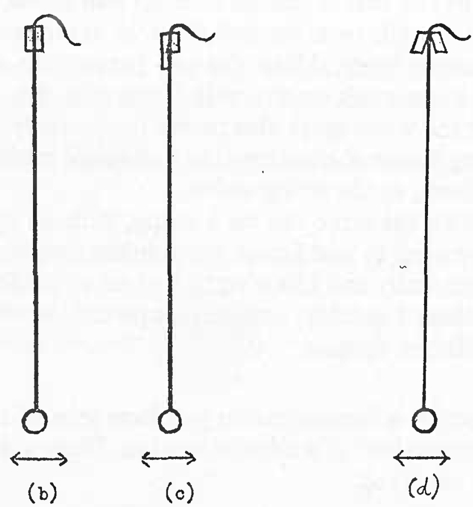


Figure 140

c. Figure 140 (*c*) shows a badly fastened pendulum. Does this pendulum oscillate in SHM? Why not?
d. *Hard.* Figure (*d*) shows another badly fastened pendulum. What would it do? (continued on next page)

e. A pendulum of length 1·0 metre has a period of 2·0 seconds. What is the period of a pendulum of length,
(*i*) 2·0 metres?
(*ii*) 4·0 metres?
(*iii*) 0·5 metres?

141 *Difficult.*

a. Suppose the trolley-and-springs arrangement, see figure 129, is taken from the Earth to the Moon. Freddie Jones thinks that its period of oscillation would be found to be the same as on the Earth. Do you agree with him? Give the reason for your answer.
b. A spring with a mass attached to it (see figure 128) is taken from the Earth to the Moon. It is found:
(*i*) that, when the spring is held vertically in the usual way, it stretches less than it does on Earth;
(*ii*) that, when the load is allowed to oscillate up and down, the period of oscillation is the same as on the Earth.

How do you explain these two results?

c. A pendulum (see figure 140 (*b*)) is taken from the Earth to the Moon. Its period is found to be greater than on Earth. How do you explain this?

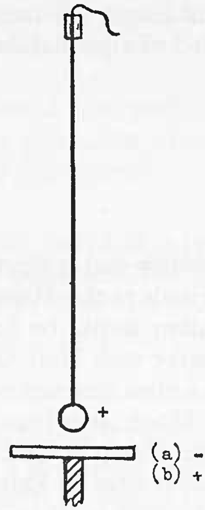


Figure 142

142 *Difficult.* A pendulum consists of a light conducting ball on a fine insulating thread. It swings above a metal plate held on an insulating handle (figure 142). The ball is charged positively. What difference will it make to the period of the pendulum if the plate is charged:

a. negatively;
b. positively?

Give the reasons for your answers.

Also,

c. do you think the pendulum, in (*a*) or in (*b*), still oscillates in a simple harmonic motion? Give the reason for your answer.
d. suppose the ball is charged (+) as above but the metal plate is connected to ground. Would there be any difference? Give the reason for your answer.

15 Electric charges moving backwards and forwards: alternating currents

Section 14 was concerned with oscillation of material objects; this section deals with oscillation of electric charge.

143 Figure 143 shows a generator, such as a bicycle dynamo (BD in the diagram) joined to a small lamp and to a meter, X. Say what is noticed in (*a*), (*b*) and (*c*) below.

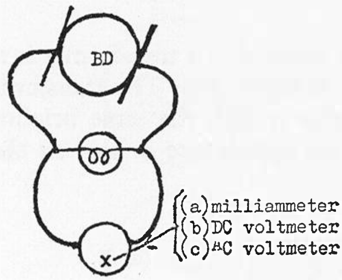


Figure 143

a. The dynamo is turned very slowly, and X is a milliammeter (possibly with a resistor in series, so as to keep the pointer deflexions on the scale).
b. X is a voltmeter designed to work with 'direct current' generators or batteries, and the dynamo is turned sufficiently rapidly to light the lamp.
c. The dynamo lights the lamp, and X is a voltmeter intended for use with alternating-current generators.

144 A narrow beam of electrons from an electron gun E, figure 144, travels along an oscillograph tube, past the plates P and Q, and makes a spot at the centre of the screen.

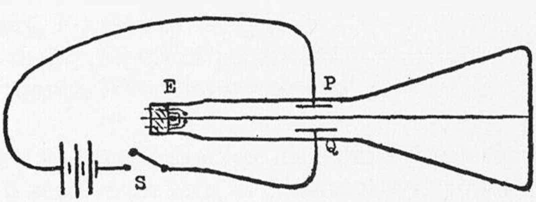


Figure 144

a. Draw a sketch of the tube showing what happens when the switch S is closed.
b. Draw a second sketch showing what happens when the switch is closed after the battery has been reversed, + for —.
c. Next, the bicycle dynamo of question 143 is connected in place of the battery. Draw a third sketch showing, by shading, all possible positions the electron beam might occupy during a time interval of, say, 1 second, when the dynamo is turned rapidly.

Note: Only the plates and the electron beam need be drawn for (*b*) and (*c*).

145 The secondary winding of a transformer is now joined in place of the three cells in figure 144. The transformer, when joined to a 6-volt bulb, lights it with the same brightness as the cells gave before. Draw the appearance *as seen on the screen* at the end of the tube:

a. with the battery;
b. with the transformer.

146 A 'time base' is now applied to the oscillograph in figure 144. This causes the spot to move across the screen from left to right at a steady speed. The spot then travels back from right to left very quickly in almost no time at all.

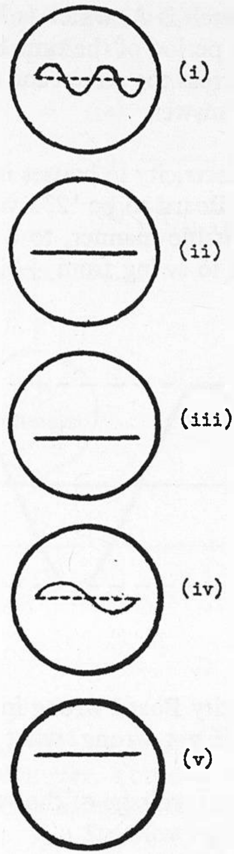


Figure 146

Five experiments are done, in which the plates P and Q are either joined together or joined to a battery or a.c. supply; see A to E below.

A = P and Q joined together, no battery or a.c. supply.
B = battery, P joined to +, Q to −
C = battery, P joined to −, Q to +
D = a.c. supply, 50 cycles per second
E = a.c. supply, 100 cycles per second.

Each time a sketch is drawn (see diagrams 1 to 5 at the side) showing what is seen on the screen. Unfortunately nobody labelled the sketches A, B, C, etc.

a. Say which sketch is A, which is B, and so on.
b. What was the period of the time base; that is, how long did the spot take to go across the screen and return to start again? Give the reason for your answer.

147 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 oscillograph, the voltage is found to swing from +325 volts to −325 volts (figure 147).

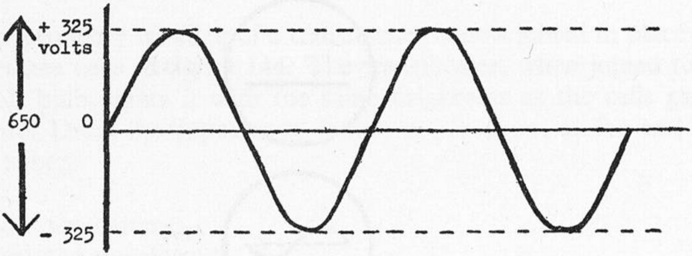


Figure 147

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 147?
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.)

148 Look back to question 145. Note that the 6-volt battery and the a.c. transformer both light the bulb with the same brightness, that is, normally bright.

a. What is the peak voltage of the a.c.?
b. If the spot on the screen is displaced 1·5 cm when the battery is applied, how wide is the trace seen on the screen when the transformer voltage is applied?

Note: Root mean square voltage or current is $\frac{1}{\sqrt{2}}$ of peak voltage or current.

149 A d.c. voltmeter is joined across a 'very slow a.c.' supply (figure 149). A 'load' consisting of:

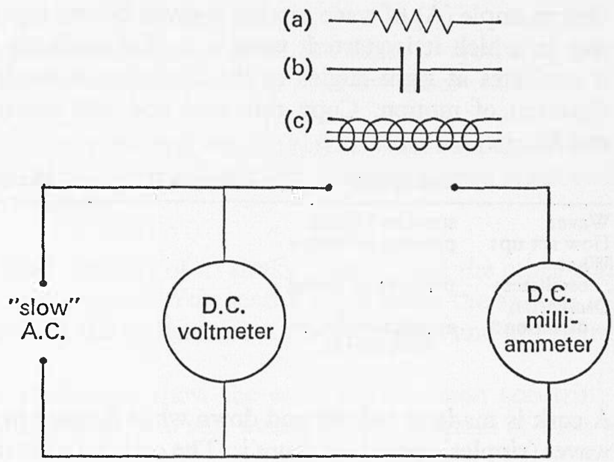


Figure 149

a. a resistor,
b. a capacitor,
c. an inductance,
is joined to the supply, and the current through the load is measured on a d.c. milliammeter. You may assume that supply, load and meters are correctly matched so that easily observable readings are obtained.

In each case, (*a*), (*b*) and (*c*), what would you notice about the readings of the two meters?

150 Look back to question 149. If a rectifier were joined in series with the milliammeter, what would then be your answer to (*a*), that is, with the resistor?

16 Revision of Year III work on waves. SHM and wave motion

151 One example (A) of wave motion is given below, together with the way in which it is started, what it is that oscillates and whether it oscillates at right-angles to the direction of motion, or in the direction of motion. Copy this, and add two more examples, B and C.

	Example A	Example B	Example C
Wave:	stretched string		
How set up:	plucked sideways		
What oscillates:	particles of string		
Oscillation direction:	at right-angles to wave travel		

152 A cork is made to bob up and down while floating in water. Small waves (ripples) spread out from it. The cork is a material substance, and so is the water. Are the waves material objects? Answer yes or no, and write a sentence or two in defence of your answer.

153 A *pulse* is a wave of very short duration, a *short piece* of wave, one or two wavelengths at most. For example, you slam the door and the window curtains flutter, or a vase falls off the mantelpiece.

a. How could the driver of a shunting engine demonstrate a pulse along a train of goods wagons?
b. How could you demonstrate a pulse, given a flat table and a number of pennies?
c. How would you demonstrate a pulse in which the wave movement is *at right-angles* to the direction the pulse travels?

(In each case, say what is done and what happens.)

154 How would you show that two waves can cross each other, or pass through each other:

a. for water waves or ripples,
b. in a stretched spring (such as 'slinky' – you may assume that another person is available to hold the other end).
Also,
c. Compare what happens in (*b*) with what happens when two balls are rolled in opposite directions along a grooved plank so that they meet head-on.

155 You hold one end of a 'slinky' spring, and the other end is fixed in a rigid support. You send a pulse down the spring; what happens when the pulse reaches the fixed end, and afterwards?

How would you show the same phenomenon occurring when a stone is thrown into still water? Give a diagram of what would be seen.

156 *a.* A stone is dropped in water. Ripples spread farther and farther, get smaller and smaller in height, and finally vanish. Why do they get smaller (two reasons)?
b. A pulse is sent along a stretched 'slinky' held horizontal above the ground, and it travels almost unchanged to the far end. If, however, the spring has half its length lying on the floor the pulse dies away before it reaches the far end. Why is there a difference?

157 *a.* What has wave motion (section 17) to do with simple harmonic motion (section 16)?

Answer by considering what happens in:

(*i*) a stretched cord, when one end is continuously moved up and down with a simple harmonic motion;
(*ii*) a stretched elastic string, or a slinky spring, when one end is continuously moved in and out along the line of the string or spring, with a simple harmonic motion.

(continued on next page)

b. Do all particles of the cord, string or spring move with:
(*i*) approximately the same amplitude?
(*ii*) the same frequency?

Also

(*iii*) Do they move all together at the same time, that is, are they 'in phase'? Write a sentence or two of explanation.

Note: Imagine that the end of the cord or spring *not* held in the hand is loose along the floor, or immersed in treacle or something, so that you do not get the complication of waves reflected at the end of the cord.

158 Optional (*difficult extra topic*). How would you set up stationary (standing) waves in:

a. a stretched rope;
b. a 'slinky' spring?

Also:

c. how would you show stationary 3-cm radio waves, produced by a 3-cm wave generator? (To be answered only if you have seen this demonstrated.)

159 Optional (*difficult extra topic*). What differences are there between 'stationary' and 'progressive' waves? Illustrate your answer with diagrams.

17 Velocity, frequency and wavelength. Ripple tank experiments (revision)

160 'The distance between the crests of two neighbouring ripples or waves (or between the troughs) is the ——.'

'The number of ripples passing a given point in unit time is the ——.'

Write out the above sentences, filling in the two blanks. If we use a centimetre rule and a watch measuring seconds, in what units would these quantities be measured?

161 Prove that $v = fl$, where f is the frequency of a wave motion, l is its wavelength and v is its velocity.

(*Note:* This is very simple even if you have never come across it before. Consider the number of waves leaving the source, or travelling by the observer at any other place, in *unit time*, in 1 second if you like. What length does this wave train occupy?)

162 Given a stroboscope, a centimetre rule and a seconds watch, how would you find (*a*) the wavelength, (*b*) the frequency, (*c*) (by calculation) the velocity of ripples in a ripple tank?

163 Figure 163 is a diagram of a set of straight ripples in a tank.

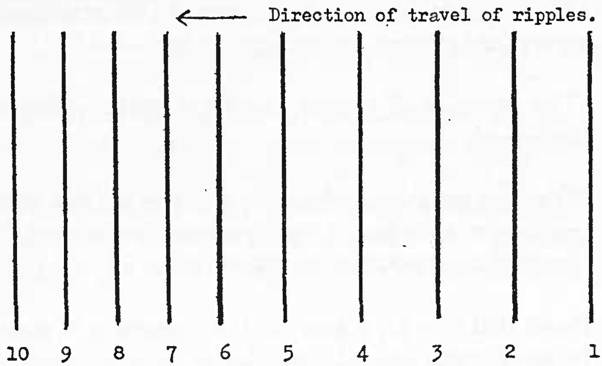


Figure 163

The ripples came from a vibrator on the right of the diagram. They appear in the positions shown when a stroboscope is used to make the ripples appear to be stationary. A flat glass plate rests on the bottom of the tank and makes the water above the plate shallower; the ripples are parallel to the edge of the plate.

a. Where is the edge of the plate situated (i.e. is it between positions two and three, or eight and nine, or between which two positions)?
b. Is the plate on the right or the left side of the diagram?
c. What can you say about the frequency of the ripples on the right and on the left (remember that the stroboscope holds all the ripples apparently stationary at *the same time*)?
d. What is the wavelength on the right? (measure on the diagram)
e. What is the wavelength on the left? (measure on the diagram)
f. If the velocity of the ripples is 21 cm/second on the right, what is the velocity on the left?

164 Diffraction of ripples: the diagrams figure 164 (*i*) (*a*), (*b*) and (*c*) (one-third actual size) represent three obstacles placed, one at a time, in a ripple tank. In each case, a series of straight ripples arrives perpendicularly at the obstacle (i.e. angle of incidence = 0°), in the manner shown in figure 164 (*ii*).

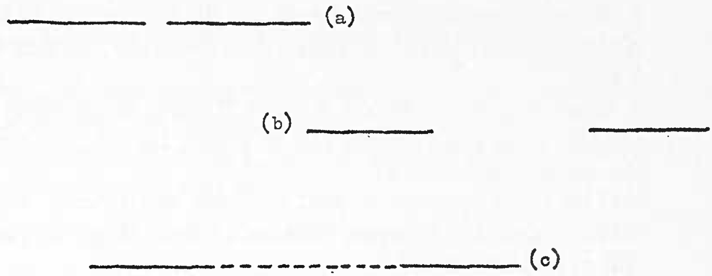


Figure 164 (*i*)

Figure (*a*) shows an obstacle with a single small hole.
Figure (*b*) shows an obstacle with a hole 6 cm wide.
Figure (*c*) shows an obstacle with a series of holes, the two farthest being about 7 cm apart.

Copy figure (*a*), three times the size shown, and show on the diagram the shape of a ripple that has travelled 3 cm beyond the obstacle. Do the same for (*b*) and (*c*).

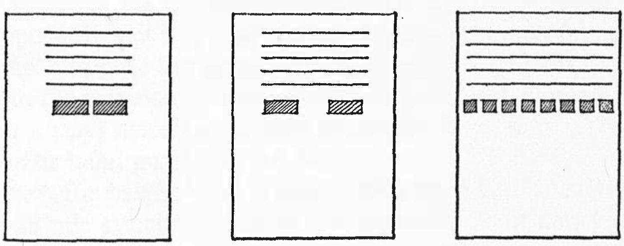


Figure 164 (*ii*)

165 Two point vibrators in a ripple tank are 5 cm apart. Each produce circular ripples in the usual way. They are in phase, that is, they bounce up and down together.

a. Describe briefly (adding a diagram if you can) the pattern produced.
b. What difference would it make to the appearance of the pattern if the vibrators were: (*i*) closer than 5 cm; (*ii*) farther apart than 5 cm?
c. What difference would it make if, instead of being in phase, the vibrators were exactly out of phase, that is, one moves up as the other moves down?
d. The ripple pattern is said to show *interference*, and the two waves are said to *interfere* with each other. Why, do you think, is this expression used?

166 Optional (*difficult extra topic*). If you have heard about 'wave-velocity' and 'group-velocity', explain the difference between these two velocities. Illustrate your answer by considering what happens *either* when you throw a stone into a pond, *or* when you start a pulse of two or three ripples in a ripple tank.

18 Using obstacles to 'break light apart': diffraction*

Latin: *frangere* (fract . . .) meaning 'break'
dif — = dis —, meaning 'asunder, away, apart'.
diffract = 'break away'
diffraction = the phenomenon of 'breaking away'.

167 You have seen ripples passing through various sizes of openings – see question 164, for example. Shown below, figure 167, is a similar arrangement using light instead of water ripples. The slit is very narrow, about $\frac{1}{4}$ mm wide.

Figure 167

a. How can you make a single narrow slit like this without any special apparatus?
b. The source may be a 'straight' filament lamp (or car-headlamp bulb). Should the direction of the slit, for best viewing, be at right-angles to the filament, parallel to it or at some other angle?
c. Suppose the slit is $\frac{1}{4}$ mm wide and the source may be regarded as a line. Suppose the distance between screen and slit is roughly equal to the distance between source and slit, each about 2 metres. *If light always travels accurately in straight lines*, how wide would the bright band on the screen be?
d. In fact, the bright band is much wider than you calculate in (*c*). What simple conclusion about the nature of light can you draw from this?
e. However, although the bright band is wider than the simple geometry of straight-line rays would lead us to expect, yet it is still quite narrow, and does not spread all round the screen. What does this suggest about the wavelength of light (if light is a wave motion) compared with the width ($\frac{1}{4}$ mm) of the slit? (Remember the ripple experiments.)

* *Interference*; see section 19.

168 When you looked at the 'pattern' produced by a single slit, you may have seen more than just one bright band.

Describe, by a rough sketch with shading, what you actually saw.

169 Hold the first two fingers of one hand closely pressed together, so that there is only a small gap. Hold them up close to your eye and look through this gap at a straight-filament lamp a few metres away, or at a distant street lamp, with, of course, the direction of the 'slit' parallel to the direction of the filament of the lamp. You see a pattern of the same kind as you saw with the slit in questions 167 and 168. Now try the effect of pressing the fingers closer, thus narrowing the 'slit'.

a. What effect on the pattern is produced by narrowing the slit?
b. Is this what you would expect from your ripple tank experiments? Explain.

170 We use the same simple apparatus as in question 169, but this time we have a ruled slit instead of two fingers, figure 170. First we look at the diffraction pattern produced by using the white-light filament, then we put a piece of green glass or gelatin in the position of the dotted line.

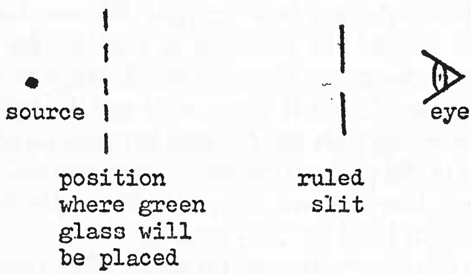


Figure 170

a. This makes the pattern green, and rather dimmer than before. What other difference does it make?
b. Next you use a piece of red glass fitted to touch the green glass, and placed so that half the filament appears red and half green. Try switching quickly green–red–green . . . what change of spacing of the bands do you notice? What conclusion about the wavelengths of red light and green light can be drawn from this? Why?

171 The experiments so far lead us to suppose that:

a. light is a wave-motion;
b. its wavelength is very small compared with that of water ripples,
c. the wavelength of green light is less than the wavelength of red light.

Describe briefly an observation that leads to conclusion (*a*), one that leads to (*b*) and one that leads to (*c*).

172 Even if you have not done any diffraction experiments with blue light, and you do not know anything about the wavelength of blue light, you might still expect that the 'single slit pattern' produced with blue light would show bands closer together than the bands obtained with green or red light. Why would you expect this?

19 Beams of light 'striking together with each other': Interference

Latin: *ferire*, meaning 'strike'
inter, meaning 'among', 'together with'.

173 Look at the diagram, figure 170 in the last section. Suppose that, instead of a very narrow single slit, we use two very narrow slits, ruled on the same piece of glass and about $\frac{1}{2}$ mm apart.

a. What difference is there between the pattern obtained with the double slit and that obtained with the single slit?
b. Suppose we insert glass in the position of the dotted line in figure 170. What difference is there between the double slit white light pattern and the double slit green light pattern?
c. We then try red glass; what difference is there in the 'spacing of the fringes' with red light and with green light?

174 *a.* Give a brief description of a ripple tank arrangement which produces an effect similar to that obtained with the double slit in question 173.
b. In the ripple tank demonstration, what difference does it make if the ripple sources are placed farther apart?
c. What difference would you expect it to make if, in the double slits experiment, you had the slits, say, 0·75 mm apart instead of 0·5 mm?

175 *a.* Given 'Young's fringes' apparatus, including a lamp with a straight filament and a 'double slit', how would you set them up in order to make a measurement of the wavelength of light? Give a diagram.
b. How would you measure the distance between one bright fringe and the next?
c. How would you measure the distance between the double slit and the place where you observe the fringes?

176 Continuing question 175:

a. How would you measure the distance apart of the two slits which form the double slit?
b. How were the double slits made in the first place?

177 White light is used to produce Young's 'double slit' fringes. The slit separation is 0·4 mm. The distance between the slits and the screen on which the fringes are formed is 1·4 metres, and the distance between successive dark spaces (or bright fringes) is 1·7 mm.

a. Find the average wavelength of white light.
b. Why 'average'?

(Formula for (*a*), will be found in part (*b*) of question 179.)

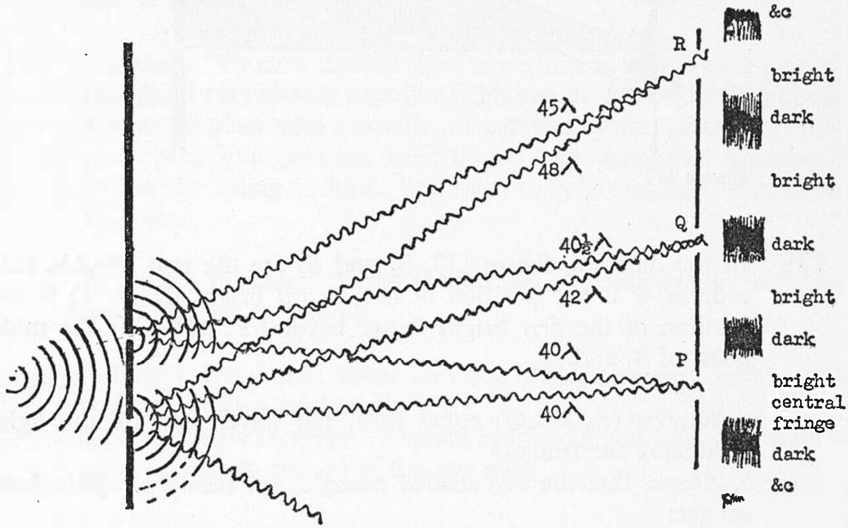


Figure 178

178

a. Explain what figure 178 is about.
b. Complete the following table by filling in path differences for 'first dark', 'first bright' etc.:

fringe	*path difference*
central bright	0
first dark	
first bright	
second dark	$1\frac{1}{2}\lambda$
second bright	
third dark	
third bright	3λ

c. What would be the *change* in path difference between the sixth bright fringe on one side, and the eighth on the other side, of the central bright fringe (which we number 'O')?

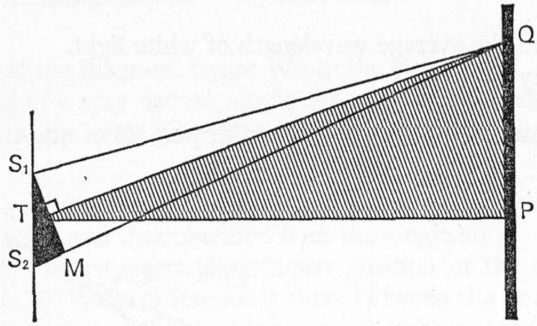


Figure 179

179 In the diagram, figure 179, S_1 and S_2 are the two 'double slit' sources, P is the position of the *central* bright fringe; Q is the position of the *first* bright fringe beyond P, and T is the mid-point of S_1 and S_2.

a. Why is (S_2Q–S_1Q) equal to λ, the wavelength of the light producing the fringes?
b. *Assume* that the two shaded triangles are similar. Explain how we get:

$$\lambda = \frac{\text{(distance between slits) (distance between fringes)}}{\text{distance from slits to fringes}}$$

c. *Difficult, do not spend long trying to do this.* Why are the shaded triangles, though not exactly similar, 'similar for all practical purposes'.

180 *a.* Two loudspeakers stand on stools out of doors, on a rough grassy non-reflecting surface. They are mounted a few feet apart, and each produces the same musical note. How will the note heard from the two speakers differ from the note heard from one?
b. Using *one* loudspeaker in a room, you can get effects similar to those obtained with *two* speakers outside. How do you explain this?

181 *Difficult.* 'If it were not for diffraction, Young's double slit interference fringes could not be produced.' Why not?

182 Each slit of a pair of slits acts as an independent light source and interference is produced. Freddie Jones says, 'Why not use two straight filament bulbs placed next to each other?' You say. 'Well, for one reason, the filaments would still be so far apart that the interference fringes would be much too close together to see.' 'All right,' says Freddie, 'get someone to put two filaments very close together in the same bulb.' 'That still wouldn't work,' you say. Why wouldn't it?

183 For these 'Young's double slits' experiments you need a pair of slits ruled very closely together. This can be done by ruling along a ruler on glass with a needle, or compass-point, or even a ball-point pen. The glass has been coated with graphite ('Aquadag') before the ruling is done. You have to rule two lines very close together.

A 'double-slit-ruler' can be made from a sewing needle, with the top of the eye broken off.

a. Give a few details about how you would use the 'double-slit-ruler' to make a double slit.
b. '*Only for the ingenious*'. Explain how you might find the distance apart (centre to centre) of the two slits.

20 Diffraction gratings

184 Take an ordinary handkerchief, pull it reasonably taut and look through the fabric at a light source sufficiently far away for it to seem like a point. (A bicycle lamp seen at a distance of several metres is good, but point the lamp to one side so that you do not get confusing reflexions from its mirror.)

a. Draw and describe the pattern of dots that you see.
b. Now take something in which the threads are more widely spaced (coarser mesh) than in a handkerchief, e.g. a tea towel. What difference is there in the pattern of dots? Is it what you expect? Why?

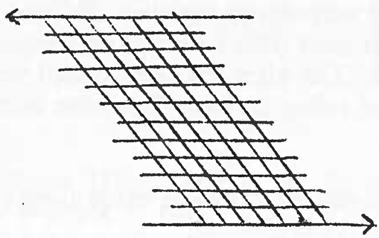


Figure 184

c. Now try pulling the mesh of the handkerchief diagonally as shown above. Pull the mesh and release it several times, in a 'concertina' fashion. Notice how the dot pattern also 'concertinas', but with a noticeable difference. What difference? Why is this?

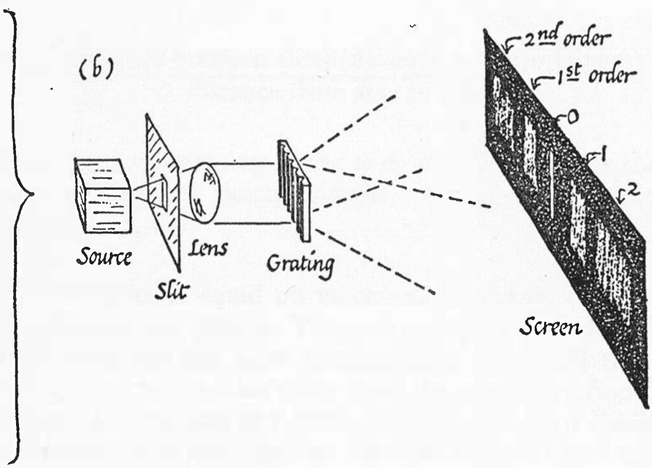


Figure 185 (see next page)

185 *a.* Figure 185 is a diagrammatic representation of a diffraction grating used to produce spectra of a filament lamp on a screen. Explain as much as you can about *what is happening* (not *why* it is happening) and what is seen on the screen. (Answer by starting 'White light from a lamp passes through a narrow slit . . .').
b. You can do away with the lens and the screen and simply put your eye up closely to the grating; you still see the spectra. What now has taken the place of: (*i*) the lens; (*ii*) the screen?
c. What is the connection between the handkerchief experiment of question 184 and the diffraction grating?

186 This question will be found on page 92.

187 In any one spectrum produced by a grating, the red colour is seen farther away from the central band than the blue colour of the spectrum. How do you explain this?

188 You hold a diffraction grating close to your eye, and with it you look at the spectra from: (*a*) a lamp filament; (*b*) a sodium flame; (*c*) a hydrogen discharge tube.

a. Describe the spectrum of the lamp filament.
b. What is a sodium flame? Draw a diagram of the spectrum it gives and write a sentence of description.
c. Draw and describe the hydrogen spectrum.

189 How is a sodium *absorption* spectrum obtained? How does its appearance differ from the sodium spectrum of question 188 (*b*)?

186 *a.* Use figure 186 to explain why a grating gives spectra of more than one 'order'.

b. If the grating has very narrow slits very close together, then only the first order spectrum, and perhaps the second, are seen. When a 'coarse' grating, like a handkerchief, is used many orders are seen very close together. Why is there this difference?

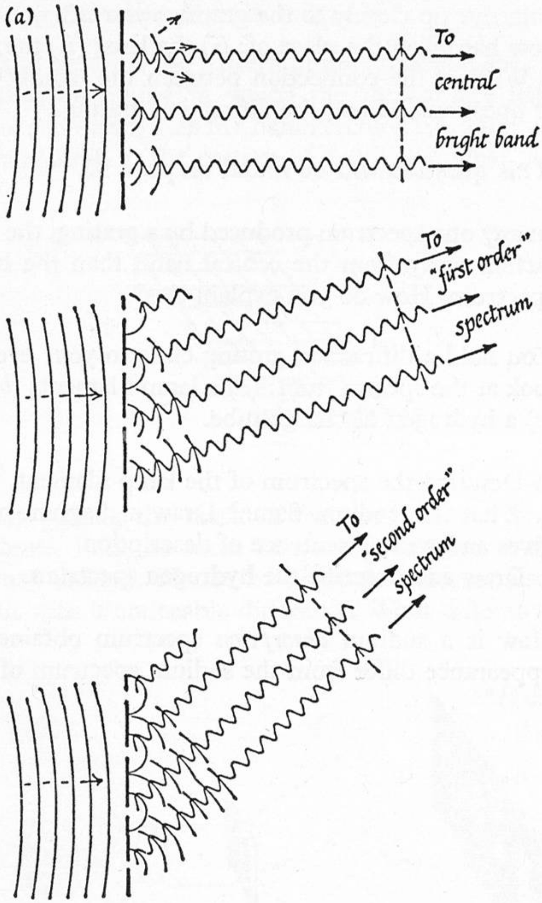


Figure 186

21 A simple theory about ions in gases

190 Figure 190 shows a lamp with a small compact filament, e.g. a car headlamp bulb, a candle and a screen, all in a darkened room.

Figure 190
side view, without vertical plates

a. What is seen on the screen?
b. How do you explain what is seen? You may assume that (*i*) hot gases are less dense than cold gases, (*ii*) bending, or *refraction*, of light varies with the density (and temperature) of the air or gas through which it passes.

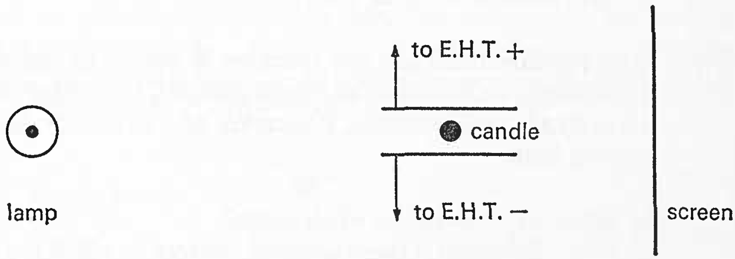


Figure 191
plan view, showing vertical plates

191 Figure 191 is a plan view of figure 190. Two vertical plates, joined to opposite sides of an 'extra-high-tension' supply of a few thousand volts, are placed on either side of the candle.
a. What is seen on the screen?
b. How do you explain it?

192 (Just a puzzle.) Suppose the negative side of the E.H.T. supply in figure 191 is 'earthed'. What is seen on the screen:
a. if the positive plate is removed completely;
b. if the positive plate is replaced and the negative plate is removed?

193 Figure 193 shows the candle-and-plates part of figure 191, but now a *highly sensitive* direct-current measuring instrument, D, is included, as shown. You can think of it as an ammeter that will read very tiny currents indeed – a micro-micro-ammeter.

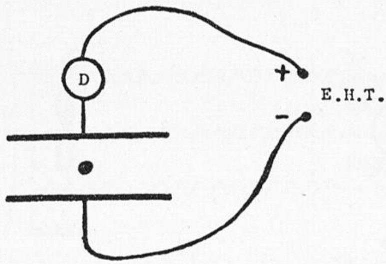


Figure 193

a. What would you see as the voltage between the plates is increased from zero to its maximum value (*i*) if the candle is not alight, (*ii*) if the candle is burning? (You may not have seen this, but it can still be a 'thought-experiment'.)
b. Give reasons for your answer (*a*).

194 The experiment in the last question is bound to remind you of something you have seen and done yourself, something which used an ordinary milliammeter, a vacuum, and a different way of producing heat.

a. What was this earlier experiment?
b. What difference is there between the way in which the current is carried between the plates in this experiment, and in that of question 193?
c. Does the experiment in question 193 show there is a difference? Give the reason for your answer.
d. Does the experiment in question 191 show there is a difference? Give the reason for your answer.

195 *Introduction.* Previous discussions of the 'Kinetic Theory of Gases', showed us much about how molecules behave: how they exert pressure, how fast they move, how big they are, and things like that. We learnt nothing at all about what molecules are like inside; we thought of them simply as being round hard things like marbles or steel balls. The only reason for supposing they are

round and hard is that, if we had (for example) supposed they were squashy cubes this would not have fitted any better with the reality that we know. We can represent our 'kinetic theory atom', or molecule, by a round blob, figure 195. Now, however, we want to try making an atom-model to explain how electricity is conducted in gases, and there before us is the invitingly unknown sphere of the kinetic theory atom, waiting for us to put some structure inside it. We find charged particles in gases and we call them *ions*. This leads to a simple picture of an 'ionic theory atom' with a positive and a negative part. We have heard about electrons and discovered that they have very little mass compared with the mass of even the lightest atom, hydrogen. So we tend to think of the negative ingredient of an atom as being very small, an electron in fact, stuck into the main bulk of the atom, which has a positive electric charge. Clearly we could put more electrons into this picture, sticking them into the positive atom-mass like plums in a plum-pudding, the electrons being the plums and the positive mass being the rest of the pudding. We may call this picture the 'plum-pudding atom'. For the moment we need only one plum, that is, electron; see figure 195. The 'positive ion' and 'electron' pictures explain themselves. The 'negative ion' picture is simply an atom with an extra electron tacked on. It has been put outside to show that it is an 'extra' and was not originally a part of the atom, but there is actually no reason for supposing that it is any different from an electron placed inside.

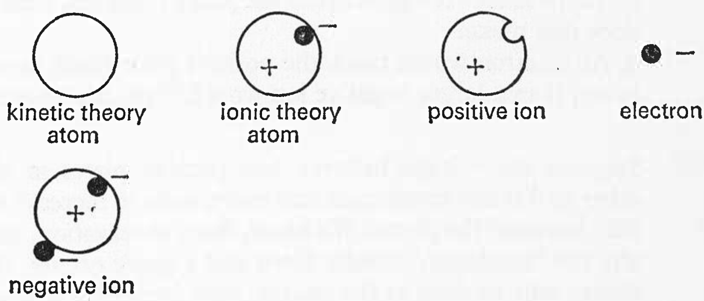


Figure 195
simple atom and ion pictures

Questions. a. Think of each of the particles pictured in figure 195, placed, *in a vacuum*, between two parallel metal plates joined to the + and the − of an E.H.T. source. What happens to the atom? the positive ion? the electron? the negative ion? (Note, an electron

is just a special sort of negative ion with the usual charge but very light.) Say whether the particle stays still, moves with constant speed, oscillates, moves with constant acceleration, starts and stops, or whatever you think; and of course, say in what direction it moves.
b. What difference would it make if the potential difference between the plates was only a few volts, instead of a few thousand? (We are still thinking of just one particle in the vacuum between the plates.)
c. What difference would there be between the motion of an electron and of a negative ion consisting of (atom + electron), in the same electric field, still in a vacuum? Why is there this difference?
d. Suppose there were a large number of positive and negative ions in the electric field between two parallel plates, what would happen? Would they all reach one or other of the plates? If not, why not?

196 *a.* Think now of just one ion, positive or negative but not an electron, between charged parallel plates *in air*, not in a vacuum. How does its motion in air differ from its motion in the vacuum? Why does it differ? (Assume that the voltage between the plates is much less than the voltage which would cause a spark.)
b. (*Difficult*) Suppose the pressure of the air is reduced to, say, half atmospheric pressure, what difference does this make to the motion of an ion? Why?
c. Suppose the voltage between the plates is halved, what difference does that make?
d. An electron would reach the positive plate much more quickly, in air, than a larger negative ion would. Give *two* reasons for this.

197 Suppose the voltage between two parallel plates in air (or any other gas) is increased more and more, so as to increase the electric field between the plates. We know, from observation, that eventually the 'insulation' breaks down and a spark occurs. Our simple theory tells us that, as the electric field increases, so the collisions a charged ion makes with gas atoms become more and more violent, with the result that it may be able to knock an electron off some of the atoms it meets.

Explain how this process can lead to the 'avalanche' of ions which we call a spark. Where does the energy (heat and light) of a spark come from?

198 A spark occurs more easily, with the same voltage, if (*a*) the plates are put closer together, or (*b*) the pressure of the gas is reduced. What is the reason for (*a*)? And for (*b*)?

22 Ionization produced by radioactive radiations. Three kinds of radiation

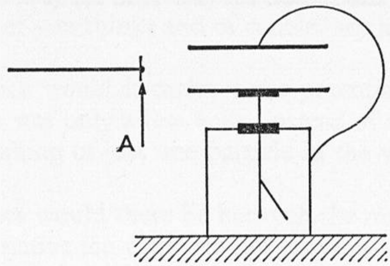


Figure 199

199 *a.* A small piece of radioactive material, A, is inserted between plates joined to a charged electroscope, figure 199. What happens? What else, placed between the plates but not touching them, would have produced the same effect?
b. You probably saw a slightly different arrangement to show the same thing: briefly describe, giving a diagram, how you showed that uranium oxide has the property of discharging an electroscope.

200 In order to discharge an electroscope, electric charge of opposite sign must be taken to it, or charge of the same sign must be taken from it. This can happen, in air, only if *ions* are present. We conclude that the uranium in the uranium oxide has the property of producing 'ionization', that is, of making ions.

a. Freddie says, 'It might equally well be the oxide part of the uranium oxide, and not the uranium at all.' What immediate reply might you make to that? And what conclusive experiments might be done, to prove your point, and to disprove Freddie's?

Mention any other substances you have tried, or know about, that do not contain uranium but do produce ionization.

201 The curious properties of uranium were first discovered by a French scientist, Henri Becquerel, in 1896. He was not looking for 'radioactivity'; obviously he could not have been looking for something he did not know existed. So the first experiment in radioactivity was accidental. The second experiment was the discharging of an electroscope.

Look in books to find out something of Becquerel's 'first experiment', and briefly describe what it was.

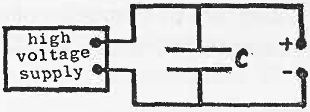


Figure 202

202 *Introduction.* The two metal knobs, figure 202, are first adjusted to the maximum distance that just produces a spark, then they are separated slightly more, so that there is no spark. A match flame is held near the knobs, and a spark jumps. Every time a flame is taken to the gap there is a spark, provided, of course, that time is allowed for the capacitor C to become recharged. This arrangement can be thought of as a 'match flame counter'; we count the sparks and that is the same as counting the matches.

The flame produces ions, but it is not these alone that constitute the spark; the spark consists of a whole 'avalanche' of ions. The flame has a 'triggering action' in starting the avalanche.

Questions. a. Explain why the flame has a triggering action in starting off a spark. This means 'explain why' in terms of the simple atom and ion pictures of figure 195.
b. Once the spark discharge has started, why does it ever stop? (It is not 'because all the ions in the spark gap are used up'. So long as the spark lasts, more ions are being made.)

203 (*Difficult*) A lightning flash can cause an interruption to power supplies from high-voltage overhead cables, even though the flash itself has not damaged cables or pylons. Why is this? What sort of mechanism is required to prevent damage to the cables after the flash has occurred? The interruption to power supply need not last more than a second or so; why not? (*Hint:* the lightning flash is itself a very large spark, and therefore a very powerful source of ionization.)

204 If we want to count, by means of sparks, single 'ion-particles' (alpha-particles) from a radioactive source we must have something more sensitive than the metal-knob arrangement of figure 202. Draw a diagram of a 'spark-counter' you have seen or used, say how it is connected to an E.H.T. source, and say how it is used.

Why is a spark counter able to respond with a visible spark to a single alpha-particle?

205 Figure 205 is a simplified diagram of a Geiger tube joined through an amplifier to a loud-speaker. Describe what is heard when:

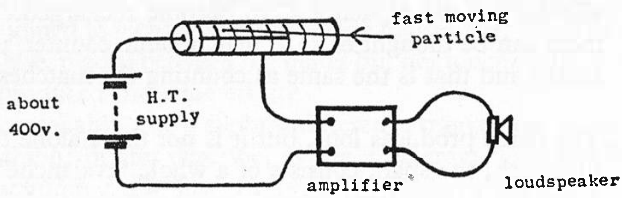


Figure 205

a. a single fast-moving charged particle, such as an alpha-particle, enters the thin mica window at the end of the tube;
b. many particles enter the tube from a small radioactive source placed near the window.

206 Figure 206 is a diagram of a part of figure 205, showing a magnification of the central wire of the Geiger tube, and the track of a charged particle. The particle has ionized many gas atoms, one of which is depicted in the diagram. The circle with + inside represents a positive gas ion, and the black dot is an electron detached from it.

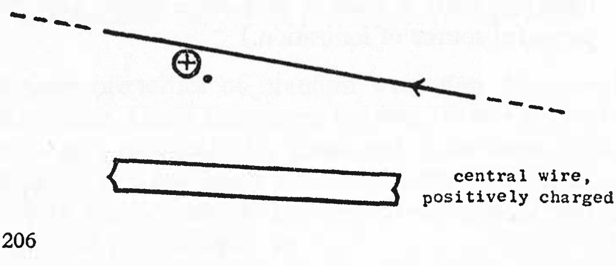


Figure 206

a. There is a potential difference between the wire and its surrounding tube (shown in figure 205 but not in figure 206), and so there is an electric field round the wire. Which way does (*i*) the positive ion, (*ii*) the electron, move under this field?
b. If the potential difference between wire and plate is sufficiently high, but not too high, the electron (figure 206) can produce more ionization, but the positive ion cannot. Explain why, under these conditions, (*i*) there is a 'pulse' of current through the tube, but (*ii*) there is no spark.

207 What is a 'scaler' (or 'counter')? What is the advantage of using it, compared with a loud-speaker?

208 We now know how to show or count moving charged particles by the ionization they produce, with a spark counter or a Geiger-tube counter. Another method, also depending upon ionization, is the *cloud chamber*.

a. Give a brief description of one type of cloud chamber you have used or seen, and say how you operate it. Draw a diagram to illustrate what you might see if a speck of radium is inside the chamber. Is this a 'diffusion' or an 'expansion' type?
b. Briefly describe the other type of cloud chamber which you did not describe in (*a*).

209 A cloud chamber does not *make* alpha-particle tracks, but it does make them visible. How does this come about? (Your explanation should make use of the fact that water or alcohol vapour, when it is near to 'saturation', that is, near to condensing into liquid, easily condenses in drops around electrically charged particles.)

210 Alpha-particle tracks from radium, observed in a cloud chamber, show that the range of an alpha-particle in air at ordinary pressures is about 7 cm.

a. What do you think happens to an alpha-particle that forms a straight track, from the moment it leaves the radium atom until it reaches the end of the track?
b. What difference would it make to the range of an alpha-particle if the pressure of the air is reduced? What would be the range in a complete vacuum?
c. How could you use a spark counter to find the range of an alpha particle in air? (continued on next page)

d. You could use a Geiger counter to measure ranges, but you would have to make allowance for . . . what? Why?

211 How would you show that alpha-particles are stopped by a piece of paper of ordinary thickness, but can penetrate through very thin paper, e.g. cigarette paper? Why is it that a thin sheet of solid material has much more 'stopping power' than several centimetres of air? (All the same, the alpha-particles go through the paper without making holes – have a look.)

Why do Geiger tubes meant for counting alpha-particles have to be handled *very* gently – especially at the 'window' end?

212 How could you use a Geiger tube to show that another kind of radiation, different from alpha-particles, also comes from an ordinary radium source?
(*Note:* Most of the effects noticed will be due to *beta-particles* from such a source. Some other radioactive sources, e.g. 'strontium 90', eject only beta-particles.)

213 *Introduction.* A few millimetres thickness of aluminium, or a sheet of perspex, or a millimetre or so of lead, will stop beta-particles completely (and of course, alpha-particles as well). We then find that there is still a third form of radiation from radioactive material, called *gamma rays*, which easily penetrates several inches of lead, and which hardly seems to be absorbed at all by atmospheric air. But of course, like anything diverging from a small source, the intensity does fall off inversely as the square of the distance from the source – that is, gamma radiation behaves in this respect like light diverging from a small lamp, or gravity at a distance from the Earth. The numbers of both alpha- and beta-particles per unit area will also fall off, with increasing distance from the source, according to an inverse square law; but in these cases we are usually more interested in the absorption that takes place.

Question. What experiment would you do to show that increasing the distance from a gamma source by five times reduced the intensity of the gamma-rays to one-twenty-fifth?

214 *Introduction.* We are constantly exposed to radiations of all three types, alpha, beta and gamma, without any noticeably harmful effects. This 'background radiation' comes partly from cosmic radiation from outside this planet, and to some extent from traces

of radioactivity in rocks and soil. Some of us get more than others; thus it is said that people in Aberdeen, who live in houses made of granite, get twice as much radioactive radiation. Even twice the normal does no apparent harm. But undue exposure to radioactive sources for long periods can produce various unfortunate effects on the human body, therefore care is needed.

Questions. a. A beta-source accidentally swallowed, and even worse, an alpha-source, would be very dangerous, but a gamma-source that somehow 'got into the works' would not be so bad. Why is this?

b. On the other hand, a large alpha-source out on the bench constitutes practically no hazard at all (though one should not finger it!), a large beta-source is more dangerous, and a powerful gamma-source is very dangerous indeed. Why is this?

c. The best protection from a gamma-source, apart from having it surrounded by a very thick and heavy casing of lead, is to be as far away as possible from it. If you are 20 metres away instead of 2 metres you may be said to be '100 times as safe'. Why is this?

23 Detective work on cloud-chamber photographs. The nature of alpha, beta and gamma radiation

215 Photograph 215 shows alpha tracks from a small radioactive source (not radium). What is especially interesting about these tracks, and what do you deduce from the photograph?

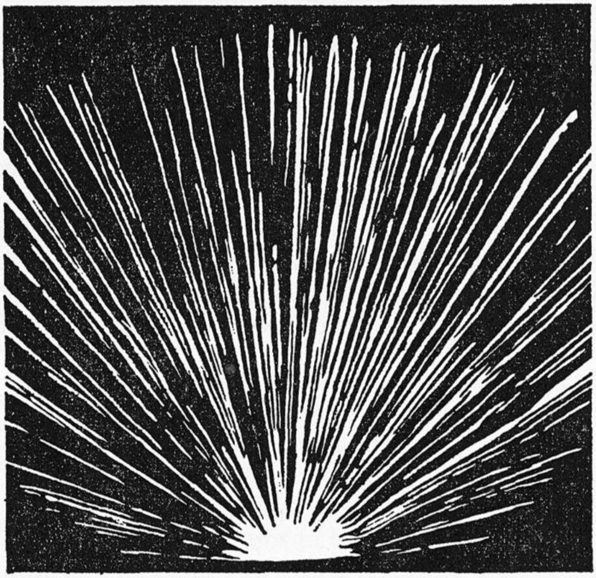


Figure 215
alpha-tracks from a small radioactive source

216 Photographs 216 (*i*) and (*ii*) lead you into another piece of detective work. Both are photographs of events that occur very infrequently. In (*i*) there has been a direct collision between an alpha-particle and a nitrogen atom. (*ii*) shows a collision with a hydrogen atom.

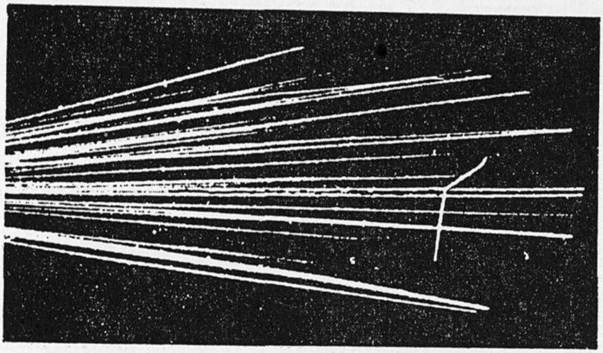


Figure 216 (i)
collision track in nitrogen

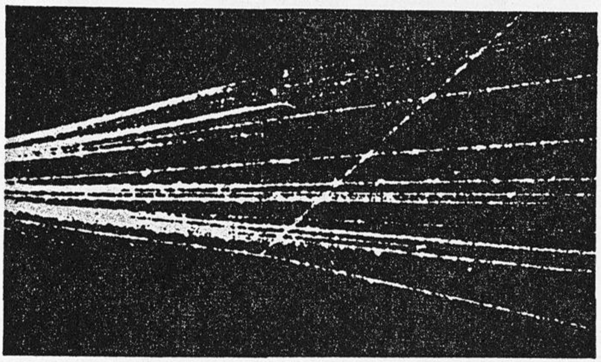


Figure 216 (ii)
collision track in hydrogen

a. Copy the two sets of collision tracks, three tracks in each diagram. Label the tracks α (for alpha-particle), N (for nitrogen), H (for hydrogen). 'α' appears on two tracks in each diagram, of course. You have to decide where to put the 'N' and the 'H'.
b. What can you deduce about the mass of an alpha-particle, compared with (*i*) a nitrogen atom, (*ii*) a hydrogen atom? Give a reason for each answer.

217 Photograph 217 shows two pictures of the same event, taken from different places. The pictures show alpha-tracks in *helium* gas, and, of course, the interesting thing is the collision between an alpha-particle and a helium atom. We have two pictures of the same collision, and you can see the 'after-collision' angles between the alpha-particle and the helium atom. Neither of the angles we see in the photographs is really the actual angle, because neither of the two photographs is exactly 'face on'. However, from these two photographs it is possible to calculate the actual angle in space, and it is found to be, as nearly as possible, 90°.

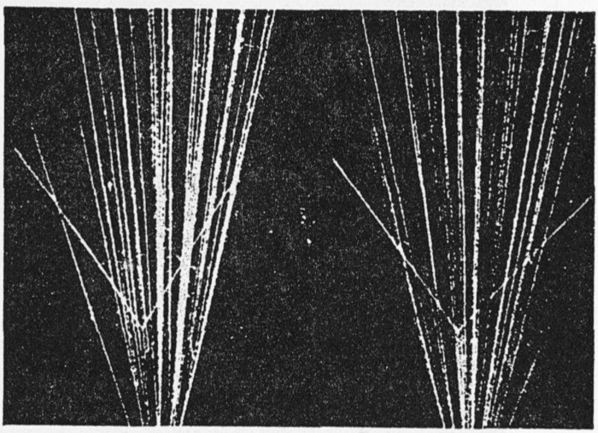


Figure 217
photographs from different view-points of the same collision between an alpha-particle and a helium atom

a. What do you infer about the mass of an alpha-particle compared with the mass of a helium atom?
b. Was your answer to (*a*) an inspired guess? Good! But now, can you give any reason that shows you are right, either (*i*) from something you have seen (experiments with colliding pendulum bobs, or colliding carbon dioxide pucks, or something else), or (*ii*) by means of a mathematical argument? If so, describe your evidence.

218 Have you heard about an experiment – usually called the 'Rutherford and Royd' experiment – which decided beyond doubt that alpha-particles were charged helium atoms? If so, give an outline of what was done, and with what result. Do not trouble about details of the apparatus, but do invent your own sketch and say how the alpha-particle helium was detected.

219 Photograph 219 shows alpha-tracks in a *very* strong magnetic field. The alpha-particles travelled from a source on the left of the picture. If they had been electrons the bending would have been *in the opposite direction.* If they had been uncharged atoms the tracks would not have been bent at all.

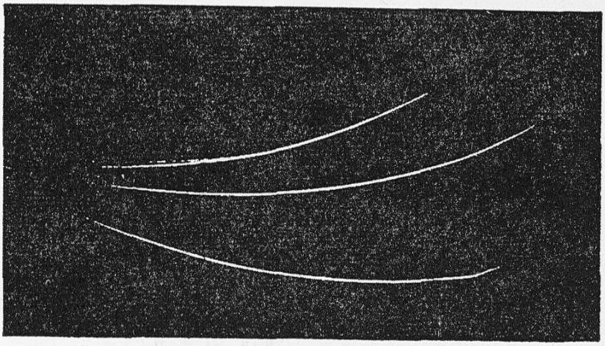


Figure 219
alpha-tracks in a very strong magnetic field

a. What do you deduce about alpha-particles? Are they charged or uncharged? If charged, positive or negative?
b. The bending is greater at the end of the track than at the beginning. How do you account for that? Give a careful explanation.

220 Experiments on beta- and gamma-radiations in magnetic fields show that beta-tracks are bent in the *same* direction as an electron beam would be, while gamma-rays are not deflected at all.

a. What do you deduce about beta- and gamma-radiations *from this alone*? (Do not deduce too much!)
b. If you have seen an experiment with a Geiger counter, to show the deflection of beta-particles by a magnetic field, give a brief description, with a diagram, explaining what was done.

221 Figure 221 is a schematic diagram of alpha-, beta- and gamma-rays, from a source such as radium, in the electric field between two plates. The diagram is not supposed to be accurate; the amount of bending depends not only on the strength of the electric field but also on the charge on each particle, e; the speed, v; and the mass, m (actually deflection is proportional to $\frac{e}{mv^2}$).

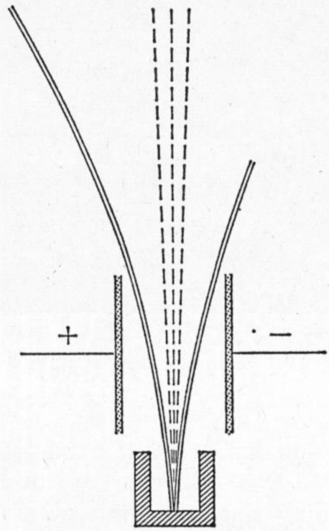


Figure 221

a. Copy the diagram and label the three sets of lines α, β, γ, as you think correct.
b. For alpha-particles and beta-particles of the *same kinetic energy* (K.E. $= \frac{1}{2}mv^4$), how would you expect the deflections to compare in size?
c. What can you say about the comparison of kinetic energies of alpha- and beta-particles in this diagram? Why?

(*Note*: you may find (*b*) and (*c*) easier to complete after finishing question 222.)

222 You can now copy out and fill in the table below. To help you do this, read the information given after the table.

Type of Radiation	Penetrating power	Particle or wave motion	Charge (electron = −1)	mass (H atom = 1)	What are they?
Alpha					
Beta					
Gamma					

Column 2: this is different for radiations from different sources, but, referring to radium, you can put, 'a few mm of metal'; 'more than 20 cm of lead'; 'less than 10 cm of air' – in the correct places of course!

Columns 4, 5, 6: experimental evidence shows that alpha-particles are charged helium atoms (ions), as you know; actually they are doubly-charged helium ions, He^{++}. Like helium atoms, they have a mass four times that of a hydrogen atom.

Beta-particles are in fact electrons, and therefore have a mass which is $\frac{1}{1800}$ of the mass of a hydrogen atom.

Gamma-rays are uncharged. You had better leave the 'mass' part unfilled. What are they? If we mean the gamma-rays from radium we can say 'like light but a much shorter wave length'.

24 Radioactivity: randomness, radioactive series, tracers

Introduction. We now have a mental picture of a particular kind of substance, called radioactive, which shoots out helium ions, electrons and gamma-rays – some or all of these. Radioactive substances include the elements uranium, radium, thorium and others, and also compounds containing these elements; obviously radioactivity is a property of the atoms of certain elements, and has nothing to do with the chemical compounds in which the elements are found. Radioactivity is something beyond chemistry, so to speak; it is something that occurs more deeply inside the atom. This immediately raises many questions. Why does a radium atom suddenly shoot out an alpha-particle? What is left behind when the alpha-particle goes? Clearly most of the atom is left: since the atomic weight of radium is 226 and the atomic weight of helium is 4; '222' is left. Is this piece of a radium atom still radium, or is it something else? These 'why?' and 'what is it?' questions are difficult to answer, sometimes unanswerable. As usual we start, instead, by asking 'how?' or 'in what way?' does something happen. How do alpha-particles come off from radioactive material; is their emission a purely random process, or does it follow some *other* laws? Randomness has its laws, its expected way of behaving. Also, if radium is somehow 'used up' in emitting alpha-particles, does this mean there will be less and less radium and alpha-particles until there are none at all, or will there always (for example) be a 'smallest piece' that will remain? – or perhaps the last piece will go off with a burst of alpha-particles, like a small explosion! These are things we can investigate. First let us remind ourselves about 'randomness', what is it like? Try this at home:

223 Take an ordinary pack of cards, without jokers, shuffle, cut and deal yourself 13 cards. How may hearts do you expect to have? How many have you got? Return the cards to the pack and repeat this, shuffling and cutting each time, so that you have seen 10 hands of 13 cards each.

a. What was the minimum and maximum number of hearts held in a 'hand'?
b. What was the total number of hearts in 10 hands? What, to one decimal place, was the number of hearts per hand?
c. What is the 'expected', i.e. most likely, number of hearts per hand? (Remember there are 13 hearts in 52 cards.)

Notice how the number of hearts in each hand varies, but the average of many hands comes nearer the expected figure. It might not of course – you might find 13 hearts in each hand, and 130 in 10 hands, but this is so *very* unlikely that you would get suspicious about the pack, and think that it must be a 'conjuror's pack' of 52 hearts!

224 Suppose you look at tracks in a cloud chamber from an alpha-particle source. You get many 'glimpses' at intervals of several seconds between glimpses. Try it if you can; if not, suppose that the average is going to be about five tracks per glimpse, and write down ten numbers showing the sort of counts you are quite likely to get in ten glimpses.

You have also seen this tried with a Geiger counter (for both alpha- and beta-particles) and a spark counter. Do your observations agree with the idea of random emission of particles? Describe what you saw, or heard in the loud-speaker.

Radioactive changes take place in a 'random' fashion, as we might expect, and there is no reason to labour the point further. Also the amount of radioactivity must alter as the radioactive material is 'used up', that is, as 'radioactive decay' takes place.

225 We will illustrate the rules about radioactive decay by using a pack of cards. The trouble is that there are only 52 cards, or rather, since we shall have to divide the pack in two, only 26, instead of the millions of atoms in only a tiny speck of radioactive material. Small numbers show up the 'chancy' nature of random decay much more than could be observed in experiments with an ordinary radioactive source.

Pick out the 26 red cards from the pack. These represent 26 radioactive atoms. Put the 26 black cards on one side; these are going to represent 26 spent or 'decayed' atoms. Take the 26 red cards and deal out 4; of course they are all red. Replace them with 4 black cards, meaning that 4 atoms have expelled an alpha-particle and have become 'dead'. Shuffle well, and deal out 4 cards. Replace any red cards dealt by black ones, so as to keep 26 cards. Do the same thing again and again, 12 times in all (but we will call it 0 to 11). I did this ten times, with the following result (only the first two sets and the average of the whole ten sets are shown):

(Imagined time), minutes	0	1	2	3	4	5	6	7	8	9	10	11
First set	4	3	3	1	1	2	1	2	2	1	0	0
Second set	4	3	3	2	4	0	2	1	2	1	1	1
Averages of 10 sets	4·0	3·2	2·4	2·7	1·9	1·7	1·2	1·6	0·9	1·1	0·4	0·8

Do this up to 10 times, i.e. 10 sets, if you have time and patience. Take the averages, plot the points on a graph and draw the best curve you can through or between the points. My graph is shown in figure 225. You can imagine the readings are 'glimpses' of a sheaf of alpha-tracks from a decaying radioactive source; perhaps taken every minute starting from time 0. Find the 'time taken' to decay from 4 to 2, from 3 to 1·5 and again from 2 to 1 (see my graph). These times should be about equal if you have taken enough readings, and represent the 'half period value'. Do this for your graph as well as for mine.

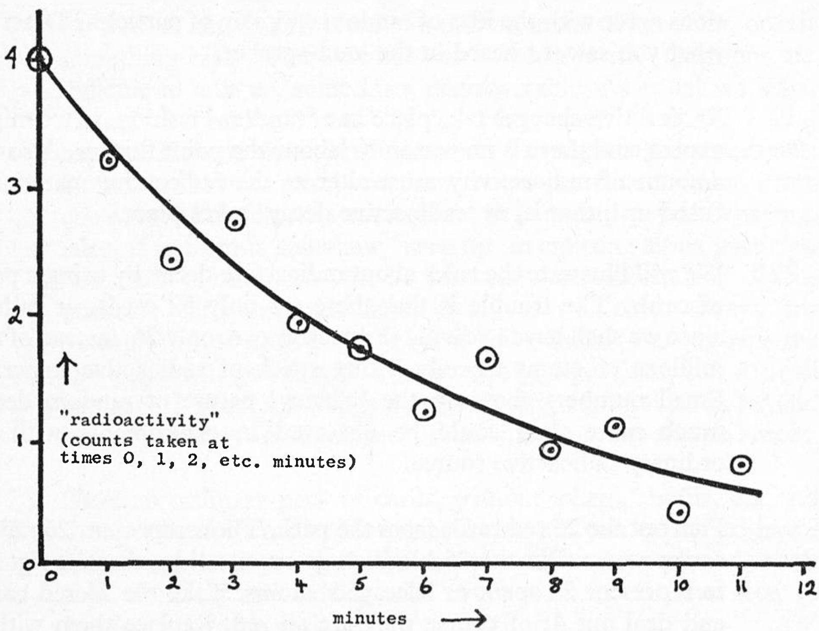


Figure 225
decay-type graph

(*Note:* Good shuffling of the cards is essential. If your grandmother plays patience, ask her the best way to shuffle cards so as to get them 'properly mixed', which means, of course, a random distribution.)

226 You should have seen a 'radioactive decay' experiment in which you determined the half-life of a radioactive element, for example:

(*i*) half-life of 'uranium X_2' by a Geiger counter method, using a chemical means of separation, or
(*ii*) half-life of thoron* by a cloud chamber experiment.

Give an outline of what was done and what you observed. Say how you calculated the half-life.

227 Uranium X_2 and thoron X_2, mentioned in question 226, have half-lives of 54 and 72 seconds respectively. Some substances have much shorter half-lives; some much larger. The half-life of radium is 1620 years. Uranium itself, or uranium I as it was called, has a half-life of 4500 *million* years. Uranium atoms, atomic weight 238, go through a whole series of changes, giving out alpha-, beta- and gamma-radiations, and finally ending as lead of atomic weight 206. Radium, atomic weight 226, is one of the substances occurring in this chain of transitions. The end-product, lead, is 'stable', meaning that it does not undergo any further change, or, if you like, that its half-life is an infinity of time! See the chart on page 114.

Questions. a. If you have 1 gm of radium now, how long would it be before this was reduced to 0·25 gm? How much longer would it take before this quarter-gram became one-sixteenth of a gram?
b. Would there ever be nothing at all left of your original 1 gm of radium?
c. The Earth is thousands of millions of years old – how, then, do you account for any measurable quantity of radium being discoverable in natural rocks?
d. Uranium, atomic weight 238, becomes 'transmuted' to lead 206. Beta- and gamma-radiations have negligible mass compared with an alpha-particle of mass 4 (hydrogen = 1). Calculate the number of alpha-particles emitted in this series of charges. Check your answer by counting in column 4 of the chart.

* Thoron is an isotope of radon; see 'uranium series' of radioactive elements, page 114. However, thoron is not a member of the uranium series; it belongs to the 'thorium series'.

" Uranium Series " of radioactive elements

Old name of element *	*Atomic number*	*Atomic weight*	*Particle ejected*	*Half life*	*Isotope of*
Uranium I	92	238	α	$4{\cdot}5 \times 10^9$ years	Uranium
Uranium X_1	90	234	β	24 days	Thorium
Uranium X_2	91	234	β	72 seconds	Protoactinium
Uranium II	92	234	α	$2{\cdot}5 \times 10^5$ years	Uranium
Ionium	90	230	α	8×10^4 years	Thorium
Radium	88	226	α	1620 years	Radium
Radon	86	222	α	3·8 days	Radon
Radium A	84	218	α	3 minutes	Polonium
Radium B	82	214	β	27 minutes	Lead
Radium C	83	214	β	19 minutes	Bismuth
Radium C_1	84	214	α	0·00016 sec.	Polonium
Radium D	82	210	β	22 years	Lead
Radium E	83	210	β	5 days	Bismuth
Radium F	84	210	α	138 days	Polonium
Radium G (lead)	82	206	—	stable	Lead

Remarks: First column gives name of element in series; last column shows its 'chemical' name in the periodic table.
Second column: number in periodic table; more about this in next section.
Third column: atomic weights (we would prefer 'atomic masses') on scale of 'hydrogen = 1'.
Fourth column: mention of gamma-radiations has been omitted.
Fifth column: notice the long half-life of the parent element, uranium I.

* The best modern name is the chemical symbol with a number to show which isotope is meant, e.g. radium C is now called Bi 214 or Bi^{214}; that shows it is bismuth in all its chemical behaviour, but with atomic mass 214, its nucleus is unstable, and so it is radioactive. We could probably manufacture this isotope by bombarding common bismuth, 210, with neutrons.

228 *a.* Helium has atomic number 2 and atomic weight 4. What would you expect to happen to (*i*) the atomic number, (*ii*) the atomic weight, of a radioactive atom that ejects an alpha-particle?
b. Quote an example from the chart that agrees with your prediction in (*a*). Are there any disagreements?

229 An electron has negative charge and negligible mass. Suppose we regard an electron as having atomic number —1 (minus one) and atomic weight 0.

a. What would you expect to happen to (*i*) the atomic number, (*ii*) the atomic weight of a radioactive atom that ejects a beta-particle?
b. Quote an example from the chart that agrees with your prediction in (*a*). Are there any disagreements?
c. Now account for the change of *atomic number* that occurs from $_{92}$uranium^{238} to $_{82}$lead^{206}.

230 Two other naturally occurring radioactive series are known, in addition to the one shown in the chart. They are:
$_{92}$uranium^{235} to $_{82}$lead^{207}, and
$_{90}$thorium^{232} to $_{82}$lead^{208}.

The existence of a fourth radioactive series was predicted, but the series was not actually found until the element neptunium, its starting-point, was produced by artificial means. Neptunium was found to have a half-life of two million years.

Explain why the uranium series in the chart was found to occur naturally, but the neptunium series was not.

231 Name, from the column 1 of the chart, three isotopes of lead. What are their atomic numbers and atomic weights? Which is the more important factor in deciding chemical properties, atomic number or atomic weight?

232 *Historical interlude.* Year 1913, an unsuccessful experiment had far-reaching results.

a. George Hevesy was a Hungarian who, after studying in Denmark, came to work under Rutherford in the physics laboratory of Manchester University. Rutherford showed him several hundred kilograms of radioactive lead, a gift from the Austrian Government. The lead contained a small proportion of Radium D (see chart), which has a half-life of 22 years and would be much more radioactive than radium, and so highly valuable. In fact, it was almost useless because the massive lead absorbed almost all the radiation produced.

'Hevesy, my lad,' said Rutherford, 'if you're as capable as you seem, try and separate the radium D from all this lead.' Hevesy was convinced he could solve the problem, but he was no nearer a solution after two years' work.

a. Why not? (You speak with later knowledge.)
b. Nevertheless, Hevesy's unsuccessful work led him to the first 'tracer' experiment, a study of the way in which plants take up lead from the soil – where the lead goes, and how quickly. Outline the way in which Hevesy might conduct such an experiment.

233 *Introduction.* However, radium D and the other naturally radioactive elements have little biological interest, and this type of experiment did not seem to have much future. Hevesy and his students used to discuss their pioneer tracer experiment over afternoon tea in the laboratory. What a pity that so promising a method should be so useless for lack of the right tracer elements! How much better if, for example, they could trace what happened to the water in the tea they were drinking! Nowadays this could easily be done by adding to the tea a trace of tritium oxide, tritium being a radioactive isotope of hydrogen.
When, in 1933, Irene Joliot-Curie and her husband announced the artificial production of radioactivity in aluminium, obtained by bombarding aluminium foil with alpha-particles, nobody believed them. In the next few years they showed beyond doubt that they had produced radioactive phosphorus, P^{30}, an isotope of phosphorus of atomic number 15 and atomic weight 30.

Questions. a. How can an alpha-particle, ${}_2He^4$, colliding with an aluminium atom, ${}_{13}Al^{26}$, produce phosphorus?

b. An amazing result of the decay of radiophosphorus was that a *positive electron*, or *positron*, was produced. Just as, in question 229, we regarded an electron as -1 in atomic number and 0 in atomic weight, so we can regard a positron as $+1$ in atomic number and 0 in atomic weight. What will be produced when radiophosphorus, $_{15}P^{30}$, decays? (Look at a copy of the periodic table.)

Phosphorus is much more use than lead as a tracer element in *biological experiments*. Many other radioisotopes can now be produced, often by bombardment by particles produced in an 'atomic reactor', or as 'fission products' in the working of the reactor itself.

234 How long does it take a hen to make an egg? This question has been answered by using tracer elements, and it is found,

a. the lime of the shell comes from material eaten the same day.
b. the inside of the egg is formed from food eaten more than a month previously. Uncle George reads the above statements and wonders how they can be verified. Outline to him a possible method – you can invent any tracer elements you like to have. (This is another Uncle George – not Uncle George Hevesy! He invented the tracer method.)

25 Rutherford Model (of an atom)

235 You have seen many alpha-tracks in cloud chambers, all showing straight, undeflected paths. Every speck of condensed water that helps to make a track visible has condensed on an electron detached from an atom by an alpha-particle passing near. Each alpha-particle track is the result of about 100,000 minor encounters between atoms and alpha-particles. *From these facts alone*, giving your reasons, say:

a. what you deduce about the *mass* of an alpha-particle compared with the *mass* of an electron,
b. what you deduce about the region where the mass of a gas atom is concentrated. Also,
c. on a scale that makes the mass of a hydrogen atom = 1, the mass of an electron is $\frac{1}{1800}$ and the mass of a helium atom is 4. Do these figures agree with your conclusion in *a*? Explain.

236 Make up a story about revolver bullets fired at a bale of straw which has steel balls inside it, and draw a comparison between this, and firing alpha-particles at atoms.

237 Look again at the photographs on pages 105 and 106. These show that head-on or nearly head-on collisions between alpha-particles and atoms do occur very occasionally. Since electrons are negatively charged, and atoms as a whole are neutral, therefore the massive central part of an atom must be positively charged. An alpha-particle is also positively charged. So a 'collision' really consists of repulsion between two positive charges in motion relative to each other.

Rutherford used to illustrate the path the alpha-particle follows by means of a magnet fixed to the bench, and another magnet swinging on a long pendulum. Another demonstration uses a metal-coated ping-pong ball and a sphere attached to a Van der Graaf or Wimshurst machine. Describe one or other of these demonstrations, and say what you saw.

238 We know that an inverse square of force between electric charges holds to a very high degree of accuracy. Rutherford assumed that the inverse-square law held right down to atomic distances and less, and showed that the observed facts opened with the assumption. Newton assumed an inverse square law of gravitation, and showed that a planet moved round the Sun in an ellipse.

a. Why is it that an alpha-particle does not move in an ellipse round the positive part of an atom?
b. Draw a small round blob to represent the positive part of an atom, and show what you think might be the path of an alpha-particle which, had it continued straight on, would have approached very near to the atom (though not a 'head-on collision'). If you know the name given to the path (not an ellipse) write the name on your drawing.

239 Considerations like those raised in question 235 caused Rutherford to propose a 'nuclear theory of the atom' in place of the so-called 'plum-pudding' theory which was at first sufficient to explain most of the elementary facts about atoms and ions (see figure 195), and which was itself an advance on the 'kinetic theory' or 'billiard ball' atom.

a. Explain (as to Uncle George) the Rutherford theory applied to (*i*) a hydrogen atom, (*ii*) a helium atom, (*iii*) a heavier atom. Give Uncle George a diagram or two, to help him. He won't read more than a few sentences, and you shouldn't confuse him with ideas about what there might be *inside the nucleus*, nor worry about the electrons possibly being in motion.
b. If Uncle George asks, 'Well, why don't the electrons fall straight into the nucleus?', then you can mention the inverse square law and particles moving in circles and ellipses. Why is it all right to talk about ellipses here, when it wasn't in question 238? (But this is only an obvious piece of guesswork; at this stage we have no evidence about how electrons move, or even what they are like, when they are attached to nuclei of atoms.)

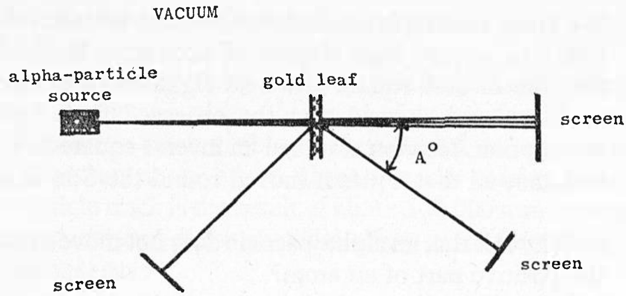


Figure 240
scattering experiment

240 Copy the diagram, figure 240 (or give something better of your own) and use it to explain in general terms the idea of Rutherford's experiment on the scattering of alpha-particles by a thin gold sheet.

241 Explain the meaning of the front three columns in the Table below and say how the fourth column provides a verification of Rutherford's model of the atom.

SCATTERING OF ALPHA-PARTICLES BY GOLD
(Experimental Test by Geiger and Marsden)

EXPERIMENTAL MEASUREMENTS		TEST OF THEORETICAL PREDICTION	
*Angle of Deflection** A°	*Experimental Count*† *N*	*Value of* $\frac{1}{(\sin \frac{1}{2}A)^4}$ from tables	*Test* $\frac{N}{1/(\sin \frac{1}{2}A)^4}$
150	33	1.15	29
135	43	1.38	31
120	52	1.79	29
105	69.5	2.53	28
75	211	7.25	29
60	477	16.0	30
45	1,435	46.6	31
30	7,800	233.3	33
15	120,570	3,445	35
10	502,570	17,330	29
5	8,289,000	276,300	30

* Of path of alpha-particles.

† Number of scintillations seen, for deflection A°, in a standard time.

Note: In the actual experiments Geiger and Marsden made one set of measurements for the larger angles of deflection, and another set, with a much smaller radioactive source, for the smaller angles. To make one complete set in the table above, the numbers for smaller angles have been multiplied up to fit the set for larger angles.

The original account may be found in *Philosophical Magazine*, Vol. 25 (1913), p. 610, Table II.

Note about $\frac{1}{(\sin \frac{1}{2}A)^4}$: Rutherford calculated theoretically that the 'experimental count' N should vary with the angle of deflection A according to the relation:

$$N = \text{a constant} \times \frac{1}{(\sin \frac{1}{2}A)^4}$$

This calculation is made by assuming:

(*i*) Newton's laws of motion,
(*ii*) inverse square law of repulsion between alpha-particle and nucleus,
(*iii*) and, of course, Rutherford's atom-model.

242 The number, Z, of 'electron charges' (positive charges in this case) on the nucleus of an atom can be calculated from scattering experiments of the type dealt with in question 241. This was done by Chadwick (1920) for copper, silver and platinum. He obtained the results:

$$\begin{aligned} \text{copper, } Z &= 29{\cdot}3 \text{ electron charges,} \\ \text{silver, } Z &= 46{\cdot}3 \text{ electron charges,} \\ \text{platinum, } Z &= 77{\cdot}4 \text{ electron charges,} \end{aligned}$$

within an experimental error of 1%.

The atomic numbers of copper, silver and platinum are 29, 47 and 78.

a. What does this suggest about the charge on the nucleus of an atom?
b. If you can, suggest a reason why the chemical properties of an element depend very much on its atomic number and not at all on its atomic weight.
c. Previously we defined atomic number as the number of the element in the periodic table. You can now give a better definition of atomic number. What is it?

26 Light particles? Matter waves?

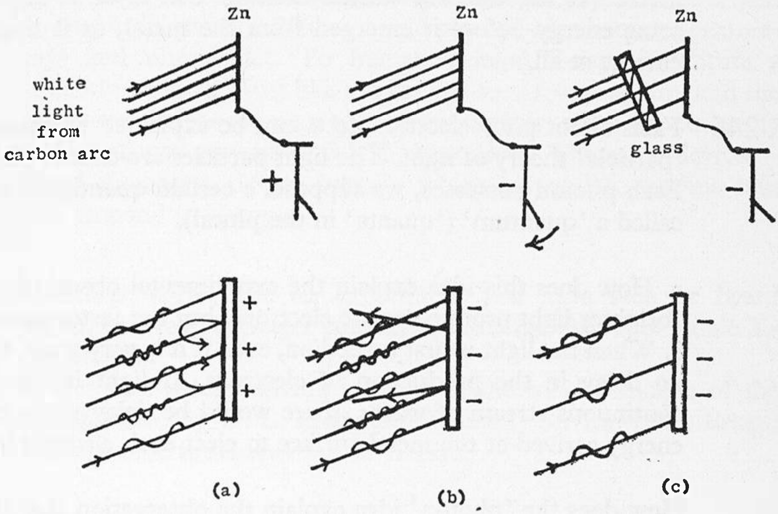


Figure 243

243 Tell a story about three experiments illustrated by six diagrams in figure 243. Copy the diagrams first. The zinc sheet is freshly cleaned and the electroscope starts by being charged positively in (*a*) and negatively in (*b*) and (*c*). Our old friend Freddie Jones says that this shows that 'Light ejects electrons from metallic surfaces'. His remark is on the right lines, but contains three quite separate over-statements. What do you say these three experiments show?

244 *a*. Of course, Freddie is right about the electrons, although the experiments in question 243 do not show that *electrons* are ejected. What sort of evidence, short of two actual measurements of (*i*) charge and (*ii*) mass, would be sufficient to convince you that the particles ejected are electrons? That is, that they are like the particles in an electron beam from a hot filament?
b. Light is absorbed at a surface and an electron, travelling with a certain velocity, is ejected. We can say:

energy lost by light = energy gained by electron.

In what two ways has the electron gained energy? You may assume that the electron was part of an atom in the outermost layer of the metal. (If the electron started beneath that layer it might lose some energy before it emerged from the metal, or it might not emerge at all.)

245 Facts about photoelectric effects can be explained by means of a 'particle' theory of light. The light particles are called 'photons'. Each photon possesses, we suppose, a certain quantity of energy, called a 'quantum' ('quanta' in the plural).

a. How does this idea explain the experimental observation that, 'brighter light produces more electrons, but not faster electrons'?
b. When the light is first turned on, even if it is very weak, there is no delay in the production of electrons. If light behaved as a continuous stream of waves, there would be delay while enough energy arrived at the metal surface to eject each electron in turn.

How does the 'photon' idea explain the observation that there is no delay?

246 Here are five kinds of 'electromagnetic radiation' you have heard about:

		↑	gamma-rays,
	more energy		
photons			ultra-violet,
carry			visible light,
	less energy		infra-red,
		↓	radio communications.

Choose *two* of these, and give what evidence you can for supposing that, for the one higher in the list, each photon carries more energy than is carried by a photon of the radiation lower down in the list.

247 *Introduction.* 'X-rays' are produced when electrons from a hot filament are accelerated to a high velocity by a potential difference of several kilovolts, and then these electrons hit a 'target' of some solid material. Any substance used as a target would produce X-rays, but in practice, because of the large amount of heat produced and for other reasons, the target is made of a high-melting-point metal such as tungsten or molybdenum. The kinetic energy of about 99% of the electrons goes into heat; hence, in large X-ray

tubes, cooling devices – external fins in the air, circulating water – have to be used to cool the target. Something less than 1% of electrons produce penetrating X-rays when they stop at the target. In the list in question 246 we would place X-rays between gamma-rays and ultra-violet. To human beings, X-rays constitute a 'radiation hazard', just like the gamma-rays from radium, and the same precautions are needed – more perhaps, since we can easily make and use very powerful X-ray sources. The same devices – cloud-chambers, Geiger tubes – which respond to gamma-rays also respond to X-rays.

Questions. a. Describe an experiment you have seen or heard about, in which a Geiger counter records the arrival of single X-ray photons.
b. Describe briefly, giving a diagram, the basic principle of the method used by W. L. Bragg (subsequently Sir Lawrence Bragg) to determine the *wavelength* of X-rays.

248 *Introduction.* In question 247 we dealt with, first, evidence that X-rays consist of particles (i.e. photons); and secondly, evidence that X-rays are waves having a definite wavelength and frequency. Which of these apparently opposing views is 'right'? The same dilemma confronts us when we consider other forms of radiation. Questions 248 and 249 serve to accentuate the contrast.

Question. Recollect your earlier work on visible light, and describe something of the evidence that led you to suppose that light behaved as a wave motion, and that the particle or 'bullet' theory, usually associated with Sir Isaac Newton, was wrong. In particular, mention the reasoning behind a so-called 'crucial experiment' on the velocity of light in air and in water which decided unmistakably in favour of a wave theory.

249 The diagrams, figure 249, illustrate a 'crucial experiment' performed to decide between a photon theory and a wave theory. (You have seen this experiment in the PSSC film *Photons*.) An 'electron multiplier tube' is used instead of a sheet of metal joined to an electroscope, but the principle is the same. A beam of light is cut off by a 'chopper' that selects a 'length' or 'sample' of it (see figure *ii*). The sample passes on to a metal surface from which electrons are ejected.

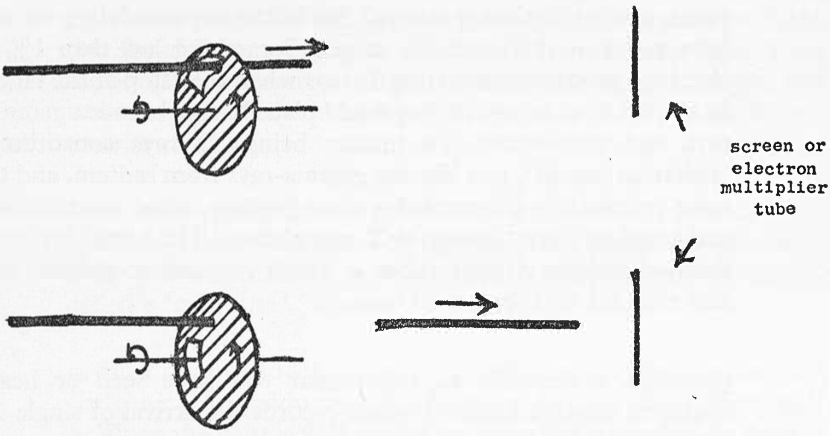


Figure 249
chopping off a sample length of light beam by a rotating 'chopper'

a. The light beam is very weak, and so, *if the light is a steady stream of waves*, we have to wait until almost the end of the sample before enough energy has arrived to eject one electron.
Do you agree?
b. But *if the light is a stream of particles* . . .? What do we expect to happen?

The experimental result agrees decisively with (*b*) rather than (*a*), and so contradicts the 'crucial experiment' in question 248.

250 The milk-bottle story in the film *Photons* is, of course, only an artificial model intended to show the idea, or the plan, of the real experiment. Try to invent another story along these lines:

'Freddie has to take some nasty-tasting medicine . . . after one sip with a straw he starts coughing, so he cannot . . . but . . . sugar-coated pill.'

251 *Introduction*. And so light is sometimes particles and sometimes waves? Is there any sense in this? One thing can be said: when light remains as light and is not changed to some other form of energy, then no question of particles arises; the light behaves entirely as if it were a wave motion. We observe the phenomena of reflection, refraction, interference, diffraction. We see light behaving like the ripples in a ripple tank. But when light energy is changed into another form – photoelectric effect or in a Geiger

tube, both of which are ionization effects, that is, ejection of electrons from atoms – in these changes light behaves as if it consists of photons each with a definite quota ('quantum') of *energy*, *not* as continuous waves.

This suggests an interesting experiment: arrange so that light is forming a Young's slits interference pattern, and then use an electron multiplier tube to find where the photons are arriving. Figure 251 is a diagrammatic representation of such an experiment.

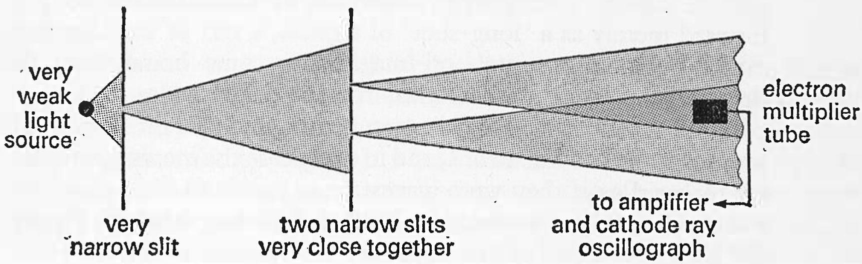


Figure 251
principle of an experiment on interference of photons

Question. Copy figure 251 and describe the experiment on 'interference of photons' which it illustrates. (You have seen a film with this title.) What does the experiment show about the numbers of photons arriving per minute at a bright band, and at a dark band? Is it possible to predict *with certainty* that the 'next photon' will arrive at a bright band? If not, what can you say instead?

We can summarize the evidence by saying:

Light consists of bundles or quanta of energy, called photons, which can be changed into other forms of energy only one at a time; we cannot exchange half a quantum. On the other hand, the photons of light are directed and guided just as if light consisted of waves.

We might think of an English bank that will exchange a French 10-franc note for shillings but will not accept anything smaller. Effectively, therefore, the smallest 'quantum' of French money that exists is 10 francs' worth. Then we think of an English town with a large number of such banks in different places, and also of a large number of people with 10-franc notes. For various reasons people go, or are guided to, various banks. Some banks exchange many notes, and these banks become bright and prosperous. Very few people go to other banks, and these are dull and dingy. Not an exact analogy! but a little like the photons and the waves. Perhaps you can think up something better.

252 *Introduction.* In 1924 a French physicist, Louis de Broglie, made an astounding suggestion. If light was to be thought of as particles guided and directed by waves, then why should not 'wave-particle duality' also apply to matter itself? This idea was not put forward merely as a 'long-shot' of a guess, a sort of outsider that might by a long stretch of imagination come home first; de Broglie gave good mathematical reasons for the idea. His suggestion has been tested for electron beams, and also for streams of protons, atoms and neutrons, and in every case the moving particles are directed as if they were waves, or to put it another way 'the waves tell us where we are most likely to find the particles'. Figure 252 illustrates a kind of 'Young's slits' interference experiment that showed an interference pattern produced by an electron beam.

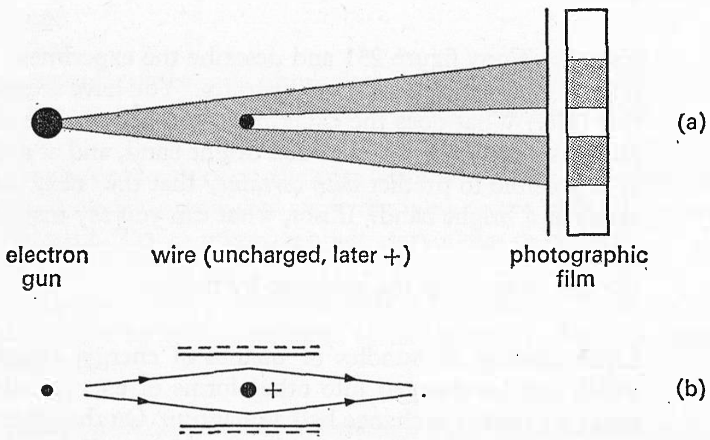


Figure 252
interference of electron beams. (Note, the interference pattern is very small, and has to be magnified by 'electron microscope lenses'.)

Question. Draw another diagram, like figure 252 (*a*), but showing what happens to the electron beam when the vertical wire is charged positively. Show the kind of blackening that now appears on the film. Figure 252 (*b*) shows the bending of the electron beam in the electric field between the wire (+) and two plates on either side of it.

You may never have heard about the experiment in figure 252, nevertheless you may be able to invent the answer to the question. In any case, you have seen the film called *Matter Waves* and can answer question 253.

253 Give a brief outline of the film *Matter Waves*, pointing out how it shows that a beam of photons and a beam of electrons each produce the same kind of interference pattern.

AND SO – AN END to all these questions. Perhaps a good place to stop, with a question mark: how can one thing be two different things, how can a wave motion also be particles and how can matter also be waves? It is easy – facile is the word – it is facile to answer 'more experiments discovering more facts leading to more theories and so to greater understanding'. But what is meant by 'understanding'? If we mean understanding in terms of what we already know about, not only the things of everyday life but also the principles of the physics we know – meaning Newton's laws, the attraction and repulsion of electric charges and all the rest – if we mean understanding in terms of these things, then we are likely to find that wave-particle duality, quantum phenomena, relativity (to mention only three) are altogether beyond understanding. Equally, however, Newton's laws of motion must have been beyond understanding to keen and active minds brought up in the tradition of Aristotelean physics. Yet *you* have taken these laws in your stride, and, without your knowing it, they have become part of your everyday common sense. For example, you are no longer surprised when you hear that a 'dead' space craft, with no motive power, continues to orbit the Earth time after time.

The same thing is probably happening to relativity and quantum theory; in the next generation after mine – which means in yours – what was astounding and inexplicable to me will become, to you, just what ought to have been expected, plain common sense. Let's end on that note: science is the complete opposite of magic; its study serves to extend the range of ideas we call common sense and to make common sense richer. So, above all, let's not be afraid of being scientists!

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

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Questions book III
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