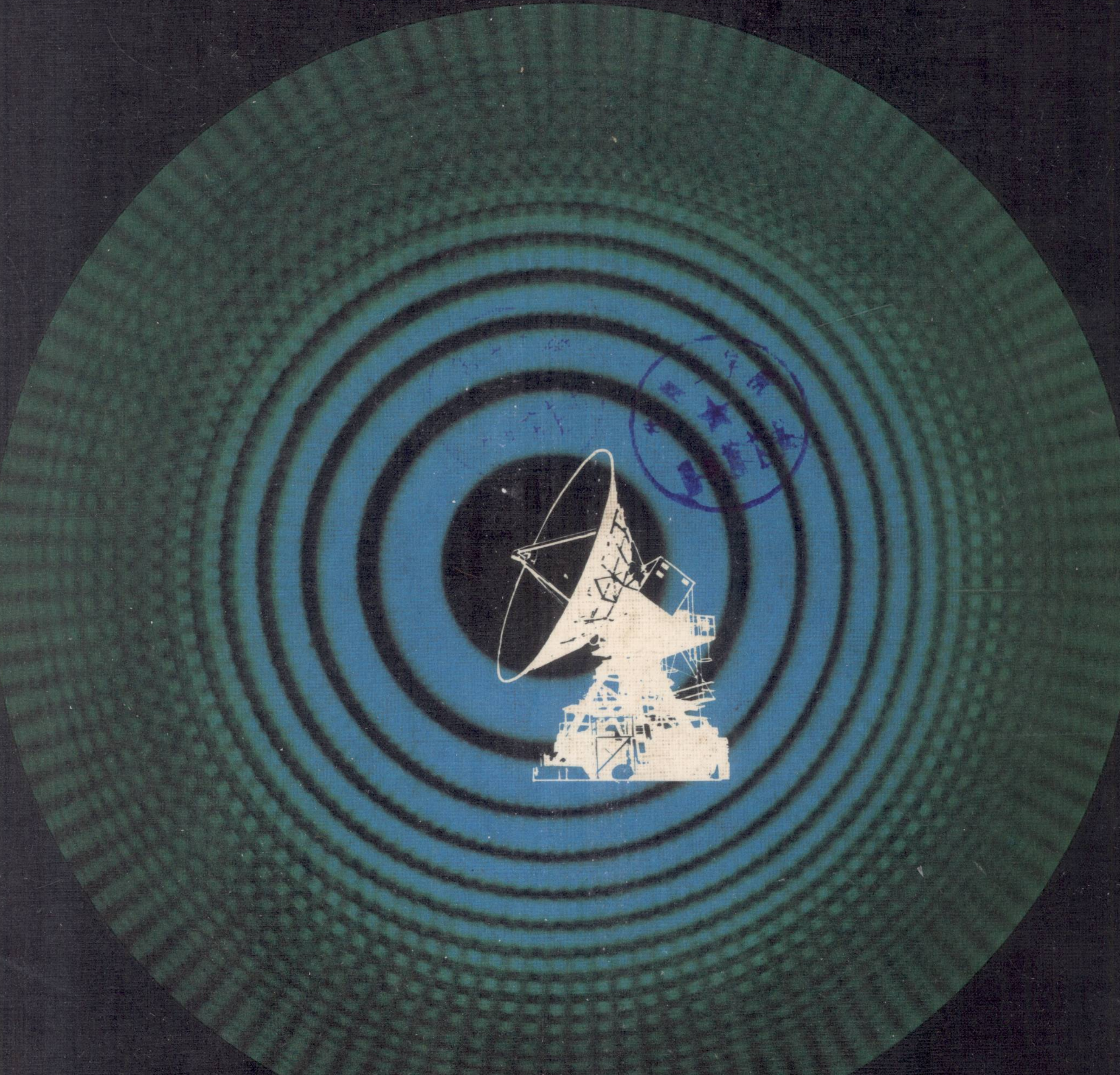
A NEW PHYSICS

D. BRYANT & D.G. KERSHAW



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Preface

Content

The main intention in writing this book has been to cover virtually all the material required by students and teachers in preparation for G.C.E. O-level physics examinations. However, it is known that schools often use one text book for ability ranges wider than that of this traditional academic pattern. To cater for this, the subject matter common to the majority of the Mode 1 C.S.E. examinations has also been included. The material is dealt with in a logical sequence – mechanics, heat, magnetism and electricity, atomic and nuclear physics, waves, geometrical optics – though not all teachers will wish to keep to this order. Many cross references are made in the text to enable different sections to be linked together and to underline the basic unity of the subject. A Revision Index has been included, in addition to the Main Index, which enables the student to easily locate definitions of units, statements of laws and principles, important formulae and equations, and important experiments.

Units

Metric units are taken for granted nowadays and this book follows the mainstream of physics teaching by developing its arguments in MKS units and following the recommendations of the A.S.E. A pedantic adherence to S.I. practice is avoided, however, by allowing the centimetre, the litre and certain derived units to appear where their sizes are convenient. (An Appendix, explaining the S.I. system, has been included.) In addition, italics are used for all symbols – whether they represent a physical quantity (magnitude *and* unit) or merely the numerical size of a quantity (for instance, in worked examples). This is done to overcome the confusion between symbols and units when both are printed in roman type. The illustrations and circuit diagrams have been drawn using symbols which conform with BS3939 and current standard practice.

Questions

At the end of each chapter there is a check list of items under the heading 'Do You Know?', intended as an aid for students' revision. Taken together these items represent the material with which a well-prepared student should become familiar before undertaking public examinations. In addition, there are descriptive and numerical problems of the types commonly found in G.C.E. and C.S.E. examination papers. It is the authors' experience, however, that the numerical parts of such questions are the most useful to teachers. We have therefore omitted the repetitive parts of questions in many cases (e.g. 'Define specific latent heat'), retaining only sufficient of them for each chapter to show what a full question contains. Where a question has been reproduced with permission from one of the Boards the fact is acknowledged by the following code:

G.C.E. Boards	AEB	Associated Examining Board
	C	University of Cambridge Local Examinations Syndicate
	JMB	Joint Matriculation Board
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	O	Oxford Delegacy of Local Examinations
	OC	Oxford and Cambridge Schools Examinations Board
	S	Southern Universities Joint Board
	W	Welsh Joint Education Committee
C.S.E. Boards	AL	Associated Lancashire Schools Examining Board
	EA	East Anglian Examinations Board
	EM	East Midlands Regional Examinations Board
	NW	North West Regional Examining Board
	SE	South East Regional Examinations Board
	WJ	Welsh Joint Education Committee
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Acknowledgements

Many industrial and commercial concerns have kindly supplied photographs for use in this book, and to them the authors are glad to record thanks: the source of each photograph is shown in the text. Many Examination Boards have given permission for their questions from recent papers to be quoted, and users of the book will, we are sure, be grateful for their cooperation: the authors certainly feel greatly in their debt. Individuals to whom indebtedness is generously acknowledged include Ian Taylor for several photographs taken personally and without profit, Noreen Bryant for many hours of painstaking typing, and both our wives for enduring seemingly endless periods of isolation from their husbands during the various stages in the preparation of the book. Special mention must be made of Roger Stone's contribution: he has exerted a moderating yet encouraging influence on our wilder ideas and has given advice and guidance at all times, but especially on the problem of unifying the approaches and styles of two very different writers.

D.B.
D.G.K.

Contents

1 The Aims of Physics

1.1. What is Physics?

Once upon a time there were *natural philosophers.* They were inquisitive men who kept asking themselves why things happened and kept trying to produce general theories which would explain parts of nature. The more they investigated the more they found out and although they were able to devise single theories which drew together many seemingly disconnected facts, the volume of knowledge grew and grew until it became convenient to think of subdivisions within Science. *Physics* is the name of one of these subdivisions and is largely concerned with fundamental ideas which are used by other branches of Science. An appreciation of the meaning of energy, for example, is essential to any scientist and the kinetic theory of matter is the basis of atomic chemistry. Another vital topic is that of waves, whilst the behaviour of electrons is important not only to the electronic engineer but to the chemist also. The physicist, however, is not content to provide a qualitative background of understanding. It is an article of his faith that there is a simple relationship between different quantities in nature and, be it the relationship between the pressure and volume of a gas or the depth of penetration and energy of gamma rays, he seeks, after completing his experimental work, to express these relationships as precisely and accurately as possible, which generally means in the form of a mathematical expression.

1.2 The Logic of Physics

The layout of most physics books is a logical one and this book is no exception. One proceeds, for example, from an understanding of velocity to an appreciation of acceleration and thence to force. Such a logical development of the subject is pleasing to most physicists, but it would be a mistake to think that physics had evolved in this way, or that it was necessarily the best way of learning about physics. There are several equally valid 'logical' routes through a physics course and many teachers will prefer to present material in an order different from that given in this book. Historically, however, the study of physics has developed in fits and starts and often a breakthrough in one branch of the subject has been dependent on a development in another. Work on radio communication depended on the discovery of the electron which, in turn, depended not only on the discovery and measurement of electrical and magnetic fields, but also on Geissler's invention of a mercury pump, which enabled the conduction of gases at very low pressure to be studied. It is an interesting exercise to imagine yourself transported back through 300 years with all the scientific knowledge that you now have. How rapidly you would rise to fame. . . . or would you? So many of the things with which you would want to impress people would be impossible, for you wouldn't be able to produce the necessary apparatus.

In spite of this haphazard development there is an underlying pattern in the methods used by the physicist when he is investigating a new discovery, as is well illustrated in the work of Röntgen and his discovery of X-rays. The discovery itself was made whilst searching for evidence of "aether waves" emitted from a low pressure discharge tube. Röntgen had already covered his tube with black cardboard to absorb any visible radiation when he noticed fluorescence on a piece of paper covered with barium platinocyanide placed some distance from his apparatus. It is a mark of Röntgen's ability that he did not disregard this chance observation, but managed to grasp its true significance in recognising it as being the first evidence of a new type of radiation, whose properties he then set out to investigate. Did it travel in straight lines? Could it pass through paper? Was it a stream of charged particles? How was its production influenced by changes to the discharge tube? It was these questions and many more which Röntgen sought to answer. The way in which he painstakingly checked every facet of these unknown or "X"-rays is an object lesson in thoroughness. Seven weeks after his initial discovery he presented the results of his work to the President of the Physical Medical Society of Würzburg: of his deductions about the rays very few have not stood the test of time.

1.3 Measurement in Physics

Whether discoveries are made by chance or as part of a systematic plan, the analysis of the discoveries will always involve detailed and careful measurements. This does not mean doing all the weighings to five significant figures when the rest of the experiment is accurate only to 1%, but it does mean getting the best out of an experiment. Indeed it was such careful observation which lead to the discovery of isotopes because of small unexplainable 'errors' in the readings. Joule's critics in the 1850s condemned his work on the grounds that he had "nothing but hundredths of a degree Fahrenheit to prove his case by". They underestimated his superb experimental skill.

1.4 The Use of Physics

When all the measurements have been done and the theories have been vindicated by experimental tests – what then? For some it is the end of the road; another chapter has been temporarily closed, and they will turn their attention towards another investigation. For others, however, this is only the beginning, for they will want to develop some of the ideas within the field of technology. This is the so-called 'spin-off' of research and many physicists find great satisfaction working in this field. As research develops, so new ideas come to light and further applications become possible. Perhaps you will think of a new idea as you read this book, for it is often the person who comes fresh to a subject who sees exciting and unthought-of possibilities. Some years ago small magnets were little more than toys, but now we find them used increasingly in a wide variety of applications. Even the electric motor, with its far-reaching industrial and social consequences, was first produced as a toy to demonstrate an aspect of physics!

1.5 The Aims of Physics

These, then, are the aims of physics:

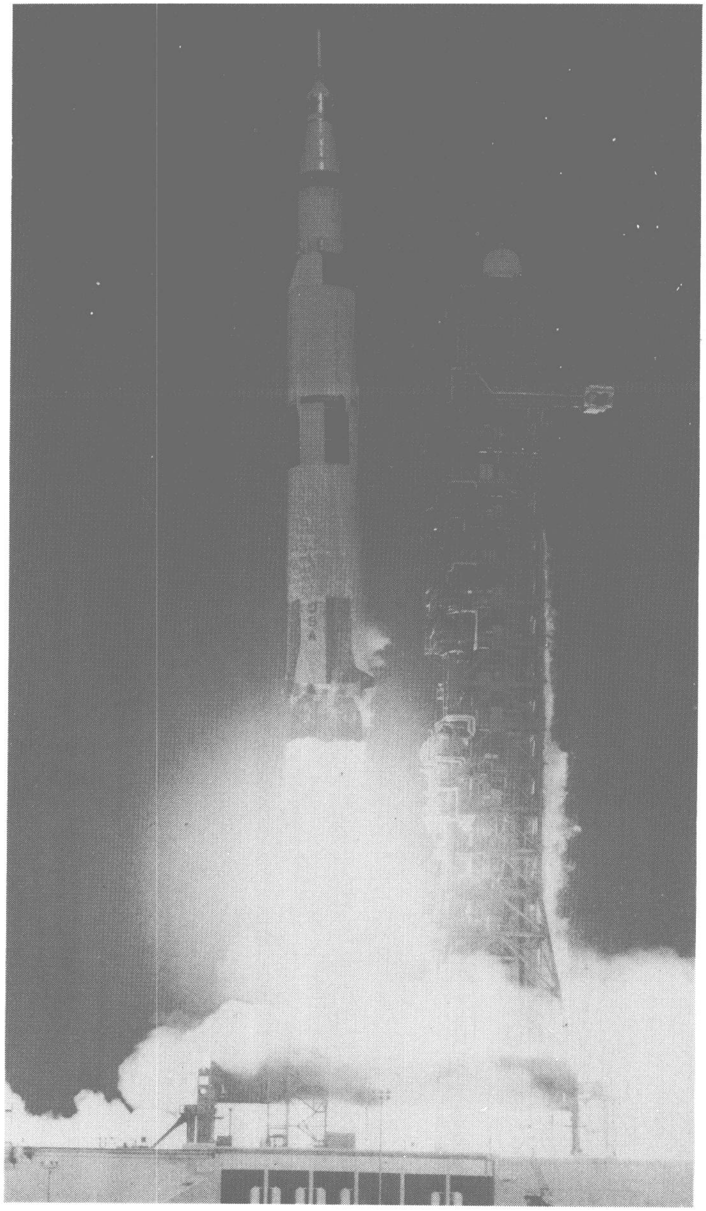
1 To produce theories in terms of which the behaviour of objects in the physical world can be described.

2 To check these theories for inconsistencies by means of experiments.

3 To make predictions from the theories about matters not yet investigated, as a means of guidance for future research.

4 To discover new ways of using the physical knowledge we have, not only to provide useful applications but also to pave the way for even more fruitful investigations.

UNIT 1
Bodies in Motion



The launch of Apollo 14

2 Bodies in Motion

2.1 Vectors and Scalars

Directions that buried treasure is to be found 15 m from a certain tree are not very useful unless the direction is also stated. Saying that it is 15 m from the tree in a direction NE completely specifies the position and we say that the treasure's *displacement* is 15 m NE. Displacement is the name given to a combination of distance and direction and is an example of a vector.

Vectors are quantities having magnitude and direction.

Many quantities (e.g. volume) can have no direction associated with them.

Scalars are quantities having magnitude only.

Whereas the addition of scalars follows the normal rules of arithmetic the addition of vectors must involve consideration of direction.

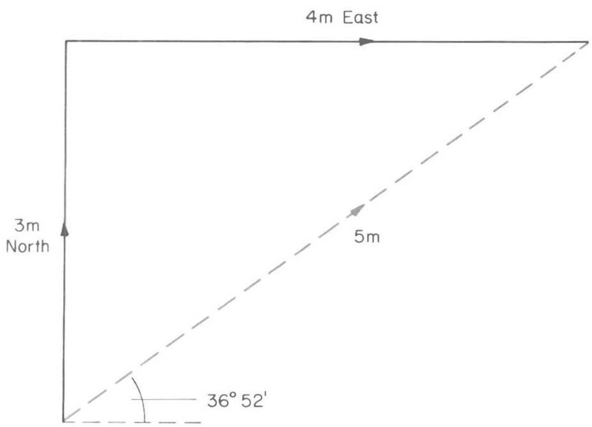


Figure 2.1 Adding displacements
The most straightforward method is to use a scale diagram.

2.2 Adding Displacements

The easiest method is to use a scale diagram, but a sketch diagram with a little elementary trigonometry is more accurate.

EXAMPLE

A man moves 3 m N and then 4 m E. Find the final displacement.

The solution is shown in Fig. 2.1 and is self explanatory. The final displacement is 5 m in a direction 36° 53′ N of E.

The same solution would have applied if it had been a crane moving 4 m due E whilst its carrier frame moved 3 m due N. The fact that the crane is moving in two directions at the same time makes no difference to the result. Nor would it matter if the two movements were not at right angles, although movement at right angles is more usual in engineering applications and is much more convenient to handle using Pythagoras's theorem.

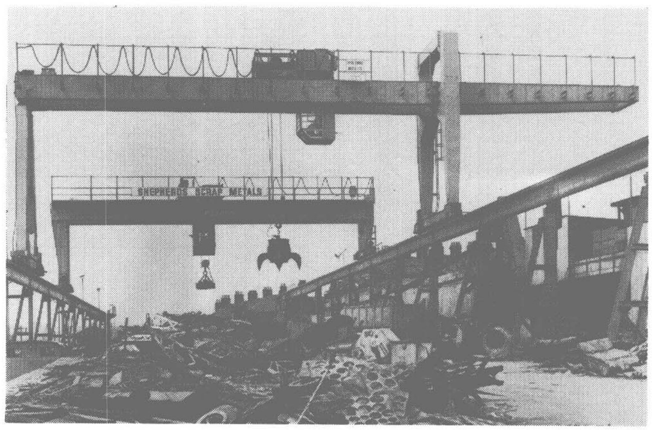


Figure 2.2
Moving the crane to a required spot by combining movements both parallel and perpendicular to the side rails is an example of vector addition. (Clyde, Crane and Booth Ltd.)

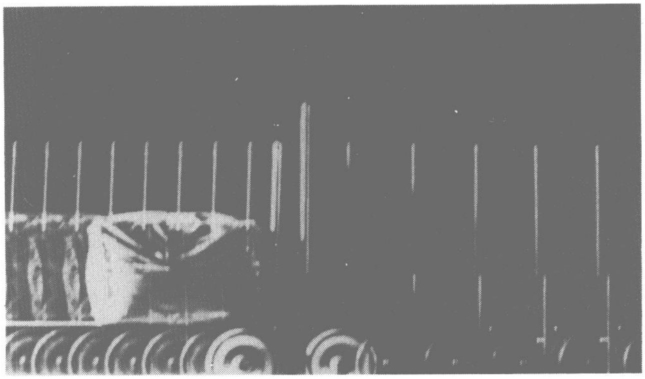


Figure 2.3 This multiflash photograph shows successive pictures of two trolleys which have been in contact with a compressed spring between them
When the spring is suddenly released the trolleys move apart, and the distance between successive pictures of the white sticks on the trolleys enables their relative speeds to be found. In this case the distances for the right-hand trolley are approximately twice those for the left-hand trolley, showing that it is moving at twice the speed. Since the mass of the left-hand trolley has been made twice that of the other trolley, by adding a sand bag, this result is in accordance with the Conservation of Momentum (Sec. 4.4). To obtain absolute measurements of the speeds we would need to know both the time lapse between the exposures, and the scale of the photograph. (Kodansha Ltd.)

2.3 Average Speed

If a boy runs 2 km in 10 minutes his average speed is 2 ÷ 10 or 0.2 km/min. The word *average* is important, for it is unlikely that he maintains the same speed the whole time.

$$\textbf{Average Speed} = \frac{\textbf{Total distance travelled}}{\textbf{Time taken}}$$

The progress of an object can be studied by means of multiflash photography or with a ticker-tape timer. Multiflash or stroboscopic photography uses a source of light which flashes on and off at a very high rate. The result is a series of exposures showing the position of the object at different times all on the same photograph (see Fig. 2.3). The ticker-tape timer is a cheaper device and stamps a piece of carbon paper every 1/100th or 1/50th second. If a piece of ticker-tape is drawn through the timer, a series of dots appears on the tape, each dot having been made 1/100th second after the previous one. Measurement of the distance between the dots enables the average speed of the tape to be found.

Figs. 2.4(a) and 2.4(b) show ticker tapes which illustrate the movement of two objects. Fig. 2.4(a) represents a speed which remains steady. The average speed is the same whether we calculate it between dot 2 and dot 3, or between dots 6 and 7.

$$\text{Average speed between dots 2 and 3} = 1{\cdot}4 \div \tfrac{1}{100}\ \text{cm/s}$$
$$= 140\ \text{cm/s}$$
$$\text{Average speed between dots 6 and 7} = 1{\cdot}4 \div \tfrac{1}{100}\ \text{cm/s}$$
$$= 140\ \text{cm/s}$$

Fig. 2.4(b) represents accelerated motion. In this case the speed is increasing and there is no reason to suppose that the average speed is the speed at the half-way mark.

Time (1/100th sec)		1	2	3	4	5	6	7	8	9	10
Distance from start (cm)	Fig. 2.4(a)	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6	14.0
	Fig. 2.4(b)	0.15	0.65	1.45	2.55	4.00	5.75	7.50	10.25	12.95	16.00

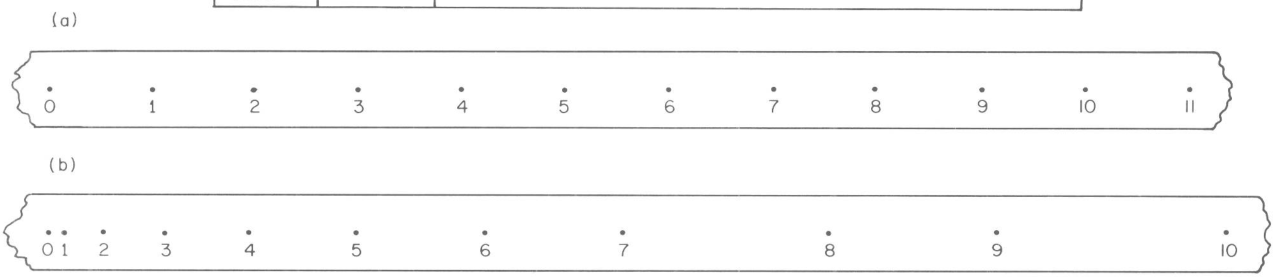


Figure 2.4 Typical results from a ticker tape experiment
Which tape represents the uniform velocity, and which the accelerated one?

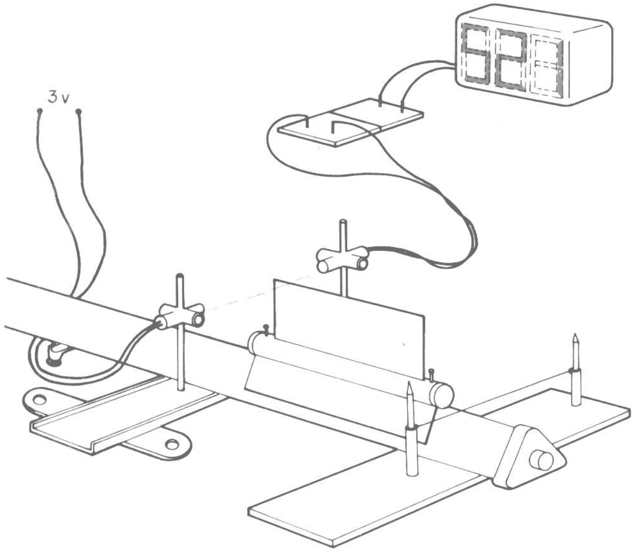


Figure 2.5 Measuring velocity by photo-timing
When the card breaks the beam of light the digital clock begins to operate, stopping only when the beam is restored. Since the clock can record to ± 0.000 01 s it is possible to measure an average velocity over a very short distance indeed.

2.4 Instantaneous Speed

In measuring the 'instantaneous' speed we usually measure the average speed over a distance which is so small that any change is negligible. This can be done very accurately with a photodiode and a suitable timer – Fig. 2.5. When light stops falling on the photodiode the timer begins to operate. It stops when the light is again restored. By this means the transit time of a small piece of card can be found and hence the average speed of the card calculated.

e.g.	Width of card	= 2.0 cm
	Time taken	= 0.0011 s
Hence,	Average speed over 1 millisecond	= 2 ÷ 0.0011 cm/s
		= 1800 cm/s

Unless the speed is changing very rapidly this may be taken as the instantaneous speed. Alternatively the value can be found from a distance : time graph.

2.5 Distance : Time Graphs

Graphs may be drawn showing the position of an object at different times; the information for Figs. 2.6(a) and 2.6(b) comes from Figs. 2.4(a) and 2.4(b). In Fig. 2.6(a) the ratio a/b is the same as c/d. The value is the same whichever points are taken. It is the gradient of the graph and represents the speed. In Fig. 2.6(b) we can think of the curve as made up of many tiny straight lines, each with a slightly different gradient or slope. The slope of the tiny bit of curve at X can be found from the line XY, which is the tangent to the curve at X. From this line we find that the object is increasing its distance from the start at 160 cm/s. Had it been possible to measure the tiny section of the curve it might have been 0.000 16 cm in 0.000 001 s but such measurements are not, of course, practicable.

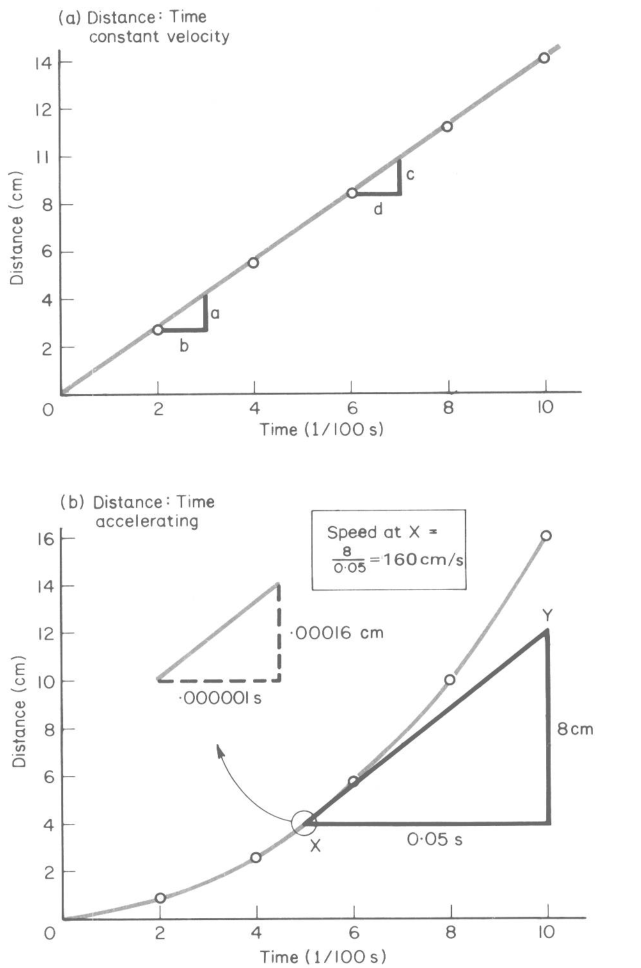


Figure 2.6 Distance : Time graph for uniform and accelerated motion
In both cases the distance travelled is represented by the area under the graph.

To find the speed at a given point find the gradient of the distance : time graph at that point.

2.6 Speed and Velocity

Town A may have a displacement 50 km NE of town B, but the road distance between them may be 60 km. This latter distance takes into account all the twists in the road, but it would be useless as a map reference. It is a scalar, whereas displacement is a vector. The *velocity* of an object is the rate at which its *displacement* is changing and is also a vector quantity. A car going round a bend may have a steady speed but, because its direction is changing, it has a changing velocity. Since velocity is a vector (it has magnitude and direction) the rules for adding velocities are those of vector addition (Sec. 2.12). It is unfortunate that the word "velocity" is often used when "speed" would have been more appropriate.

2.7 Acceleration

$$\text{Acceleration} = \frac{\text{Change of Velocity}}{\text{Time taken}}$$

$$= \frac{\text{Final velocity} - \text{Initial Velocity}}{\text{Time taken}}$$

The table below represents the velocity of a car at different times.

Velocity (km/hr)	0	9	18	27	32
Time (seconds)	0	5	10	15	20

In the interval from 5s to 10s the average acceleration is

$$\frac{18-9}{10-5} = 1.8 \text{ km/hr per second.}$$

Up to 15 seconds the rate of increase is steady. We have *uniform acceleration.*

It is more useful for the unit of time in both the velocity and the time interval to be the same. A change of velocity from 8 m/s to 13 m/s in 2 s, for example, gives an acceleration of

$$\frac{13-8}{2} = 2.5 \text{ m/s per second.}$$

The standard way of writing this is 2.5 m/s^2

N.B. A negative acceleration is a retardation or slowing down.

EXAMPLE

The velocity of a car is retarded from 10 m/s to 4 m/s in 2 s. What is its acceleration?

$$\text{Acceleration} = \frac{\text{Final Velocity} - \text{Initial Velocity}}{\text{Time taken}}$$

$$= \frac{4-10}{2} \text{ m/s}^2$$

$$= -3 \text{ m/s}^2$$

Figure 2.7 The Advanced Passenger Train (APT)
This train is capable of building up to a speed of 240 km/hr (150 mph) in 7½ minutes. A speed of 100 km/hr is achieved after only one minute. (British Rail)

2.8 Formulae for uniformly accelerated motion

Let x be the distance from the start,
t the time taken,
u the initial velocity,
v the final velocity
and a the acceleration.

From the definition of acceleration

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

or

$$\boxed{v = u + at}$$

Since we have uniform acceleration,

$$\text{average velocity} = \frac{v+u}{2}$$

and the total distance travelled is given by

distance travelled = average velocity × time taken

$$\therefore \boxed{x = \frac{v+u}{2} \times t}$$

Substituting for v in this equation we get

$$\boxed{x = ut + \tfrac{1}{2}at^2}$$

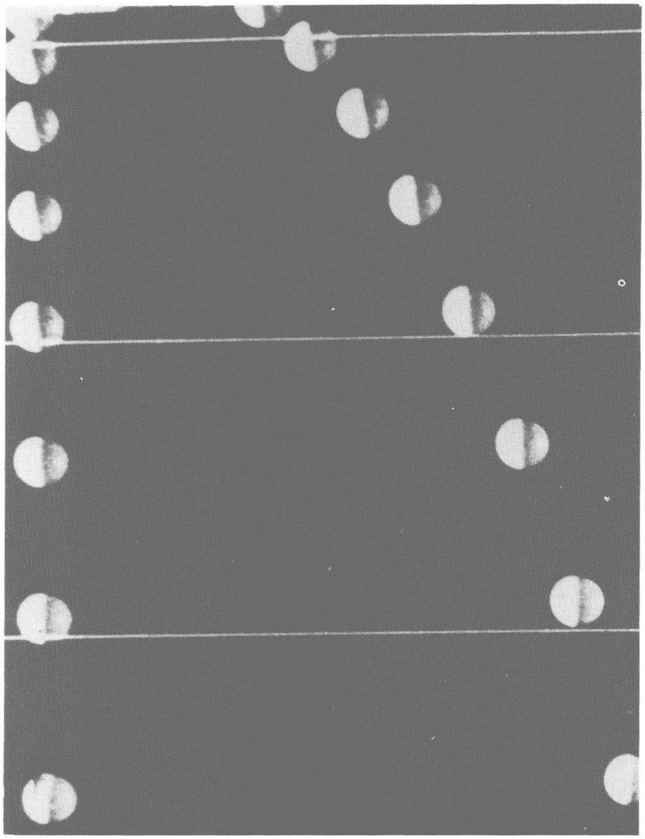


Figure 2.8
The two balls in this multiflash photograph were released at the same time, the right-hand one having been given a horizontal velocity. It is seen that the vertical movement of each is identical, both covering the same vertical distance in the same time. Gravitational acceleration is not affected by horizontal movement. (Kadansha Ltd.)

Substituting for u gives

$$x = vt - \tfrac{1}{2}at^2$$

Substituting for t gives

$$2ax = v^2 - u^2$$

Although confined to uniform acceleration these formulae are very important, because objects under the influence of gravity accelerate uniformly, Indeed a special symbol g is usually given to the acceleration due to gravity.

EXAMPLE 1

An object is dropped into a well and hits the water 2 s after being released. How deep is the well? Take g as 10 m/s^2.

Let the depth of the well be x m.

We know that $t = 2$ s, $u = 0, a = 10$ m/s^2.

The formula we require is $x = ut + \frac{1}{2}at^2$

$$\therefore \quad x = (0 \times 2) + (\tfrac{1}{2} \times 10 \times 2^2)$$
$$= 20$$

The well is 20 m deep.

EXAMPLE 2

A ball is thrown vertically into the air at 50 m/s. How high will it rise, and how long will it take to reach that height? Take g as 10 m/s^2.

After being released the ball slows down until, at the top of its flight, it is stationary.
Let the height reached be x m and the time taken be t s.
We know that $u = 50$ m/s^2, $v = 0$, $a = -10$ m/s^2.

The formula we require is $v - u^2 = 2ax$

$$\therefore \quad 0 - 50^2 = 2 \times (-10) \times x$$
$$\therefore \quad x = 125$$

The height reached is 125 m.

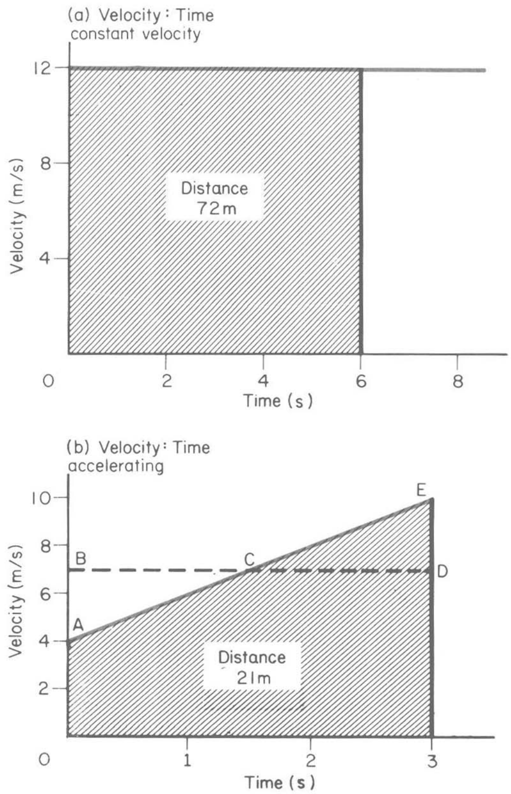


Figure 2.9 Velocity: Time graphs for uniform and accelerated motion
The results for these graphs come from the ticker tape of Fig. 2.4.

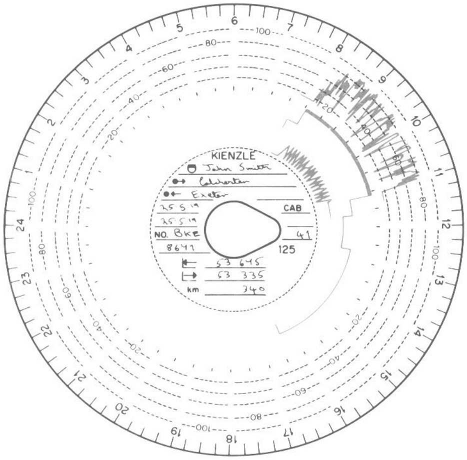


Figure 2.10 The Tachograph

Under E.E.C. regulations many vehicles need to carry a tachograph, which produces an automatic velocity-time graph. The circular chart is rotated, and is marked by three styli. The innermost one oscillates every 10 km, thus recording the distance travelled, whilst the middle one shows whether or not the vehicle is moving. The outer line records speed changes. Could this line also be used to calculate the total distance travelled?

To find the time taken use $v = u + at$

$$\therefore \; 0 = 50 - (10 \times t)$$

$$\therefore \; t = 5$$

The time taken is 5 s.

2.9 Velocity : Time Graphs

If the velocity of a body is found at different times it is frequently useful to plot these on a graph. Fig. 2.9(a) shows the simplest graph, which represents constant velocity.

Total distance travelled is velocity × time, which is represented by the area under the line (shown shaded). The units used, of course, are those of the axes.

If $v = 12$ m/s and $t = 6$ s then the 'area' represents

$$6 \text{ s} \times 12 \text{ m/s} = 72 \text{ m}.$$

Uniform acceleration is shown in Fig. 2.9(b) and the *gradient* gives the value of the acceleration. The distance travelled is given by $\left(\frac{u+v}{2}\right)t$ which, in this case, is $\left(\frac{4+10}{2}\right) \times 3$ or 21 m. For an object travelling at a steady speed of 7 m/s this distance would be represented by the area under the graph and, since triangle ABC has the same area as triangle CDE, we find that the area under the line AE also represents the total distance travelled. This rule applies equally, even to situations in which the acceleration is not uniform.

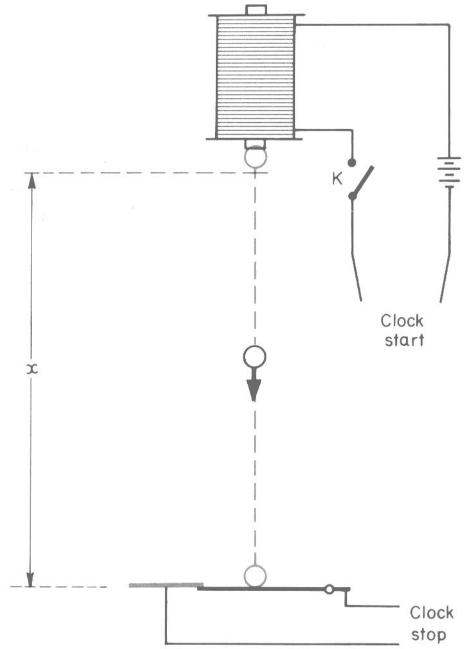


Figure 2.11 Apparatus for the measurement of g

The area under the velocity: time graph represents the distance travelled.

2.10 Measurement of g

Although the most accurate determinations of g are made by indirect methods a simple method using a special timer can be used as in Fig. 2.11. When the switch K is opened it cuts off the current to the electromagnet and simultaneously starts the timer. The ball-bearing is then released* and accelerates steadily until it strikes the gate at the bottom. The impact opens the gate which breaks the circuit to the timer and stops it, thus recording the transit time of the ball-bearing. The distance x is now measured with a metre rule.

*In practice it is sometimes found that the electromagnet does not release the ball-bearing immediately, due to residual magnetism. It is best to have the ball only just held by the electromagnet at the start.