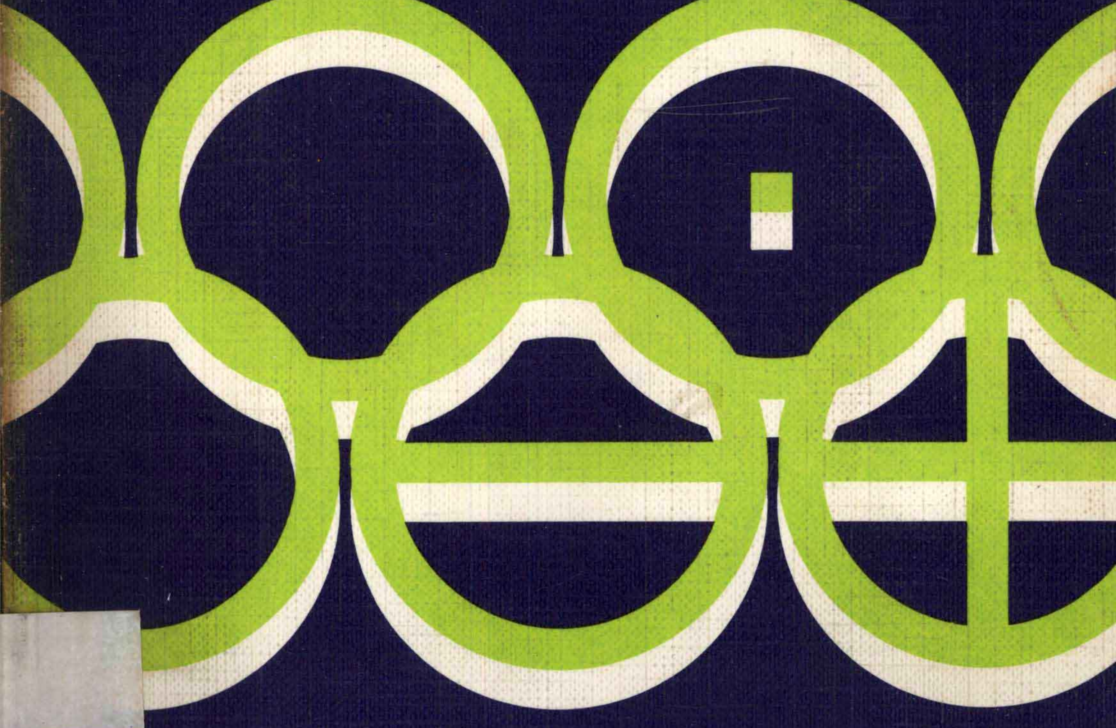
Physical Science for Technicians

W. Bolton



First Level Unit

Physical science for technicians

A first level unit

W. Bolton
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Physical science for technicians
A first level unit

By the same author
Patterns in Physics

Introduction

This book has been designed to meet the needs of technicians studying a first level Physical Science unit in programmes leading to the certificate and diploma awards of the Technician Education Council. The objectives listed in the Technician Education Council Physical Science unit TEC U75/004 are covered. In fact, the book covers more than the objectives in that unit, and so might be appropriate for many first level units of a similar form.

The following is a list of the general objectives that the book is designed to cover; the references in brackets alongside the objectives refer to the related general objective references in the unit TEC U75/004. General objectives, within the form adopted by the Technician Education Council, give the main teaching goals. The specific objectives are not given here, these being the means by which the student demonstrates his attainment of the general objectives. All the objectives below should be considered to be prefixed by words such as 'The expected learning outcome is that the student...'.

Chapter 1

1. Describes the relationship between mass and volume for a substance, and defines the term density (A1).
2. Recognizes in words, graphs, and equations, what is meant by the term 'proportional to'.
3. Describes the effect of forces on materials (A2).
4. Describes the structure of matter in terms of atomic building blocks (A3).
5. Distinguishes between compounds and mixtures, compounds and elements (A3).
6. Uses SI units and the common multiples and submultiples of those units (D10).

Chapter 2

7. Solves problems involving forces in static equilibrium situations (F16).

Chapter 3

8. Solves straight line motion problems involving uniform speed or uniform acceleration (E14).
9. Recognizes an acceleration as being the result of a net force (E14).

10. Describes energy and its transformations (B4).
11. Describes and calculates frictional forces between two surfaces in contact (E15).

Chapter 4

12. Defines pressure and calculates pressures in static fluids (F17).
13. Explains and measures atmospheric pressure (F17).

Chapter 5

14. Measures temperature (B5).
15. Defines and solves problems involving specific heat capacity (B6).
16. Describes changes of state and solves problems involving specific latent heats (B6).
17. Describes the effects of heat (B8).
18. Describes the transfer of heat (B7).

Chapter 6

19. Assembles simple series and parallel circuits and solves problems involving V, I, and R (D10).
20. Defines resistivity and solves problems involving resistivity (I22).
21. Describes the effects of currents (F11).
22. Defines power and solves electrical problems involving power (F12).
23. Describes the concepts of e.m.f. and internal resistance (I23).
24. Describes the magnetic field concept and the relationships between magnetic fields and electric currents (F13).
25. Describes the production of charge by friction.

Chapter 7

26. Describes waves and their properties of reflection and refraction (C9).
27. Describes the basic properties of sound (C9).
28. Describes the basic properties of light (H21).

Chapter 8

29. Describes oxidation (G18).
30. Describes and explains the conduction of electricity through solutions (G19).
31. Describes the production of electricity from chemical reactions (G19).
32. Distinguishes between acids and alkalis (G20).
33. Explains the concept of a chemical equation (G20).

W. BOLTON
1976

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Introduction

1 Materials

2 Structures

3 Forces and motion

4 Fluids

5 Heat

6 Electricity

7 Waves

8 Chemical reactions

1. Materials

1.1 The diversity of materials

Look around you at the different materials used. The window frames might be wood or metal; the walls might be brick or reinforced concrete; there are probably some plastics items. The material chosen for a particular item will depend on what job that item is to do. What is the best material for carrying electricity? What is the best material for the bodywork of a car? Over the years new materials have been developed, and what might have been the best material at one particular time might not be the best available at some later time. What are the properties which enable us to decide the 'best' for some particular purpose?

This chapter looks at some of the properties of materials which can enable us to make some of the decisions towards deciding the 'best'; later chapters will give yet more information about the properties.

Without working through this chapter, you might like to consider what you feel are the reasons for car bodies being predominantly made of steel. Why steel? Why not wood? Why not a plastics material? Steel first started being used for car bodies in the year 1912; the first glass-reinforced plastics saloon car body was produced in 1953. What do you think will be the material used for car bodies in the year 2000? This assumes that we will still have cars in that year. At the end of this chapter, and at later stages in your course, you might like to consider how your answers to these questions will change.

1.2 Density and mass

If you pick up a one centimetre cube of wood and then a one centimetre cube of iron you can easily tell the difference—the iron is heavier than the wood. Though the two blocks have the same volume they have different masses. We say that iron is denser than wood. The amount of mass per unit volume is called the density.

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

The volume of a cube is the side length cubed, i.e., length × length × length, so that a cube with sides of length 1 centimetre (cm) has a volume of 1 cubic centimetre (cm^3). The block of wood might have a mass of 0·7 grammes and so the density would be 0·7 grammes per cm^3. The iron block might have a mass of 7·9 grammes and so would have a density of 7·9 grammes per cm^3. The iron has a higher density than the wood. The density of the iron is more than ten times that of the wood, and so, for identical volumes of iron and wood, the iron block will have a mass more than ten times that of the wooden block.

Suppose we have, in one hand, a 1 cm cube of wood and, in the other hand, another cube of wood but this time the sides of the cube have lengths of 2 cm instead of the 1 cm. Which block would be the heavier? The obvious answer is the bigger block. But how much heavier? The volume of a cube with sides of length 2 cm is $2 \times 2 \times 2 = 8$ cm^3. If you used a balance to measure the mass of this bigger cube, the result obtained would be about 5·6 g. The following table gives the results of an experiment in which different blocks of wood had their volumes determined from measurements of the lengths of their sides, and their masses measured using a balance.

Mass in grammes	0	0·7	5·6	18·9
Volume in cm^3	0	1	8	27

The greater the volume of a cube the greater the mass. If the volume is increased by a factor of eight, i.e., from 1 cm^3 to 8 cm^3, then the mass increases from 0·7 grammes to 5·6 grammes. But $8 \times 0{\cdot}7 = 5{\cdot}6$. Increasing the volume by a factor of eight has increased the mass by a factor of eight.

If the volume is increased by a factor of 27, i.e., from 1 cm^3 to 27 cm^3, then the mass increases from 0·7 grammes to 18·9 grammes. But $27 \times 0{\cdot}7 = 18{\cdot}9$. Increasing the volume by a factor of twenty-seven has increased the mass by a factor of twenty-seven.

We say that the mass is *proportional to* the volume. This can be written as

$$\text{mass} \propto \text{volume}$$

$\propto$ is the sign used to mean ‘proportional to’. The mass being proportional to the volume means that if we have double the volume we must have double the mass. If we have treble the volume we must have treble the mass. By whatever factor we increase the volume we must increase the mass by the same factor. Mass thus seems to be the term applied to indicate the ‘quantity of matter’ in a body. The bigger the body the greater the quantity of matter present and so the greater the mass.

You might in the laboratory have measured the mass of an object by using a balance. This could have the form of what is essentially a beam pivoted at its centre; Fig. 1.1. The unknown mass is suspended from one end of the beam and, at the other end, an equal distance from the pivot point, calibrated masses are placed. When the pivoted beam resumes its initial horizontal position it is assumed that the object has a mass equal to the known mass at the other end of the beam.

The units of mass are grammes. A kilogramme is a thousand grammes. Instead of writing out the word grammes in full every time the unit is written the abbreviation g is used. Thus 20 grammes would be written as 20 g. The abbreviation for kilogrammes is kg. Thus 4 kilogrammes is written as 4 kg.

A beam balance, like that shown in Fig. 1.1, or a spring balance, actually measures the gravitational forces acting on the masses. You can, however, accept as an experimental fact that the gravitational force is proportional to the mass. If a block of wood has twice the gravitational force of a '1 kg mass' then its mass will be twice that of '1 kg', i.e., it will have a mass of 2 kg.

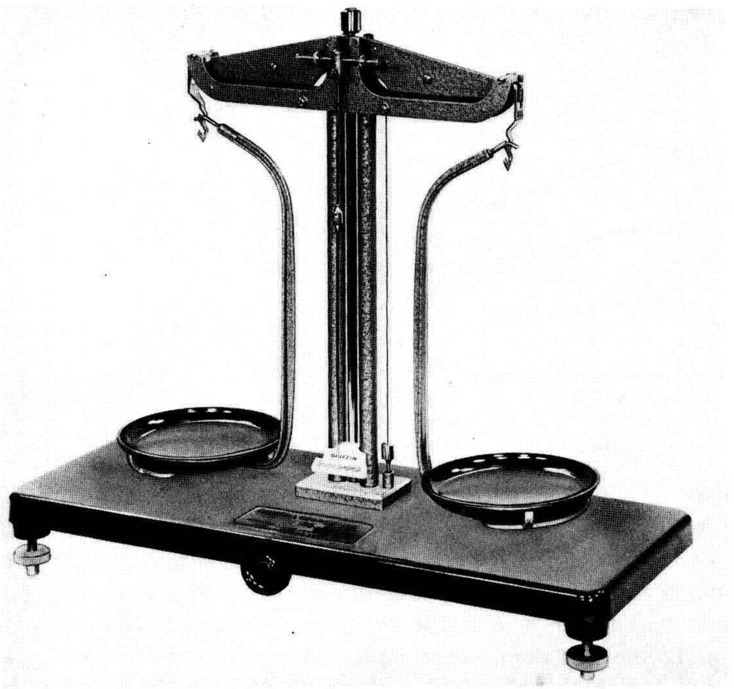

Fig. 1.1 A simple balance (courtesy Griffin and George Ltd)

1.3 Graphs

The following are data showing how the masses of blocks of the same wood are related to their volumes.

Mass in grammes	0	0·7	1·4	2·1	2·8
Volume in cm^3	0	1	2	3	4

The mass is directly proportional to the volume. If the volume is doubled the mass doubles.

There are many examples in science, and elsewhere, where changing one thing results in another thing changing. In this case, changing the volume changes the mass. There is a relationship between the one set of quantities and the other. With a volume of 1 cm^3 we link a mass of 0·7 g. With a volume of 2 cm^3 we link a mass of 1·4 g. Figure 1.2 shows the links between the two sets of data.

There is another way of showing the relationship between two sets of data, and that is by means of a graph. To find a point on a map it is convenient to refer, for example, to the distance the point is east of some origin and the distance it is north of the same origin; Fig. 1.3. These two distances, e.g., 3 km east and 5 km north, give what are called the coordinates of the point.

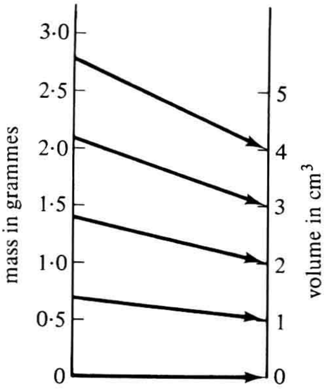

Fig. 1.2

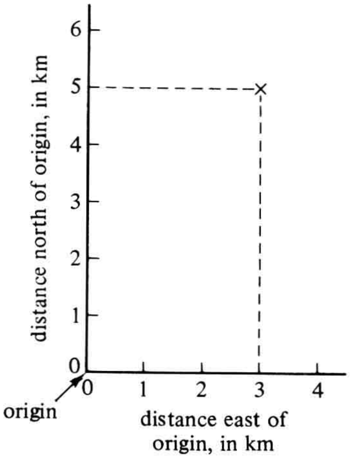

Fig. 1.3

The map has two reference lines, one running north–south and the other east–west. These are called axes. To find the point referred to, we need to move 3 km along the east–west axis in an easterly direction from the origin, and then north a distance of 5 km. In the case of our relationship between mass and volume we would represent the axes as mass and volume scales; Fig. 1.4. To find the point representing the volume of 1 cm^3 and mass 0·7 g we would move, from the origin, a distance related to a volume of 1 cm^3 and then in a direction at right-angles a distance related to a mass of 0·7 g. The resulting position is then taken to represent 1 cm^3 volume having 0·7 g mass. The complete graph for the volume–mass data, given in Fig. 1.4, is a straight line passing through the origin. This is always the case where the two quantities are directly proportional.

1.4 Force

We might describe forces as pushes and pulls. If somebody pushes or pulls you, we can say they are applying forces to you. If you pull a spring between your hands we can say that your hands are applying forces to the ends of the spring. A spring balance measures forces. Spring balances are given scales: grammes, kilogrammes or perhaps newtons. Grammes and kilogrammes are units of mass. A spring balance measures the gravitational force acting on a mass, and because this force is directly proportional to the mass we tend to ignore the conversion factor and just calibrate the scale in terms of the mass. Thus when the balance indicates, say, 10 g it means that the balance is recording the force that a 10 g mass experiences when subject to gravitational forces, near the surface of the Earth. If we wish to record the results as a force it is convenient to call the force 10 g force, 10 gf. A spring balance recording say 2 kg is really recording the force on 2 kg due to gravity, i.e., 2 kgf. The unit of force is the newton (N). A force of one newton is approximately the gravitational force experienced by a 100 g mass at the surface of the Earth. Thus 1 N is about 100 gf. In a later chapter the reason for this conversion will be dealt with and the more exact factor considered. The newton is actually defined as the force required to give a mass of 1 kg an acceleration of 1 metre per second.

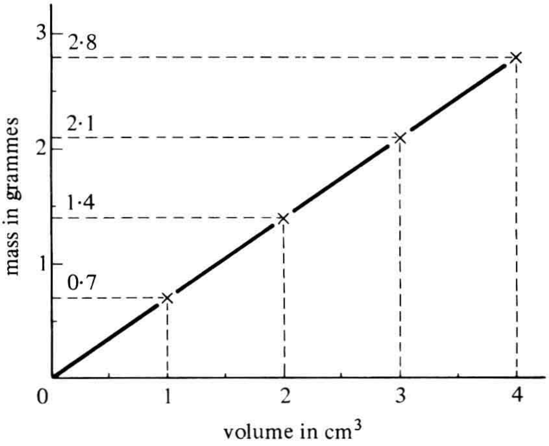

Fig. 1.4

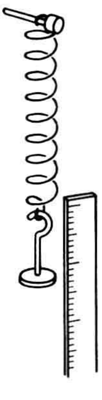

Fig. 1.5

1.5 Stretching and compressing

If you pull at the two ends of a strip of rubber it stretches; if you press a block of rubber between your fingers, an eraser for example, it becomes compressed. When the rubber stretches it increases in length, when it is compressed it becomes shorter. We talk of the rubber being under tension when it is stretched and under compression when compressed. We can stretch, or we can compress, many things: pieces of rubber, springs, blocks of concrete metal rods, blocks of wood, pieces of plastic, etc. A knowledge of the stretching and compressing properties of materials is relevant to an understanding of the behaviour of materials in use. Rubber stretches more easily than aluminium—what would it be like if aeroplanes had fuselages built of rubber and not aluminium?

Suppose we take a spring, hook one end over a nail and then attach masses to the lower end (Fig. 1.5): the spring stretches. If we clamp a rule alongside the spring we can measure how much the spring stretches when the masses are attached. The following might be the type of results obtained if you did the experiment:

Load in g	0	50	100	150	200	250
Extension in cm	0	1·9	4·0	6·0	7·9	10·1

A 50 g load produces an extension of 1·9 cm; twice the load, 100 g, gives an extension of 4·0 cm. Twice the load has produced about twice the extension. Three times the load gives about three times the extension. The extension is proportional to the load.

$$\text{extension} \propto \text{load}$$

Figure 1.6 shows the above results as a graph. Because the graph is a straight line passing through the zero load, zero extension point this informs us that the extension is proportional to the load. The statement ‘extension is proportional to the applied load’ is known as *Hooke’s law* (obtained in 1676).

If we had applied very large loads to the spring we would have found that the extension, beyond some particular load value, ceased to become proportional to the load. The spring also ceases to be elastic, that is when the load is removed the spring no longer returns to its original dimension, but remains permanently elongated. Many materials obey Hooke’s law up to this *elastic limit*.

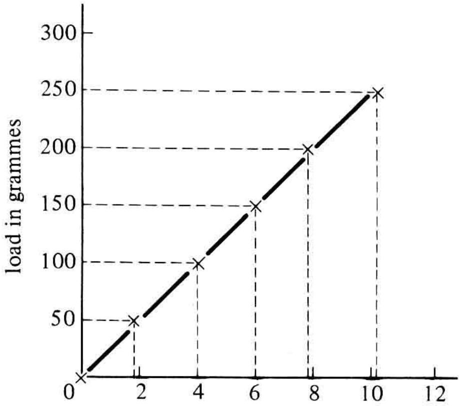

Fig. 1.6

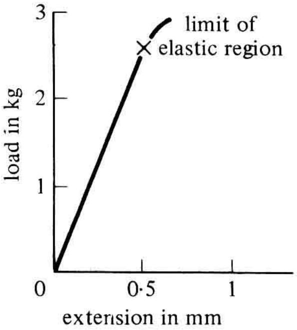

Fig. 1.7

Figure 1.7 shows a load–extension graph for a bar of cast iron. The iron obeys Hooke’s law up to the elastic limit. In fact, the iron cannot be extended much beyond the elastic limit before it breaks. This makes it difficult to give cast iron permanent deformation without breaking it. If we want to bend a bar of cast iron without breaking it, but so that when we release the load the bar remains bent, then we have to apply loads which stretch the iron to values falling between the elastic limit and the breaking point. Cast iron is considered a *brittle* material because it does not significantly deform.

Figure 1.8 shows a load–extension graph for a strip of rubber. The rubber obeys Hooke's law only for quite small loads, loads far below the elastic limit. The elastic limit for rubber is nowhere near the limit of proportionality, i.e., the end of the initial straight line part of the graph. Rubber can be stretched a very long way and still return to its original dimensions when released. Rubber is what we call an *elastic* material.

Figure 1.9 shows a load–extension graph for a piece of copper. The copper obeys Hooke's law initially. There is, however, quite a significant part of the load–extension graph beyond the elastic limit. Copper is, thus, more easily bent into permanent shapes than the cast iron. A material which can be given quite large permanent deformations before it breaks is said to be *ductile*.

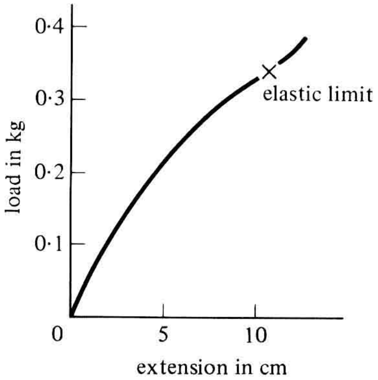

Fig. 1.8

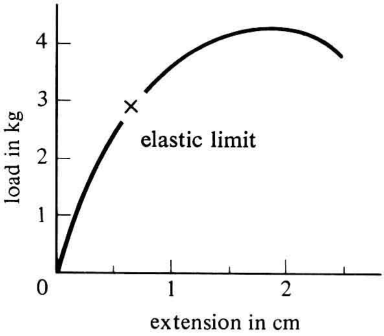

Fig. 1.9

China is a brittle material, and there is virtually no deformation prior to fracture, so that, if you drop a china cup and it breaks, it is possible to take all the pieces and stick them together again. The elastic limit is almost the same as the breaking point. If a car is hit by another car the wing of the car may just be pushed out of shape, i.e., deformed. By hammering, the wing can be bent back to its original shape. The steel of the bodywork of the car is ductile, quite a lot of deformation being possible before breaking occurs.

The elastic limit and the limit of proportionality are not the same thing and, in general, they are not the same point on a load–extension graph.

1.6 The structure of solids

Metals, wood, plastics, crystals such as those of common salt, all look different in appearance, but scientists believe that they are all built up of basic building blocks called atoms. Liquids and gases are also built up of atoms. We can represent this view of the atom as being comparable to that of the common brick used in constructing buildings. Many different buildings can be produced from the same building block. But what evidence have we that solids have a structure, that they are built up from building blocks?