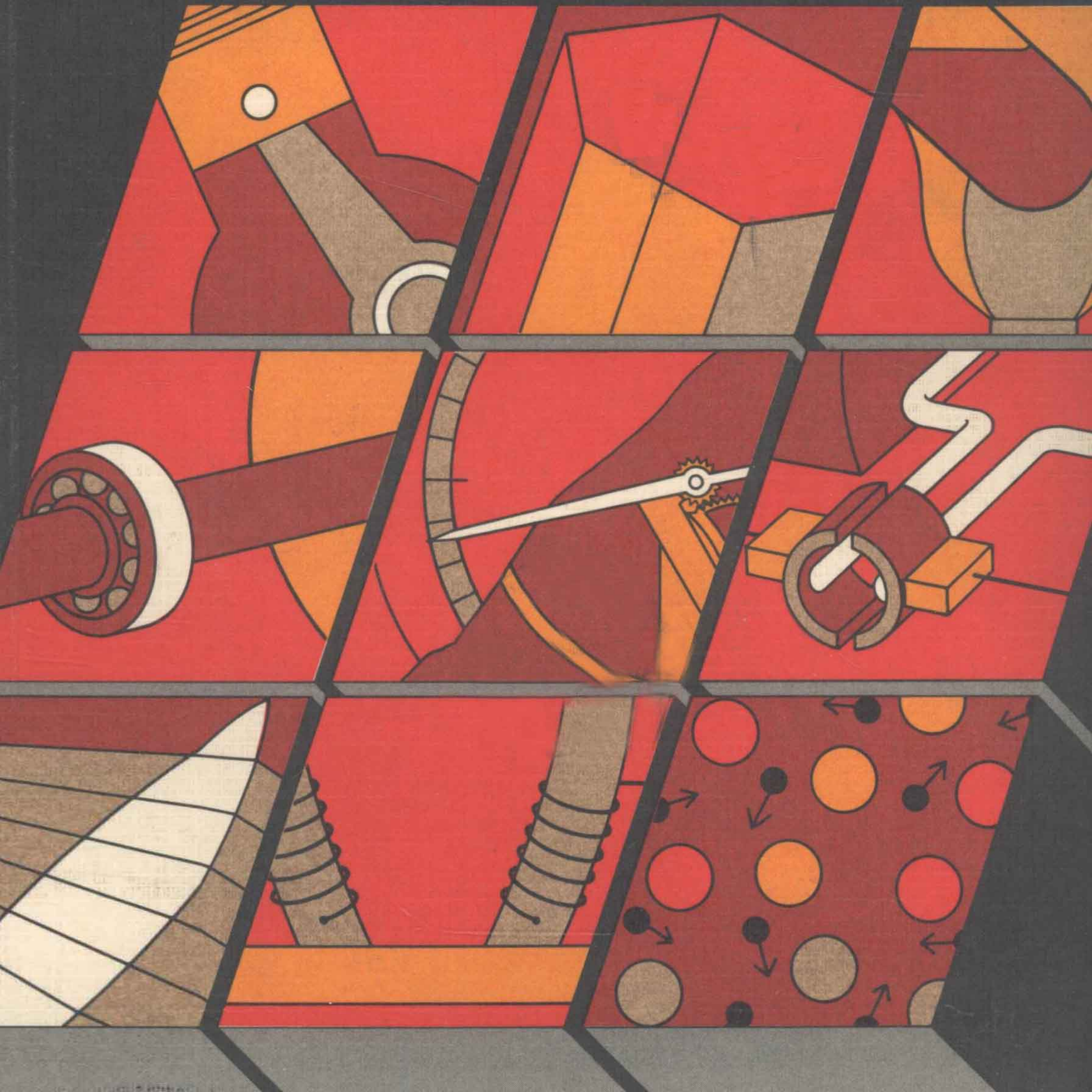
S.T.(P) Technology Today Series

Engineering Science Level II

Redford, Rees & Greer



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Engineering Science Level II

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PREFACE

Engineering Science Level II follows on naturally from our earlier book *Engineering and Physical Science Level I*. The new book has been written to meet the needs of technicians following the TEC standard unit on the A5 programme, and it will also be found to meet nearly all the requirements of students taking the half-units on the A1 programme.

The objectives covered have been listed at the head of each chapter and, as in the previous book, the text is supported with numerous worked examples and exercises.

G D Redford
D T Rees
A Greer
1982

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CONTENTS

1 ELECTRICAL CIRCUITS

After reaching the end of this chapter you should be able to:

1. *Define current as the rate of movement of charge.*
2. *Define the coulomb as 1 ampere second.*
3. *Define potential difference in terms of energy per coulomb.*
4. *Define electromotive force in terms of the total energy per coulomb produced by the source.*
5. *Define internal resistance as the resistance offered by the source to the flow of current.*
6. *Define terminal potential difference as the voltage between the source terminals (and across the external circuit) when a current is flowing.*
7. *Solve problems involving a d.c. source with internal resistance.*

CIRCUIT DIAGRAMS

An electrical circuit consisting of a battery, bulb and switch is shown in Fig. 1.1. The parts are connected by wires, usually made of copper, which is assumed to have negligible resistance. The circuit can be represented by a circuit diagram (Fig. 1.2) which uses standard graphical symbols to represent each component of the circuit. A table of standard symbols is shown in Fig. 1.3.

A basic electrical circuit, showing a resistor connected to a battery would, using these symbols, appear as in Fig. 1.4.

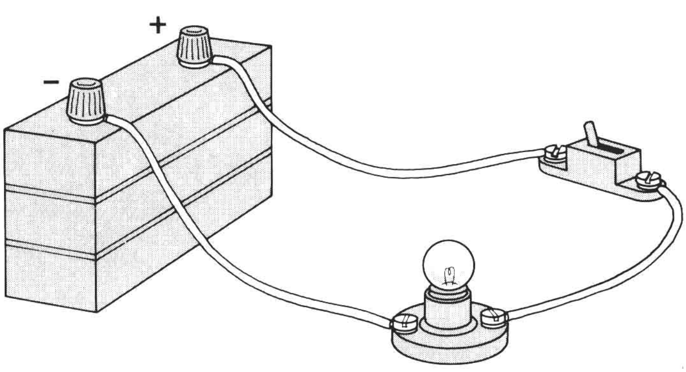


Fig. 1.1 Real-life circuit

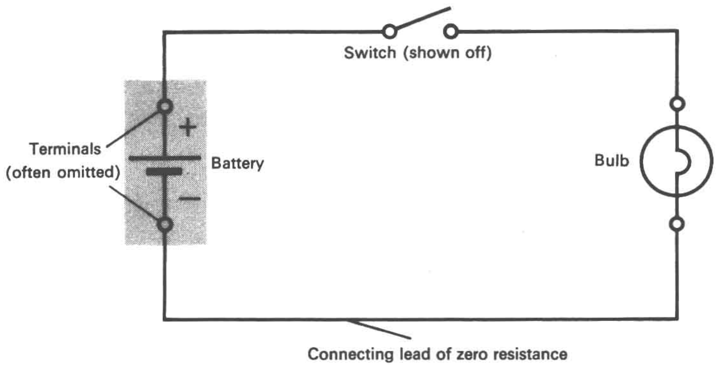


Fig. 1.2 Circuit diagram of Fig. 1.1

The battery voltage and the voltage across the resistor are indicated by *E* and *V* respectively in association with + and − signs, and the current represented by the arrow and symbol *I*. Other symbols used for electrical quantities are given in Table 1.1.

TABLE 1.1
Electrical Quantities and Their Symbols

Quantity	Symbol	Unit	Symbol
Voltage	*E* or *V*	volt	V
Current	*I*	ampere	A
Resistance	*R*	ohm	Ω
Charge	*Q*	coulomb	C
Energy	*E* or *W*	joule	J
Power	*P*	watt	W
Time	*t*	second	s

It is useful to think of circuit diagrams as representing the flow of power from left to right (Fig. 1.5). Thus the battery is a *source* or *input* of power and the heat produced in the resistor the *output*. When circuit diagrams are drawn in this way you should acquire the habit of 'reading' them from left to right.

Sometimes it may be more appropriate to consider the output as current or voltage or even a magnetic field if a magnetic circuit is involved.

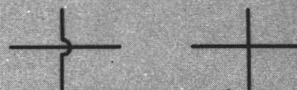
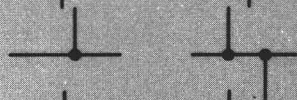
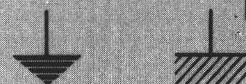
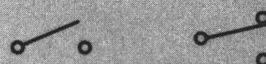
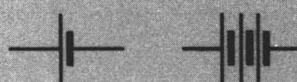
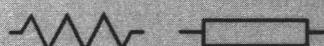
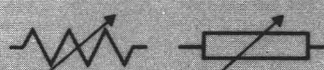
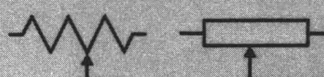
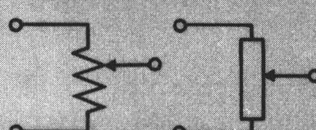
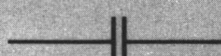
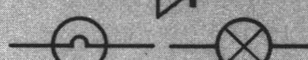
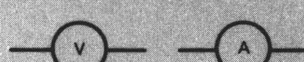
Component	Symbols	Notes
Conductor, wire or lead		Implies zero resistance
Crossing wires		No electrical connection between wires
Junction of two or more conductors		
Earth connection		Second symbol also used for connection to metal case
Switch (single way and two way)		Called 'single pole' since it 'breaks' only one conductor
Battery (one cell and multi cell)		Positive terminal is longer line. Either symbol is also used for any d.c. source
Resistor		
Variable resistor		
Potential or voltage divider		May also be used as a symbol for a variable resistor
Alternative method of showing voltage divider		Often referred to as a 'pot'
Capacitor		
Inductor (coil)		
Diode or Rectifier		Arrow indicates 'easy' direction of current flow
Bulb (lamp)		Second symbol is used for indicator lamps
Fuse link		Rating is usually shown by a number
Voltmeter and Ammeter		For millivoltmeter and milliammeter letters mV and mA are used

Fig. 1.3 Symbols for electrical components

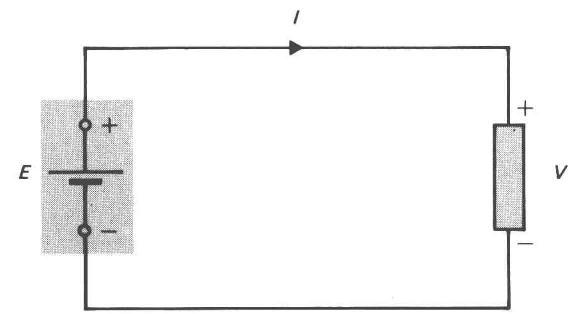


Fig. 1.4 Basic circuit

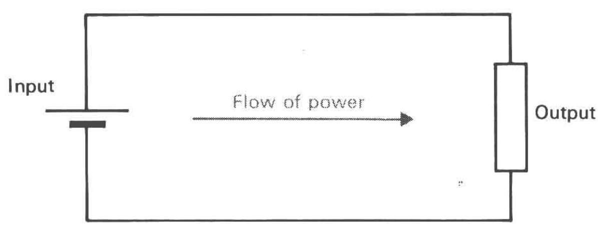


Fig. 1.5 Direction of power flow

CURRENT, VOLTAGE AND RESISTANCE

CURRENT

In the circuit of Fig. 1.1, if the switch is closed, an electric current will flow through the circuit. This current is a *flow of electrons*. As the electrons pass through the bulb filament heat will be generated. If the heat is sufficient, the bulb filament will reach a temperature at which it emits light.

Electrons are negatively charged particles, and therefore *a current may be defined as a flow of electric charge* (symbol Q). Electrical charge is measured in *coulombs* (symbol C), and if one coulomb per second flows in a wire the current is said to be one *ampere* (A) (Fig. 1.6). That is,

1 ampere = 1 coulomb per second

$$I = \frac{Q}{t} \qquad [1.1]$$

It is of interest to note that one electron carries a charge of only 1.6×10^{-19} C, so there are 6.25×10^{18} electrons in every coulomb.

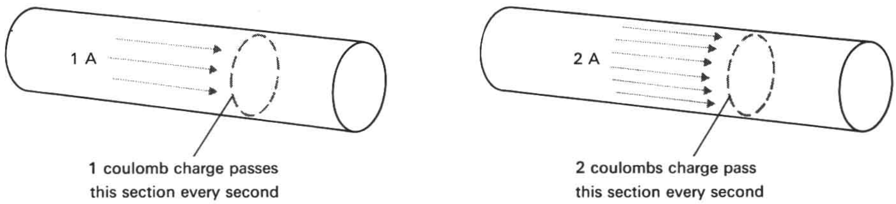


Fig. 1.6 Current is the rate of flow of charge

From the above it can be seen that the charge flowing past a point in a circuit is given by

$$\text{Charge} = \text{Current} \times \text{Time}$$
$$\text{or} \quad Q = It \qquad [1.2]$$

It should be noted that the convention used for current is that it flows out of the positive terminal of the battery (Fig. 1.4). This convention was adopted before the discovery of the electron when it was thought that electric current was a flow of *positive* charge. Now we know it is the flow of electrons, which are *negative* charge carriers, and so the 'real' current made up of electron flow is in the opposite direction to that indicated. However, we have decided to live with the mistake our forefathers made, and there is no harm in thinking for this work that current is a flow of positive charge.

WORKED EXAMPLE 1

A current of 0.3 A flows through a bulb for 10 s. Calculate: (a) the total charge transferred through the bulb, (b) the number of electrons that have passed through.

SOLUTION

(a) Since Charge = Current × Time (equation [1.2])
$Q = 0.3\text{ A} \times 10\text{ s} = 3\text{ C}$

(b) Since $1\text{ C} = 6.25 \times 10^{18}$
Number of electrons in 3 C $= 3 \times 6.25 \times 10^{18} = 18.75 \times 10^{18}$

WORKED EXAMPLE 2

Fig. 1.7 shows current against time for two different circuits. In which circuit is the transfer of charge greatest over the first 30 seconds?

SOLUTION

For circuit 1 Charge $= 2\text{ A} \times 30\text{ s} = 60\text{ C}$

For circuit 2 Charge for first 20 s $= \frac{1}{2}$ A × 20 s = 10 C

Charge over next 10 s = $2\frac{1}{2}$ A × 10 s = 25 C

Total charge transferred = 10 + 25 = 35 C

Circuit 1 transfers the greatest charge over 30 s.

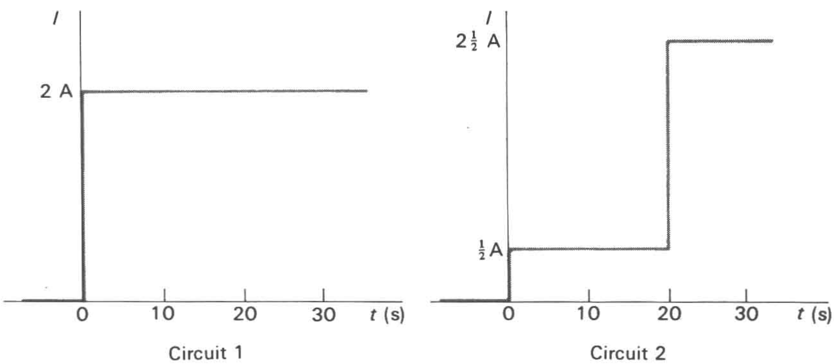


Fig. 1.7 Information for Worked Example 2

It can be seen from the above that the charge transferred is equal to the area under the current–time curve. This fact can be used to calculate the total charge in cases where the current is not constant.

VOLTAGE

The energy to move electrons around the circuit is provided by the battery. The fact that the battery possesses energy is evident by the existence of a voltage across its terminals. This can be shown by connecting a voltmeter across the terminals, and for the type of battery shown the voltmeter would read $4\frac{1}{2}$ V, say. If this was so, to move a total charge of 1 coulomb around the circuit would use up $4\frac{1}{2}$ *joules* of energy. In other words $4\frac{1}{2}$ J of energy would be produced as heat in the bulb for every coulomb of charge that passes through it. If the voltage across the bulb was 10 V, it means that the work done in moving 1 C of charge through the bulb would be 10 J.

From the above we can say that if *1 joule of work is done in moving 1 coulomb of charge between two points in a circuit, the voltage between the points is 1 volt.*

Thus the volt may be defined as

1 Volt = 1 Joule per coulomb

Therefore

$$\text{Energy or work done} = \text{Voltage} \times \text{Charge}$$
$$\text{or} \quad W = VQ \qquad [1.3]$$

POTENTIAL DIFFERENCE (PD) AND ELECTROMOTIVE FORCE (EMF)

The voltage between any two points in a circuit is also known as the difference in electrical potential between these points. Therefore, potential difference (abbreviated to p.d.) is measured in volts, and this is what a voltmeter connected between the two points would indicate.

The potential difference or voltage that exists across a part of a circuit, say a resistor, can be represented in one of three ways, as shown in Fig. 1.8. In Fig. 1.8(a) symbols + and − are placed at the ends of the resistor and the V alongside. The + is placed at the end where the current enters the resistor. These signs give us a reference direction for the voltage, so that if we say $V = +8$ V it means the + end of the resistor is positive with respect to the − end. If $V = -3$ V, it would mean that the end we have labelled + would actually, at that instant, be negative with respect to the other end. In Fig. 1.8(b) voltage or p.d. is represented by an arrow, the tip of the arrow indicating the positive end. A third method is to use double subscripts as in Fig. 1.8(c). If $V_{AB} = +3$ V, this means that 'A is positive with respect to B' by 3 V.

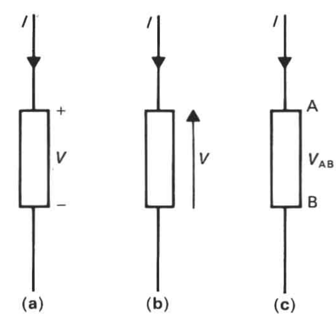


Fig. 1.8 Three ways of representing a voltage across a resistor

Potential difference may be thought of as a difference in 'electrical height'. In the same way as we measure the height of a mountain with reference to sea level, so the electrical potential of a point A is its electrical 'height' above some reference B as shown in Fig. 1.9(a). If the voltages or p.d.s between each of two points and a common reference are known, then the voltage between those two points can easily be calculated. For example, see Fig. 1.9(b).

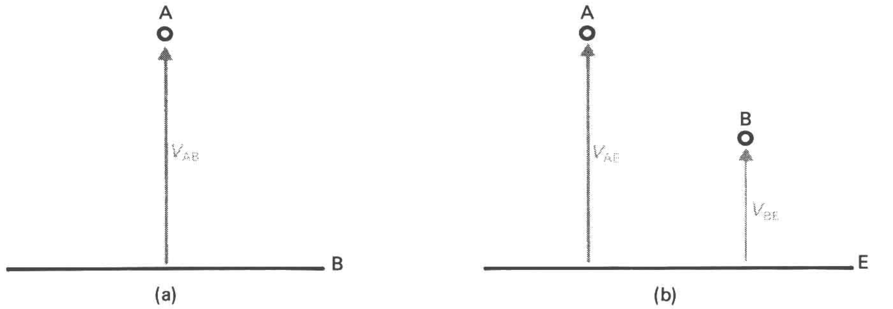


Fig. 1.9 Electrical potential as height

If we require V_{AB} but only know V_{AE} and V_{BE}, then

$$V_{AB} = V_{AE} - V_{BE}$$

So if $V_{AB} = +10$ V and $V_{BE} = +7$ V, then the potential difference between A and B, V_{AB}, will be 3 V. The analogy with measuring height above a common reference point should be obvious.

We have seen that the voltage across a part of a circuit is related to the work done in joules for a coulomb of charge passing through it. The energy comes, of course, from the *electrical source* in the circuit, in our case the battery, as previously stated. The fact that a voltage exists across the battery terminals is an indication that it possesses energy. This voltage known as the battery *terminal voltage* may be slightly less than the voltage actually 'generated' within the battery, due to losses in the battery itself. The voltage existing within the battery is the real 'force' responsible for driving a current through a circuit, and is known as *electromotive force* (e.m.f.). It is, of course, also measured in volts.

Thus, a battery of e.m.f. 9 V would have to supply 9 J of energy to cause 1 C of charge to flow through a circuit. Some of the energy would be used internally in the battery (losses) the remainder being converted into heat or mechanical work in the 'external' circuit. To summarise:

The e.m.f. (V) is a measure of the energy generated per C by the source. The p.d. (V) is a measure of the energy dissipated per C by the external circuit.

Both e.m.f. and p.d. are measured in volts, and frequently it is better to refer to e.m.f. as *generated voltage*, i.e. the voltage produced by any source, be it a battery or electromechanical generator such as an alternator. Similarly p.d. is frequently referred to as *voltage drop* or simply as *voltage*.