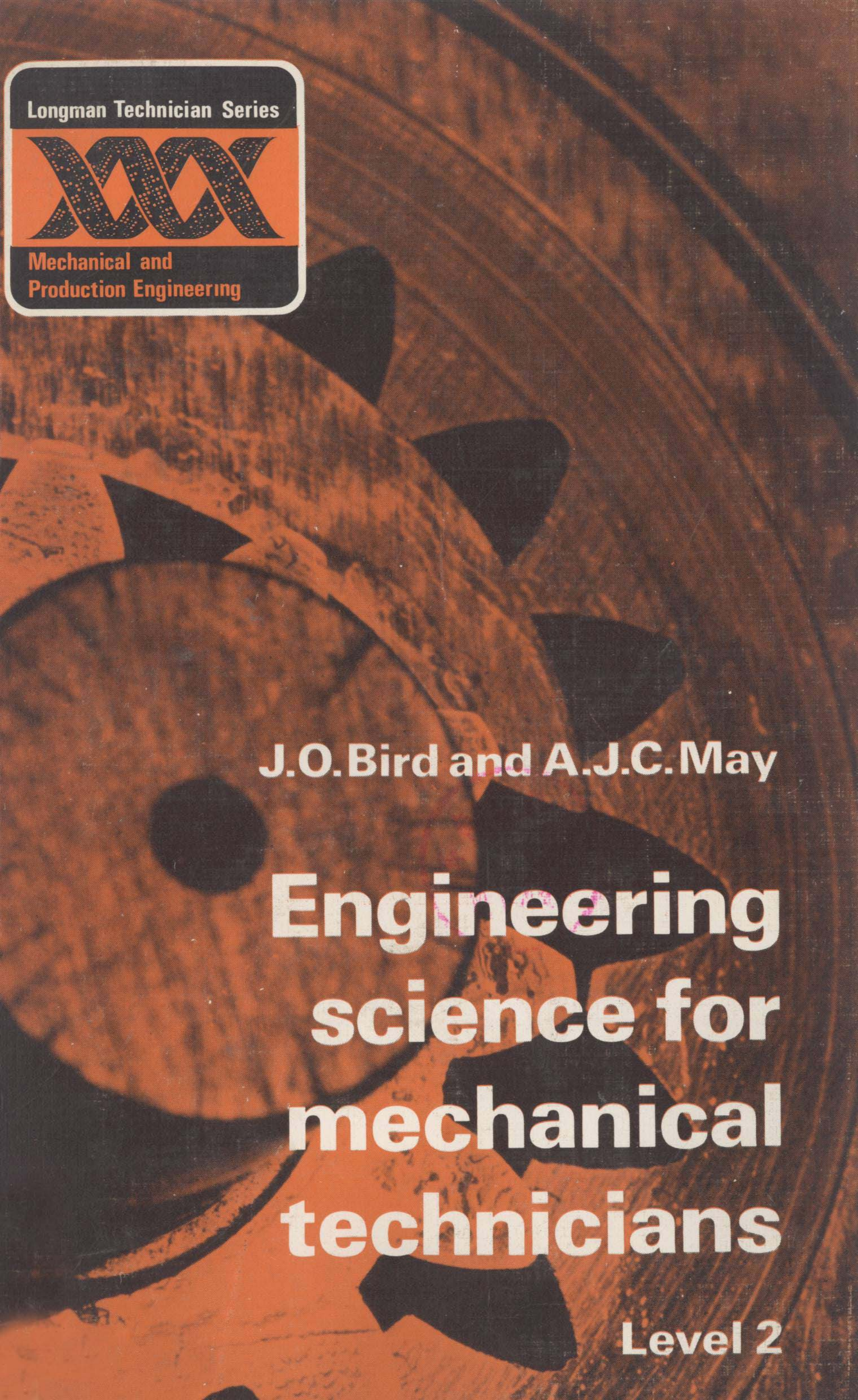

Longman Technician Series

Mechanical and Production Engineering

J.O. Bird and A.J.C. May

Engineering science for mechanical technicians

Level 2

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Preface

This textbook provides a clear and comprehensive coverage of the new Technician Education Council level II Engineering Science course for mechanical technicians on the A5 programme (syllabus TEC U76/053). However, it can also be regarded as a basic textbook in Engineering Science for a much wider range of courses.

The aim of this book is to give a basic electrical and mechanical science background for engineering manufacturing technology technicians.

Each topic considered in the text is presented in a way that assumes in the reader only the knowledge attained at TEC level I in Mathematics (TEC U75/005) and in Physical Science (TEC U75/004) or its equivalent.

This practical Engineering Science book contains over 160 illustrations, nearly 120 detailed worked problems, followed by some 700 further problems with answers. The further problems at the end of each chapter are categorised into short answer type, objective type and conventional type and are designed to meet the various needs of assessment as a result of the introduction of TEC courses.

Some of the conventional type problems have been taken from examination papers and for the permission to reproduce these questions we are grateful to the Union of Educational Institutions (U.E.I.), the Northern Counties Technical Examinations Council (N.C.T.E.C.) and the Union of Lancashire and Cheshire Institutes (U.L.C.I.). The authors accept the responsibility for the solutions to the problems provided by the aforementioned bodies.

The authors would like to thank Gwyn Davis and Gordon Hicks for their valuable assistance in their capacity as General Editors of the Mechanical and Production Engineering sector of the Longman Technician Series. They would also like to express their appreciation for the friendly cooperation and helpful advice given to them by the publishers.

Thanks are also due to Mrs Elaine Mayo for the excellent typing of the manuscript.

Finally, the authors would like to add a word of thanks to their wives, Elizabeth and Juliet, for their patience, help and encouragement during the preparation of this book.

Highbury College of Technology
Portsmouth, 1979

J. O. Bird
A. J. C. May

Contents

Chapter 1

Series-parallel electrical circuits

1.1 Electric current

All **atoms** consist of **protons, neutrons** and **electrons.** The protons, which have positive electrical charges, and the neutrons, which have no electrical charge, are contained within the **nucleus.** Removed from the nucleus are minute negatively charged particles called electrons. Atoms of different materials differ from one another by having different numbers of protons, neutrons and electrons. An equal number of protons and electrons exist within an atom and it is said to be electrically balanced, as the positive and negative charges cancel each other out. When there are more than two electrons in an atom the electrons are arranged into **shells** at various distances from the nucleus.

All atoms are bound together by powerful forces of attraction existing between the nucleus and its electrons. Electrons in the outer shells of an atom, however, are attracted to their nucleus less powerfully than are electrons whose shells are nearer the nucleus.

It is possible for an atom to lose an electron; the atom, which is now called an **ion**, is not now electrically balanced, but is positively charged and is thus able to attract an electron to itself from another atom. Electrons that move from one atom to another are called free electrons and such random motion can continue indefinitely. However, if an electric pressure or **voltage** is applied across any material there is a tendency for electrons to move in a particular direction. This movement of free electrons, known as **drift**, constitutes an electric current flow.

Thus current is the rate of movement of charge.

1.2 Quantity of electricity and unit of current

The unit used to measure the **quantity of electrical charge Q** is called the **coulomb C.**

1 Coulomb = 6.24×10^{18} electrons.

If the drift of electrons in a conductor (a conductor being a material which allows the movement of free electrons) takes place at the rate of one coulomb per second, the resulting current is said to be a current of one ampere.

2 Thus, 1 ampere = 1 coulomb per second

or 1 A = 1 C/s

Hence, 1 coulomb = 1 ampere second

or 1 C = 1 A s

Generally, if I is the current in amperes and t the time in seconds during which the current flows, then $I \times t$ represents the quantity of electrical charge in coulombs, i.e.

quantity of electrical charge transferred, $\boldsymbol{Q = I \times t}$ **coulombs.**

Worked problems on quantity of electricity

Problem 1. If a current of 7.5 amperes passes for 3 minutes, find the quantity of electricity transferred.

Quantity of electricity, $Q = It$ coulombs,
where $I = 7.5$ A and $t = 3 \times 60$ seconds
$Q = 7.5 \times 3 \times 60$ C
i.e. Quantity of electricity transferred Q = 1 350 C.

Problem 2. If a total charge of 630 coulombs is to be transferred in 15 seconds, what current must flow?

If $Q = It$

then $I = \dfrac{Q}{t}$

$Q = 630$ C and $t = 15$ s

Hence $I = \dfrac{630}{15}$ A

i.e. current flowing, $\boldsymbol{I = 42}$ A.

Further problems on quantity of electricity may be found in Section 1.9 (c) (problems 1 to 4).

1.3 Equivalent resistance of a series–parallel combination of resistors

The flow of electrical current, like any other flow, is subject to friction. This friction, or opposition, is called **resistance, *R***. The unit of resistance is the **ohm**, the Greek letter omega Ω being used as the unit symbol. One ohm is defined as the resistance which will have a current of 1 A flowing through it, when 1 V is connected across it. There are two basic ways in which electric circuits can be connected, namely the **series** arrangement and the **parallel** arrangement. In most practical circuits however, series and parallel connections exist together.

Resistors in series

When, say, three resistors R_1, R_2 and R_3 are connected in series, as shown in Fig. 1.1 (*a*), then the equivalent resistance R ohms is given by:

$R = R_1 + R_2 + R_3$ ohms

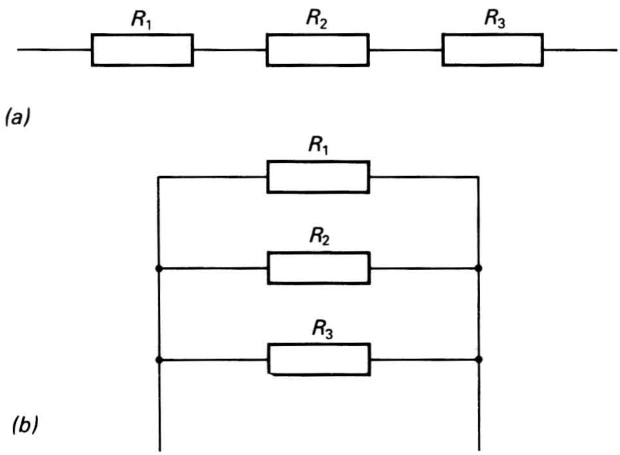

Fig. 1.1

Thus, a single resistor of value R ohms can replace the three resistors shown to give the same circuit resistance. When resistors are connected in series the equivalent resistance is obtained by adding together the resistance values of the individual resistors.

Resistors in parallel

When, say, three resistors R_1, R_2 and R_3 are connected in parallel, as shown in Fig. 1.1 (*b*), then the equivalent resistance R ohms is given by:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Hence the reciprocal of the equivalent resistance equals the sum of the separate reciprocal resistances for a parallel circuit.

The reciprocal of resistance, i.e. $\frac{1}{\mathbf{R}}$, is called **conductance**. The symbol used for conductançe is G and its unit is the **sieman, S**. Hence for the parallel circuit shown in Fig. 1.1 (*b*) the conductance of the equivalent resistor is equal to the sum of the conductances of the three branch resistors, i.e.

$\boldsymbol{G = G_1 + G_2 + G_3}$ **siemens**

In the case when only two resistors are connected in parallel the formula for the equivalent resistance is given by:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2},$$

which becomes $\frac{1}{R} = \frac{R_2 + R_1}{R_1 R_2}$

$$\text{Thus } \boldsymbol{R = \frac{R_1 R_2}{R_1 + R_2}} \text{ ohms } \left(\text{i.e. } \frac{\text{product}}{\text{sum}}\right)$$

Resistors in series-parallel

A series-parallel circuit is one which is made up of series and parallel parts in combination and the possible number of combinations is endless. The equivalent resistance may be determined by simplification as shown in the following worked problems.

Worked problems on the equivalent resistance of series-parallel combinations

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Problem 1. Find the equivalent resistance for the circuits shown in Fig. 1.2 (*a*) and (*b*).

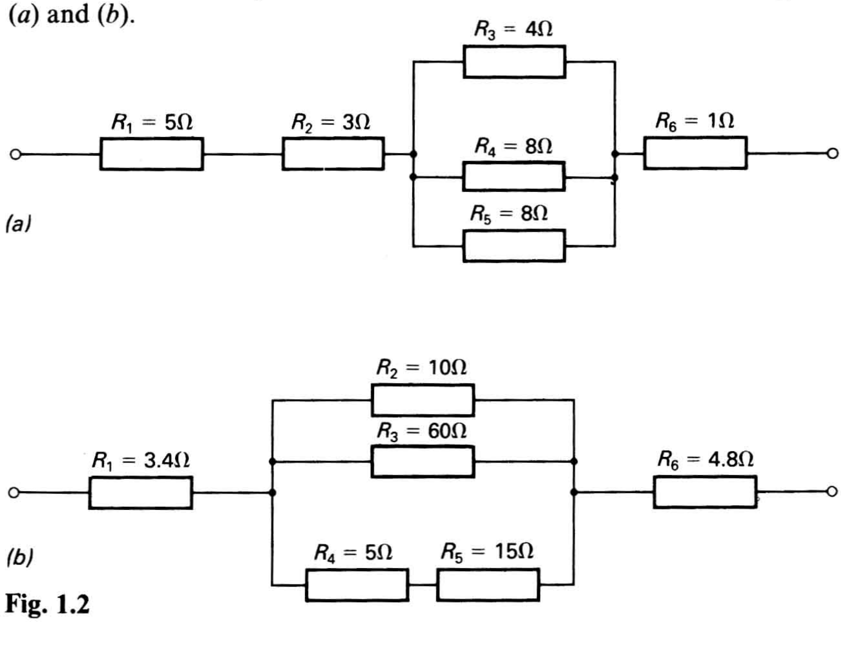


Fig. 1.2

(*a*) R_1 in series with R_2 gives an equivalent resistance of $5\Omega + 3\Omega = 8\Omega$.
R_3, R_4 and R_5 are in parallel and the equivalent resistance R is given by:

$$\frac{1}{R} = \frac{1}{4} + \frac{1}{8} + \frac{1}{8} = \frac{2+1+1}{8}$$
$$= \frac{4}{8} = \frac{1}{2}$$

Hence $R = 2\Omega$

Thus the equivalent circuit is shown in Fig. 1.3 (*a*).

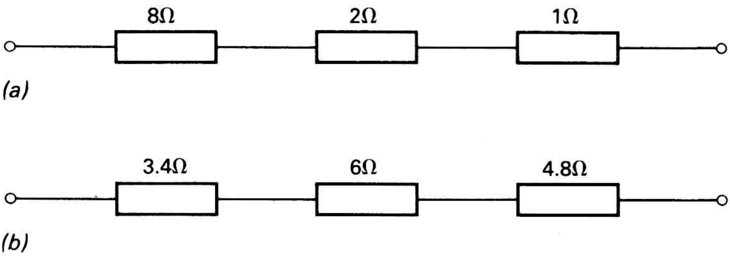


Fig. 1.3

8Ω, 2Ω and 1Ω resistors in series gives an equivalent resistance of $8\Omega + 2\Omega + 1\Omega = 11\Omega$.

Hence the equivalent resistance for the circuit shown in Fig. 1.2 (*a*) is 11Ω.

(*b*) Resistors R_4 and R_5 are in series and may be replaced by a single resistor of value $5\Omega + 15\Omega$, i.e. 20Ω. This 20Ω resistor is connected in parallel with R_2 and R_3 and the equivalent resistance R of this combination is given by:

$$\frac{1}{R} = \frac{1}{10} + \frac{1}{60} + \frac{1}{20}$$
$$= \frac{6+1+3}{60} = \frac{10}{60} = \frac{1}{6}$$

Hence $R = 6\Omega$
Thus the equivalent circuit is shown in Fig. 1.3 (*b*).

3.4Ω, 6Ω and 4.8Ω resistors in series give an equivalent resistance of $3.4\Omega + 6\Omega + 4.8\Omega = 14.2\Omega$.

Hence the equivalent resistance for the circuit shown in Fig. 1.2 (*b*) is 14.2Ω.

 Problem 2. Calculate the equivalent resistance between the points A and B for the circuit shown in Fig. 1.4.

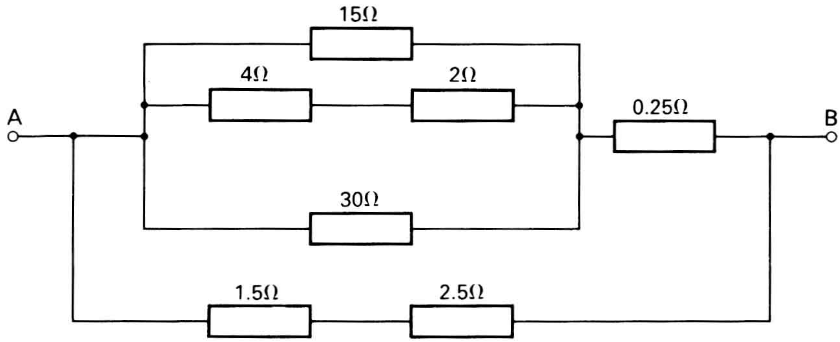


Fig. 1.4

Combining the 4Ω and 2Ω resistors in series, and the 1.5Ω and 2.5Ω resistors in series gives the simplified equivalent circuit of Fig. 1.5 (*a*).

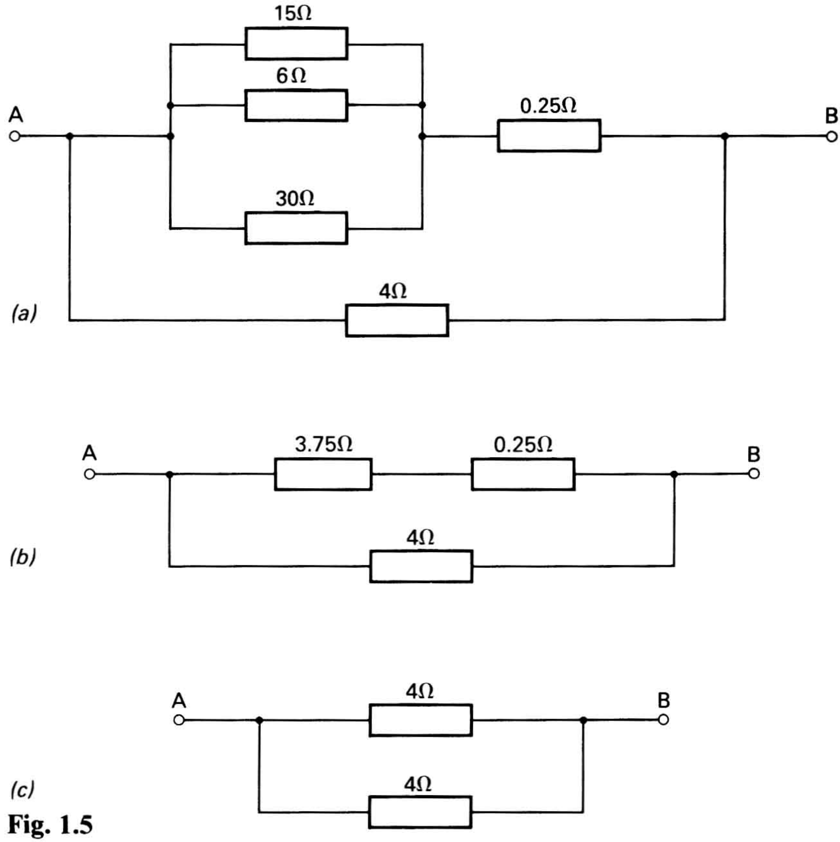


Fig. 1.5

The equivalent resistance R of 15Ω, 6Ω and 30Ω in parallel is given by:

$$\frac{1}{R}=\frac{1}{15}+\frac{1}{6}+\frac{1}{30}$$
$$=\frac{2+5+1}{30}=\frac{8}{30}$$
$$\text{Thus } R=\frac{30}{8}=3.75\Omega$$

The equivalent circuit is now as shown in Fig. 1.5 (*b*). Combining the 3.75Ω and 0.25Ω resistors in series gives an equivalent resistance of 4Ω. Thus the circuit is simplified as shown in Fig. 1.5 (*c*).

The equivalent resistance R of a 4Ω resistor in parallel with another 4Ω resistor is given by:

$$R=\frac{4\times 4}{4+4}=\frac{16}{8}=2\Omega$$

(Note that when two resistors having the same value are connected in parallel the equivalent resistance will always be half the value of one of the resistors.)

Hence the circuit of Fig. 1.4 can be replaced by a 2Ω resistor placed between the points A and B.

Problem 3. Calculate the equivalent resistance for the series-parallel arrangement shown in Fig. 1.6.

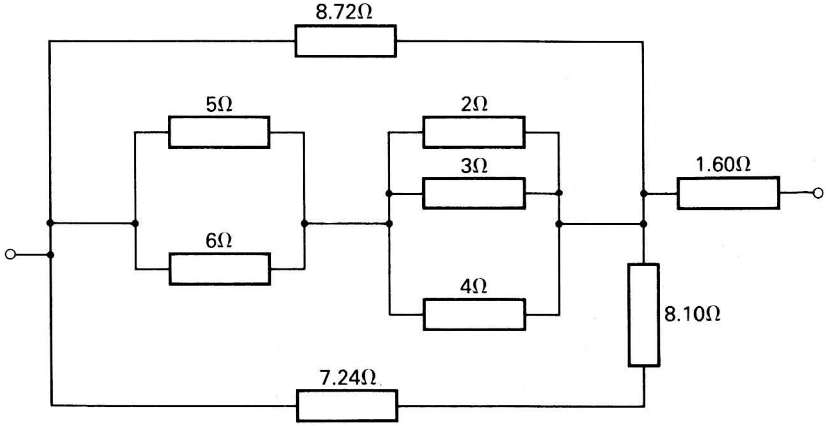


Fig. 1.6

The equivalent resistance of 5Ω in parallel with 6Ω is

$$\frac{5 \times 6}{5 + 6} = \frac{30}{11} = 2.73\Omega$$

The equivalent resistance R of 2Ω, 3Ω and 4Ω in parallel is given by:

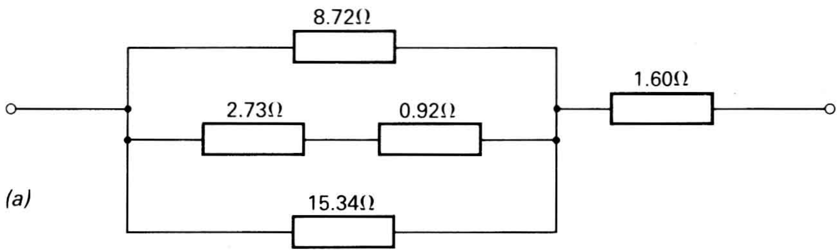
$$\frac{1}{R} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4} = \frac{6 + 4 + 3}{12}$$

$$\frac{1}{R} = \frac{13}{12}$$

Hence $R = \frac{12}{13} = 0.92\Omega$

The equivalent resistance of 7.24Ω and 8.10Ω in series is 7.24Ω + 8.10Ω = 15.34Ω.

Thus a simplified circuit diagram is shown in Fig. 1.7 (*a*).



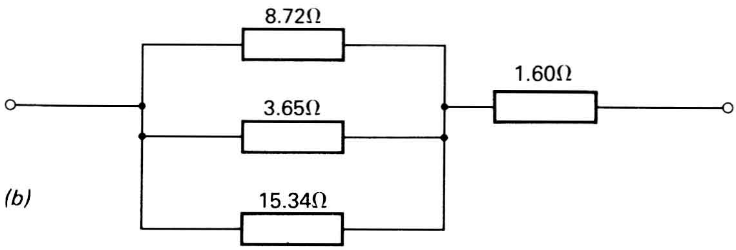


Fig. 1.7

The equivalent resistance of 2.73Ω in series with 0.92Ω is 3.65Ω, hence the simplified circuit diagram of the circuit shown in Fig. 1.7 (*a*) is shown in Fig. 1.7 (*b*).