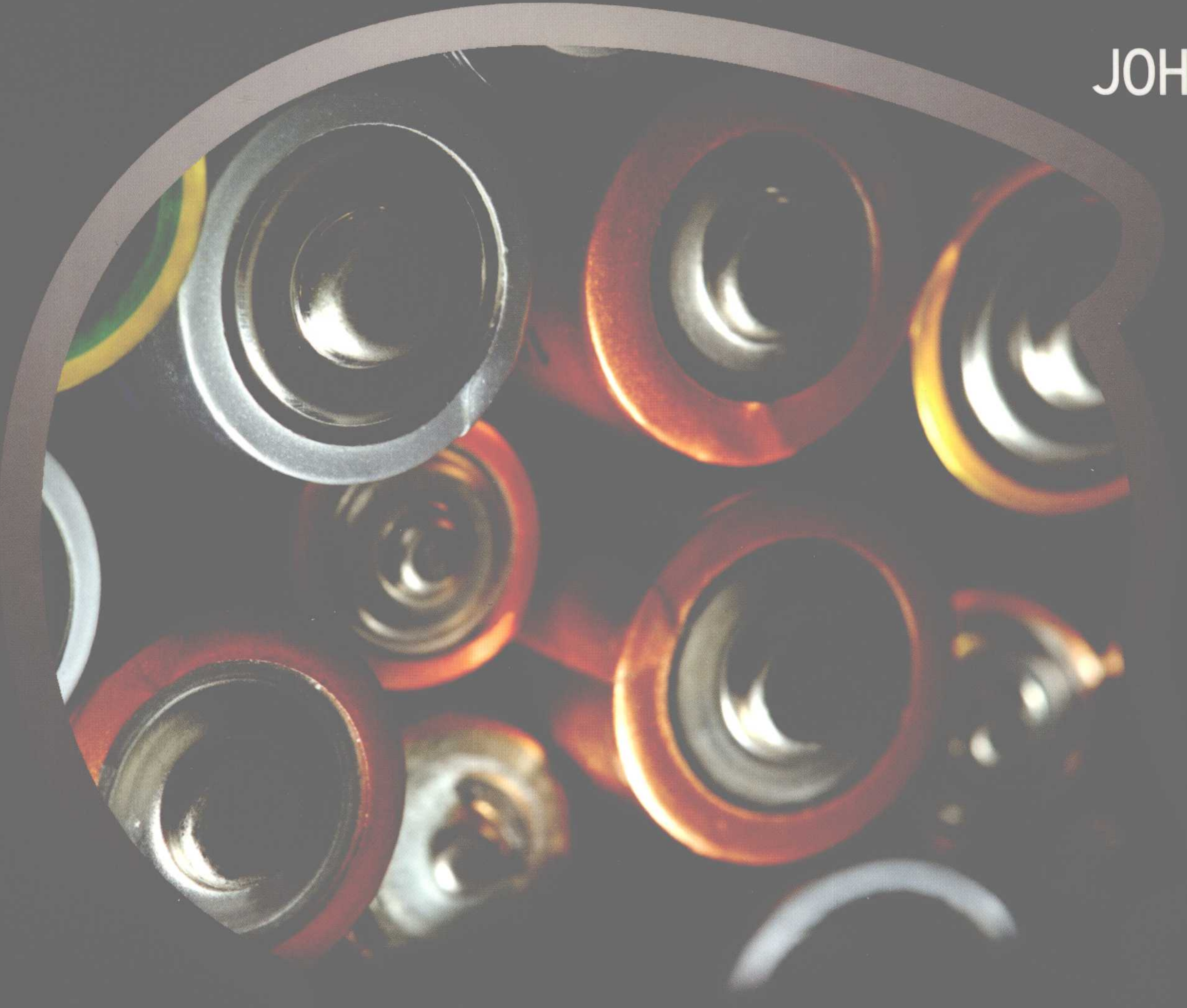
JOHN BIRD



ELECTRICAL AND ELECTRONIC PRINCIPLES AND TECHNOLOGY

FOURTH EDITION

Electrical and Electronic Principles and Technology

Fourth edition

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Preface

'Electrical and Electronic Principles and Technology 4th Edition' introduces the principles which describe the operation of d.c. and a.c. circuits, covering both steady and transient states, and applies these principles to filter networks, operational amplifiers, three-phase supplies, transformers, d.c. machines and three-phase induction motors.

In this edition, new material has been added on resistor construction, the loading effect of instruments, potentiometers and rheostats, earth potential and short circuits, and electrical safety with insulation and fuses. In addition, a new chapter detailing some **10 practical laboratory experiments** has been included. (These may be downloaded and edited by tutors to suit local availability of equipment and components).

This fourth edition of the textbook provides coverage of the following latest syllabuses:

(i) **'Electrical and Electronic Principles'** (BTEC National Certificate and National Diploma, Unit 5) – see Chapters 1–10, 11(part), 13 (part), 14, 15 (part), 18(part), 21(part), 22(part).

(ii) **'Further Electrical Principles'** (BTEC National Certificate and National Diploma, Unit 67) – see Chapters 13, 15–18, 20, 22, 23.

(iii) Parts of the following BTEC National syllabuses: Electrical Applications, Three Phase Systems, Principles and Applications of Electronic Devices and Circuits, Aircraft Electrical Machines, and Telecommunications Principles.

(iv) Electrical part of 'Applied Electrical and Mechanical Science for Technicians' (BTEC First Certificate).

(v) Various parts of City & Guilds Technician Certificate/Diploma in Electrical and Electronic Principles/Telecommunication Systems, such as Electrical Engineering Principles, Power, and Science and Electronics.

(vi) 'Electrical and Electronic Principles' (EAL Advanced Diploma in Engineering and Technology).

(vii) Any introductory/Access/Foundation course involving Electrical and Electronic Engineering Principles.

The **text** is set out in four main sections:

Section 1, comprising Chapters 1 to 12, involves essential **Basic Electrical and Electronic Engineering Principles**, with chapters on electrical units and quantities, introduction to electric circuits, resistance variation, batteries and alternative sources of energy, series and parallel networks, capacitors and capacitance, magnetic circuits, electromagnetism, electromagnetic induction, electrical measuring instruments and measurements, semiconductors diodes and transistors.

Section 2, comprising Chapters 13 to 19, involves **Further Electrical and Electronic Principles,** with chapters on d.c. circuit theorems, alternating voltages and currents, single-phase series and parallel networks, filter networks, d.c. transients and operational amplifiers.

Section 3, comprising Chapters 20 to 23, involves **Electrical Power Technology**, with chapters on three-phase systems, transformers, d.c. machines and three-phase induction motors.

Section 4, comprising Chapter 24, detailing **10 practical laboratory experiments**.

Each topic considered in the text is presented in a way that assumes in the reader little previous knowledge of that topic. Theory is introduced in each chapter by a reasonably brief outline of essential information, definitions, formulae, procedures, etc. The theory is kept to a minimum, for problem solving is extensively used to establish and exemplify the theory. It is intended that readers will gain real understanding through seeing problems solved and then through solving similar problems themselves.

To aid tutors/lecturers/instructors, the following **free Internet downloads** are available with this edition (see page x for access details):

(i) a **sample of solutions** (some 410) of the 540 further problems contained in the book.

(ii) an **Instructors guide** detailing full worked solutions for the **Revision Tests**.

(iii) **10 practical laboratory experiments**, which may be edited.

(iv) **Suggested lesson plans for BTEC units 5 and 67**, together with **Practise Examination questions (with solution)** for revision purposes.

(v) a **PowerPoint presentation of all 538 illustrations** contained in the text.

'Electrical and Electronic Principles and Technology 4th Edition' contains **410 worked problems**, together with **341 multi-choice questions** (with answers at the back of the book). Also included are over **455 short answer questions**, the answers for which can be determined from the preceding material in that particular chapter, and some **540 further questions**, arranged in **146 Exercises**, all with answers, in brackets, immediately following each question; the Exercises appear at regular intervals - every 3 or 4 pages - throughout the text. **538 line diagrams** further enhance the understanding of the theory. All of the problems - multi-choice, short answer and further questions - mirror practical situations found in electrical and electronic engineering.

At regular intervals throughout the text are seven **Revision Tests** to check understanding. For example, Revision Test 1 covers material contained in Chapters 1 to 4, Revision Test 2 covers the material contained in Chapters 5 to 7, and so on. These Revision Tests do not have answers given since it is envisaged that lecturers/instructors could set the Tests for students to attempt as part of their course structure. Lecturers/instructors may obtain a free Internet download of full solutions of the Revision Tests in an **Instructor's Manual** – see next column.

A list of relevant **formulae** are included at the end of each of the three sections of the book.

'Learning by Example' is at the heart of 'Electrical and Electronic Principles and Technology 4th Edition'.

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Free web downloads

A suite of five sets of support material is available to tutors/lecturers/instructors - only from Elsevier's textbook website.

To access material, please go to *http://www.booksite.elsevier.com/newnes/bird*, find the correct title, and click on to whichever of the following resource materials you need.

(i) Solutions manual

Within the text there are some 540 further problems arranged within 146 Exercises. A sample of about 410 worked solutions has been prepared for lecturers.

(ii) Instructor's manual

This manual provides full worked solutions and mark scheme for all 7 Revision Tests in this book.

(iii) Laboratory Experiments

In Chapter 24, 10 practical laboratory experiments are included. It maybe that tutors will want to edit these experiments to suit their own equipment/component availability. These have been made available on the website.

(iv) Lesson Plans and revision material

Typical 30-week lesson plans for 'Electrical and Electronic Principles', Unit 5, and 'Further Electrical Principles', Unit 67 are included, together with two practise examinations question papers (with solutions) for each of the modules.

(v) Illustrations

Lecturers can download electronic files for all 538 illustrations in this fourth edition.

Contents

Section 1

Basic Electrical and Electronic Engineering Principles

Chapter 1

Units associated with basic electrical quantities

At the end of this chapter you should be able to:

- state the basic SI units
- recognize derived SI units
- understand prefixes denoting multiplication and division
- state the units of charge, force, work and power and perform simple calculations involving these units
- state the units of electrical potential, e.m.f., resistance, conductance, power and energy and perform simple calculations involving these units

1.1 SI units

The system of units used in engineering and science is the Système Internationale d'Unités (International system of units), usually abbreviated to SI units, and is based on the metric system. This was introduced in 1960 and is now adopted by the majority of countries as the official system of measurement.

The basic units in the SI system are listed below with their symbols:

Quantity	Unit
length	metre, m
mass	kilogram, kg
time	second, s
electric current	ampere, A
thermodynamic temperature	kelvin, K
luminous intensity	candela, cd
amount of substance	mole, mol

Derived SI units use combinations of basic units and there are many of them. Two examples are:

Velocity – metres per second (m/s)

Acceleration – metres per second squared (m/s^2)

SI units may be made larger or smaller by using prefixes which denote multiplication or division by a particular amount. The six most common multiples, with their meaning, are listed below:

Prefix	Name	Meaning
M	mega	multiply by 1 000 000 (i.e. $\times 10^6$)
k	kilo	multiply by 1000 (i.e. $\times 10^3$)
m	milli	divide by 1000 (i.e. $\times 10^{-3}$)
μ	micro	divide by 1 000 000 (i.e. $\times 10^{-6}$)
n	nano	divide by 1 000 000 000 (i.e. $\times 10^{-9}$)
p	pico	divide by 1 000 000 000 000 (i.e. $\times 10^{-12}$)

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1.2 Charge

The **unit of charge** is the coulomb (C) where one coulomb is one ampere second (1 coulomb $= 6.24 \times 10^{18}$ electrons). The coulomb is defined as the quantity of electricity which flows past a given point in an electric circuit when a current of one ampere is maintained for one second. Thus,

$$\text{charge, in coulombs} \quad Q = It$$

where I is the current in amperes and t is the time in seconds.

Problem 1. If a current of 5 A flows for 2 minutes, find the quantity of electricity transferred.

Quantity of electricity $Q = It$ coulombs

$I = 5$ A, $t = 2 \times 60 = 120$ s

Hence $\quad Q = 5 \times 120 = \mathbf{600\,C}$

1.3 Force

The **unit of force** is the **newton (N)** where one newton is one kilogram metre per second squared. The newton is defined as the force which, when applied to a mass of one kilogram, gives it an acceleration of one metre per second squared. Thus,

$$\text{force, in newtons} \quad F = ma$$

where m is the mass in kilograms and a is the acceleration in metres per second squared. Gravitational force, or weight, is mg, where $g = 9.81\,\text{m/s}^2$.

Problem 2. A mass of 5000 g is accelerated at $2\,\text{m/s}^2$ by a force. Determine the force needed.

Force = mass × acceleration

$= 5\,\text{kg} \times 2\,\text{m/s}^2 = 10\,\text{kg m/s}^2 = \mathbf{10\,N}$.

Problem 3. Find the force acting vertically downwards on a mass of 200 g attached to a wire.

Mass $= 200\,\text{g} = 0.2\,\text{kg}$ and acceleration due to gravity, $g = 9.81\,\text{m/s}^2$

$$\left.\begin{array}{l}\text{Force acting}\\ \text{downwards}\end{array}\right\} = \text{weight}$$
$$= \text{mass} \times \text{acceleration}$$
$$= 0.2\,\text{kg} \times 9.81\,\text{m/s}^2$$
$$= \mathbf{1.962\,N}$$

1.4 Work

The **unit of work or energy** is the **joule (J)** where one joule is one newton metre. The joule is defined as the work done or energy transferred when a force of one newton is exerted through a distance of one metre in the direction of the force. Thus

$$\text{work done on a body, in joules,} \quad W = Fs$$

where F is the force in newtons and s is the distance in metres moved by the body in the direction of the force. Energy is the capacity for doing work.

1.5 Power

The **unit of power** is the watt (W) where one watt is one joule per second. Power is defined as the rate of doing work or transferring energy. Thus,

$$\text{power, in watts,} \quad P = \frac{W}{t}$$

where W is the work done or energy transferred, in joules, and t is the time, in seconds. Thus,

$$\text{energy, in joules,} \quad W = Pt$$

Problem 4. A portable machine requires a force of 200 N to move it. How much work is done if the machine is moved 20 m and what average power is utilized if the movement takes 25 s?

Work done = force × distance

$= 200\,\text{N} \times 20\,\text{m}$

$= \mathbf{4\,000\,Nm\ or\ 4\,kJ}$

$$\text{Power} = \frac{\text{work done}}{\text{time taken}}$$

$$= \frac{4000\,\text{J}}{25\,\text{s}} = \mathbf{160\,J/s = 160\,W}$$

Problem 5. A mass of 1000 kg is raised through a height of 10 m in 20 s. What is (a) the work done and (b) the power developed?

(a) Work done = force × distance

and force = mass × acceleration

Hence,

$$\text{work done} = (1000\,\text{kg} \times 9.81\,\text{m/s}^2) \times (10\,\text{m})$$
$$= 98\,100\,\text{Nm}$$
$$= \mathbf{98.1\,kNm} \text{ or } \mathbf{98.1\,kJ}$$

(b) $\text{Power} = \dfrac{\text{work done}}{\text{time taken}} = \dfrac{98100\,\text{J}}{20\,\text{s}}$

$$= 4905\,\text{J/s} = \mathbf{4905\,W} \text{ or } \mathbf{4.905\,kW}$$

Now try the following exercise

Exercise 1 Further problems on charge, force, work and power

(Take $g = 9.81\,\text{m/s}^2$ where appropriate)

1. What quantity of electricity is carried by 6.24×10^{21} electrons? [1000 C]
2. In what time would a current of 1 A transfer a charge of 30 C? [30 s]
3. A current of 3 A flows for 5 minutes. What charge is transferred? [900 C]
4. How long must a current of 0.1 A flow so as to transfer a charge of 30 C? [5 minutes]
5. What force is required to give a mass of 20 kg an acceleration of $30\,\text{m/s}^2$? [600 N]
6. Find the accelerating force when a car having a mass of 1.7 Mg increases its speed with a constant acceleration of $3\,\text{m/s}^2$. [5.1 kN]
7. A force of 40 N accelerates a mass at $5\,\text{m/s}^2$. Determine the mass. [8 kg]
8. Determine the force acting downwards on a mass of 1500 g suspended on a string. [14.72 N]
9. A force of 4 N moves an object 200 cm in the direction of the force. What amount of work is done? [8 J]
10. A force of 2.5 kN is required to lift a load. How much work is done if the load is lifted through 500 cm? [12.5 kJ]
11. An electromagnet exerts a force of 12 N and moves a soft iron armature through a distance of 1.5 cm in 40 ms. Find the power consumed. [4.5 W]
12. A mass of 500 kg is raised to a height of 6 m in 30 s. Find (a) the work done and (b) the power developed. [(a) 29.43 kNm (b) 981 W]
13. Rewrite the following as indicated:
(a) 1000 pF = ... nF
(b) 0.02 μF = ... pF
(c) 5000 kHz = ... MHz
(d) 47 kΩ = ... MΩ
(e) 0.32 mA = ... μA
[(a) 1 nF (b) 20000 pF (c) 5 MHz (d) 0.047 MΩ (e) 320 μA]

1.6 Electrical potential and e.m.f.

The **unit of electric potential** is the volt (V), where one volt is one joule per coulomb. One volt is defined as the difference in potential between two points in a conductor which, when carrying a current of one ampere, dissipates a power of one watt, i.e.

$$\text{volts} = \frac{\text{watts}}{\text{amperes}} = \frac{\text{joules/second}}{\text{amperes}}$$
$$= \frac{\text{joules}}{\text{ampere seconds}} = \frac{\text{joules}}{\text{coulombs}}$$

A change in electric potential between two points in an electric circuit is called a **potential difference**. The **electromotive force (e.m.f.)** provided by a source of energy such as a battery or a generator is measured in volts.

1.7 Resistance and conductance

The **unit of electric resistance** is the **ohm**(Ω), where one ohm is one volt per ampere. It is defined as the resistance between two points in a conductor when a constant electric potential of one volt applied at the two points produces a current flow of one ampere in the conductor. Thus,

$$\textbf{resistance, in ohms}\quad R = \frac{V}{I}$$

where V is the potential difference across the two points, in volts, and I is the current flowing between the two points, in amperes.
The reciprocal of resistance is called **conductance** and is measured in siemens (S). Thus

$$\textbf{conductance, in siemens } G=\frac{1}{R}$$

where R is the resistance in ohms.

Problem 6. Find the conductance of a conductor of resistance: (a) 10 Ω (b) 5 kΩ (c) 100 mΩ.

(a) Conductance $G=\frac{1}{R}=\frac{1}{10}$ siemen $=\mathbf{0.1\,S}$

(b) $G=\frac{1}{R}=\frac{1}{5\times10^3}\text{S}=0.2\times10^{-3}\text{S}=\mathbf{0.2\,mS}$

(c) $G=\frac{1}{R}=\frac{1}{100\times10^{-3}}\text{S}=\frac{10^3}{100}\text{S}=\mathbf{10\,S}$

1.8 Electrical power and energy

When a direct current of I amperes is flowing in an electric circuit and the voltage across the circuit is V volts, then

$$\textbf{power, in watts } P=VI$$

$$\textbf{Electrical energy} = \textbf{Power} \times \textbf{time}$$
$$= VIt \textbf{ joules}$$

Although the unit of energy is the joule, when dealing with large amounts of energy, the unit used is the **kilowatt hour (kWh)** where

$$1\,\text{kWh} = 1000 \text{ watt hour}$$
$$= 1000 \times 3600 \text{ watt seconds or joules}$$
$$= 3\,600\,000\,\text{J}$$

Problem 7. A source e.m.f. of 5 V supplies a current of 3 A for 10 minutes. How much energy is provided in this time?

Energy = power × time, and power = voltage × current. Hence

$$\textbf{Energy} = VIt = 5\times3\times(10\times60)$$
$$= 9000\,\text{Ws or J} = \mathbf{9\,kJ}$$

Problem 8. An electric heater consumes 1.8 MJ when connected to a 250 V supply for 30 minutes. Find the power rating of the heater and the current taken from the supply.

$$\text{Power} = \frac{\text{energy}}{\text{time}} = \frac{1.8\times10^6\,\text{J}}{30\times60\,\text{s}}$$
$$= 1000\,\text{J/s} = 1000\,\text{W}$$

i.e. **power rating of heater = 1 kW**

$$\text{Power } P=VI, \text{ thus } I=\frac{P}{V}=\frac{1000}{250}=4\,\text{A}$$

Hence the current taken from the supply is 4 A.

Now try the following exercise

Exercise 2 Further problems on e.m.f., resistance, conductance, power and energy

1. Find the conductance of a resistor of resistance (a) 10 Ω (b) 2 kΩ (c) 2 mΩ [(a) 0.1 S (b) 0.5 mS (c) 500 S]
2. A conductor has a conductance of 50 μS. What is its resistance? [20 kΩ]
3. An e.m.f. of 250 V is connected across a resistance and the current flowing through the resistance is 4 A. What is the power developed? [1 kW]
4. 450 J of energy are converted into heat in 1 minute. What power is dissipated? [7.5 W]
5. A current of 10 A flows through a conductor and 10 W is dissipated. What p.d. exists across the ends of the conductor? [1 V]
6. A battery of e.m.f. 12 V supplies a current of 5 A for 2 minutes. How much energy is supplied in this time? [7.2 kJ]
7. A d.c. electric motor consumes 36 MJ when connected to a 250 V supply for 1 hour. Find the power rating of the motor and the current taken from the supply. [10 kW, 40 A]

1.9 Summary of terms, units and their symbols

Quantity	Quantity Symbol	Unit	Unit Symbol
Length	l	metre	m
Mass	m	kilogram	kg
Time	t	second	s
Velocity	v	metres per second	m/s or $m\,s^{-1}$
Acceleration	a	metres per second squared	m/s^2 or $m\,s^{-2}$
Force	F	newton	N
Electrical charge or quantity	Q	coulomb	C
Electric current	I	ampere	A
Resistance	R	ohm	Ω
Conductance	G	siemen	S
Electromotive force	E	volt	V
Potential difference	V	volt	V
Work	W	joule	J
Energy	E (or W)	joule	J
Power	P	watt	W

Now try the following exercises

Exercise 3 Short answer questions on units associated with basic electrical quantities

1. What does 'SI units' mean?
2. Complete the following:
   Force = ... × ......
3. What do you understand by the term 'potential difference'?
4. Define electric current in terms of charge and time
5. Name the units used to measure:
   (a) the quantity of electricity
   (b) resistance
   (c) conductance
6. Define the coulomb
7. Define electrical energy and state its unit
8. Define electrical power and state its unit
9. What is electromotive force?
10. Write down a formula for calculating the power in a d.c. circuit
11. Write down the symbols for the following quantities:
    (a) electric charge (b) work
    (c) e.m.f. (d) p.d.
12. State which units the following abbreviations refer to:
    (a) A (b) C (c) J (d) N (e) m

Exercise 4 Multi-choice questions on units associated with basic electrical quantities (Answers on page 420)

1. A resistance of 50 kΩ has a conductance of:
   (a) 20 S (b) 0.02 S
   (c) 0.02 mS (d) 20 kS
2. Which of the following statements is incorrect?
   (a) $1\,N = 1\,kg\,m/s^2$ (b) $1\,V = 1\,J/C$
   (c) $30\,mA = 0.03\,A$ (d) $1\,J = 1\,N/m$
3. The power dissipated by a resistor of 10 Ω when a current of 2 A passes through it is:
   (a) 0.4 W (b) 20 W (c) 40 W (d) 200 W
4. A mass of 1200 g is accelerated at $200\,cm/s^2$ by a force. The value of the force required is:
   (a) 2.4 N (b) 2,400 N
   (c) 240 kN (d) 0.24 N

5. A charge of 240 C is transferred in 2 minutes. The current flowing is:
(a) 120 A (b) 480 A (c) 2 A (d) 8 A

6. A current of 2 A flows for 10 h through a 100 Ω resistor. The energy consumed by the resistor is:
(a) 0.5 kWh (b) 4 kWh
(c) 2 kWh (d) 0.02 kWh

7. The unit of quantity of electricity is the:
(a) volt (b) coulomb
(c) ohm (d) joule

8. Electromotive force is provided by:
(a) resistances
(b) a conducting path
(c) an electric current
(d) an electrical supply source

9. The coulomb is a unit of:
(a) power
(b) voltage
(c) energy
(d) quantity of electricity

10. In order that work may be done:
(a) a supply of energy is required
(b) the circuit must have a switch
(c) coal must be burnt
(d) two wires are necessary

11. The ohm is the unit of:
(a) charge (b) resistance
(c) power (d) current

12. The unit of current is the:
(a) volt (b) coulomb
(c) joule (d) ampere