# **ELECTRICAL PRINCIPLES**

# FOR THE ELECTRICAL TRADES

**VOLUME 1** 

**6TH EDITION** 

Jim Jenneson and Bob Harper

The **McGraw·Hill** Companies

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# **WorldSkills International Competition**

### CATEGORY: ELECTRICAL INSTALLATIONS

### Australia's Silver Medallist

At just 23 years of age, John Rudge has achieved what many people only dream about—the honour of representing one's country.

After winning a Gold Medal in the Electrical Installations category at the WorldSkills Australia Macquarie Regional Competition in 2005, John progressed to the WorldSkills Australia National Competition in Melbourne 2006, where he won a Gold Medal and the accolade of Australia's Best.

At the 2007 WorldSkills International Competition in Shizuoka, Japan, John competed against the world's best electricians, returning home with a Silver Medal.

'It has been an amazing eye opener to compete at an international level. It has also given me the confidence to tackle any challenge.'

Following his success in Japan, John started a new job with OMYA Australia where his role is to maintain and update PLC software for their five plants throughout Australia and New Zealand. In 2008 John was named the Electrical Installations International Expert, mentoring and training the 2009 Electrical Installations *Skillaroo*, Gavin Press.

'WorldSkills Australia has made me a stronger person and my work is up to international standards, keeping the client, my boss and myself a lot happier.'



John Rudge: 2007 Skillaroo

### WORLDSKILLS AUSTRALIA

WorldSkills is Australia's largest and most prestigious trade and skills competition, encouraging young people to rise to the challenge of stimulating competition. For the past 28 years this not-for-profit organisation has motivated over 70 000 young Australians to participate in WorldSkills Australia programs.

Its mission is to challenge young people, their teachers, trainers and employers to achieve world class standards in work skills and promote the status of vocational education and training across Australia. Through a program of competitions, aligned to the National Training Packages, WorldSkills Australia works to ensure that today's young people have the skills and abilities to compete within a rapidly changing global marketplace.



A portion of the profits from this book will go to WorldSkills Australia.

For further information about WorldSkills Australia competitions visit www.worldskills.org.au.

# Text at a Glance

8.0

### SETTING A CLEAR AGENDA

 $\rightarrow$ 

Each chapter begins with a brief introduction and a list of objectives that the reader can aim to achieve.



conductor, or coil, is rotated within a uniform magnetic field. While DC has advantages in some applications such as portable or mobile power and in most electronic circuits, ac is best for power transmission, transformers, simple motors up to the most powerful electric motors and effects requiring self- or mutual inductance

Pure DC and pure sinusoidal ac allow the easiest mathematical calculations when dealing with circuits and components.

The sine wave is the waveform generated by a theoretically perfect alternator. However, real alternators must be carefully designed and manufactured to generate a perfect sine wave



### WORKED EXAMPLES

Each chapter supports the theoretical aspects by providing practical applications of the theory covered. The theory is illustrated by fully worked examples. These examples give students a template to use when completing similar exercises (e.g. page 39)

EXAMPLE 2.3	C.
Find the amount of zinc deposited by an electrolytic refining bath in 24 hours if the current is 5000 A.	00
 $t = Hours \times Minutes \times Seconds $ (1) = 24 × 60 × 60 (2) = 86400 (seconds) (3)	Q'as
$m = Itz  (4) = 5000 \times 86400 \times 3.39E^{-7}  (5) = 146.5 kg (ans)  (6)$	



### SUMMARY

Each chapter ends with a comprehensive summary listing the core concepts covered, making it an excellent tool for revision and reference (e.g. page 63).

### **EXERCISES**

Each chapter contains Questions to test a student's understanding of the chapter content (e.g. page 114).

### QUESTIONS.

#### Exercises

- Define the term 'inductor' 6.1
- 6.2 List the factors that determine the value of selfinduced EMF. Discuss how each affects the value of self-induced EMF.
- What effect does the core material have on an 6.3 inductor?
- 6.4 Name the unit of inductance and define the unit.
- What is the 'permeability' of free space? 6.5
- 6.6 What is the value of the permeability of free space? 6.7
- What is meant by 'relative permeability'? Give an example
- Give two formulas that could be used to calculate

- 6.16 What is the value of curren time constant?
- 6 17 What happens when a high quickly opened? What adv from this?
- 6.18 List types of inductors and What faults are likely to occ 6.19
- it to fail? 6.20 Explain how you would tes
- if it is a good component.

### Calculations

6.21 An inductance has 200 turn of a hollow 50 mm d

#### Calculations

- 5.21 What is the resistance of a full roll (100 m) of 2.5 mm<sup>2</sup> copper cable based on a resistivity of 1.72  $\Omega$ m? 5.22 How much cable is left of that 2.5 mm<sup>2</sup> roll when the
- resistance of the conductor is only 0.4  $\Omega$ ? What is the resistivity of a 4 mm<sup>2</sup> conductor if 300 m of 5.23
- it has a resistance of 2.13  $\Omega$ ? 5.24 Using the inferred zero method, calculate the 'hot'
- resistance of a set of windings at 90°C that has a resistance of 20 Ω at 20°C. Repeat the calculation for the question above using
- the temperature coefficient method, assuming that the value for alpha is 0.00393.
- If a 3Ø motor winding at room temperature (20°C) 5.26 has the following resistances, 18  $\Omega$ , 18.6  $\Omega$  and 19.2  $\Omega,$  and at full running temperature the resistances are 25.4  $\Omega,$  26.3  $\Omega$  and 27  $\Omega,$  what is the full running



### CALCULATIONS

Calculations are mathematical exercises designed to give the student experience at solving typical problems found in the electrical trades (e.g. page 96).

They cover:

- 1. Power and energy meters
- 2. Greek letters used in the text
- 3. List of the elements
- 4. Standard SI quantities and units used in the text

### **ANSWERS TO SELF-TESTING PROBLEMS**

Answers to calculations are placed at the end of each chapter to allow the student to check the answers (answers are inverted to ensure students think before taking the easy way out) (e.g. page 128).

### **AUXILIARY CHAPTER**

An auxiliary chapter is included at the back of the book for ease of reference and revision of basic concepts, including:

- units and physical quantities
- SI base units
- SI derived units
- multiples and sub-multiples
- scientific notation
- engineering notation

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128			

- transposition
- work, power and energy
- scalar and vector quantities
- periodic table
- characteristics of materials
- formulae
- graphs
- zample pages Greek letters and applications.

### Preface

This sixth edition of *Electrical Principles for the Electrical Trades* is the first volume of a two-volume set, the second volume of which is to be *Electrical Machines for the Electrical Trades* 6th edition, reflecting its original publication as the second part of the original text.

Many of the ideas and suggestions for this edition were forthcoming from an Australia-wide representation of teachers and instructors who have been associated with previous editions of this book.

The symbols used in this book should comply with the latest drawing standards given in SAA/SNZ HB3:1996, as updated. In some cases, more pictorial symbols have been used where doing so assists new students to understand the material. At times I had to make a teacher's decision in selecting which symbol to use, rather than a drafting decision. Colleges and individual teachers quite rightly have their own preferences and this puts me in the invidious position of knowing that I cannot please everyone. So it is!

There have been modifications to the general text to meet other suggestions, but some of these suggestions, while meriting earnest consideration, became somewhat impracticable within the confines of this volume and current teaching practices. Some sections of the text have been deleted and other sections added. Diagrams have in most cases been modified, updated or simply coloured in! Some required corrections and some were simplified, while others were added, amended or deleted as required to match the text.

There were many requests for the book to be modified to fit exactly with the current training package. It is considered unacceptable to adopt this approach, since even a minor change in a competency would immediately make the book almost useless. The text is intended for a greater range of uses and hopefully as a long-term reference for tradespeople. Therefore a more logical approach, a more natural flow or pathway, has returned in this edition. The book was originally written to be used as both a guide for students and, hopefully, as a reference that tradespeople can use for many years.

### ACKNOWLEDGEMENTS

The modifications incorporated in this sixth edition of *Electrical Principles for the Electrical Trades* are the result of the work of many Australian TAFE instructors. This comprises a great deal of hard work undertaken in addition to their normal duties, in their own private time. Particular thanks go to Bob Moore, Kevin Dennis, Dave McKee, Ted Harwood, Drew O'Shea and Peter Waley, all from (Skills Tech Australia), as well as many from other TAFE colleges and RTOs whose comments and suggestions were valued contributions to the revision process. Without their input, the book wouldn't be what it is.

A student's initial studies are usually undertaken with the assistance of an experienced instructor. As a consequence, even with the extensive material within the text, the book should not be expected to stand alone. Individual teachers should have the opportunity to expand the basic theories within this book with practical examples of real, local technology. There are, however, more than enough diagrams to make the text meaningful, while the instructor, as part of the teaching process, is encouraged to supply additional material of direct interest to the particular class.

Each chapter has a summary of its salient points and this is followed by both exercises and calculations. The student exercises and calculations from the previous edition have been updated and changed to reflect the move to 230/400V ac distribution. Many calculations are new, with more examples starting at a simpler level. In general, examples range from the simple, through the chapter material, to challenge questions which require the student to apply the theory to more practical applications. Hopefully teachers will agree that this helps students to learn to apply their newfound knowledge.

### Teacher resources

Teachers may contact me via the McGraw-Hill website or via online feedback on the site for the latest range of resources that are available. Any corrections, omissions, updates or new information will be made available to teachers using this text. There is a solutions manual with full workings on each question from each chapter, in PDF form. More questions are expected to be generated for each chapter and a bank of exam questions is to be developed. Images and diagrams will be available, most likely in PDF format, and some SWF demonstrations are in preparation. Much has been learned in the eLearning field and eMedia materials are expected to become a big part of the average classroom in the future.

### **Bob Harper**

The organisation, production and success of such a book is due to the hard work of not only the editors but many other staff members of McGraw-Hill Australia, particularly Michael Buhagiar (Acquisitions editor), Astred Hicks (Art director), Fiona Howie (Editorial coordinator), Michael McGrath (Production editor) and Mary-Jo O'Rourke (Copyeditor). Thank you all for your good work, advice and support; it is greatly appreciated.

### Bob Harper, Beerwah

### CHAPTER OBJECTIVES

- → understand the factors that affect resistance
- → understand the effect resistance has on circuits
- → understand the effect resistance has on conductors
- → know of the various types of resistor
- → know of special types of resistor
- → understand resistor colour coding
- → know about standard value sets
- → use colour coding in circuit calculations

# Resistors

### CHAPTER

### CHAPTER TOPICS

### 5.0 **RESISTANCE**

- 5.1 FACTORS AFFECTING RESISTANCE
  - 5.1.1 Length
  - 5.1.2 Cross-sectional area (CSA)
  - 5.1.3 Type of material (resistivity)
  - 5.1.4 Temperature
  - 5.1.5 Superconductors
  - 5.1.6 Superconductor applications

### 5.2 EFFECTS OF CONDUCTOR RESISTANCE

- 5.2.1 Power loss in a conductor
- 5.2.2 Current-carrying capacity
- 5.2.3 Voltage drop in conductors

### 5.2.4 Resistance tables

### 5.3 **RESISTOR TYPES**

- 5.3.1 Cast grid resistors
- 5.3.2 Co-axial sheathed elements
- 5.3.3 Wire-wound resistors
- 5.3.4 Carbon-compound resistors
- 5.3.5 Resistor colour-coding
- 5.3.6 Reading resistors
- 5.3.7 Preferred resistor values

### 5.4 NON-LINEAR RESISTORS

- 5.4.1 Positive Temperature Coefficients (PTC)
- 5.4.2 Negative Temperature Coefficients (NTC)

- 5.4.3 Low temperature coefficient resistors
- 5.4.4 Voltage-Dependent Resistors (VDRs)
- 5.4.5 Light-Dependent resistors (LDRs)
- 5.4.6 Non-inductive resistors
- 5.4.7 Liquid resistors

### SUMMARY

### QUESTIONS

Exercises Calculations Answers

## Resistance

5.0

5.1

Resistance is the opposition to current flow or the restriction caused by the atomic attraction between protons and electrons. Resistance was first quantified by Georg Ohm, who established the relationship R = V/I. As current flowing through a resistance results in a voltage drop and heat generation, these two effects are the most common uses of resistors. Resistors are used to limit current flow, reduce voltage and generate heat, which is often used for cooking and lighting.

The resistance value of a conductor is controlled by four factors: length, cross-sectional area, the resistivity of the material used to make the resistor, and the temperature coefficient of the resistance material. Resistors can be labelled with their resistance, tolerance and power dissipation or encoded with a simple code of coloured bands.



# Factors affecting resistance

Electrical resistance is defined as the opposition to current flow, but what factors affect resistance? To begin with, there are two categories of materials that must be recognised. Ohmic materials are materials that have a fixed resistance regardless of the applied voltage. The voltage versus current graph will be a straight line showing a constant resistance value. Most common resistors are ohmic resistors and so the word ohmic is generally not mentioned.

In electronics, non-ohmic resistors change their resistance according to some other parameter such as applied voltage, pressure, temperature etc. Again the particular type of resistor is named and the word non-ohmic is not normally used. Examples of non-ohmic resistors are tungsten lamp elements, photo-resistors, voltage-dependent resistors and temperature-sensitive resistors.

All parts of an electric circuit offer resistance to current flow: the supply source, the conductors and the load. Even the chemicals inside a battery have resistance that changes with temperature, state of charge and the gases desolved in the electrolyte. To understand resistance, and therefore electric circuits, students need to recognise that resistance is most commonly determined by four factors:

- length
- cross-sectional area
- type of material
- temperature.

### 5.1.1 LENGTH

Electrical resistance is associated with the collisions between moving electrons (the electric current) and the atoms of the conducting material. Just like driving down a road, the risk of having a collision increases the further one travels. In fact, travelling twice the distance doubles the risk of a collision. That is, the resistance of a conductor is proportional to its length.



Prove this quite simply by measuring the resistance of the active conductor in a 100 m roll of 1 mm<sup>2</sup> cable (it should be about 1.7  $\Omega$ ). Then measure the resistance of the neutral conductor (yes, about 1.7  $\Omega$ ). Finally, measure the resistance of both the active and neutral joined together in the middle of the roll (i.e. now 200 m of wire). The resistance should be twice the resistance of either wire, as the total length is twice as long (approximately 3.4  $\Omega$  or twice what was measured for one wire).

### 5.1.2 CROSS-SECTIONAL AREA (CSA)

The roll of cable used above should be labelled  $CSA = 1 \text{ mm}^2$ . That is the area of the end of the wire if it is cut across at 90°, which is known as the cross-section

of the wire. The area of the cross-section is called the cross-sectional area or CSA (not to be confused with the diameter).

If the CSA is doubled, then it is easy to imagine that more electrons can pass easily down the wire, and therefore the wire will have less resistance. We say that the resistance is proportional to the inverse of the CSA. In other words, as the CSA increases, the resistance decreases.

### $R \propto 1/A$

Using the roll of cable again and knowing the resistance of the conductors, connect both ends together, which is the same as increasing the CSA to 2 mm<sup>2</sup> or double what it was. The resistance of 100 m of 2 mm<sup>2</sup> wire should be half the resistance of one wire (approximately 0.85  $\Omega$ ).

### 5.1.3 TYPE OF MATERIAL (RESISTIVITY)

The effect of the length and CSA of the conductors are easy to prove, as shown above, trusting that the figures measured were reasonably close to those predicted. So how can the resistance values be predicted? A roll of cable should of course have the same resistance as any other roll of the same length and CSA, so it might be that, as an electrician or teacher, I have measured another roll at some time. I have, but there is a better answer; one that is based on the material used as the conductor.

The copper used to make the wire has a known value of resistance. A cube of copper 1 m on each side has a resistance approximately  $1.7E-8 \Omega$ . That's a very small resistance for a large lump of copper, around 9 tonnes, so a more manageable size is used such as 100 m of wire with a constant CSA of 1 mm<sup>2</sup>, which will have a resistance of 1.7241 ohms.

The standard of one square metre of material one metre long is based on the SI system, but no lab would attempt to measure the resistance of such a large lump of material. Instead a sample, such as our 100 m of 1 mm<sup>2</sup>, is used and the resistivity is calculated mathematically. Resistivity is given the Greek letter 'rho' ( $\rho$ ) which looks like a rounded 'p' (pronounced 'rho').

### $\mathbf{R} \propto \rho$

Resistivity of a material is defined as the resistance between the opposite faces of a 1 metre cube at a specified temperature (e.g. 25°C)

### $\rho = \text{RA/l}$

or transposing to define R:

### $\mathbf{R} = \rho \mathbf{l} / \mathbf{A}$

where  $\rho$  = resistivity.

Knowing the resistivity of any material, the resistance of any conductor can be calculated, due allowances being made for temperature differences where necessary. In Table 5.1, some electrical materials are listed together with their resistivity values.

	Resistivity ( $\rho$ ) @	
Conductor	20° C	Use
Aluminium	<b>2.83 E–8</b> Ωm	Pure metals used
Copper	1. <b>72 Ε–8</b> Ωm	for conductors
Gold	<b>2.44 E–8</b> Ωm	
Lead	<b>2.04 E–8</b> Ωm	
Platinum	10.09 E–8 Ωm	
Silver	1.63 E–8 Ωm	
German silver	<b>33 Ε–8</b> Ωm	Alloys used as
Advance	<b>49 Ε–8</b> Ω <b>m</b>	resistance wire
Manganin	<b>48 Ε–8</b> Ω <b>m</b>	
Nichrome	112 F-8 Om	

**TABLE 5.1** RESISTIVITY OF SELECTED MATERIALS

The values given in the table are given in ohm-metres because the formula  $R(\Omega) \times A(m^2)/l(m)$ , when simplified, becomes: RA/l ( $\Omega$ m) i.e m<sup>2</sup>/m = m.

Note that the resistivity also changes depending on whether the material is mechanically hard or soft. Annealed copper has a higher resistivity than hard copper.

The resistivity of a conductor also depends on the purity of the material and the nature of any gaseous inclusions in the material. Hi-fi speaker installers pay higher prices for 'oxygen-free' speaker leads.

Table 5.1 shows that silver has the least resistance, closely followed by copper, but copper is less expensive than silver so copper is used extensively as an electrical conductor.

The four materials listed at the end of the table are alloys that are generally used for making resistors; that is, they restrict the flow of electricity far more than those above them.

Note: When calculating the resistance of a solid material, there are 1000  $\times$  1000 square millimetres in a square metre, 1 m<sup>2</sup> = 1E-6 mm<sup>2</sup>.

EXAMPLE 5.

Find the resistance of a copper cable 500 m in length if it has a cross-sectional area of 2.5  $mm^2$ . Take the resistivity of copper to be 1.72E8  $\Omega$ m.

Note that  $2.5 \ mm^2$  is  $2.5E-6 \ m^2$ .

$$R = \frac{\rho l}{A}$$
(1)  
$$= \frac{1.72E - 8 \times 500}{2.5E - 6}$$
(2)  
$$= \underline{3.44 \Omega} (ans)$$
(3)

### EXAMPLE 5.2

If 100 m of copper cable has a resistance of 1.35  $\Omega$ , what is the resistance of 1000 m of the same cable?

Note: R is proportional to length,

1000 <i>m</i> is $10 \times 100$ <i>m</i> ,	(1)
$\therefore R_2$ is 10 $ imes$ 1.35 $\Omega$	(2)
$=$ 13.5 $\Omega$ (ans)	(3)

### EXAMPLE 5.3

To manufacture a 15  $\Omega$  resistor from 0.2  $mm^2$  cross-sectional area manganin wire, what length of wire is required?

$\rho = 48E - 8 \Omega m$	(1)
(from Table 5.4)	(2)
-1	

$$R = \frac{p_i}{A} \tag{3}$$

$$l = \frac{RA}{\rho} \tag{5}$$

$$= \frac{15 \times 0.2E - 6}{40E - 9} \tag{6}$$

(4)

$$= 6.25 m (ans)$$
 (7)

### 5.1.4 TEMPERATURE

In all of these calculations, the resistance value is accurate only at 20°C. As the temperature increases or decreases, allowances may have to be made for a change in resistance.

For some materials, an increase in temperature causes an increase in resistance; these materials are said to have a 'positive temperature coefficient' (PTC). When a material has a lower resistance at higher temperatures, it is said to have a 'negative temperature coefficient' (NTC). Some resistors are made from specific materials to take advantage of these characteristics.

The temperature coefficient of resistance is defined as the change in resistance per ohm per degree Celsius (or Kelvin).

Resistivity values are specified at a particular temperature because resistance can change with temperature. The resistance of most metallic conductors increases with temperature (PTC) and over a limited range. The increase is a linear function of temperature or very close to it within that range. This leads to a method of calculating the resistance of conductors at another temperature by what is called the inferred zero method. The inferred zero value varies for different materials, but the method is illustrated in Figure 5.1.



Copper has an inferred zero resistance at  $-234.5^{\circ}$ C and the increase of resistance plotted against temperature is basically linear. The resistance of a length of copper wire can be given as a resistance of R<sub>0</sub> at 0°C and the increase in resistance per degree C will continue to be linear through R<sub>1</sub> and R<sub>2</sub>. Therefore, at any temperature significantly above  $-234.5^{\circ}$ C, the resistance can be calculated from any other known resistance at a known temperature. The calculation is a simple ratio:

### $R_2/R_1$ proportional $t_2/t_1$ .

Temperatures are normally taken as relative to  $0^{\circ}$ C, so the formula needs to recognise the inferred zero resistance at -234.5°C plus the resistor temperature.

$$R_2 = R_1 \frac{234.5 + t_2}{234.5 + t_1}$$

where:  $R_1$  = resistance at temperature  $t_1$  $R_2$  = resistance at temperature  $t_2$ 

EXAMPLE 5.4

The resistance of a coil of copper wire is  $34 \Omega$  at  $15^{\circ}$ C. What would be its resistance at  $70^{\circ}$ C?

$$R_{2} = R_{1} \frac{234.5 + t_{2}}{234.5 + t_{1}}$$
(1)  
=  $34 \times \frac{234.5 + 70}{234.5 + 15}$ (2)  
=  $34 \times \frac{304.5}{249:5}$ (3)  
=  $41.49 \Omega$  (ans) (4)

An electric motor may be tested to see how hot the windings become in full load use. To measure the temperature directly would require the motor to be disassembled for a temperature probe to be inserted into the windings, but another method is often used.

The motor winding resistance is measured when the motor is cold and then measured immediately after the motor is shut down. The temperature can be calculated from the cold temperature and the resistance change of the windings using the formula above.

EXAMPLE 55

A motor at 20°C has a winding resistance of 16  $\Omega$ . After running up to temperature at full load the resistance is measured as 24.8  $\Omega$ . What is the temperature of the windings?

$$R_{2} = R_{1} \left[ \frac{234:5 + t_{2}}{234:5 + t_{1}} \right]$$
(1)  
transposition: (2)

by transposition:

$$t_2 = \frac{R_2}{R_1} \times (234.5 + t_1) - 234.5$$
(3)

$$= \frac{24.8}{16} \times (234.5 + 20) - 234.5 \tag{4}$$

$$= 1.55 \times 254.5 - 234.5 \tag{5}$$

 $= 160^{\circ}C (ans)$ (6)

Resistance values can also be calculated from the temperature coefficient of resistance, which is defined as the change in resistance per ohm per degree change in temperature (symbol  $\alpha$ , pronounced 'alpha').

### $\alpha = \frac{\text{Change in resistance per }^\circ\text{C}}{}$ Resistance at t,

Table 5.2 opposite lists a selection of conductors and the temperature coefficients of resistance for those conductors at 0°C and 20°C

For most metals, the change in resistance per ohm per °C is relatively constant, but the coefficient does change as temperature changes. The temperature at which the value of the coefficient is effective is usually given by a subscript to the symbol (e.g.  $\boldsymbol{\alpha}_{_{0}}$  and  $\boldsymbol{\alpha}_{_{20}}$  , indicating the temperature coefficients at 0°C and 20°C respectively).

Mathematically, the new resistance can be calculated by adding the change in resistance to the original resistance, which in turn is the change in temperature multiplied by the temperature coefficient.

$$R_{2} = R_{1}[1 + \alpha (t_{2} - t_{1})]$$
where:  

$$R_{1} = \text{resistance at temperature } t_{1}$$

= resistance at temperature  $t_{a}$ 

= temperature coefficient of resistance  $(\Omega / \Omega / \circ C)$ 

Temperature coefficient of resistance (Ω/Ω/° <b>C</b> )		
Conductor	α	α_20
Aluminium	0.004 23	0.003 9
Copper	0.004 27	0.003 93

**TABLE 5.2** TEMPERATURE COEFFICIENTS OF RESISTANCE

Copper	0.004 27	0.003 93
Gold	0.003 68	0.003 43
Lead	0.004 11	0.003 9
Platinum	0.003 67	0.003 9
Silver	0.004	0.004
Zinc	0.004 02	0.004
German silver	0.000 4	0.000 4
Advance	0.000 02	0.000 02
Manganin	0.000 01	0.000 01
Nichrome	0.000 2	0.000 2

EXAMPLE 5.6

A copper conductor has a resistance of 10  $\Omega$  at 0°C. Find the value of its resistance at 25°C.

$R_2$	$= R_{1}[1 + \alpha (t_{2} - t_{1})]$	(1)
	$= 10 \times [1 + 0.00427 \times (25 - 0)]$	(2)
	$= 10 \times [1 + 0.00427 \times 25]$	(3)
	$= 10 \times [1 + 0.10675]$	(4)
	$= 10 \times 1.10675$	(5)
	$= 11.0675 \Omega (ans)$	(6)

Note: Do the sums within the brackets first!

EXAMPLE 5

Copper conductors of 2.5 mm<sup>2</sup> cross-sectional area are supplying a current of 15 A to an airconditioner. If the conductors have a total resistance of 0.43  $\Omega$ , calculate the power lost in the conductors.

)	$= I^2 R$	(1)
	$= 15^2 \times 0.43$	(2)
	$= 225 \times 0.43$	(3)
	= 96.75 W (ans)	(4)

#### SUPERCONDUCTORS 5.1.5

Many materials produce an effect known as 'superconductivity' when they are cooled below a certain temperature.

Even lead is a superconductor at around -256.8°C. At the critical temperature, electrons can pass through the material with seemingly zero resistance. Other materials, mostly pure metals and some special alloys, have different critical temperatures but exhibit the same total lack of resistance below that temperature.

Since a superconductor has no resistance, once a current flow is initiated the current will continue to flow at the same value without an applied potential. If a conductor has no resistance, then current flow through it generates no heat. If no heat is generated in a conductor, the amount of current passed through it can be increased far beyond normal values.

The current flowing through a superconductor creates a magnetic field that becomes equal and opposite to any applied magnetic field, with the result that extremely powerful electromagnets can be constructed.

Research has been done for many years in an endeavour to produce a superconductor effect at higher temperatures. Although breakthroughs could occur at any time, at the time of writing superconductors still need to be chilled to temperatures well below freezing point, below the temperatures where most gases become liquids.

Although materials may be made superconductive, it has been discovered that their current capacity is not

unlimited, and current over a certain level destroys the superconductivity.

### 5.1.6 SUPERCONDUCTOR APPLICATIONS

### **Magnetic levitation**

Japan and other countries are investigating the use of superconductors to levitate electric trains. The use of ceramic magnets operating in liquid nitrogen allows very strong electromagnetic fields to support the trains so that they float above their tracks. With no friction they can travel much faster and more quietly than conventional trains.

### Magnetic Resonance Imaging (MRI)

Powerful electromagnets are used to excite atoms which then give off telltale radio frequencies that are used to generate images of the human body in far greater detail than any X-ray technology.

### Particle accelerators

Extremely strong magnets are used to accelerate atomic particles to very high speeds and energy levels, in order to smash atoms into their parts for study by physicists.

# Effects of conductor resistance

The size of the conductors used to supply electrical equipment is governed by the current-carrying capacity of the conductor for that installation and the voltage drop of the conductors.

### 5.2.1 POWER LOSS IN A CONDUCTOR

In a conductor supplying a load, there is an inherent resistance and a current flowing through that resistance. Accordingly, the power consumed in the conductor is 'lost' as far as the load is concerned. This loss shows up as heat, by raising the temperature of the conductor and its surrounding insulation. Heat lost in the conductors is waste which reduces the efficiency of the circuit.

This is almost equal to the heat produced by a 100 W incandescent lamp. For each hour the load is connected, 348.3 kJ of heat is lost.

### 5.2.2 CURRENT-CARRYING CAPACITY

For each size of conductor, there is a value of resistance (R =  $\rho$ l/A), so the power loss per unit length will depend on the current passing through the cable. The heat

produced causes the conductor temperature to rise and, if the conductor temperature exceeds the temperature rating of the cable, the insulation can be damaged. Depending on the installation, heat may not be dissipated and a fire could result.

Because the current flowing through the conductor generates heat, standards have been determined which govern the maximum amount of current that can be allowed to flow in a conductor in an installation. A conductor in the open air can lose heat more readily than if it were one of several conductors in a conduit, all generating heat. Standards Australia recommends currentcarrying values for conductors and these are listed in the *Australian Wiring Rules*, which are generally adopted throughout Australia.

### 5.2.3 VOLTAGE DROP IN CONDUCTORS

In Example 5.7, mention was made of power loss due to the conductor resistance. Associated with this is a voltage drop (Ohm's Law, V = IR). The Standards Australia publication *AS 3000* also stipulates the maximum conductor voltage drop. The rule states that the voltage

0°e

(5)

drop is not to exceed 5 per cent of the supply voltage; this means that, on a 230 V supply, 11.5 V is the maximum allowable voltage drop.

EXAMPLE 5.8

In example 5.7, where the conductor resistance is 0.43  $\Omega$  and the current is 15A. V = IR, the voltage drop is equal to  $15 \times 0.43$  or 6.45 V. (Less than 11.5 volts so the circuit is acceptable.)

If the circuit run is 25m long, what is the voltage drop per metre? (*ans A*)

How long could the cable run be before the allowable voltage drop was exceeded on a 230V supply? (*ans B*)

$$V_{d/m} = \frac{V_d}{Length} \tag{1}$$

$$=\frac{0.43}{25}$$
 (2)

$$= 0.258 V/m (ans A)$$
 (3)

$$V_d = V_{d/m} \times Length$$
 (4)

$$ength = \frac{V_d}{V_{d/m}}$$
(6)  
11.5

$$\begin{array}{c} 0.258 \\ = 46.5 \ m \ (ans \ B) \end{array} \tag{7}$$

### 5.2.4 RESISTANCE TABLES

I

Conductor resistance can be established comparatively easily by reference to appropriate tables such as in *AS 3000*. The nominal resistance is given in ohms per 1000 metres of cable and, by proportionate scaling either up or down, the resistance of any particular length of conductor can be obtained. For example, for 10 mm<sup>2</sup> cable the resistance of 1000 m is 1.79 ohms. The resistance of 100 m would then be 0.179 ohms.

Care should be taken that the values expressed in *AS 3000* are not identified with the value given for the resistivity of copper as given in Table 5.1. The resistivity value given in Table 5.1 is for 100 per cent pure copper, while the purity of commercial copper conductors is in the region of 95 per cent. Effectively the resistance of electrical cables is about 4–5 per cent higher than that of pure copper at the same temperature.



# Resistor types

An electrical component that has the property of opposing current flow, and hence causing a voltage drop, has resistance and is naturally called a resistor. Resistors are used in circuits to limit current flow, reduce voltage or produce heat or light.

Electric stoves use resistors to generate the heat that is used to cook food. Electric light bulbs are resistors that are driven with such a high current that they emit heat at such a high temperature that they produce light.

One of the most common uses of electricity is to produce heat and light, and resistors are the main method employed. Remember that a heating element, or lighting filament, is another type of resistor.

Any conductor connecting a load to a supply has resistance, but is not called a resistor unless the resistance is drawn in a circuit for circuit analysis.

In conductors, resistance is considered a disadvantage, since unwanted voltage drop and heat are generated. Conductors must therefore be made of low-resistance materials such as copper or aluminium, and be made thick enough that the resistance is not noticed. Insulators have a very high resistance, but this is low enough that most insulators have a small leakage, perhaps just a few nano-amps. Resistance can also result from current passing through a liquid or gas or a semiconductor.

For most electrical work, resistors are constructed from alloys of metals or from conductive chemical compounds. A few materials have non-ohmic properties, and they are used to make non-linear resistors that change their resistance when exposed to heat or light.



Resistors are chosen according to a number of parameters, including their resistance, current-carrying capacity, voltage rating and power dissipation. Generally the size of a resistor is determined by all of these parameters.

### 5.3.1 CAST GRID RESISTORS

Large high-power resistors were once commonly cast from iron or an iron alloy. They may be cooled by forced air blown over the resistors, or by a liquid such as water flowing through a hollow core. Cast resistors are generally used only where a very high current needs to be controlled, such as for speed control of winding motors for large lifts and cranes, and traction motors.

### 5.3.2 CO-AXIAL SHEATHED ELEMENTS

The heating elements used in electric stoves, electric frypans and strip heaters are commonly made from a resistive conductor inside an insulating ceramic powder, which is in turn within an earthed metal sheath. As used in stoves, the element heats the sheath to a cherry-red temperature if left without a cooking utensil in place. That's around 660°C; hot enough to melt aluminium if an empty saucepan were to be left on the element unattended!

### 5.3.3 WIRE-WOUND RESISTORS

Smaller resistors, from 5 watts to several hundred watts, are commonly made by winding a resistance wire around



Resistors

a ceramic former. An insulating layer is generally used to cover the wire, not only as insulation but also to protect the wire from damage and corrosion. Large resistors, designed to dissipate a lot of heat, generally have a large surface area or some other means of conveying the heat away from the resistor. Some resistors come in their own finned heatsink.

Wire-wound resistors are usually large enough to have their resistance and power rating printed on the body of the resistor.

Some wire-wound resistors are made to be tapped or adjusted and some are even able to be adjusted by the operator via a panel-mounted shaft and knob.

Resistors that can be adjusted by a moving tap may simply be called adjustable resistors, while resistors that can be controlled from a control panel are often called variable resistors. In between there is a class of resistors that are intended to be adjusted by using a tool such as a screwdriver, and they are known as trimmer resistors or preset resistors.

### 5.3.4 CARBON-COMPOUND RESISTORS

Carbon-compound resistors are physically smaller and have lower power ratings. Common ratings are <sup>1</sup>/<sub>4</sub> W, <sup>1</sup>/<sub>2</sub> W, 1 W and 2 W. The construction of a carbon-compound resistor is shown in Figure 5.2. The resistive material is placed on the ceramic tube and laser cut into the spiral to attain the exact resistance required (within the tolerance required). During manufacture, the thickness and composition of the compound can be varied to make resistors of different values between 0.01  $\Omega$  and 10 M $\Omega$ .

Carbon-compound resistors are small, so their resistor size and rating cannot easily be printed on them. This has led to the development of a standard colour-coding scheme for identification. The coloured bands on fixed-value resistors are placed closer to one end of the body during manufacture.

Carbon-compound resistors can age and their resistance can change as they age, so a better type of small resistor has had to be used instead. The metal-film resistor is similar to the carbon resistor in size and looks. Only the base colour of the resistor identifies it as not being a carbon resistor. Carbon resistors have a brown or cream base colour, while metal-film resistors are normally blue or green.

Carbon-film variable resistors are also manufactured, by applying a conductive paint to a phenolic base material. A wiper contact slides over the conductive paint to allow the terminal resistance to be controlled.

Variable resistors with three terminals are often called 'potentiometers' as their main function is to control a voltage. Two-terminal variable resistors that are normally used to control a current are known as 'rheostats'. Often a three-terminal potentiometer will have the middle terminal connected to one end to make it into a rheostat, even though it may still be called a potentiometer or 'pot' for short. The volume control on a conventional radio is an example of a variable resistor.

### TABLE 5.3 RESISTOR COLOUR CODES

	7			
Colour	Value	Multiplier	Ехр	Tolerance
black	0	1	E0	
brown	1	10	E1	1%
red	2	100	<b>E2</b>	2%
orange	3	1 000	E3 (F	cilo)
yellow	4	10 000	E4	
green	5	100 000	E5	0.5%
blue	6	1 000 000	E6 (I	Mega)
violet	7			
grey	8	—		
white	9	_		
gold		—	E-1	5%
silver		—	E-2	10%
none				20%

### 5.3.5 RESISTOR COLOUR-CODING

Resistors and other components may be so small that, in the past, writing the value on them was impossible with the manufacturing processes of the day. Ironically, as component sizes have decreased to the requirements of 'surface-mount devices' found in modern electronic circuits, writing the value has become the method of choice. Reading very thin coloured lines is more difficult than reading the values when the device is as small as  $0.8 \text{ mm} \times 1.2 \text{ mm}.$ 

The resistor colours are listed in Table 5.3 but the colours can remembered using a mnemonic such as 'Barney's bull ran over your great big violet garden, why?' to represent black-brown-red-orange-yellow-green-blue-violet-grey-white. Otherwise, simply memorise the colours by noting that the list progresses from black to white through a natural spectrum. The quickest way to learn the colours is by handling and identifying resistors, for instance by sorting them for a grateful teacher.

### 5.3.6 READING RESISTORS

Look at the resistor and identify which end the main group of colours is nearest to. On four-band resistors, the colours are all together at one end. Make that end the left

### EXAMPLE 5.10

Determine the resistance values for the following resistors:



end, by turning the resistor into that position. This is best explained with a particular resistor in mind. Let's assume a resistor has four colour bands: red, violet, yellow and gold. Reading from the band nearest to the end, the first band indicates the first significant figure and the second band the second significant figure. That is the value of the resistance. In our example, these are red and violet, which are 2 and 7 in that order. That makes the value 27. The next band is the multiplier, so the colour here simply specifies the number of zeros to write after the value. In our example, the fourth band is yellow, which means four zeros. So the resistance is 270,000 ohms or 270 k $\Omega$ .

The final band on our resistor is the tolerance. Gold represents a tolerance of 5 per cent which indicates that the resistor has been made to be 270 k $\Omega$  +/-5 per cent, or +/-54 k $\Omega$ . So the value will be between 216 k $\Omega$  and 324 k $\Omega$ . With 1 per cent or better resistors, there are three significant figures in the value.

The gold and silver colours are mainly used in the fourth band (tolerance), but on small values of resistance, less than 10  $\Omega$ , gold and silver are multipliers of 0.1 and 0.01 respectively.

### 5.3.7 PREFERRED RESISTOR VALUES

Manufacturers cannot be expected to produce resistors in every possible value, so initially only the most common values were produced. Later a plan was adopted to make specific values, which would have overlapping or very nearly overlapping tolerances.

For example, on the 10 per cent tolerance scale, 10% of 10  $\Omega$  is 1  $\Omega$ . Approximately twice 10 per cent (1  $\Omega$ ) distant, there should be another standard value resistor, and that means 12  $\Omega$ . The tolerance of the 12  $\Omega$  resistor is 1.2  $\Omega$ , and 12  $\Omega$  plus twice that, 2.4  $\Omega$ , is almost 15  $\Omega$ . The tolerance of the 15  $\Omega$  resistor is actually 1.5  $\Omega$ , so 1.5  $\Omega$  plus 1.2  $\Omega$  is actually 2.7  $\Omega$ , so the tolerances very nearly overlap. Therefore the E12 scale very nearly covers the whole range from 10 to 100  $\Omega$ , and then starts over again in another decade. The next decade has values from 100–1000  $\Omega$  and so on. Table 5.4 shows the preferred values for three E series of tolerances. Note that there is also an E48 range which, naturally enough, has 48 values.

E6	E12	E24
20% tolerance	10% tolerance	% tolerance
10	10	10
		11
	12	12
		13
15	15	15
		16
	18	18
		20
22	22	22
		24
	27	27
		30
33	33	33
		36
	39	39
		43
47	47	47
		51
	56	56
		62
68	68	68
		75
	82	82



5.4

# Non-linear resistors

Resistance varies according to temperature and the type of material used to make the resistor. Non-ohmic resistors exist that change resistance according to other physical parameters such as voltage, current flow and magnetism. These resistors are useful as sensors in instrumentation. Variable resistors are otherwise known as 'transducers'.

### 5.4.1 POSITIVE TEMPERATURE COEFFICIENTS (PTC)

Metals generally have a positive temperature coefficient of resistance, but a PTC resistor is one in which the change in resistance is greatly increased over that of a normal conductor. Two main materials are used. One is a metallic oxide such as barium oxide, which has a large PTC over a limited range; the other is silicon-based, with a smaller PTC over a larger range.

The typical characteristic is shown in Figure 5.3 (a). The usual method is to show the resistance values on a logarithmic scale, but in order to show the sharp knee of the curve as the PTC heats up, a representative curve has been drawn from test results on an actual resistor. It can be seen that the resistance is only 4  $\Omega$  at room temperature, but rises rapidly once the temperature rises above about 50°C.

### 5.4.2 NEGATIVE TEMPERATURE COEFFICIENTS (NTC)

NTC resistors are made from oxides of chromium or nickel that have been modified by the addition of small amounts of semiconductor material. Similar tests were conducted on an NTC resistor and the results are shown in Figure 5.3 (b). Again the usual logarithmic scales have been avoided. The test resistor had a resistance of 2000  $\Omega$  at room temperature of 10°C and when raised to 80°C the resistance fell to 4  $\Omega$ . The characteristic is shown in Figure 5.2 (b).

### 5.4.3 LOW TEMPERATURE COEFFICIENT RESISTORS

In some circumstances a resistor is required to retain its value over a range of temperatures. One such material is manganin which has a temperature coefficient of resistance given as 0.00001 (1E–5)  $\Omega/\Omega/^{\circ}C$ . Its resistance



change is so small compared to other metallic elements generally that it is often listed as zero. Manganin is used where resistors of high-temperature stability are required, for instance in measuring instruments.

#### **VOLTAGE-DEPENDENT RESISTORS** 5.4.4 (VDRS)

A voltage-dependent resistor is manufactured from a mixture of materials to have a very high resistance at lower voltages, but a very low resistance above a certain critical value. A VDR is usually presented in disc form with two leads for connection into a circuit. The VDR is connected in parallel with the voltage supply, close to the circuit it has to protect. The VDR normally does not conduct but, when the supply voltage exceeds a designed limit, the VDR breaks down and conducts the excess energy away from the circuit it is protecting.

The primary purpose of a VDR is to protect equipment against voltage surges such as lightning strikes. The response time is extremely quick, an obviously necessary characteristic.

In some circuits, VDRs are intended to blow a fuse or trip a circuit breaker to isolate the electric circuit being protected. Sometimes a VDR is built into a package called a surge protector, which can be installed in the main switchboard or on the consumer's terminals. Depending on the individual device and on the severity of the surge, a VDR might have to be replaced after it has operated.



Figure 5.6

#### 5.4.5 LIGHT-DEPENDENT RESISTORS (LDRS)

Light-dependent resistors are used to detect light levels such as in PE (photo-electric) cells on power poles to turn street lights on and off, or to control other night lighting. When light falls on the resistor, the resistance changes and an electronic circuit senses that change to turn a relay or solid-state switch on or off.

Light-dependent resistors are usually made from cadmium-sulphide film mounted on a ceramic or phenolic plate and covered with a conductive grid. To ensure there is no buildup of contamination and to protect the active material, the resistor is mounted in an evacuated glass envelope or covered with a clear plastic encapsulation.

The resistance of the device varies considerably with the amount of light received on the surface. Typically the resistance in complete darkness can be as high as 10 M $\Omega$ , reducing to possibly 100  $\Omega$  in sunlight. The construction and characteristic curve is shown in Figure 5.4.

#### 5.4.6 **NON-INDUCTIVE RESISTORS**

At times, resistors are required to be as purely resistive as possible. This means as little inductance as possible. (Note that inductance is treated in the next chapter.)

To avoid inductance, which is simply a coil of wire, the wire-wound resistor is wound back on itself, to hopefully cancel any inductive effect.

#### LIQUID RESISTORS 5.4.7

A recent innovation in resistances for motor starters uses a liquid which is stored in a tank as the resistance. Two electrodes conduct the power to the resistance. The resistance is free to cool through convection and conduction through the tank suface, so the tank size can be designed to suit the dissipation required of the resistance.

One advantage of liquid resistance is that the resistance value decreases as the temperature rises (NTC), which is useful for motor starters. Liquid resistors will be explained further in Volume 2, Electrical machines.



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- The resistance of a metallic conductor is governed by four factors.
- Resistance increases as length increases:

### R ∝ L

 Resistance increases as cross-sectional area (CSA) decreases:

 $R \propto 1/A (1/CSA)$ 

• Resistance increases as resistivity increases:

### **R** ∝ ρ (**rho**)

• Resistance of a conductor can be calculated from:

$$\mathbf{R} = \rho \mathbf{L} / \mathbf{A}$$

- Resistivity is the resistance per cubic metre of a material i.e. the resistance of a cube of the material 1 m x 1 m x 1 m, measured between two of the faces.
- The unit of resistivity is the ohm-metre e.g. copper is 1.72E–8  $\Omega m.$
- Resistance increases as temperature increases in positive temperature coefficient materials (PTC).
- Resistance decreases as temperature increases in negative temperature coefficient materials (NTC).
- The resistance at a given temperature may be calculated by several methods:
  - Inferred zero method for copper, the inferred zero resistance occurs at -234.5°C. Resistance can be calculated from:

 $R_2 = R_1[234.5 + T_2]/[234.5 + T_1]$ 

– Temperature coefficient method — for copper at 20°C,  $\alpha$  = 3.93E–3. Resistance can be calculated from:

### $R_2 = R_1[1 - \alpha(T_2 - T_1)]$

- $\alpha$  changes as temperature changes.
- Superconductors have zero resistance at very low temperatures.

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### Exercises

- 5.1 What factors affect the resistance of a conductor?
- 5.2 How does length affect resistance?
- 5.3 How does CSA affect resistance?
- 5.4 How does resistivity affect resistance?
- 5.5 How is resistivity defined?

- Resistance in a conductor results in voltage drop, limitation of current flow and heat generation.
- Excess current flow results in heat being generated that increases the temperature of a conductor, possibly burning the insulation or melting the conductor.
- Resistors are conductors made from high-resistance materials.
- Resistors made of special alloys have a resistance that is constant over a wide range of temperatures.
- Resistors are ordered by their resistance value and their power dissipation value e.g.  $100 \Omega 5W$ ,  $27\Omega 100 W$ .
- Dissipation means the amount of power that can be safely dissipated by a resistor in ambient air (free airflow at 25°C).
- Carbon-compound resistors are low-power components with low inductance.
- Metal-film resistors are more reliable than carboncompound resistors but have higher inductance.
- Wire-wound resistors are applicable to high power ratings.
- Small and low-power dissipation resistors have coloured bands to indicate their resistance value.
- The resistor colour code is: black-brown-red-orangeyellow-green-blue-violet-gray-white.
- Resistors are made in a range of preferred values and tolerances known as E series e.g. E12, E24.
- Power resistors often have the decimal point in the resistance value replaced by a letter representing the multiplier value e.g. R = ohms, k = kilo-ohms, M = Megaohms i.e 47R = 47 ohms, 6k8 = 6800 ohms, 1M2 = 1.2 Megaohms, etc.
- Thermistors are resistors designed to change their resistance as the temperature changes (PTC or NTC).
- Varistors are resistors designed to change their resistance as the voltage changes.
- Photoresistors are resistors designed to change their resistance as the light level changes.

- 5.6 How does temperature affect resistors?
- 5.7 What do PTC and NTC mean when speaking about resistance?
- 5.8 How can resistance be calculated when length, CSA and resistivity are known? What formula is used?
- 5.9 What is meant by the 'inferred zero method' of calculating resistance after the temperature

has changed? What formula is used for copper conductors?

- 5.10 What is meant by the 'temperature coefficient method' of calculating resistance after the temperature has changed? What formula is used?
- 5.11 Which method of calculating resistance after the temperature has changed is best for aluminium conductors?
- 5.12 What is a superconductor?
- 5.13 What are the effects of resistance in a circuit?
- 5.14 How does voltage drop affect a circuit?
- 5.15 What problems are caused by the heat generated by the resistance of a conductor?
- 5.16 What two values are specified when resistors are ordered?
- 5.17 How is heat dissipated from a resistor?
- 5.18 What is the colour code for resistors? What colours are there and what do the colours define?
- 5.19 What is meant by 'preferred values' when referring to resistors used in electronics?
- 5.20 Define 'thermistor' (PTC and NTC), 'varistor' and 'photoresistor'. Give an example of how each is used.

### Calculations

- 5.21 What is the resistance of a full roll (100 m) of 2.5 mm<sup>2</sup> copper cable based on a resistivity of 1.72  $\Omega$ m?
- 5.22 How much cable is left of that 2.5 mm<sup>2</sup> roll when the resistance of the conductor is only 0.4  $\Omega$ ?
- 5.23 What is the resistivity of a 4 mm<sup>2</sup> conductor if 300 m of it has a resistance of 2.13  $\Omega$ ?
- 5.24 Using the inferred zero method, calculate the 'hot' resistance of a set of windings at 90°C that has a resistance of 20  $\Omega$  at 20°C.
- 5.25 Repeat the calculation for the question above using the temperature coefficient method, assuming that the value for alpha is 0.00393.
- 5.26 If a 3Ø motor winding at room temperature ( $20^{\circ}$ C) has the following resistances, 18  $\Omega$ , 18.6  $\Omega$  and 19.2  $\Omega$ , and at full running temperature the resistances are 25.4  $\Omega$ , 26.3  $\Omega$  and 27  $\Omega$ , what is the full running temperature of the windings?
- 5.27 If a 2.5 kW single-phase pump motor is located 60 m from the supply board, which supplies 230 volts, what voltage will be available at the pump terminals if 2.5 mm<sup>2</sup> cable is used? ( $p = 1.72E-8 \Omega m$ )
- 5.28 If a 4WD ute has four 100 W spotlights running directly off the 12 volt battery via 6 m (total) of 4 mm<sup>2</sup> copper cable, what voltage will be present at the terminals of the spotlights?
- 5.29 If a 100  $\Omega$  resistor has a tolerance of 5 per cent, what are the lowest and highest values that it could be?

5.30 Find the resistance and tolerance of each of the following resistors.



5.31 Calculate the total resistance in the following circuit.



5.32 Calculate the total resistance in the following circuit.



5.33

### R<sub>1</sub> R<sub>3</sub> + R<sub>Total</sub> R<sub>5</sub> R

Calculate the total resistance in the following circuit.

5.34 Calculate the total resistance in the following circuit.



Calculate the total resistance in the following circuit. 5.35



Calculate the total resistance in the following circuit. 5.36



Calculate the total resistance in the following circuit. 5.37



5.38 Calculate the total resistance in the following circuit.



Calculate the total resistance in the following circuit. 5.39



5.40 Calculate the total resistance in the following circuit.













Ω [4 ± Ω 028(p)	02.3
(t) 2.7 ko ± 135 o	02.3
Ω 86 ± Ω 086 (∋)	02.3
(q)470 kΩ ± 23.5 kΩ	02.3
(c) 3.3 kv ± 165 v	02.3
(p)26 kひ ± 2800 ひ	02.3
Ω Γ ± Ω ΟΓ (6)	02.3
100 $\Omega\pm5\%$ = 95 $\Omega$ to 105 $\Omega$	62.3
7°4°C	82.3
221 A	72.8
124.6°C, 125.3°C, 123.4°C	97.8
52°2 (5	92.8
52°2 V	Þ2.3
mΩ 8–348.2	22.3
m ſ.82	22.5
(Ωm 886) Ω 886.0	12.3
- O`	
Sali	

2085

### **ANSWERS**

	(e) variac (MOV or VDR.
	potentiometer, (d) carbon-compound resistor,
(6) î <sup>4</sup> .ð	slide potentiometer, (b) wire-wound pot, (c) rotary
07.8	26k//(10R+3k3//(470R+2k7+820R)+10R) = 3.71 kΩ
65.8	ג 8.61 = (אזו+(אַגאַגאַגאַגאַגאַגאַגאַגאַגאַגאַגאַגאַגא
85.3	520K+680R//(220R+220R+220R) = 357 \
75.2	12K+100K\\(18K+82K) = 62 T
92°S	98K/\82K/\120K/\510K = 52.7 K
55.2	JK2/\2K9/\JK5/\2K9 = 484 \3
42.2	2K3/\3K3\\5K5\\5K5 = 660 22
55.2	JOK+2K2+J8K+JK5+5K5 = 24°.7 KW
5.32	290K+120K+330K+68K+47R = 955 Ω
۶.3 I	1K0+680R+270R+82R+27R = 2259 \
(į) 0č.2	J Mび ∓ 20 Kび
(i) 0č.č	2.2 ko ± 110 o
(4) 02.2	1.8 ko ± 90 o