Government of **Western Australia**
North Metropolitan **TAFE**

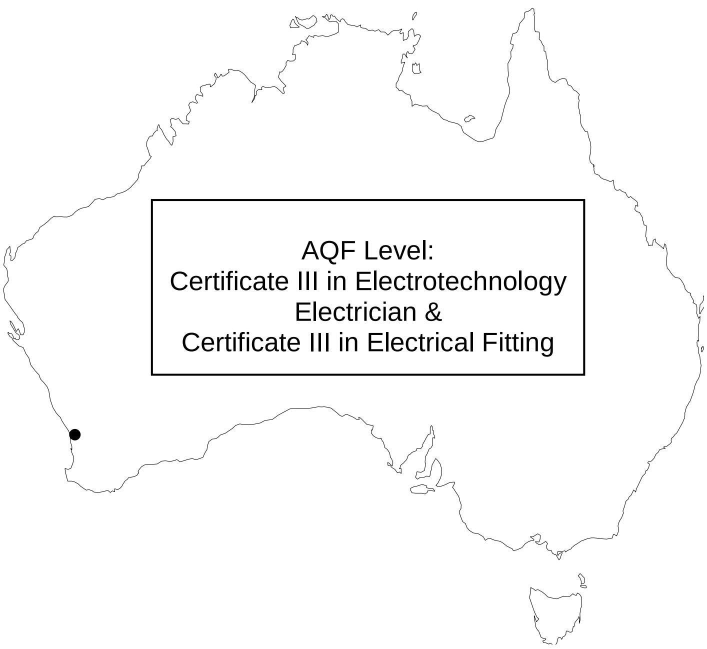
UEE 11 Training Package Support Materials
(Non-Endorsed Component)

Based on:
National Electro-technology Industry Standards

Resource Book

UEENEEE104A

Solve problems in DC circuits.



AQF Level:
Certificate III in Electrotechnology Electrician &
Certificate III in Electrical Fitting

North Metropolitan TAFE
Edited by Terry O'Grady
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Version 13 – 01/2021 – aligned to AS/NZS 3000:2018 (A1)

Acknowledgements

This Unit Guide has been prepared by Balga Campus Lecturers.

It is intended for North Metropolitan TAFE students only.

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UEENEEE104A – Solve problems in DC circuits.

C O N T E N T S

UEENEEE104A Training Achievement Record

Name:	Student No:	Apprenticeship No
Employer:		College:

Activity	Topic	Date	Lecturer	
Part A				
Worksheet 1 - 1	Electrical and Mechanical Units (17)			
Worksheet 1 - 2	Basic Electrical Physics (23)			
Activity 1	Conductors and Insulators			
Worksheet 1 – 3	Transposition of Equations (8)			
Worksheet 2 – 1	Practical Electrical Circuits and Protection (14)			
Activity 2 -1	Protection Devices			
Worksheet 3 – 1	Ohms Law (9)			
Worksheet 4 – 1	Resistance Measurement (10)			
Activity 4 – 1	Resistance Measurement			
Worksheet 5 – 1	Selection of meters to measure circuit quantities (24)			
Activity 5 – 1	Selection of meters to measure circuit quantities			
Worksheet 6 – 1	Electrical Power			
Activity 6 – 1	Measuring Electrical Power			
Worksheet 7 – 1	Effects of Electric Current			
Worksheet 8 – 1	Sources of Electro-motive Force			
Activity 8 – 1	Sources of Electro-motive Force			
Worksheet 9 – 1	Practical Resistors (16)			
Activity 9 – 1	Identification of Practical Resistors			
Activity 9 – 2	Resistor Colour Code			
Activity 10 – 1	Circuit analysis and voltage drops			
Worksheet 11 – 1	Factors Effecting Resistance (8)			

Part B				
Worksheet 12 -1	Series Circuits (26)			
Activity 12 - 1	Series Circuits			
Worksheet 13 - 1	Parallel Circuits (11)			
Activity 13 – 1	Parallel Circuits			
Worksheet 14 – 1	Series/parallel Circuits (5)			
Activity 14 – 1	Series/parallel Circuits			
Worksheet 15 – 1	Capacitors and Capacitance (22)			
Activity 15 – 1	Capacitor Identification			
Activity 15 – 2	Capacitor Testing			
Activity 15 – 3	RC Time Constants			

References

- Electrical Principals – Volumes 1 & 2 (6th ed.) Jenneson & Harper
- AS/NZS 3000 (current edition)
- Code of Practice – Safe electrical work on low voltage electrical installations
- WA Electrical Requirements

UEENEEE104A – Solve problems in DC circuits.

Prerequisite Units
Granting competency in this unit shall be made only after competency in the following unit has been confirmed:

UEENEEE101A – Apply occupational health and safety regulations, codes and practices in the workplace.

Elements and Performance Criteria

ELEMENT		PERFORMANCE CRITERIA	
1	**Prepare to work on DC electrical circuits**.	1.1	OHS procedures for a given work area are identified, obtained and understood.
		1.2	OHS risk control work preparation measures and procedures are followed.
		1.3	The nature of the circuit problem is obtained from documentation or from work supervisor to establish the scope of work to be undertaken.
		1.4	Advice is sought from the work supervisor to ensure the work is coordinated effectively with others.
		1.5	Sources of materials that may be required for the work are identified and accessed in accordance with established procedures.
		1.6	Tools, equipment and testing devices needed to carry out the work are obtained and checked for correct operation and safety.
2	**Solve DC circuit problems.**	2.1	OHS risk control work measures and procedures are followed.
		2.2	The need to test or measure live is determined in strict accordance with OHS requirements and when necessary conducted within established safety procedures.
		2.3	Circuits are checked as being isolated where necessary in strict accordance OHS requirements and procedures.
		2.4	Established methodological techniques are used to solve DC circuit problems from measure and calculated values as they apply to electrical circuit.
		2.5	Unexpected situations are dealt with safely and with the approval of an authorised person.
		2.6	Problems are solved without damage to apparatus, circuits, the surrounding environment or services and using sustainable energy practices.
3	**Complete work and document problem solving activities.**	3.1	OHS work completion risk control measures and procedures are followed.
		3.2	Work site is cleaned and made safe in accordance with established procedures.
		3.3	Justification for solutions used to solve circuit problems is documented.

ELEMENT	PERFORMANCE CRITERIA	
	3.4	Work completion is documented and appropriate person(s) notified in accordance with established procedures.

Required Skills and Knowledge

This describes the essential skills and knowledge and their level, required for this unit.Evidence shall show an understanding of electrical fundamentals and direct current multiple path circuits to an extent indicated by the following aspects:

T1 Basic electrical concepts encompassing:

- electrotechnology industry
- static and current electricity
- production of electricity by renewable and non-renewable energy sources
- transportation of electricity from the source to the load via the transmission and distribution systems
- utilisation of electricity by the various loads
- basic calculations involving quantity of electricity, velocity and speed with relationship to the generation and transportation of electricity.

T2 Basic electrical circuit encompassing:

- symbols used to represent an electrical energy source, a load, a switch and a circuit protection device in a circuit diagram
- purpose of each component in the circuit
- effects of an open-circuit, a closed-circuit and a short-circuit
- multiple and sub-multiple units

T3 Ohm's Law encompassing:

- basic DC single path circuit.
- voltage and currents levels in a basic DC single path circuit.
- effects of an open-circuit, a closed-circuit and a short-circuit on a basic DC single path relationship between voltage and current from measured values in a simple circuit
- determining voltage, current and resistance in a circuit given any two of these quantities
- graphical relationships of voltage, current and resistance
- relationship between voltage, current and resistance

T4 Electrical power encompassing:

- relationship between force, power, work and energy
- power dissipated in circuit from voltage, current and resistance values
- power ratings of devices
- measurement electrical power in a DC circuit
- effects of power rating of various resistors

T5 Effects of electrical current encompassing:

- physiological effects of current and the fundamental principles (listed in AS/NZS 3000) for protection against the this effect
- basic principles by which electric current can result in the production of heat; the production of magnetic fields; a chemical reaction
- typical uses of the effects of current
- mechanisms by which metals corrode
- fundamental principles (listed in AS/NZS3000) for protection against the damaging effects of current

T6 EMF sources energy sources and conversion electrical energy encompassing:

- basic principles of producing an emf from the interaction of a moving conductor in a magnetic field.
- basic principles of producing an emf from the heating of one junction of a thermocouple.
- basic principles of producing a emf by the application of sun light falling on the surface of photovoltaic cells
- basic principles of generating a emf when a mechanical force is applied to a crystal (piezo electric effect)
- principles of producing an electrical current from primary, secondary and fuel cells
- input, output, efficiency or losses of electrical systems and machines
- effect of losses in electrical wiring and machines
- principle of conservation of energy

T7 Resistors encompassing:

- features of fixed and variable resistor types and typical applications
- identification of fixed and variable resistors
- various types of fixed resistors used in the Electro technology Industry. e.g. wire-wound, carbon film, tapped resistors.
- various types of variable resistors used in the Electro technology Industry e.g. adjustable resistors: potentiometer and rheostat; light dependent resistor (LDR); voltage dependent resistor (VDR) and temperature dependent resistor (NTC, PTC).
- characteristics of temperature, voltage and light dependent resistors and typical applications of each
- power ratings of a resistor.
- power loss (heat) occurring in a conductor.
- resistance of a colour coded resistor from colour code tables and confirm the value by measurement.
- measurement of resistance of a range of variable' resistors under varying conditions of light, voltage, temperature conditions.
- specifying a resistor for a particular application.

T8 Series circuits encompassing:

- circuit diagram of a single-source DC 'series' circuit.
- Identification of the major components of a 'series' circuit: power supply; loads; connecting leads and switch
- applications where 'series' circuits are used in the Electro technology industry.
- characteristics of a 'series' circuit - connection of loads, current path, voltage drops, power dissipation and effects of an open circuit in a 'series' circuit.
- the voltage, current, resistances or power dissipated from measured or given values of any two of these quantities
- relationship between voltage drops and resistance in a simple voltage divider network.
- setting up and connecting a single-source series dc circuit
- measurement of resistance, voltage and current values in a single source series circuit
- effect of an open-circuit on a series connected circuit

T9 Parallel circuits encompassing:

- schematic diagram of a single-source DC 'parallel' circuit.
- major components of a 'parallel' circuit (power supply, loads, connecting leads and switch)
- applications where 'parallel' circuits are used in the Electrotechnology industry.
- characteristics of a 'parallel' circuit. (load connection, current paths, voltage drops, power dissipation, effects of an open circuit in a 'parallel' circuit).

- relationship between currents entering a junction and currents leaving a junction
- relationship between branch currents and resistances in a two branch current divider network.
- calculation of the total resistance of a 'parallel' circuit.
- calculation of the total current of a 'parallel' circuit.
- Calculation of the total voltage and the individual voltage drops of a 'parallel' circuit.
- setting up and connecting a single-source DC parallel circuit
- resistance, voltage and current measurements in a single-source parallel circuit
- voltage, current, resistance or power dissipated from measured values of any of these quantities
- output current and voltage levels of connecting cells in parallel.

T10 Series/parallel circuits encompassing:

- schematic diagram of a single-source DC 'series/parallel' circuit.
- major components of a 'series/parallel' circuit (power supply, loads, connecting leads and switch)
- applications where 'series/parallel' circuits are used in the Electrotechnology industry.
- characteristics of a 'series/parallel' circuit. (load connection, current paths, voltage drops, power dissipation, effects of an open circuit in a 'series/parallel' circuit).
- relationship between voltages, currents and resistances in a bridge network.
- calculation of the total resistance of a 'series/parallel' circuit.
- calculation of the total current of a 'series/parallel' circuit.
- calculation of the total voltage and the individual voltage drops of a 'series/parallel' circuit.
- setting up and connecting a single-source DC series/ parallel circuit
- resistance, voltage and current measurements in a single-source DC series / parallel circuit
- the voltage, current, resistances or power dissipated from measured values of any two of these quantities

T11 Factors affecting resistance encompassing:

- four factors that affect the resistance of a conductor (type of material, length, cross-sectional area and temperature)
- affect the change in the type of material (resistivity) has on the resistance of a conductor.
- affect the change in 'length' has on the resistance of a conductor.
- affect the change in 'cross-sectional area' has on the resistance of a conductor.
- effects of temperature change on the resistance of various conducting materials
- effects of resistance on the current-carrying capacity and voltage drop in cables.
- calculation of the resistance of a conductor from factors such as conductor length, cross-sectional area, resistivity and changes in temperature
- using digital and analogue ohmmeter to measure the change in resistance of different types of conductive materials (copper, aluminium, nichrome, tungsten) when those materials undergo a change in type of material length, cross-sectional area and temperature.

T12 Effects of meters in a circuit encompassing:

- selecting an appropriate meter in terms of units to be measured, range, loading effect and accuracy for a given application.
- measuring resistance using direct, volt-ammeter and bridge methods.
- instruments used in the field to measure voltage, current, resistance and insulation resistance and the typical circumstances in which they are used.
- hazards involved in using electrical instruments and the safety control measures that should be taken.

- operating characteristics of analogue and digital meters.
- correct techniques to read the scale of an analogue meters and how to reduce the 'parallax' error.
- types of voltmeters used in the Electrotechnology industry – bench type, clamp meter, Multimeter, etc.
- purpose and characteristics (internal resistance, range, loading effect and accuracy) of a voltmeter.
- types of voltage indicator testers. e.g. LED, neon, solenoid, volt-stick, series tester, etc. and explain the purpose of each voltage indicator tester.
- operation of various voltage indicator testers.
- advantages and disadvantages of each voltage indicator tester.
- various types of ammeters used in the Electrotechnology industry – bench, clamp meter, multimeter, etc.
- purpose of an ammeter and the correct connection (series) of an ammeter into a circuit.
- reasons why the internal resistance of an ammeter must be extremely low and the dangers and consequences of connecting an ammeter in parallel and/or wrong polarity.
- selecting an appropriate meter in terms of units to be measured, range, loading effect and accuracy for a given application
- connecting an analogue/digital voltmeter into a circuit ensuring the polarities are correct and take various voltage readings.
- loading effect of various voltmeters when measuring voltage across various loads.
- using voltage indicator testers to detect the presence of various voltage levels.
- connecting analogue/digital ammeter into a circuit ensuring the polarities are correct and take various current readings.
-

T13 Resistance measurement encompassing:

- Identification of instruments used in the field to measure resistance (including insulation resistance) and the typical circumstances in which they are used.
- the purpose of an Insulation Resistance (IR) Tester.
- the parts and functions of various analogue and digital IR Tester (selector range switch, zero ohms adjustment, battery check function, scale and connecting leads).
- reasons why the supply must be isolated prior to using the IR tester.
- where and why the continuity test would be used in an electrical installation.
- where and why the insulation resistance test would be used in an electrical installation.
- the voltage ranges of an IR tester and where each range may be used. e.g. 250 V d.c, 500 V d.c and 1000 V d.c
- AS/NZS3000 Wiring Rules requirements – continuity test and insulation resistance (IR) test.
- purpose of regular IR tester calibration.
- the correct methods of storing the IR tester after use
- carry out a calibration check on a IR Tester
- measurement of low values of resistance using an IR tester continuity functions.
- measurement of high values of resistance using an IR tester insulation resistance function.
- volt-ammeter (short shunt and long shunt) methods of measuring resistance.
- calculation of resistance values using voltmeter and ammeter reading (long and short shunt connections)
- measurement of resistance using volt-ammeter methods
-

T14 Capacitors and Capacitance encompassing:

- basic construction of standard capacitor, highlighting the: plates, dielectric and connecting leads
- different types of dielectric material and each dielectric's relative permittivity.
- identification of various types of capacitors commonly used in the Electrotechnology industry (fixed value capacitors -stacked plate, rolled, electrolytic, ceramic, mica and Variable value capacitors – tuning and trimmer)
- circuit symbol of various types of capacitors: standard; variable, trimmer and polarised
- terms: Capacitance (C), Electric charge (Q) and Energy (W)
- unit of: Capacitance (Farad), Electric charge (Coulomb) and Energy (Joule)
- factors affecting capacitance (the effective area of the plates, the distance between the plates and the type of dielectric) and explain how these factors are present in all circuits to some extent.
- how a capacitor is charged in a DC circuit.
- behaviour of a series DC circuit containing resistance and capacitance components. - charge and discharge curves
- the term 'Time Constant' and its relationship to the charging and discharging of a capacitor.
- calculation of quantities from given information: Capacitance (Q = VC); Energy (W =½CV2); Voltage (V = Q/C)
- calculation one time constant as well as the time taken to fully charge and discharge a given capacitor. (τ = RC)
- connection of a series DC circuit containing capacitance and resistor to determine the time constant of the circuit

T15 Capacitors in Series and Parallel encompassing:

- hazards involved in working with capacitance effects and the safety control measures that should be taken.
- safe handling and the correct methods of discharging various size capacitors
- dangers of a charged capacitor and the consequences of discharging a capacitor through a person
- factors which determine the capacitance of a capacitor and explain how these factors are present in all circuits to some extent.
- effects of capacitors connected in parallel by calculating their equivalent capacitance.
- effects on the total capacitance of capacitors connected in series by calculating their equivalent capacitance.
- Connecting capacitors in series and/or parallel configurations to achieve various capacitance values.
- common faults in capacitors.
- testing of capacitors to determine serviceability.
- application of capacitors in the Electrotechnology industry.

E104A Work Performance Tasks – (Q Tracker tasks):

UEENEEE104A – Solve problems in DC circuits

1. Performance requirements:
1a. Related to the following elements:
1. Prepare to terminate cables, cords and conductors.
2. Terminate cables cords and conductors.
3. Test terminated cables and cords.

1b. For each element demonstrate performance:
- across a representative body of performance criteria,
- on at least 2 occasions,
- autonomously and to requirements,
- within the timeframes typically expected of the discipline, work function and industrial environment.

2. Representative range includes the following:
All listed tasks related to performance across a representative range of contexts from the prescribed items below:

The minimum number of items on which skill is to be demonstrated **Group No**		**Item List**
A.	All of the following: **Series circuits**	• Correctly connect series DC circuits • Select test equipment • Connect test equipment • Read meters / instruments correctly • Predict results from circuit configuration / parameters • Apply ohms law to determine voltage, current and resistance • Determine the power dissipated in a load • Solve problems in series DC circuits
B.	All of the following: **Parallel circuits**	• Correctly connect parallel DC circuits • Select test equipment • Connect test equipment • Read meters / instruments correctly • Predict results from circuit configuration / parameters • Apply ohms law to determine voltage, current and resistance • Determine the power dissipated in a load • Solve problems in parallel DC circuits
C.	All of the following: **Series-parallel circuits**	• Correctly connect series / parallel DC circuits • Select test equipment • Connect test equipment • Read meters / instruments correctly • Predict results from circuit configuration / parameters • Apply ohms law to determine voltage, current and resistance • Determine the power dissipated in a load • Solve problems in series-parallel DC circuits
D.	All of the following: **Capacitors**	• Correctly connect capacitors in DC circuits • Solve problems relating to capacitors in DC circuits

Workplace Rules:

Rule 1	Follow the instructions
Rule 2	Tolerate ambiguity
Rule 3	Meet your obligations

Note: This information and current details of critical aspects for each competency standard unit (CSU) in this qualification can be found at the Australian Training Standards website www.training.gov.au**.**

UEENEEE104A – Solve problems in DC circuits.

Learning and Assessment Plan

Name of Lecturer: ____

Contact Details: ____

Delivery Mode/s: □ Face to Face □ On-Line □ Blended Delivery □ Other

Using: UEENEEE104A – Solve Problems in DC Circuits Resource Book

Session	Nominal Duration	Program of Work (Topics to be covered)	Primary Reference
Part A			
1	1 hour	Introduction to UEENEEE104A Recognition of Prior Learning of CSU	Resource Book
2	3 hours	Electrical and Mechanical Units	Resource Book – Section 1
3	4 hours	Basic Electrical Physics	Resource Book – Section 1
4	2 hours	Practical Electrical Circuits and Protection	Resource Book – Section 2
5	4 hours	Ohms Law	Resource Book – Section 3
6	2 hours	Resistance Measurement	Resource Book – Section 4
7	4 hours	Selection of meters/ circuit quantities	Resource Book – Section 5
8	4 hours	Electrical Power	Resource Book – Section 6
9	2 hours	Effects of Electric Current	Resource Book – Section 7
10	3 hours	Sources of Electromotive Force	Resource Book – Section 8
11	3 hours	Practical Resistors	Resource Book – Section 9
12	4 hours	Circuit analysis and voltage drops	Resource Book – Section 10
13	4 hours	Factors affecting resistance	Resource Book – Section 11
14	4 hours	**Revision – Part A** **Knowledge Assessment Part A (RSAK Topics 1 to 8, 11 to 13)**	
15	4 hours	**Practical Demonstration Assessment Part A**	
Part B			
16	4 hours	Series Circuits	Resource Book – Section 12
	3 Hours	Parallel Circuits	Resource Book – Section 13
17	4 hours	Series-Parallel Circuits	Resource Book – Section 14
18	2 hours	Capacitors and Capacitance	Resource Book – Section 15
19	2 hours	RC Time Constants	Resource Book – Section 16
21	4 hours	**Revision & Knowledge Assessment Part B (RSAK Topics 8 - 10, 14 & 15)**	
22	3 hours	**Practical Demonstration Assessment Part B**	

I acknowledge that I have received and read a copy of the Learning and Assessment Plan Student Name:____________________ Signature: __________________ Date: ________		
Lecturer Name	Lecturer Signature	Date

Assessment Strategy

Conditions of Assessment:

Normally learning and assessment will take place in an integrated classroom/ laboratory environment.

It is essential to work through the worksheets and activities in this workbook and follow the guidance of your lecturer. The worksheets and practical activities will provide the required skills and knowledge outlined in this Unit and assists you in achieving competency.

Assessment Methods:

Resource Book - The satisfactory completion of all worksheets and practical activities is required.

Written Question-based Assessment – based on the **REQUIRED SKILLS AND KNOWLEDGE**. You must achieve a mark of **75%** or more in this assessment.

Observed Practical Assessment – based on the Elements and Performance Criteria of this Competency Unit UEENEEE104A. You must achieve a mark of **100%** in this assessment.

On-Job-Training:

It is expected that the off-job component of this competency unit will be complemented by appropriate on-job development involving exposure to re-occurring workplace events and supervised experiences. (See: Work Performance Tasks). You are required to log your on-the-job training in your on line 'Q-Tracker' account.

Sufficiency of Evidence:

In all instances competency is to be attributed on evidence sufficient to show that a person has the necessary skills required for the scope of work. These include:

- Task skills - performing individual tasks
- Task management skills - managing a number of different tasks
- Contingency management skills - responding to irregularities and breakdowns in routines
- Job/role environment skills - dealing with the responsibilities and expectations of the work environment including working with others.

Evidence must demonstrate that an individual can perform competently across the specified range of activities and has the essential knowledge, understanding and associated skills underpinning the competency.

DANGER TAG PROCEDURE for ELECTRICAL TRADE LABORATORIES

THE FOLLOWING PROCEDURE IS COMPULSORY

1. The student is to attach a DANGER TAG on to the plug top of the project lead before proceeding with the allocated project. A danger tag must be attached to the plug top at all times, when the lead is NOT plugged into the supply outlet. Plug tops or leads are not to be connected to the supply outlet WHILE A DANGER TAG is attached.

2. The student is to assemble the project according to project instruction procedure and lecturer's directions in its isolated and de-energised state and report to the lecturer as necessary and on completion.

3. The lecturer is to:-
   a. Check the project for safety and
   b. Ensure that the student has performed a safety check, including **short circuit test** using the recommended procedure.

4. When the lecturer is satisfied that the project is safe to connect and energise, the lecturer is to instruct the student to REMOVE the DANGER TAG from the plug top.

5. The student is to plug in the project and switch it on in the presence of the lecturer.

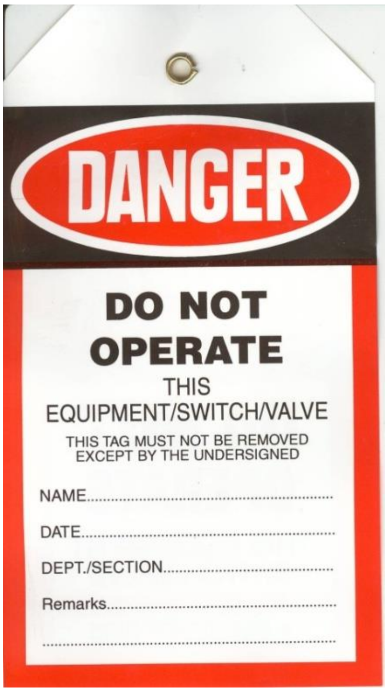
6. The lecturer is to determine whether or not the project is operating satisfactorily.

7. If the project operates satisfactorily the student may take measurements using correct meters with regard to the safety risks associated with using the particular item of test equipment including;
   a. Selecting correct meter function,
   b. Holding meter probes correctly during measuring with fingers behind knurls (finger guards) at all times.

   This is to be done under general supervision of lecturer. The student is NOT to modify, disassemble or carry out ANY unsafe act.

8. If the circuit is to be modified the student must:
   a. Switch the circuit off,
   b. Disconnect the project from the supply,
   c. Attach the DANGER TAG to the plug top,
   d. Report to the lecturer for instructions,

   In the lecturer's presence the student is to:-
   e. TEST and VERIFY for ZERO VOLTAGE.
   f. Restart the DANGER TAG procedure from step 2 above.



9. When the student is satisfied that the project has been completed the student is to:-
   a. Switch the project off,
   b. Remove the plug,
   c. Replace the DANGER TAG on the plug top,
   d. Report to the lecturer for instructions,

   In the lecturer's presence the student is to:-
   e. TEST and VERIFY for ZERO VOLTAGE.

   The lecturer is then to instruct the student to:-
   f. Disassemble the project
   g. Remove the DANGER TAG and store the equipment in its designated place.

LABORATORY SAFETY

Students working in laboratories at North Metropolitan TAFE Balga Campus do so, on condition that they agree to abide by the following safety instructions. Failure to observe the safety instructions will result in **IMMEDIATE SUSPENSION.**

1. No circuit is to be plugged in or switched on without the specific permission of the lecturer in charge of the class. A circuit must be switched off and tested for **ZERO VOLTS** before any supply leads are removed. The **DANGER TAG PROCEDURE** must be used at all times.

2. Do not leave any circuit switched on any longer than necessary for testing. Do not leave any circuit switched on unattended.

3. Check each item of equipment before using. Report any broken, damaged or unserviceable equipment to your Lecturer.

4. All wiring must be disconnected at the end of each practical class or as each project is completed.

5. Make all connections in a safe manner with an appropriate connecting device. Unshielded 4mm banana plugs are not to be used for wiring.

6. Switch off, remove the plug from the socket and attach your **DANGER TAG** to the plug top before working on any project. It is not sufficient to simply turn the switch off.

7. When disconnecting your wiring from a connection made under a screw, undo the screw to remove the wiring, do not cut the wire off.

8. Observe the correct colour code for all wiring projects.

9. Test your circuit for short circuits with your multimeter before asking your Lecturer to switch circuit on. Test the Tester before and after **EACH** test.

10. Skylarking and horseplay is not permitted at any time.

11. Proper clothing and safety footwear must be worn at all times. Thongs, sandals and singlets are not permitted. Hard capped safety boots or safety shoes **MUST** be worn **AT ALL TIMES** at North Metropolitan TAFE Balga Campus.

12. Where an activity sheet is issued for a project, complete each step in the Procedure before moving to the next step. Advise your Lecturer when you have completed the activity.

13. Draw **ALL DIAGRAMS** in **PENCIL** so that they can be easily changed or corrected. Mark off each connection on your diagram as it is made.

14. Check the range before taking a reading with a multimeter.

15. Make sure that it is **YOUR** plug before inserting plug into an outlet.

16. Always switch multimeter **OFF**, or to the highest possible **AC VOLTS** range when you have finished using it.

17. Report any unexpected situations or events to your Lecturer.

Student's Signature :___________________ **Date :___/___/_____**

Basic Electrical Concepts

Task:

Describe the general nature and behaviour of electric current flow in conductors and insulators and the main units in which fundamental and derived electrical units are measured. Measure the voltage, the current and the resistance in basic circuits. Perform basic electrical calculations involving voltage, current, resistance and power.

Why:

Electrical devices are used in virtually all areas of modern industry. Knowledge of the basic theory of electric current flow and associated units will provide you with a better understanding of the nature and capabilities of electrical devices in the workplace.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.

2. You must satisfactorily complete the set activities and laboratory tasks.

3. You must achieve 100% in a final practical competency test.

Equipment:

Sample conductors and insulators
Digital and analogue measuring instruments
Scientific calculator

References:

* Electrical Principles: For Electrical Trades (6th ed.) J. Jenneson, B. Harper & B. Moore.
* Electrical Wiring Practice (7th ed.) K. Pethebridge & I. Neeson.
* AS 1000 the International System of Units (SI) and its Application.

* AS 1046 Letter Symbols for Physical Quantities for Use in Electrotechnology and Abbreviations and Symbols for Units for such Quantities.

Basic Electrical Concepts

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles: For Electrical Trades (6th Edition)

Chapter 1 Elementary Electricity Page 2- 29

Electrical Wiring Practice - Volume 1 (7th Edition)

Chapter 1 Electrical Energy – past, present and future Page 1 - 21

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the activities and laboratory projects in this Section.

5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion and assessment.

Overview of the Electrotechnology Industry

Electrotechnology is a high tech, diverse industry that impacts every aspect of daily life.

It encompasses occupations such as electrical, communications, electronics and instrumentation.

People employed in the industry can be found across all major sectors such as generation, transmission and distribution of electricity, manufacturing, maritime, mining, construction and renewable energy technologies.

Electricity has been heavily reliant on fossil fuels for generation in the past, especially coal and oil.

The drive to reduce damage to the environment has forced a shift in technology towards sustainable, greener ways to generate electricity such as wind, solar and tidal energy.

Generated electricity from power stations around the country are transported over high voltage transmission lines to substations, where the voltage, through the aid of transformers will be reduced to a more manageable level and is distributed to households and businesses.

Once the electricity reaches its final destination it is used, or converted by a load. This load will convert the electrical energy to another form whether it is heat for cooking, mechanical energy for motors or light for us to see.

Electrical and Mechanical Units

The SI System of Measurement

1. The SI System is a metric system which has been the standard system of measurement in Australia since the early 1970's. It is used in many other countries with the notable exception of the United States of America.

2. In the superseded imperial system of measurement, different units of the same basic quantity had different names.

For example, the quantity 'length' could be expressed in inches, feet, yards, chains and miles, and there was no apparent relationship between the units (12 inches = 1 foot, 3 feet = 1 yard, 22 yards = 1 chain and so on).

3 In the metric system there are seven base units. Each unit can be expressed as a multiple (larger unit) or sub-multiple (smaller unit) by applying metric prefixes such as kilo or milli - the metric prefixes always vary the base unit by a multiple of 10.

All other units are derived from these seven base units, and all multiples and sub-multiples can be expressed using the metric prefixes.

4. The seven base metric units are:

Quantity	Quantity Symbol	Unit	Unit Symbol
Length	L	Metre	m
Time	t	Second	s
Mass	m	Kilogram	kg
Current	I	Ampere	A
Temperature(absolute)	T	Kelvin	K
Amount of substance	n	Mole	mol
Luminous intensity	I	Candela	cd

5. There are many other quantities used in electrical work. All other quantities are derived from the base units, so they are called 'derived units'. The most common units used in basic electrical or electronic work are:

Quantity	Quantity Symbol	Unit	Unit Symbol
Force	F	newtons	N
Pressure	P	newtons/m^2	Pa
Electromotive force	E or V	volts	V
Electrical resistance	R	ohms	Ω
Electric Current	I	amperes	A
Energy	E	joules	J
Work	W	joules	J
Power	P	watts	W
Temperature	t	degrees Celsius	◦C
Charge(or quantity)	Q	coulomb	C

Note: Students must learn and remember the relevant QUANTITY SYMBOLS so that their respective values can be inputted into given equations and formulas. Just as important are the UNIT SYMBOLS so the student can apply the correct symbols denoting the unit values!

Force

6. Force can be generally defined as that which produces changes or stops the motion of a body (mass x acceleration). The basic unit of force is the newton (N). One newton is the force required to move a mass of 1 kg in free space (away from the force of gravity). The amount of force required to lift a body vertically at sea level is 9.8 newtons per kilogram.

Pressure

7. Pressure is the force exerted on a given area. The basic unit of pressure is the newton per square metre (N/m^2). One newton per square metre is given a special name, one Pascal (Pa). Since the Pascal is a small unit, a more common unit of pressure is the kilopascal (kPa). In imperial units a common unit of pressure is the pound per square inch (psi). 1 psi = 6.89 kPa.

Electromotive Force

8. An electromotive force (emf) is a force which causes electrons ('electricity') to flow in a conductor. This electrical force is also described as a POTENTIAL DIFFERENCE or a VOLTAGE DROP between two points. Electromotive force or potential difference is measured in VOLTS, and the unit symbol for volts is V. The quantity symbol for electromotive force is E. The quantity symbol for potential difference is V or U.

Electric Current

9. Electric current is the flow of electrons in a material. The base unit of electric current flow is the AMPERE, and the unit symbol is A. The quantity symbol for electric current flow is I. One ampere is the current which will flow in a circuit with a resistance of one ohm if the applied voltage is one volt.

Resistance

10. Electrical resistance is the opposition to the flow of current in any material (solids, liquids or gases). Resistance to current flow is measured in OHMS, and the unit symbol is the Greek 'omega' (Ω). The quantity symbol is R.

Energy and Work

11. Energy is the ability to do work. Energy cannot be created or destroyed; it can only be converted from one form to another. The most common forms of energy in electrical trade applications are electrical energy, mechanical energy, light energy and heat energy. Work is done whenever energy is converted from one form to another. An electric motor, for example, converts electrical energy to mechanical energy. The basic unit of energy is the joule. The quantity symbol for energy is E and the basic unit symbol is J.
Work (W) is also expressed in joules.

Power

12. Power is the rate of doing work, or the rate at which energy is converted from one form to another (e.g. electricity into heat). The basic unit of power is the watt which is 1 joule per second. The quantity symbol for power is P and the basic unit symbol is W. The basic unit of power in the old imperial system is the horsepower. There are 746 watts in one horsepower. A 100 watt electric motor converts electrical energy to mechanical energy (or work) at the rate of 100 joules per second (J/s). A 200 watt motor would do the same amount of work in half the time so the relationship between power and work or energy can be shown as the following equations:

$$\text{Energy} = \text{Power} \times \text{Time}$$

$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

Where:
Energy is in joules
Power is in watts
Time is in seconds

Temperature

13. Temperature is the level of heat in a body. The quantity symbol for temperature is t and the customary unit is the degree Celsius (ºC).

The imperial unit of temperature is the degree Fahrenheit (ºF). Although degrees C and degrees F are both units of temperature, they are on different scales. Water freezes at 0ºC or 32ºF, and boils at 100ºC or 212ºF.

Quantity of Electricity (Charge)

14. The unit of electrical quantity is the coulomb, i.e. the quantity of electricity passing a given point when a current of 1 ampere is maintained for 1 second.

The quantity symbol for charge is Q and the basic unit symbol is C. The basic equation for calculating the quantity of electricity is:

$Q = I \times t$ i.e. Coulombs (C) equals Amps (A) multiplied by Seconds (s)

Where Q is in Coulombs (C)
I is in amperes (A)
t is in seconds (s)

Metric Prefixes

15. The metric prefixes mean 'multiply the unit by a power of 10'. In electrical engineering applications the preferred metric prefixes are those which are a multiple of 3. The specific powers of 10 referred to in the most common prefixes are:

Common Metric Prefixes

Term	**Symbol**	**Multiply by**	**Example**
tera	T	1 000 000 000 000 (10^{12})	4 TB = 4 000 000 000 000 bytes
giga	G	1 000 000 000 (10^{9})	3 GW = 3 000 000 000 watts
mega	M	1 000 000 (10^{6})	62 MΩ = 62 000 000 ohms
kilo	k	1 000 (10^{3})	22 kV = 22 000 volts
Base Unit		1 (10^{0})	
milli	m	0.001 (10^{-3})	8 mA = 0.008 amps
micro	µ	0.000 001 (10^{-6})	1 µF = 0.000 001 farads
nano	n	0.000 000 001 (10^{-9})	5 nA = 0.000 000 005 amps
pico	p	0.000 000 000 001 (10^{-12})	2 pA = 0.000 000 000 002 amps

16. **Examples:** Examples of the most commonly used prefixes in electrical and electronic work are:

5 MΩ means 5 times 1 000 000 ohms or 5 000 000 ohms.
3 mA means 3 times 0.001 amps or 0.003 amps.
9 mm means 9 times 0.001 metres or 0.009 metres.
2 kV means 2 times 1000 volts or 2000 volts.
6 nV means 6 times 0.000 000 001 volts or 0.000 000 006 volts.
7 µA means 7 times 0.000 001 amps or 0.000 007 amps.

17. When expressing metric quantities there are several conventions recommended in Australian Standards (AS 1000 and AS 1046). For example:

a. When a metric prefix is combined with a unit name the resulting multiple is written as one word:

millimetre not milli metre

b. A space should be left between the number and the unit symbol:

10 mm not 10mm

c. Separate groups of three digits with a space if there are five or more digits (in some countries the comma is used as the thousands separator):

20 000 not 20000

d. A leading zero should always be placed in front of a decimal number less than 1 (in some countries the comma is used as the decimal point):

0.001 not .001

18. It is frequently necessary to convert a quantity from one metric unit to another. All that is necessary is to move the decimal point to the right or left the number of places which corresponds to the meaning of the metric prefix.

Prefix	Symbol	To add prefix, move decimal point	To remove prefix, move decimal point
mega	M	6 places to the left e.g. 1000 000 Ω = 1 MΩ	6 places to the right e.g. 1 MΩ = 1 000 000 Ω
kilo	k	3 places to the left e.g. 1000 V = 1 kV	3 places to the right e.g. 1 kV = 1 000 kV
BASE Unit			
milli	m	3 places to the right e.g. 0.001 A = 1 mA	3 places to the left e.g 1 mA = 0,001 A
micro	µ	6 places to the right e.g. 0.000 001 A = 1 µA	6 places to the left e.g. 1 µA = 0.000 001 A

a. Convert 867 mm to metres. The symbol m means ‘milli’ or times 0.001, so to convert the unit back to metres shift the decimal point three places to the left.
867 mm = 0.867 metres.

b. Convert 0.027 amps to milliamps. The prefix 'milli' means times 0.001, so to convert amps to milliamps shift the decimal point three places to the right.
0.027 amps = 27 milliamps.

c. Convert 2000 volts to kilovolts. The prefix 'kilo' means times 1000, so to convert volts to kilovolts shift the decimal point three places to the left.
2000 volts = 2 kilovolts.

19. When converting quantities from one prefix to another it is important to look carefully at your result to see that it makes sense. If you converted 5 kW to 0.005 watts by shifting the decimal place three places to the left it should be obvious that you have shifted the decimal point in the wrong direction because 0.005 is less than 1.

20. **Exercise** Convert the following units as indicated:

a. Convert 11 kV to volts. ____________________

b. Convert 0.002 A to milliamps. ____________________

c. Convert 12 MΩ to ohms. ____________________

d. Convert 0.000 001 V to microvolts. ____________________

e. Convert 3859 mm to m. ____________________

f. Convert 0.0003 mA to microamps. ____________________

Engineering Notation

21. In electrical work it is frequently necessary to work with very small or very large quantities such as millionths of amps or millions of ohms. In such cases it is often convenient to express the value as a decimal number between 1 and 10 followed by a power of ten - this is known as scientific notation.

22. In engineering applications the number is arranged so that the power of 10 (also called the index or exponent) is given as **a multiple of 3** -this is a special form of scientific notation known as 'engineering notation'.

The following examples illustrate engineering notation:

230 000 volts = **1.23 x 10^6 volts**

0.000 001 2 amps = **1.2 x 10^{-6} amps**

0.0025 watts = **2.5 x 10^{-3} watts**

11 230 ohms = **11.23 x 10^3 ohms**

23. When performing calculations involving quantities expressed in engineering notation the main rules are:

For multiplication: Add the exponents
For division: Subtract the exponents

Examples:

12 x 10^3 times 5 x 10^6 = 12 x 5 x 10^{3+6} = **60 x 10^9**

6 x 10^6 divided by 3 x 10^3 = 6/3 x 10^{6-3} = **2 x 10^3**

Scientific Notation

24. When calculating equations involving very large and small numbers and using multiplication or division, it is more practical to convert those numbers into "Scientific Notation".

Essentially the same as Engineering Notation with the exception that the number to the power of ten can be any whole number in either a positive or negative sign. The number is best expressed as a primary number between 1 and 9.99 multiplied by 10^{X}. The primary number is rounded to 2 decimal points.

When numbers are expressed in this format it is possible to simply add the powers of ten when multiplying or subtracting the powers when dividing to find the resulting power of ten.

Example 1:

Multiply: 2,447,002 times 304,799

Round off: $2.45 \times 10^6 \times 3.05 \times 10^5$

Join powers and multiply primary numbers:

$2.45 \times 3.05 = 7.47$ and $10^6 \times 10^5$ is $10^{6+5} = 10^{11}$

Note: for electrical units it is best to convert the 10 to the power of digit to a multiple of three to align with unit prefixes.

i.e. 7.47×10^{11} rewritten as 747×10^9 or if units were ohms then 747 Gigaohms

Example 2:

Divide: 287,765,223 by 6,853,924

Round off: 2.88×10^8 divided by 6.86×10^6

Join powers and divide primary numbers:

$2.88 / 6.86 = 0.42$ and $10^8 / 10^6$ is $10^{8-6} = 10^2$

Ans. = 42

25. Note that the process of adding or subtracting exponents does NOT apply when adding or subtracting numbers expressed in engineering notation.

When adding or subtracting numbers expressed in scientific notation it is usually preferable to write the numbers in their decimal form, perform the operation, then convert them back into engineering notation.

Significant Figures

26. When quantities are being calculated or measured it is often necessary to use approximations rather than exact figures.

Approximations are often adequate, bearing in mind that measuring instruments are not 100% accurate. When using approximations in a practical situation you need to make a judgement about how many figures are significant - this is usually governed by the type of measuring instrument you are using.

27. If a calculation gave a result of 12.345 678 volts it is unlikely that an instrument would be available to indicate to that degree of accuracy, so you would approximate the result by rounding to 3 or 4 significant figures.

The most significant figures are those with the largest place value (i.e. from left to right).

28. When you have decided on the number of significant figures you then consider the digit after the number of significant figures - if it is 5 or more the last digit is increased by 1.

29. The number 12.342 678 rounded to four significant figures would become 12.34. If the same number was rounded to five significant figures it would become 12.343 (the last digit is increased by 1 because the sixth digit is greater than 5).

30. **Exercise:** Round the following numbers to the values indicated.

Round 3.7892 to 2 significant figures ____________________
Round 0.3452 to 2 significant figures ____________________
Round 82.002 to 3 significant figures ____________________

Rounding Decimals

31. Rounding a decimal to a given number of places is similar to the process of rounding to significant figures except that the rounding always begins at the decimal point.

When you have decided on the number decimal places required you consider the digit after the number of places if it is 5 or more the last digit is increased by 1.

32. **Examples**

145.456 34 rounded to three decimal places is 145.456
0.266 98 rounded to two decimal places is 0.27
3.6 to three decimal places is 3.600
0.004 53 rounded to three decimal places is 0.005

33. **Exercise:** Round the following numbers to the places indicated.

Round 1342.15 to 1 decimal place ____________________
Round 0.000 161 to 4 decimal places ____________________
Round 412 234.574 to 2 decimal places ____________________

34. When you are performing electrical calculations it is usually adequate to round to two decimal places or three significant figures depending on the accuracy required.

Examples:

1.42
556
0.021
327,000

Electrical and Mechanical Units

1. Complete the following tables:

Common SI Units:

Quantity	Quantity Symbol	Unit	Unit Symbol
		metre	
Temperature			
			s
	m		
Electric current			
		volt	
			W
	R		
		joule	
	Q		
Pressure			

Common Metric Prefixes:

Metric Prefix	Meaning of Prefix	Symbol
		m
	times 0.000 001	
giga		
	times 1 000	
	times 0.000 000 001	
		p
		M

2. Write the quantity symbol for time? _____________

3. Write the quantity symbol for length? ______________

4. Write the quantity symbol for electromotive force? __________

5. Write the quantity symbol for electrical resistance? ___________

6. Write the quantity symbol for electric current? __________

7. Write the quantity symbol for power? ___________

8. Write the unit symbol for EMF? __________

9. Write the unit symbol for the basic unit of resistance? _________

10. Write the unit symbol for the base unit of current? _________

11. Write the unit symbol for the basic unit of power? _________

12. Write the unit symbol for the basic unit of energy? __________

13. Write the unit symbol for the basic unit of mechanical pressure? __________

14. How many watts are there in one horsepower? __________

15. Express 0.000 000 017 2 ohms in scientific notation. ______________

16. Express 2 400 000 watts in engineering notation. ______________

17. Round 231 825 to three significant figures. _________

Basic Electrical Physics

Structure of the Atom

1. Matter can be described as anything which occupies space. Matter exists in three forms:-

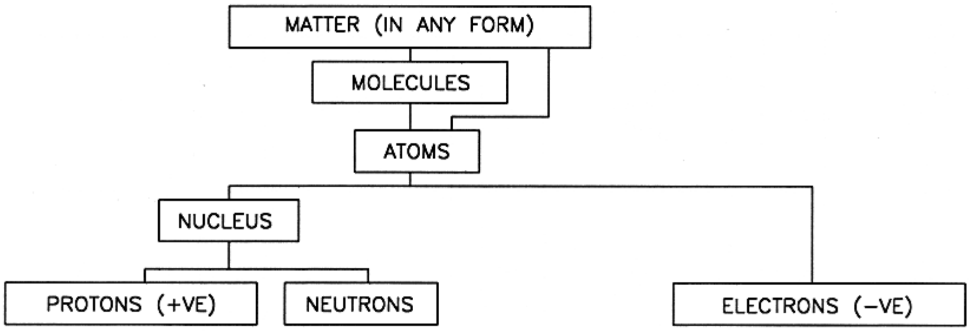
   a. Solid - In this form matter maintains its own shape.

   b. Liquid - In this form matter takes the shape of the container.

   c. Gas - In this form matter expands to fill the container.

2. All matter consists of the same basic parts, but in different combinations. The basic parts are the electron, the proton and the neutron. Each proton has a positive electrical charge. Neutrons have no electrical charge. An electron has a negative charge equal in magnitude to that of a proton (but opposite in polarity). The movement of these small negative particles (electrons) is known as a current flow.

3. Different combinations of these basic particles make up ATOMS and different combinations of atoms make up MOLECULES of a substance. A material which consists of only atoms of the same material is known as an ELEMENT.
   Two or more elements can combine to form a COMPOUND.



4. Electrons revolve around the nucleus in much the same way as the earth revolves around the sun.

5. A stable atom of a material has as many protons (positively charged) as it has electrons (negatively charged) so the overall charge is neutral.

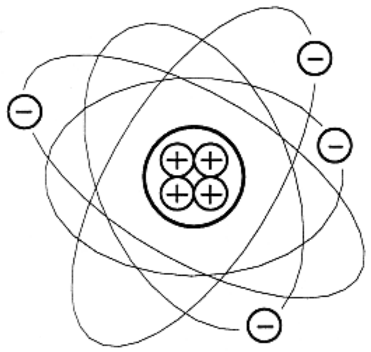
Ionisation

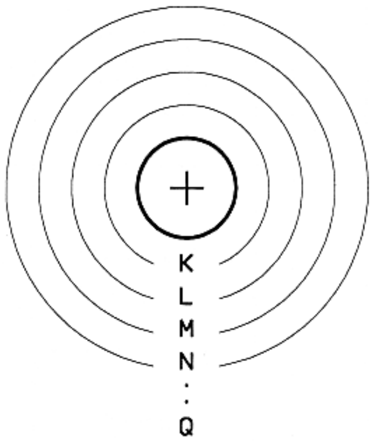
6. If an electron is added to or removed from an atom the resulting particle is known as an **ion**. An ion with a deficiency of electrons is positively charged and is known as a positive ion. An ion with an excess of electrons is negatively charged and is known as a negative ion. The process whereby ions are produced is called ionisation. When an electrical arc (or spark) occurs as in an arc welder, or when contacts open, the visible arc is air which has been momentarily ionised.

Electrons in Orbit

7. All of the electrons orbit their associated nucleus but not all of them are the same distance away. Each orbit is known as a ring or shell. More than one electron can exists in one shell.

8. Electrons in the inner rings or shells are held to the nucleus more tightly than those in the outer rings or shells. The outer orbit is known as the valency ring or valency shell.





9. In some materials the electrons in the outer or valency shell are not tightly bound to the nucleus and move freely about within the material. These electrons are known as free electrons.

10. Materials with many free electrons are usually good conductors of electricity.

11. Materials with 1, 2 or 3 electrons in the valency shell are usually good CONDUCTORS. Silver, copper and aluminium are good conductors of electricity. Brass, lead and iron are also common metallic electrical conductors, but all metals are relatively good conductors. Tap water is a good conductor. Conductors are used to provide a path for the flow of electrons.

Typical conducting materials and their applications are:

a.	Copper	Used for many electrical cables
b.	Aluminium	Large cables and busbars
c.	Brass	Structural parts which carry current
d.	Nichrome	A resistance wire designed to heat up when current passes through it - as in a heating element
e.	Carbon	Brushes in rotating electrical machines
f.	Mild steel	The outer metal casing of electrical devices
g.	Silver	Contacts for switches and contactors.

Tap water and sea water are good conductors of electricity, so they must be kept away from electrical appliances unless they are designed to operate under damp or wet conditions. All metals are conductors.

12. Materials with 4 electrons in the valency shell are called SEMI-CONDUCTORS. Silicon and germanium are semi-conductors used in the manufacture of electronic components such as diodes and transistors.

Semiconductors are special materials which are conductors under some conditions and insulators under others.

Semiconductors in the form of devices such as transistors, diodes and integrated circuits form the basis for the electronic industry.

The two most common types of semiconductor material are silicon and germanium.

13. Material with 7 or 8 electrons in the valency shell are called INSULATORS. Mica, glass, PVC and porcelain are good insulators.

Under normal operating conditions insulators are used to prevent the flow of electrons.

The term 'insulator' is a relative term which means that the material does not allow current to flow through it under normal operating conditions.

However, if the electrical pressure (or voltage) is increased to a value above a designed limit the insulation may 'break down' and allow current to flow through it (and the material is destroyed).

Insulating materials are available in hundreds of types, including solids, liquids and gases - often with special names or trade names.

Common insulating materials and typical applications are:

a.	PVC	Used as insulation on many electrical cables
b.	Glass	Glass-cartridge fuses
c.	Porcelain	Structural insulating components such as fuses
d.	Rubber	Protective gloves and cable insulation
e.	Air	Parts separated by air are insulated from each other at low voltages
f.	Bakelite	Structural moulded insulating components
g.	Mylar	Sheet insulation in electrical coils
h.	Red fibre	General purpose sheet or solid insulation
i.	Transformer oil	Liquid insulation in large transformers
j.	Mica	Insulation or supports for heating elements.

The term 'insulation resistance' is used to describe the resistance of the insulation between live parts - in most cases it is required to be one million ohms (1 meg-ohm) or more for appliances which operate on 240 volts.

14. In special cases some atoms may share an electron. This is known as covalent bonding and is very important in electronic devices such as and transistors.

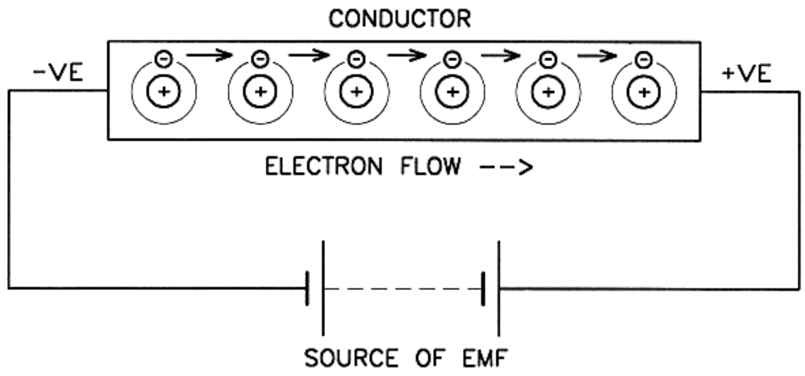
15. Electric current flow is based on the principle that LIKE CHARGES REPEL and UNLIKE CHARGES ATTRACT.

Electromotive Force

16. An electromotive force (emf) is a force which causes electrons ('electricity') to flow in a conductor. This electrical force is also described as a POTENTIAL DIFFERENCE or a VOLTAGE DROP between two points.

Electron Theory of Current Flow

17. **Electron Flow:** When an electromotive force is applied to a conductor, the free electrons are repelled by the negative charge and they move from atom to atom along the conductor and out through the source of the electromotive force. The controlled movement of electrons in a conductor is known as an ELECTRIC CURRENT or an ELECTRON FLOW and the direction of an electron flow is from NEGATIVE to POSITIVE.



18. **Conventional Current Flow:** Early scientists assumed that current flowed from positive to negative because deposits form on the negative terminal of an electroplating bath, and many magnetic rules were based on this direction. Current flow from positive to negative in the external circuit is known as conventional current flow, and it is the opposite of electron flow (negative to positive). However, many modern text books retain the use of conventional current flow for their magnetic laws so care must be taken when studying, to establish which theory of current flow is used.

19. **The direction of electric current flow for the remainder of this course is assumed to be CONVENTIONAL FLOW which is from POSITIVE to NEGATIVE in the external circuit. However, for the purposes of DC circuits without electronic or magneto-motive components it matters little which direction the current flows as the heating effect is the same.**

20. **HEAT and ELECTRO-MAGNETISM are always produced when an electric current is flowing in any part of a material.**

Current Flow in Gases and Liquids

21. Current flow in gases and liquids is similar to that in metallic conductors, except that as electrons move in one direction the ions produced (by the removal of an electron from an atom) move in the opposite direction. The liquid in a typical car battery (sulphuric acid) acts as a conductor, whereas special oil known as transformer oil is a good insulator. Liquids which conduct electricity are often known as electrolytes. A fluorescent tube contains a gas

(mainly argon) which becomes ionised and acts a conductor. A VACUUM acts as an insulator.

Resistance

22. All materials offer some opposition to the flow of electric current. This property is known as **RESISTANCE**, and each material has a different value. Materials which offer comparatively little resistance to the flow of current are known as conductors, and materials which do not allow current to flow through them under normal operating conditions are known as insulators. Silver and copper are good conductors and porcelain and PVC are good insulators.

23. Resistance to current flow is measured in OHMS, and the unit symbol is the Greek 'omega' (Ω). The quantity symbol is R.

24. The factors which govern the resistance of any material are: **(MALT)**

    a. **Type of Material** All materials have a different resistance for a given quantity of the material.
    b. **Cross Sectional Area** As the cross sectional area of a material INCREASES the resistance DECREASES. Thus a large conductor has LESS resistance than a small conductor of the same length, material and temperature

    c. **Length** As the length of a material increases the resistance increases if all other factors remain the same.

    d. **Temperature** All materials change their resistance as their temperature changes. Some materials increase in resistance as the temperature increases, while others decrease in resistance as the temperature increases. The resistance of most metals increases as the temperature increases.

25. A conductor with a low resistance allows more electric current to flow than a conductor with a high resistance if the voltage remains constant. Electrical devices designed to reduce the current flow in a circuit supplied from a constant voltage source are known as RESISTORS and they are available in several forms.

26. The lowest possible resistance is ZERO ohms (or NO resistance). If a circuit has NO resistance MAXIMUM current can flow in the circuit. In practical terms a circuit approaching zero ohms is known as a **SHORT CIRCUIT**.

27. The highest possible resistance is an infinite number of ohms (or infinity). If a circuit has an infinite resistance NO CURRENT can flow in the circuit. In practical terms a circuit approaching infinity is known as an **OPEN CIRCUIT**.

28. An OPEN switch has infinite resistance which means the circuit is off.

29. A CLOSED switch has zero resistance meaning the circuit is on.

30. The “better” a conductor is the lower its resistance will be, meaning the electrons which are moving in a current can flow more easily through it. All materials will have some amount of resistance.

31. The better an insulator is then the less likely any current at all will flow through the material. Good insulators have infinite resistance.

Basic Electrical Physics

1. In what three forms can matter exist?

2. Draw a simple diagram showing the relationship between the major parts of an atom. Indicate the electrical polarity of each.

3. In which direction do electrons flow in an electrical conductor with regards to electron flow?
a.) From Positive to Negative? b.) Negative to Positive?

4. What is the main difference between an electrical conductor and an insulator with regard to their atomic structure?

5. Is a vacuum an insulator, a conductor or a semi-conductor?

6. What is the special name given to an atom which has an excess of electrons?

7. Would two adjacent free electrons attract or repel each other?

8. What is the basic unit of electrical charge (or quantity of electricity) and what is the unit symbol?

9. What is the basic unit of electromotive force and what is the unit symbol?

10. What is the base unit of electric current flow and what is the unit symbol?

11. What is the basic unit of electrical resistance and what is the unit symbol?

12. What are the four factors which govern the resistance of any material?

13. What is the approximate resistance of a 'short circuit'?

14. What is the approximate resistance of an 'open circuit'?

16. Name six common conducting materials.

17. Name six common insulating materials.

18. What are the names of the two most common semiconductor materials?

19. Is tap water a conductor or an insulator?

20. Describe the general process of electrical conduction in solids, liquids or gases?

21. Under what special conditions can an electrical insulator become a conductor?

22. What is the direction of 'conventional current flow' in any material?

23. What is the name given to the force which causes current flow in any material?

Notes:

Conductors and Insulators

Objective

To identify electrical conductors and insulators from the samples provided.

Equipment

Prepared samples of insulating materials
Prepared samples of conducting materials
Resource book and writing equipment

Procedure

1. Occupation Safety and Health must be adhered to at all times with reference to the Laboratory Safety procedure, Danger Tag procedure and JHA risk analysis procedure.

2. Examine each of the materials provided and determine whether it is a conductor or an insulator (by inspection). Record your results in Table 1.

3. Submit your work to your Lecturer for comment and assessment.

4. Work site is cleaned and made safe in accordance with established procedures and return all equipment to its proper place.

Table 1

Number	Material	Conductor	Insulator
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Satisfactory:	

Not Satisfactory:	

Lecturer: ______________________________ Date: ______________

Transposition of Equations

1. An essential process in electrical calculations is transposing an equation for any variable in the equation.

2. An equation or formula is a mathematical statement of equality.

The value to the left of the equals sign is exactly equal to the value on the right hand side. In equations, symbols are called variables because they can take on a variety of different values.

3. To 'solve' an equation means to find the value for the variable which makes the equation a true statement.

The process of solving an equation for a given variable is also known as 'transposing' the equation, or making a nominated variable the 'subject'.

a) The solution of equations is based on the following rules:

Both sides of an equation are equal

b) If the same mathematical operation is performed on EACH SIDE of the equals sign the sides remain equal (as long as it does not involve division by a value which could be zero).
c) Any value which appears on the top and bottom of the same side of an equation which does not involve plus and minus signs can be cancelled.
d) Cross multiplication is always valid across an equals sign – i.e. multiply the top of each side by the bottom of the other side to bring all the terms to the top line.

5. The examples which follow illustrate the method of solving simple equations. Note that equations involving terms with plus and minus signs are handled differently to those involving multiplication and division only.

As a class exercise, your lecturer will explain how to transpose the following examples.

Note: Electrical Principles for Electrical Trades Vol. 1, (6th ed.) Jenneson, J. & Harper, B., provides examples of how to do transposition in the Tools and resources section, page 213.

Note: Jenneson uses the acronym BOMDAS where most WA students are more familiar with the acronym **BIMDAS**

B	Brackets	(x), {x} or [x]
I	Indices	x^2, √x
M	Multiplication	X x Y, or X.Y
D	Division	x ÷ y or x/y
A	Addition	x + y
S	Subtraction	x - y

Examples:

1. $X_L = 2\pi f L$ find for **f**

2. $H = \dfrac{I N}{\ell}$ find for **N**

3. $X_C = \dfrac{1}{2\pi f C}$ find for **C**

4. $\% \text{ eff} = \dfrac{\text{output} \times 100}{\text{Input}}$ find for **input**

5. $P = \dfrac{2\pi n T}{60}$ find for **n**

6. $Q = It$ find for **t**

7. $P = I^2R$ find for **I**

8. $R = \dfrac{\rho \ell}{A}$ find for ℓ

9. $P = \sqrt{3}.V.I.\text{Cos}Ø$ find for **V**

10. $V_C = \dfrac{1000\ Vd}{L\ I}$ find for **I**

Transposition of Equations

1	Make ***V*** the subject of the following equation: $R = \frac{V}{I}$	
2	If $P = I^2.R$, what is the value of ***I*** if $P = 960$ and $R = 60$?	
3	Transpose the following equation for ***C*** $X_C = \frac{10^6}{2\pi f C}$ Note: X_C is a single symbol - it is not C.	
4	If $c^2 = a^2 + b^2$, what is the equation for calculating **a**?	
5	If $a = \sqrt{c^2 - b^2}$ what is the equation for calculating **c**?	
6	Transpose the following equation for ***r*** . $A = \pi r^2$	
7	Transpose the following equation for ***Vd.*** $Vc = \frac{1000\ Vd}{L \times I}$	
8	Transpose the following equation for **R1**. $\frac{R1}{R2} = \frac{R3}{R4}$	

Practical Electrical Circuits and Protection

Task:

Demonstrate knowledge of key components in simple electrical circuits, and describe the types and characteristics of basic circuit protection devices.

Why:

A sound knowledge of the characteristics of basic electrical circuits and their related units is essential to the study of electricity in any form.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set activities and laboratory tasks.
3. You must achieve 100% in a final practical competency test.

Equipment

Samples of typical circuit protection devices.

References

* Electrical Principles for Electrical Trades. (6th ed.) J. Jenneson, B. Harper & B Moore.
* Electrical Wiring Practice (7th ed.) K. Pethebridge & I. Neeson
* AS/NZS 3000:2018 Wiring Rules, Standards Australia.

Practical Electrical Circuits and Protection

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for Electrical Trades (6th ed.)
Chapter 4 DC circuits Pages 65 - 77

Electrical Wiring Practice Vol 2 (7th ed.)
Chapter 1 Electrical protection and protection devices Pages 3 -7

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the laboratory projects in this Section.

5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion and assessment.

Practical Electrical Circuits and Protection

Parts of a Circuit

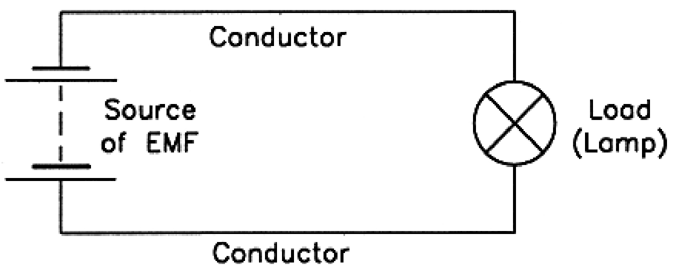
1. Electric current can only flow in a closed circuit. Any electrical circuit must have at least three basic parts - these parts are:

   a. A voltage source such as a battery, a generator or an alternator. This provides the electromotive force (emf) necessary to force current to flow in the circuit.

   b. Conductors to provide a path for the current. The path must always be continuous for current to flow. The most common type of conductor is insulated copper wire.

   c. A load such as a lamp, motor, heating element, solenoid or coil. The load is usually some device designed to convert electrical energy into some other form of energy. A load can consist of several components connected in 'parallel'.

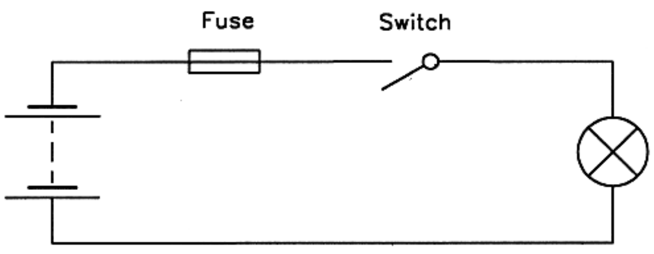
2. The individual parts of an electrical circuit are usually represented by symbols. A typical basic circuit is shown below.



3. An electrical circuit MUST have the three parts listed above, but most have additional components such as a switch to control the circuit and a fuse to protect it.

A fuse is designed to automatically disconnect the voltage source from a load under certain fault conditions.

A fuse is connected in 'series' with the circuit it protects. A series circuit which incorporates a switch and a fuse is shown below.



Short Circuits

4. Electric current is inversely proportional to the resistance of a circuit.

This means that as the resistance decreases the current increases. If the resistance of a particular circuit falls to a value approaching zero ohms a SHORT circuit is said to have occurred and a high current flows in the circuit.
A short circuit is said to have a resistance of 'zero' ohms.

5. The degree of the short circuit is often described using the terms 'dead short' and 'partial short', where a dead short is virtually no resistance between the two points.

Open Circuits

6. If an unwanted break occurs in a series circuit no current can flow, and an OPEN circuit is said to exist. An open circuit is said to have a resistance of 'infinity' ohms.

Overload

7. Circuits are usually designed to have a maximum current rating - a value of current which should not be exceeded under normal operating conditions.

The maximum current rating or the current carrying capacity of a circuit depends mainly on the size of cable and the current rating of the protective device.

8. If the current rating of a circuit or component is exceeded, it results in overheating of the component or circuit and they can be permanently damaged.

The condition where the maximum current rating of a circuit or component is exceeded is known as an overload.

Protective Devices

9. The purpose of an electrical protective device is to automatically take some pre-determined action if a specified type of fault occurs in a circuit while it is operating.

Typical types of faults which can be protected against include:

a. Short circuits
b. Open circuits
c. Sustained over current
d. Sustained under voltage
e. Sustained over voltage
f. Transient (momentary) under voltage
g. Transient (momentary) over voltage.
h. Earth faults (a live part comes in contact with an outer metal casing or the general mass of earth).

10. The most common types of overcurrent protective devices are fuses and circuit breakers.

11. **Wiring Rules**

A fuse is a device which has a short length of wire of known current carrying capacity (called the fusible element), enclosed in a suitable insulated carrier (known as the fuse carrier or fuse wedge) - See AS/NZS 3000 (Wiring Rules) Clause 1.4.68.

The fuse is connected in series with the supply line, so that if the current flow in the circuit exceeds a critical value the fusible element will melt, thus interrupting the supply of current to the circuit.

Clause 2.5 of the AS/NZS 3000 Wiring Rules contains the requirements relating to the devices for protection against overcurrent, current rating and types of protective device.

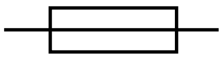
In general, the protective device must interrupt overload currents flowing in the circuit before such currents cause a temperature rise detrimental to insulation, joints, terminations or surroundings of the conductors.

12. **Fuses**

The most common types of fuses are:

a. High rupturing capacity (HRC) fuses
b. Glass cartridge fuses
c. Semi-enclosed rewire-able fuses (older existing installations only)

The symbol for a fuse is shown below:



13. Fuses are rated according to the maximum current which they can carry continuously under normal conditions (not the current at which they will interrupt the supply).

A 10 amp fuse does not 'blow' at 10 amps.

14. The fusing current depends on the type of fuse and the **magnitude and duration** of the fault current. A 10 amp semi-enclosed rewire-able fuse element may not melt until the current reaches about 18 amps if the fault current is increased gradually; an HRC fuse element (or link) would melt at more than 10 amps but less than about 18 amps.

Thus fuses provide protection against high short circuit currents, but not against relatively small excess currents which would occur if a motor was slightly overloaded. In the latter case additional motor protection would need to be provided in the form of motor 'overloads' or direct temperature sensing devices such as Thermistors, Microtherms or Klixons.

15. If a fuse operates it indicates a fault condition in the relevant circuit. The fault must be located and corrected before the fuse element is replaced. When the fault has been corrected the procedure for replacing the fuse element(s) is as follows:

a. Turn the main isolating switch off.

b. Carefully withdraw the fuse carrier from the fuse base.

c. Replace the fuse with the same size and type as the original (after checking to see that the size of fuse matches the fuse rating marked on the fuse base).

d. Turn the main isolating switch on.

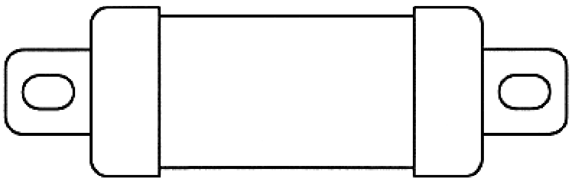
16. Typical approximate current ratings for fuse elements composed of tinned copper wire for existing semi-enclosed rewireable fuses are:

8 amps - 0.315 mm diameter
10 amps - 0.355 mm diameter
16 amps - 0.500 mm diameter
20 amps - 0.560 mm diameter

17. Semi-enclosed rewire-able fuses **shall not** be installed in electrical installations, see AS/NZS3000:2018 clause no. 1.7.2 (h).

High Rupturing Capacity (HRC) Fuses

18. A high rupturing capacity (HRC) fuse link is a special type of cartridge fuse in which the silver fusible element is completely sealed inside a thick ceramic tube. When an HRC fuse 'blows' the resulting arc is contained inside the ceramic tube. The time taken to interrupt the supply in an HRC fuse is much more predictable than a semi-enclosed rewire-able fuse. A typical shape for an HRC fuse is shown below:



19. HRC fuse links are not repairable and must be replaced with the same size and type as the original. It would be highly dangerous to replace an HRC fuse link with a length of fuse wire of the same current rating, because the HRC fuse carrier is not designed to contain the arc which would result if the fuse blew. The time taken for an HRC fuse to interrupt a circuit under fault conditions is much more predictable than semi-enclosed rewire-able fuses, so rewire-able fuses are rarely used for currents over about 100 amps.

20. The fusing requirements for a motor circuit are different to those of, say, a circuit involving resistive components because motors have a high short-time starting current. Most HRC fuse manufacturers provide different fuse links for each purpose and they are generally known as either motor fuse links or general fuse links. Information on the characteristics and ratings of each type is available from fuse manufacturers.

Circuit Breakers

21. A circuit breaker is a switch which automatically opens a circuit under pre-determined fault conditions (see Wiring Rules Clause 1.4.30).

The operating mechanism can be thermal, magnetic or a combination of both, but in all cases the circuit breaker must be capable of interrupting any current up to and including the prospective short circuit current at the point where the device is installed (see Clause 2.5.2).

Small moulded case circuit breakers (MCCB's) are sealed and are not usually repairable. The symbol for a **circuit breaker** is shown below:

22. Air circuit breakers (ACBs) have similar operating characteristics to HRC fuses, but they have the advantage that power can be restored to the circuit by simply turning them back on (after the fault has been corrected).

Another advantage is that multi-phase circuit breakers disconnect all phases if a fault occurs on one phase.

23. Care must be taken when examining the status of air circuit breakers because they are usually ON in the fully UP position; this is the reverse of the usual convention used for switches in W.A., where the UP position is OFF.

24. When an air circuit breaker trips due to overcurrent in the circuit the operating toggle usually remains in a position slightly less than fully up.

25. All circuit breakers must automatically switch OFF to clear a fault when the current exceeds 1.45 X of the nominal current rating of the circuit breaker (see AS/NZS 3000 Clause 2.5.3.1).

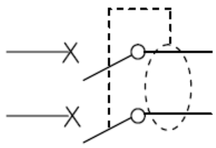
To reset these circuit breakers (after the fault has been located and cleared) it is necessary to push the operating toggle down to the OFF position, then back up to the ON position.

Residual Current Devices (RCDs)

26. A residual current device (RCD) or 'safety switch' is a means of providing protection from electric shock if a person touches a live terminal while in electrical contact with earth.

RCDs can be installed as the main switch for an installation, or they can be incorporated in extension sets which have multiple socket-outlets. Installation of an RCD does not remove the need to earth single insulated appliances.

The symbol for a single phase residual current device (RCD) is shown below:



27. An RCD is designed to interrupt the supply to the protected circuit if the current in the incoming active conductor is not the same as the current in the associated neutral conductor.

If a person comes in contact with a live terminal while an appliance is switched on, some current will flow through him or her instead of returning to the supply via the neutral conductor.
If this earth leakage current exceeds 10 to 30 milliamps (depending on the design and setting of the RCD), the RCD will operate and isolate the circuit from the supply within about 10 to 50 milliseconds, thus reducing the possibility of a lethal electric shock.

28. RCDs do not provide protection against a person coming in contact with active and neutral simultaneously, nor do they provide protection against excessive current or overload faults.

29. RCDs are mandatory for the protection of **all** final subcircuits in domestic installations (see AS/NZS 3000 Clause 2.6.3.2.2).

30. Each RCD should protect no more than three circuits and not all of the same circuit type i.e. power and light circuits (see AS/NZS 3000 Clause 2.6.2.4 (b)).

Other Types of Protection

31. Other types of protection such as under-voltage protection, over voltage protection and overload protection will be covered later in this course.

Practical Electrical Circuits and Protection

1. What are the three BASIC parts of any electrical circuit essential to permit current to flow?

2. Practical electrical circuits must consist of three BASIC components but almost always have two additional components. Name the other two.

3 What is necessary to include a FUSE or circuit breaker in all electrical circuits?

4. What is the approximate current at which a 10 amp circuit breaker would automatically switch off to clear a fault?

5. What essential step must a person take before attempting to replace a fuse?

6. What two basic functions can most circuit breakers perform as part of an electrical circuit?

7. HRC is the name given to the most common type of cartridge fuse for high current circuits, what does “HRC” stand for?

8. When the toggle of a Circuit Breaker is in the UP position, is it ON or OFF?

9. Can semi-enclosed rewireable fuses be used in new installations? State the Clause No.

more….

10. Are fuses and circuit breakers connected in series or parallel with the protected components of a circuit?

11. What is the approximate resistance of an ‘open circuit’?

12. What is the approximate resistance of a ‘short circuit’?

13. What does an RCD provide protection against?

14. What type of protection is not provided by an RCD?

15. In a domestic installation, which circuits must be protected by RCD’s?

Protection Devices

Objective

To identify basic electrical protection devices

Equipment

Prepared protection project board
Fuses: SER, HRC, bottle, glass, automotive
Air- break circuit breakers (2 types)
Overload Relay
Sample RCDs

Procedure

1. Occupation Safety and Health must be adhered to at all times with reference to the Laboratory Safety procedure, Danger Tag procedure and JHA risk analysis procedure.

1. Inspect each of the electrical protection devices and record the details of each in Table 1. Operate the device if applicable.

3. Submit your work to your Lecturer for comment and assessment.

4. Work site is cleaned and made safe in accordance with established procedures and return all equipment to its proper place.

No.	**Name**	**Purpose**	**Voltage Rating**	**Current Rating**	**Basic Operation**
e.g.	bottle fuse	protect wiring	250V	15A	melting of fusible element
1					
2					
3					
4					
5					
6					
7					
8					

Satisfactory:			Not Satisfactory:	

Lecturer: ______________________________ Date: ______________

Ohm's Law

Task:

Demonstrate knowledge of the relationships between voltage, current and resistance and how they affect operating parameters of DC circuits.

Why:

Ohm's Law details the fundamental operational characteristics of all electrical circuits.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set activities and laboratory tasks.
3. You must achieve 100% in a final practical competency test.

Equipment

Samples of typical simple circuit components
Digital and analogue meters

References

* Electrical Principles for Electrical Trades (6th ed.), J. Jenneson, B. Harper & B. Moore
* AS/NZS 3000:2018 Wiring Rules, Standards Australia.

Ohm's Law

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for Electrical Trades (6th ed.)
Chapter 4 Page 68

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the laboratory projects in this Section.

5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion and assessment.

Ohm's Law

1. In any direct current electrical circuit there is a specific relationship between the voltage, the resistance and the current flow. This relationship is often expressed as 'Ohm's Law' which states that:

"The current flowing in a DC circuit or any part of a circuit is directly proportional to the applied voltage and inversely proportional to the resistance of a circuit".

2. This means that if the voltage across a particular component is increased the current flow will increase (a DIRECTLY proportional relationship), and if the resistance of the circuit is decreased the current flow will increase (an INVERSELY proportional relationship).

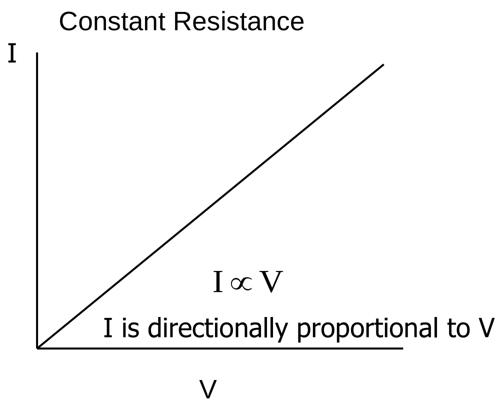
Thus the current in any DC circuit can be determined by dividing the voltage by the resistance.

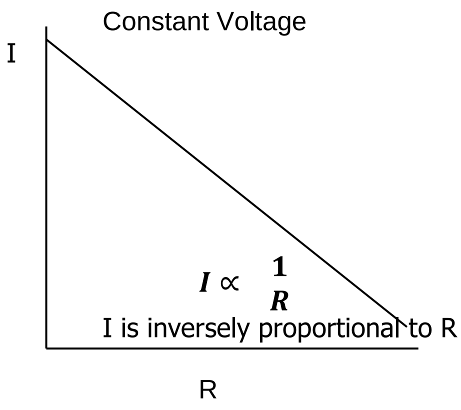
3. Ohm's Law can be expressed as a mathematical relationship or equation:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \quad \text{or} \quad I = \frac{E}{R}$$

4. Since voltage can be expressed as an electromotive force, E (the CAUSE of the current flow), or as a potential difference (the EFFECT of the current flow), the mathematical equation for Ohm's Law can also be written as:

$$\text{Current} = \frac{\text{Potential Difference}}{\text{Resistance}} \quad \text{or} \quad I = \frac{V}{R}$$





When the resistance in a circuit stays constant, current will change proportionately with the applied voltage. That is, value of current is directly proportional to applied voltage.

If the voltage doubles the current flow doubles and if voltage halves the current flow halves for a constant value of resistance.

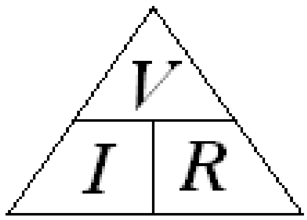
When the applied voltage stays constant, current changes are inversely proportional to changes in resistance.

That is if resistance doubles, the current flow halves and if resistance halves, the current flow doubles when the applied voltage is constant.

5. The equation for Ohm's Law can be transposed to find any value if the other two are known, so the three ways which Ohm's Law can be expressed are:

(Current)	(Voltage)	(Resistance)
$I = \frac{V}{R}$	$V = I \times R$	$R = \frac{V}{I}$

6. A memory aid which is frequently used to show these relationships is:



Note: Cover the wanted variable to see the mathematical expression which can be used to find it.

Solving Ohm's Law Problems

7. An Ohm's Law problem is one in which two circuit values are known and the third is to be found.

Most Ohm's Law problems can be solved using the same basic sequence.

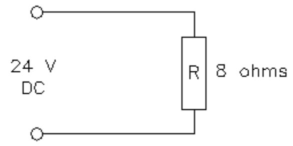
8. **Example**

Find the current flowing in a circuit in which a voltage of 24 volts DC is connected to a resistance of 8 ohms.

9. **Steps for Solution**

a.) Read the question carefully and make sure you know what value is to be found.

a.) Draw a circuit diagram and insert the known values in BASIC units (e.g. amps, not milliamps if applicable).



c.) Select the correct equation for the problem.

$$I = \frac{V}{R}$$

d.) Substitute the known valued in the equation (in BASIC units).

$$I = \frac{24}{8}$$

e.) Solve the problem using arithmetic.

$$I = 3$$

f.) Express the answer in convenient units (using multiples or sub-multiples where required).

I = 3 A
=======

g.) Check your answer - does it LOOK correct?

10. All Ohm's Law problems can be solved in the above sequence, but in circuits involving more than one component, care must be taken to use the correct values in each calculation.

It is often useful to add the calculated values to the diagram as they are determined.

11. **Examples for Practice**

Note: You should always draw a diagram of the circuit.

a. How much current would flow in a circuit in which a 6 ohm resistor was connected to a 24 volt supply?

b. If 24 amps flowed in a circuit when a potential difference of 12 volts was applied to it, what would be the resistance of the circuit?

c. What voltage would have to be applied to a 100 ohm resistor to cause a current of 0.25 amps to flow through it?

d. The potential difference across a 3 kilo ohm resistor is 9 volts. How much current would be flowing in the circuit?

e. A particular resistor allows 2 milliamps to flow when the potential difference across it is 40 volts. What is the resistance of the resistor?

f. What value of voltage would be required to allow a current of 50 micro-amps to flow through a resistance of 1 meg-ohm?

Ohm's Law

1. How much current would flow in a circuit that includes a 3 ohm resistor connected across a 24 volt supply? Draw a diagram to show the circuit. Write the formula used.

2. If 6 amps flowed in a circuit when a potential difference of 12 volts was applied to it, what would be the resistance of the circuit? Draw a diagram to show the circuit. Write the formula used.

3. What voltage would have to be applied to a 10 ohm resistor to cause a current of 5 amps to flow through it? Draw a diagram to show the circuit. Write the formula used.

4. The potential difference across a 2 kilo ohm resistor is 20 volts. How much current would be flowing in the circuit? Draw a diagram to show the circuit. Write the formula used.

5. A particular resistor allows 2 milliamps to flow when the potential difference across it is 40 volts. What is the resistance of the resistor? Draw a diagram to show the circuit. Write the formula used.

more…

6. What value of voltage would be required to allow a current of 20 micro-amps to flow through a resistance of 1 meg-ohm? Draw a diagram to show the circuit. Write the formula used.

7. Write the three equations which represent 'Ohm's Law'.

8. A 12 volt circuit is connected to a single 6 ohm resistor. How much current would flow in the circuit if the resistor became open circuited? Draw a diagram to show explain the circuit.

9. A 12 volt circuit has a single 2 ohm resistor. How much current would flow in the circuit if the resistor was short circuited? Draw a diagram to show explain the circuit.

Notes:

Resistance Measurement

Task:

Measure resistance using a range of digital and analogue ohm-meters

Why:

You need to be able to safely measure resistance so that you can analyse the behaviour of a circuit. The types of resistance measurement undertaken will include; continuity of circuits and insulation resistance checks of cables

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.

2. You must satisfactorily complete the set activities and laboratory tasks.

3. You must achieve 100% in a final practical competency test.

Equipment

Prepared laboratory projects
Prepared resistive components
Multimeters (digital and analogue)
Insulation Resistance Testers (Meggers)
Bridge Meggers

References

* Electrical Principles for the Electrical Trades (6th ed.), J. Jenneson, B. Harper & B. Moore.

* AS/NZS 3000:2018 Wiring Rules

Resistance Measurements

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) Volume 2

Chapter 11 Test Equipment
Section 11.9 Continuity and resistance testing
Section 11.12 Resistance measuring circuits

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheet. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Submit your answers to the Work Sheets to your Lecturer for discussion and assessment.

Resistance Measurements

1. The resistance measuring instruments you are likely to use most frequently in the electrical industry are:

   a. Multimeters - to measure voltage, current and resistance.
   b. Insulation Resistance testers (Meggers) – to test the insulation resistance of circuits
   c. Bridge meggers (Wheatstone bridge) – to accurately test circuit resistance

2. Two general forms of resistance measuring instruments are available - analogue and digital. An analogue instrument has a pointer or needle moving across a scaled or graduated background plate, a digital instrument gives a direct numerical read-out with an LED screen.

All types of digital instruments and resistance indicating instruments require a battery to operate their electronic systems; these types of instruments usually incorporate a battery test function to ensure the battery has sufficient voltage. Most analogue types of ammeters and voltmeters do not require a battery as they derive their power directly from the circuit.

You should switch all battery operated instruments off when you are not using them to avoid premature battery failure.

3. The general rule for testing the resistance of an electrical circuit is to ensure the power supply is disconnected and no other component is connected in parallel with the circuit to be tested.

The reason is that resistance testers including insulation resistance testers will be damaged sometimes beyond repair, if connected to an external power supply.

4. Connecting a multimeter set on the Ohms range can cause catastrophic damage to the meter than can injure the operator. Always test an existing circuit for voltage before connecting a meter to read resistance.

Ohmmeters

5 An ohmmeter has a small internal battery which causes a small current to pass through the component being measured; an incorrect reading will be obtained if the battery voltage is not above a specified value.

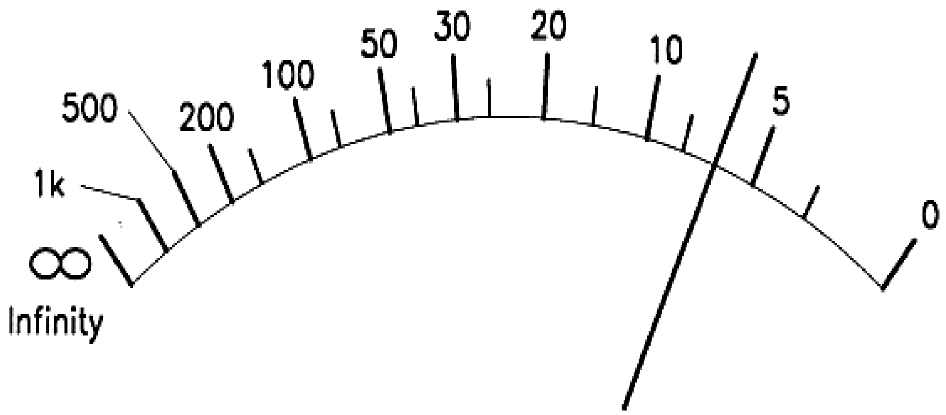
Stand-alone ohmmeters are not always available so it is more usual to use a multimeter with resistance ranges for general resistance measurement.

Most ohmmeters (including analogue multimeters with ohms ranges) have a reverse scale - the lowest value is at the RIGHT end of the scale and highest value is at the LEFT.

Scales on ohmmeters are usually non-linear, meaning that the distance between divisions is not equal.

Example scale over the page:

Example Scale of an analogue multimeter:



You must take the following precautions when measuring resistance with an ohmmeter or multimeter:

e. Make sure that the supply has been disconnected from the component to be measured.

f. Use the 'Ohms Adjust' knob to set the instrument to full scale deflection (FSD) with the test probes short circuited. If the pointer on the instrument cannot be adjusted to zero ohms it indicates that the internal battery needs replacing.

g. Make sure that there are no other components in parallel with the one being measured.

h. Switch the instrument off after use.

Multimeters

6. A multimeter is an instrument which has various functions and ranges so that it can be used for measuring various values.

The most common functions are current, voltage and resistance, but some digital types have special functions such as audible continuity, diode test and transistor test.

Multimeters are connected in series for current ranges and parallel for voltage ranges. You must take care to select the correct function and range on the selector mechanism.

Multimeters should be switched off or to the highest available a.c. range when they are not in use.

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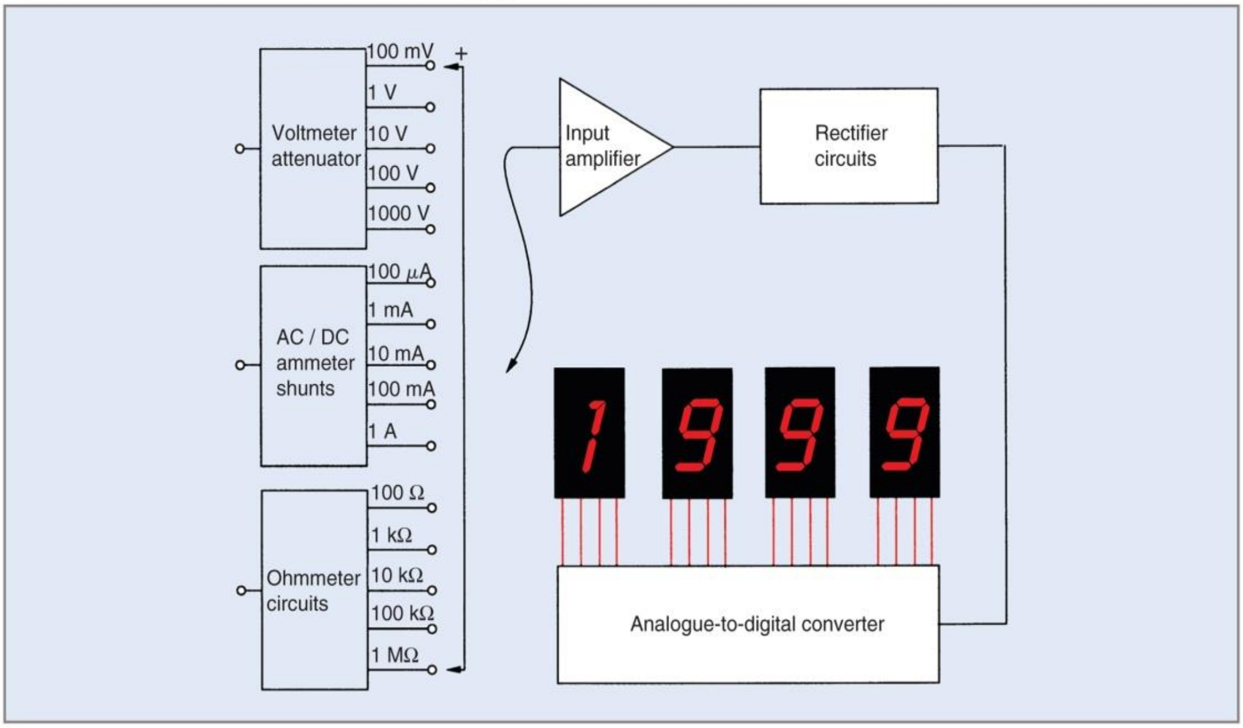


Block diagram of the internal circuits of a digital multimeter

Circuit Continuity

7. Continuity is a term used to describe the condition in which a conductor is continuous from one end to the other.

The most common method of checking continuity is to use a resistance measuring instrument such as a multimeter; if a zero or low resistance is indicated the circuit is usually continuous.

A reading of infinity between the two ends of the conductor indicates that the conductor is open circuited.

8. If you are to check a conductor for continuity, you <u>must</u> disconnect the supply voltage and at least one end of the conductor to avoid obtaining a false reading through other conductors in the circuit.

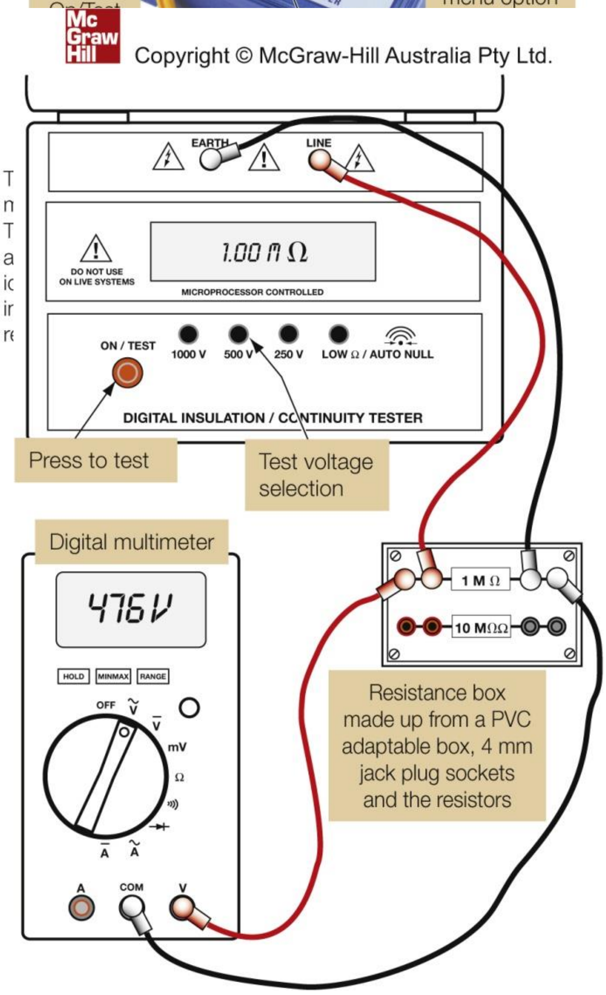
Insulation Resistance Testers (Meggers)

9. The purpose of an insulation resistance tester is to ensure that the live parts (Active and neutral conductor) do not come in contact with exposed parts or earth, of an electrical installation.

The insulation between any live part and earth, or any exposed metal frame of a single insulated appliance or installation must be capable of withstanding a direct current at 500 volts (see AS/NZS3000:2018 clause no. 8.3.6.2.)

10. Insulation resistance testers are available in hand driven generator or battery operated electronic push button types; with a range of output voltages: typically: 250 V DC to 1000 V DC

11. The scale on an insulation resistance tester is usually calibrated in Meg-ohms (MΩ) from zero to infinity (∞)



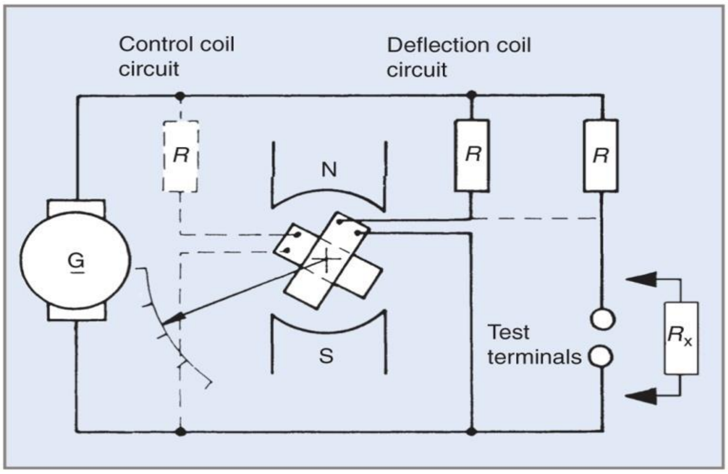
Calibration checks for IR Testers

12. Insulation resistance tester must maintain a consistent terminal voltage for valid test results. AS/NZS 3000 Wiring Rules states that an IR tester must maintain its terminal voltage within +20% and -10% of the nominal open circuit voltage of 500 V DC when measuring a resistance of 1MΩ.

(see AS/NZS3000:2018 clause 8.3.6.2)

Bridge Meggers

13. A bridge megger is a test instrument which has several functions. It can be used as a 500 volt high voltage insulation tester (megger), or an accurate ohmmeter (bridge).



Bridge megger circuit

14. To use the instrument to measure an unknown resistance:

a. Make sure that the component to be tested is not connected to the supply.
b. Set the function to 'bridge'.
c. Connect the component or circuit to the test terminals L and G.
d. Set the bridge ratio switch to a value based on the estimated resistance. The available ratios are: $\div 100$, $\div 10$, $\times 1$, $\times 10$ and $\times 100$.
e. Wind the handle and turn the four decade dials until the balance indicator remains steady in the mid position.
f. Note the four numbers showing on the decade dials. The resistance reading is the four numbers showing on the decade dials multiplied by the ratio setting.

Care and Storage of Instruments

15. Electrical measuring instruments contain delicate components that can be easily damaged by rough handling, excessive temperatures or using them on incorrect ranges.

When they are not in use you should switch them off (if they are battery operated) and store them with any connecting leads neatly wrapped.

You should avoid storing them with other equipment on top of them.

16. It is a bad practice to tap the glass on any measuring instrument because the glass can be dislodged.

17. If you are to transport an analogue multimeter, setting it to the highest available current range will provide maximum damping for the pointer, however, setting it to the highest current range also means that there is a very low resistance between the connecting leads, so you must take care to select the appropriate function and range before you use it.

If the instrument is to be stored you should switch it off or set it to the highest available a.c. voltage range.

18. All clips, probes and leads should be maintained in safe working order.
If any connecting lead becomes damaged you should have it replaced immediately.

Resistance Measurement

1. What is the specific name given to the instrument that is used to measure the RESISTANCE of a circuit?

2. What are the names of the numerical values at the upper and lower limits on the indicating scale of an analogue OHMMETER?

3. For which function of an analogue multimeter is it essential to incorporate its internal battery?

4. What is the purpose of the 'OHM'S ADJUST' control on a typical portable ohmmeter?

5. There are two important precautions that must ALWAYS be taken when using a meter to measure the ohms of an unknown resistance in a circuit, what are they?

6. What is the minimum permissible insulation resistance value to earth, in ohms, of a 415 volt motor or appliance?

7. Before testing a cable for continuity one end must be disconnected first, why?

8. At what voltage and which current type must be used if performing an insulation resistance to earth test on a 3-phase 415V motor or appliance?

9. What is the minimum permissible insulation resistance to earth of a 230 volt appliance that incorporates a heating element? Provide the AS/NZS3000:2018 clause number.

10. Name two special measurement functions of a Bridge Megger.

Resistance Measurement

Objective

Take measurements of resistance using different types of instruments.

Equipment

Analogue multimeter
Digital multimeter
Insulation resistance tester (megger)
Bridge megger
Typical electrical devices incorporating Heating elements and windings;
e.g. Appliances, Power Tools, Hotplates, Transformers, Motors, resistors, etc.
Personal Danger Tag (Danger- Do Not Operate)

Procedure

1. Ensure the item to be tested has been isolated from the supply

2. Check no parallel paths are present that may cause false readings.

3. Under instruction from your Lecturer, take measurements using both digital and analogue type instruments, taking care to avoid *parallax error*. Note: Measurements may be taken from several variations of resistive devices, wire wound resistors, appliances, electronic resistors, etc.

Measuring Resistance using multimeters

4. Measure the resistance across the connection terminals of the four given devices with a digital multimeter and an analogue multimeter. Record the results in the Results Table.

Results Table – Measured Resistance

Device	Measured Resistance (Analogue Multimeter)	Measured Resistance (Digital Multimeter)

5. Have your results checked by your lecturer.

6. Briefly explain how to avoid Parallax Error when using an Analogue meter type.

7. Use the measured resistance value of an appliance that incorporates a heating element and calculate its power rating.

Part B – Measuring Insulation Resistance

Objective.

Determine the insulation resistance between all live conductors and the frame (earth) of 240V Mains powered appliances. Note: An IR tester

Equipment

Analogue or Digital IR (Insulation Resistance) Tester
Assorted mains powered **Class 1 type appliances**

Procedure

1. Set the IR Tester on the 500VDC Range
2 Check IR tester leads by touching together and pressing the Test button, instrument should read Zero ohms.
3. Connect one of the IR Tester leads to the metal frame of the appliance, then place the other lead across both live pins and press the test button. If the appliance incorporates an on/off switch, make sure it is in the "on" position.
4. Observe the reading indicated on the IR Tester and write down the result in the table below.

Results Table – Measured Insulation Resistance Values

Appliance Type	Measured Insulation Resistance(Meg-ohms)	Condition (Pass/ Fail)
Toaster	>1MΩ	Pass

2. Have your results checked by your lecturer.

3. According the Wiring Rules, what is the minimum permissible insulation resistance between the live conductors and earth?

4. For appliances that contain ***sheathed*** heating elements, is there an exception to the value required for the above question? Yes/ No.

What is the allowable value?

Part C Measuring Earth Continuity (Low Ohms)-

Objective

To measure the continuity of the Protective Earthing conductor on a Class 1 appliance.

Equipment

Analogue or Digital IR (Insulation Resistance) Tester
Assorted mains powered Class 1 type appliances

Procedure

1. Set the IR Tester on the 0 - 3Ω Range
2 Check IR tester leads by touching together and pressing the Test button, instrument should read Zero ohms, if not use the Zero adjustment knob to correct.
3. Connect one of the IR Tester leads to the metal frame of the appliance, then place the other lead the appliance plug top earthing pin and press the test button.
4. Observe the reading indicated on the 0-3Ω range and write down the result in the table below.

Results Table – Measured Earth Continuity Values

Appliance Type	Measured Earth Continuity (Ohms)	Condition (Pass/ Fail)
Toaster	< 0.5Ω	Pass

2. Have your results checked by your lecturer.

3. According the Wiring Rules, what is the minimum resistance of the protective earthing conductor between the metal body/ frame and the earthing pin on the plug top?

4. For Class II appliances that display the Double Square □ symbol, is it necessary to perform an Earth continuity test? Yes/ No.

Measuring resistance using a bridge megger

Objective.

The lecturer will demonstrate how to measure very low resistances using a Bridge Megger.

Equipment

Bridge Megger
DC shunts 50 - 250A

Procedure

1. Short the leads of the bridge megger together and measure the lead resistance.

2. Connect the leads across the DC shunt.

3. Measure the resistance using the bridge function.

Results Table – Measured Resistance of windings

Shunt type	Measured Resistance (Bridge Megger Ω)

4. Save the results for later.

Selection of meters to measure electrical circuit quantities

Task:

Measure voltage, current and resistance in any part of a DC circuit using digital and analogue meters.

Why:

It is not possible to see electricity but it is possible to detect it and see its effects. Electricity behaves in predictable ways and this behaviour can often be monitored using relatively simple measuring instruments and techniques. You need to be able to safely measure voltage, current and resistance so that you can analyse the behaviour of a circuit.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set activities and laboratory tasks.
3. You must achieve 100% in a final practical competency test.

Equipment

Prepared laboratory projects
Lab-volt laboratory equipment
Prepared resistive components
Extra low voltage power supplies
Ammeters, voltmeters and multimeters (digital and analogue)
Volt-sticks

References

* Electrical Principles for the Electrical Trades (6th ed.), J. Jenneson, B. Harper & B. Moore.

Selection of meters to measure electrical circuit quantities

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) Volume 2

Chapter 11: Test Equipment

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheet. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Submit your answers to the Work Sheets to your Lecturer for discussion and assessment.

Selection of meters to measure electrical circuit quantities

1. The measuring instruments you are likely to use most frequently in the electrical industry are:

a.	Ammeters	to measure electric current.
b.	Voltmeters	to measure electrical pressure.
c.	Multimeters	to measure voltage, current and resistance.
d.	Non-contact testers	volt-sticks (to test for the presents of power)
e.	Circuit indicators	series test lamps (to test for voltage)

2. Two general forms of measuring instrument are available - analogue and digital.

An analogue instrument has a moving pointer and a graduated scale, and a digital instrument gives a direct numerical read-out.

All types of digital instruments and resistance indicating instruments require a battery; most analogue ammeters and voltmeters do not require a battery.
You should switch all battery operated instruments off when you are not using them to avoid premature battery failure.

3. Some instruments are designed to operate on alternating current, some are designed to operate on direct current, and others are designed to operate on both a.c. and DC

You must examine the markings on an instrument before you use it, otherwise it could be damaged. A straight line under the function marking on an instrument (A or V), indicates a DC instrument, and a small sine curve indicates an a.c. instrument.

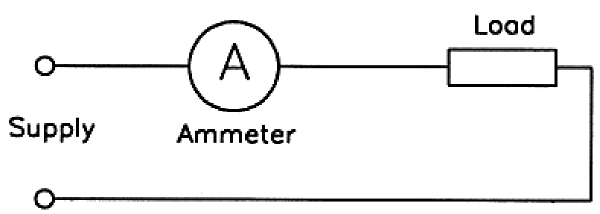
If an instrument is designed for DC the connecting terminals are usually colour coded red and black to indicate their polarity; red is positive and should be connected to the more positive terminal.

4. You must determine the FUNCTION and RANGE of a measuring instrument before you connect it into a circuit. Typical functions are DC volts, DC amps, a.c. volts, a.c. amps and resistance. Typical ranges are 0-1, 0-5, 0-10, 0-100 and 0-500, but many others are used.

Ammeters

5. An ammeter (not amp-meter) is used to measure the current flow in a circuit, therefore you must connect it in SERIES with the component in which the current is being measured - as shown below.

A typical ammeter has a very low internal resistance; an explosion can result if it is incorrectly connected in parallel with a supply.



6. If you are to measure the current in an existing circuit or component you must isolate the supply and temporarily alter the wiring in order to connect an ammeter in series with the relevant part of the circuit.

7. **Clip-on Ammeters**

A special type of ammeter is available which can be used to measure the circuit current without having to disconnect any wiring.

They are known as clip-on ammeters, link-test meters, clamp-meters or Tong-testers.

The instrument is designed to detect the magnetic field resulting from the current in the conductor and convert it to an indication on an analogue or digital meter.

Analogue instruments are available in two general types - moving iron and inductive or transformer types - inductive clip-on ammeters are only suitable for use on a.c.

They are not usually as accurate as fixed ammeters, but the accuracy can be improved by looping the insulated conductor around the magnetic jaws two or more times, then dividing the reading by the number of times the conductors pass through the jaws.

8. Both analogue and digital clip-on ammeters have a meter lock which enables the reading on the instrument to be locked so that meter can be read in a more convenient and safe position.

You must check the meter lock to see that it is off before attempting to take another reading.

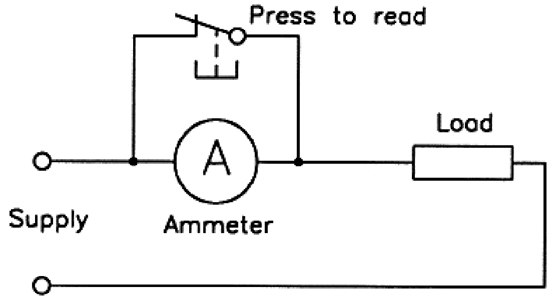
9. Analogue clip-on instruments have provision for selecting different scales; it can be a normal range selection control, a mechanical mechanism which physically changes the scale under the pointer, or a system which allows the entire meter mechanism to be replaced with another with a more convenient scale.

Clip-on instruments can also have provision for voltage and resistance ranges so that they can be used as a multimeter, in which case external test probes are required.

10. **Press-To-Read Button**

If you are to use an ammeter to determine the current in an electric motor the meter needs to be able to safely withstand an initial starting current of about 5 to 8 times the full load current.

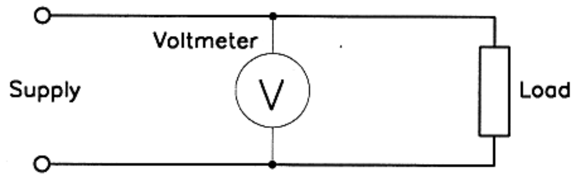
Damage to the meter can be prevented by connecting a normally closed 'press-to-read' button in parallel with the ammeter as shown below; the reading must be taken with the button pressed.



Voltmeters

11. A voltmeter is used to measure the electrical pressure between two points in a circuit; therefore you have to connect it in PARALLEL with the component across which the pressure is being measured - as shown below.

A typical voltmeter has a comparatively high internal resistance.



Voltmeter Loading Effect

12. When you connect a voltmeter to measure the voltage in a circuit it becomes part of the circuit and current flows through it.

Although it has a high resistance, the effect is to place additional load on the circuit in parallel with the component - this voltmeter loading effect can result in false readings on the voltmeter.

The loading effect is most evident in low current electronic circuits.

13. The loading effect of a voltmeter is known as its sensitivity and it is expressed in ohms per volt.

Individual voltmeters can have sensitivities ranging from about 500 ohms per volt to several meg-ohms per volt.

A sensitivity of 1 meg-ohm per volt or more is usually preferable in electronic circuits. Digital multimeters typically have a high sensitivity on voltage ranges.

15. You **must** take the following precautions when measuring resistance with an ohmmeter or multimeter:

a. Make sure that the supply has been disconnected from the component to be measured.

b. Use the 'Ohms Adjust' knob to set the instrument to full scale deflection (FSD) with the test probes short circuited. (*Note: If the pointer on the instrument cannot be adjusted to zero ohms it indicates that the internal battery needs replacing).*

c. Make sure that there are no other components in parallel with the one being measured.

d. Switch the instrument off after use.

Multimeters

15a. **Safe use of multimeters**

All multimeter and test equipment probes necessarily have bare ends so that they can make proper electrical contact at the point being tested.

The bare ends often extend back up to about 25 mm from the point of the probe so that it can be inserted in sockets and other confined spaces.

You need to take extreme care when using such probes. Do not touch the metal probe tips.

If you do not have a correct grip (fingers behind knurls) on the probes your fingers can slip down and come in contact with a live conductor, or if you position the probe carelessly it may provide a short circuit between adjacent metallic parts and result in the unexpected operation of a part of the circuit or, in the case of a short circuit to earth, an **explosion**.

16. A multimeter is an instrument which has various functions and ranges so that it can be used for measuring various values.

The most common functions are: current, voltage and resistance. Some digital types have special functions such as audible continuity, diode test and transistor test.

Multimeters are connected in series for current ranges and parallel for voltage ranges.

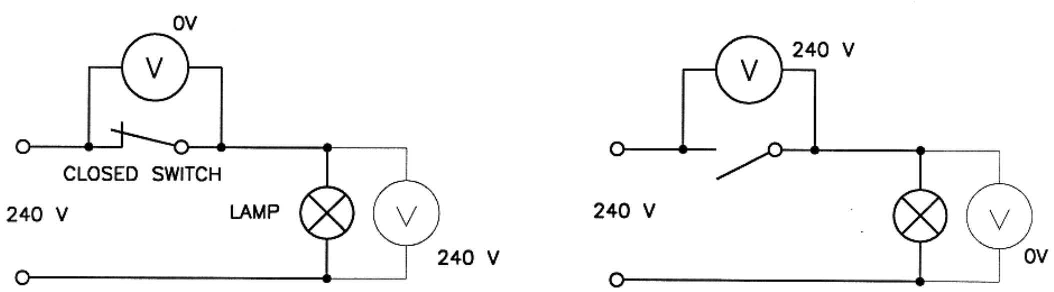
You must take care to select the correct function and range on the selector mechanism.

Multimeters should be switched off or to the highest available a.c. range when they are not in use.

17. When measuring an unknown voltage or current with a multimeter you should set the instrument to the highest available range first.

18. Multimeters set to an appropriate voltage range are frequently used for fault finding in operational circuits.

You should note that the voltage across an open switch or contact (or blown fuse) in a circuit which is otherwise complete is the line voltage, and the voltage across a closed switch is zero - as shown below:



Circuit Continuity

19. Continuity is a term used to describe the condition in which a conductor is continuous from one end to the other.

The most common method of checking continuity is to use a resistance measuring instrument such as a multimeter; if a zero or low resistance is indicated the circuit is usually continuous.

A reading of infinity between the two ends of the conductor indicates that the conductor is open circuited.

20. Continuity can also be checked using a battery connected in series with a suitable incandescent lamp (a battery test lamp), bell or buzzer. If the lamp lights up when the two free ends of the test lamp are connected to the conductor it indicates that the circuit is continuous.

Battery test lamps are not reliable when testing an element or winding for continuity because the resistance of the element or winding may be too high to allow the lamp to light up.

It is essential to check the checker before and after any continuity test.

21. If you are to check a conductor for continuity, you must disconnect the supply voltage and at least one end of the conductor to avoid obtaining a false reading through other conductors in the circuit.

Care and Storage of Instruments

22. Electrical measuring instruments contain delicate components that can be easily damaged by rough handling, excessive temperatures or using them on incorrect ranges.

When they are not in use you should switch them off (if they are battery operated) and store them with any connecting leads neatly wrapped.

You should avoid storing them with other equipment on top of them.

23. It is a bad practice to tap the glass on any measuring instrument because the glass can be dislodged.

24. If you are to transport an analogue multimeter, setting it to the highest available current range will provide maximum damping for the pointer, however, setting it to the highest current range also means that there is a very low resistance between the connecting leads, so you must take care to select the appropriate function and range before you use it.

If the instrument is to be stored you should switch it off or set it to the highest available a.c. voltage range.

25. All clips, probes and leads should be maintained in safe working order.

If any connecting lead becomes damaged you should have it replaced immediately.

Selection of meters to measure electrical circuit quantities

1. What is the name of the electrical measuring instrument used to measure the CURRENT flowing in a circuit?

2. What is the name of the electrical measuring instrument used to measure the electrical PRESSURE in a circuit or part of a circuit?

3. What is the name of the electrical measuring instrument used to measure the RESISTANCE of a circuit?

4. How should AMMETERS be connected in a circuit?

5. How should VOLTMETERS be connected in a circuit?

6. What colour is usually used to indicate the POSITIVE terminal of a DC voltmeter or ammeter?

7. What type of measuring instrument gives a direct numerical readout as distinct from one which has a pointer and a graduated numbered scale?

8. What is the main advantage of a clip-on ammeter over a wired ammeter?

9. What type of measuring instrument should always be switched to the OFF position when not in use?

10. Which type of measuring instrument has the lowest internal resistance, an ammeter or a voltmeter?

11. Which common type of measuring instrument often has a 'press to read' button?

12. What common marking is used to indicate that a particular ammeter or voltmeter is designed for DC only?

13. What common terminal marking is used to indicate that a particular ammeter or voltmeter is designed for AC only?

14. What are the names given to the upper and lower limits of the indicating scale on a typical OHMMETER?

15. What is meant by the term “SENSITIVITY” of an electrical measuring instrument (meter)?

16. What is the purpose of the small slotted screw near the pivot point of the needle on an analogue measuring instrument?

17. What safety precaution must ALWAYS be taken before attempting to connect a fixed ammeter into an operational circuit?

18. Why is it bad practice to tap the glass of any measuring instrument?

19. What measuring instrument would be most appropriate for checking an existing circuit for ‘loss of supply’?

20. Describe a method of overcoming ‘parallax’ error when reading an analogue scale.

21. Provide one advantage and one disadvantage of using a ‘volt-stick’ tester compared to a multimeter.

Notes:

Selection of meters to measure electrical circuit quantities

Objective

To measure resistance, voltage and current using appropriate measuring instruments.

Equipment

Typical electrical devices such as:

Heating elements	Single phase transformers
Incandescent lamps	Motor windings
Resistors	Fluorescent ballasts

Analogue multimeter
Digital multimeter
Resistor project board (with SPST switch)
Fixed a.c. voltmeters
Fixed DC voltmeters
Fixed DC ammeter (0-5 A DC)
Variable power supply - up to 50 volts DC and a.c. (50 Hz)
Personal Danger Tag (Danger- Do Not Operate)

Procedure

Part A - Measuring Resistance

1. Measure the resistance of the four given devices with a digital multimeter and an analogue multimeter. Record the results in the Results Table.

Results Table – Measured Resistance

Device Number	Measured Resistance (Analogue Multimeter)	Measured Resistance (Digital Multimeter)
1.		
2.		
3.		
4.		

2. Have your results checked by your lecturer.

Part B - Measuring Voltage

DANGER TAG PROCEDURE REQUIRED

1. Set up the variable power supply using the danger tag procedure (do not plug it into the supply). Identify the appropriate output terminals.

2. Set the variable power supply to any voltage up to 50 volts a.c.

3. Set the analogue multimeter to an appropriate range and scale.

4. Have your settings checked by your lecturer.

5. Plug the power supply into the outlet and switch it on. Measure the voltage at the output terminals for any 3 positions of the output voltage control. Record the results in the Results Table.

6. Measure the voltage at the same 3 settings with a digital multimeter and record the results in the Results Table.

7. Select a suitable fixed voltmeter and measure the voltage at any one of the settings used for the multimeters. Record the results in the Results Table.

Results Table – Measured Voltage

Voltage Settings	Measured Voltage (Analogue Multimeter)	Measured Voltage (Digital Multimeter)	Fixed Voltmeter

8. Switch the circuit off and remove the plug from the outlet. Attach your danger tag to the plug top.

9. Have your results checked by your lecturer.

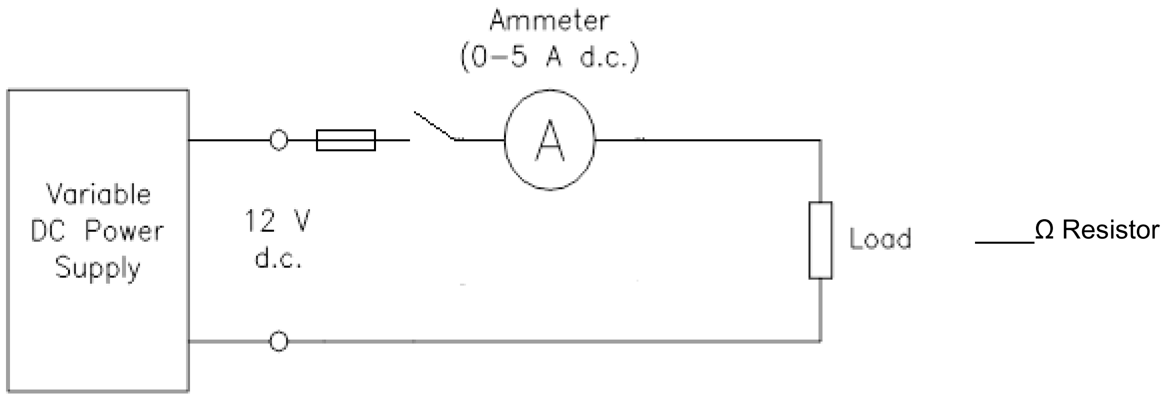
Part C - Measuring Current

1. Identify the DC output terminals on the power supply.

2. Set the variable power supply to 12 volts DC (with the power supply switched OFF).

3. Examine the resistor project board and identify the resistor which has a resistance of approximately 4 ohms (use a multimeter if necessary).

4. Connect the components according to the following circuit diagram:



5. Check your circuit for short circuits with an analogue multimeter set to the ohms times 1 range.

6. Have your connections checked by your lecturer.

7. Plug the power supply into the outlet and switch it on. Measure the current and record the value in the Results Table.

8. Close the switch and record the reading on the ammeter.

9. Switch the circuit off and remove the plug from the outlet. Attach your danger tag to the plug top.

Results Table – Measuring Current

Resistance Of R1	**Measured Current (S1 open)**	**Measured Current (S1 closed)**

10. Have your results checked by your lecturer.

Questions

1. What are the five most common electrical quantities that may be measured by a typical multimeter?

____

2. How did the measured values of resistance and voltage compare using both types of multimeter? Was there a notable difference and why?

____

____

3. What fault would be present if the ammeter indicated negative or if the needle moved to the left when the circuit was energised? How could this fault be corrected?

____

4. Calculate much power is being dissipated by the resistor in this circuit? Show your working out.

Satisfactory:	

Not Satisfactory:	

Lecturer: ______________________________________ Date: ______________

Electrical Power

Task:
To demonstrate an understanding of electrical power and how it effects circuit components.

Why:
Electric power, like other forms of power is the rate of doing work. All electrical appliances have a power rating.

To Pass:
1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set activities and laboratory tasks.
3. You must achieve 100% in a final practical competency test.

Equipment
Samples of typical simple circuit components
Digital and analogue meters
Digital D C wattmeter

References

* Electrical Principles for Electrical Trades (6th ed.) J. Jenneson, B. Harper & B. Moore.
* AS/NZS 3000:2018 Wiring Rules, Standards Australia.

Electrical Power

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for Electrical Trades (6th ed.) Vol. 1

Chapter 4 DC Circuits Page 64 -77

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.
4. Complete the laboratory project in this Section.
5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion and assessment

Electrical Power

1. Power is the rate at which work is done or the rate at which energy is converted from one form to another.

   All electrical devices have a power 'rating' which must not be exceeded under normal operational conditions - if the power rating is exceeded the device will overheat and permanent damage may result.

   Power (P) is expressed in watts (W). 1 watt = 1 joule per second.

2. Since the power dissipated by a resistor is critical to safe operation, it is often necessary to calculate the actual power dissipation for a given fixed or variable resistor to ensure that it is not exceeded.

   The actual power dissipation on DC can be calculated using any one of the three basic power equations:

   $P = V \times I$ $\qquad$ $P = I^2 \times R$ $\qquad$ $P = \frac{V^2}{R}$

3. **Example 1:**

   Calculate the power dissipated by a resistor if the current through it is 10 amps and the applied voltage is 100 volts.

   $$P = V \times I = 100 \times 10 = 1000 \text{ watts (W)}$$

4. **Example 2:**

   Calculate the power dissipated by a 100 ohm resistor if the applied voltage is 20 volts.

   $$P = \frac{V^2}{R} = \frac{20^2}{100} = 4 \text{ watts (W)}$$

   = 4 watts

5. **Example 3:**

   Calculate the power dissipated by a 5 ohm resistor if the current through it is 10 amps.

   $$P = I^2 \times R = 10^2 \times 5 = 500 \text{ watts}$$

6. **Example 4:**

A particular 240 volt heating element has a power rating of 1200 watts. How much current would be drawn by the element?

$$P = V \times I \quad \text{so} \quad I = \frac{P}{V} \quad \text{(by transposition)}$$

$$I = \frac{P}{V}$$

$$= \frac{1200}{240}$$

= 5 amps.

7. It is important to be aware that the power dissipated by a resistor increases in proportion to the **square** of the current – i.e. if the current is doubled the power dissipated is quadrupled!

Quantities: **Voltage - 12V** **Current – 3A** **Resistance - 4Ω**

8. **Example 1** $P = I^2R$ $P = 3^2 \times 4$ $P = 9 \times 4$ $P = 36\ W$

If we double the current value to 6A

$P = I^2R$ $P = 6^2 \times 4$ $P = 36 \times 4$ $P = 144\ W$

9. **Example 2**

$$P = \frac{V^2}{R} \qquad P = \frac{12^2}{4} \qquad P = \frac{144}{4} \qquad P = 36\ W$$

If we double the voltage to 24V

$$P = \frac{V^2}{R} \qquad P = \frac{24^2}{4} \qquad P = \frac{576}{4} \qquad P = 144\ W$$

10. **Example 3**

$P = V \times I$ $P = 12 \times 3$ $P = 36\ W$

If we double the current to 6A

$P = V \times I$ $P = 12 \times 6$ $P = 72\ W$

This value is only doubling the power not quadrupling. This is because we know from basic ohms law that voltage and current are directly proportional. Therefore if we are to use this formula we must also double the voltage.

$P = V \times I$ $P = 24 \times 6$ $P = 144\ W$

Exercises

11. **Exercise 1**

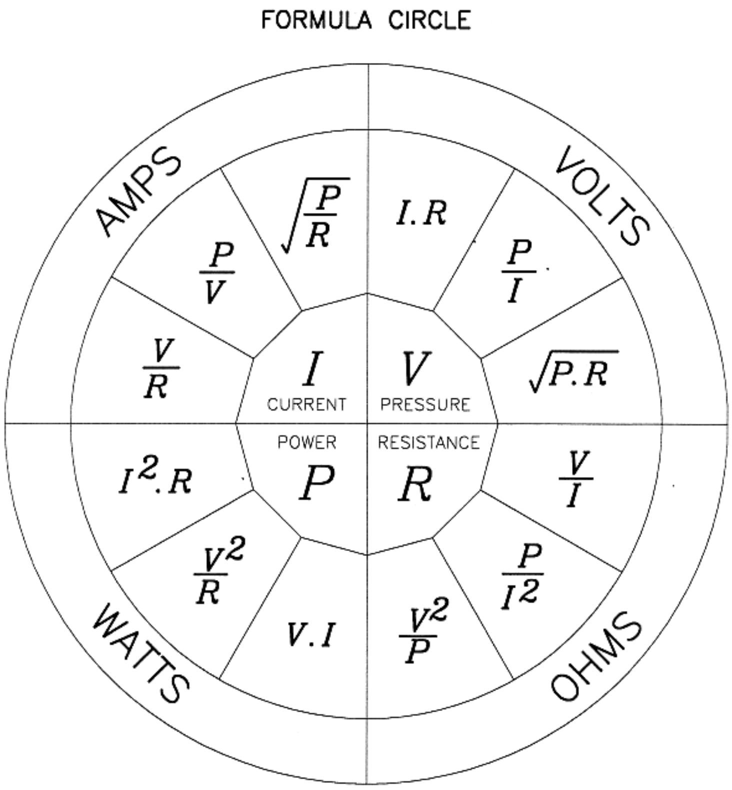
A particular 12 volt heating element has a power rating of 40 watts and a resistance of 4 ohms. How much power would it dissipate on 12 volts? How much power would it dissipate if the applied voltage was increased to 24 volts?

12. **Exercise 2**

A 120 ohm, 10 watt resistor is found to have a voltage of 40 volts across it. What effect would you expect this to have on the operation of the resistor?

Formula Circle

13. The relationships between voltage, current, resistance and power can be summarised in the following Formula Circle:



Electrical Power

1. A 240 volt heating element has a resistance of 48 ohms. How much power would be dissipated by the element when it is connected to the 240 volt supply? Write the equation.

2. A 240 volt lighting circuit consists of 4 x 60 watt lamps and 2 x 100 watt lamps. Calculate the current flow in the circuit. ? Write the equation.

3. Calculate the resistance of a 1200 watt - 240 volt rated heating element. Write the equation.

4. Calculate the volt drop across a 100 watt resistor when 8.33 amperes is flowing through the circuit. Write the equation.

5. If the current in a circuit is doubled, what factor does the power dissipated in the circuit increase by? Prove by example.

Measuring Electrical Power

Objective

To connect all the components of a basic electrical circuit (see diagram) and measure electrical power.

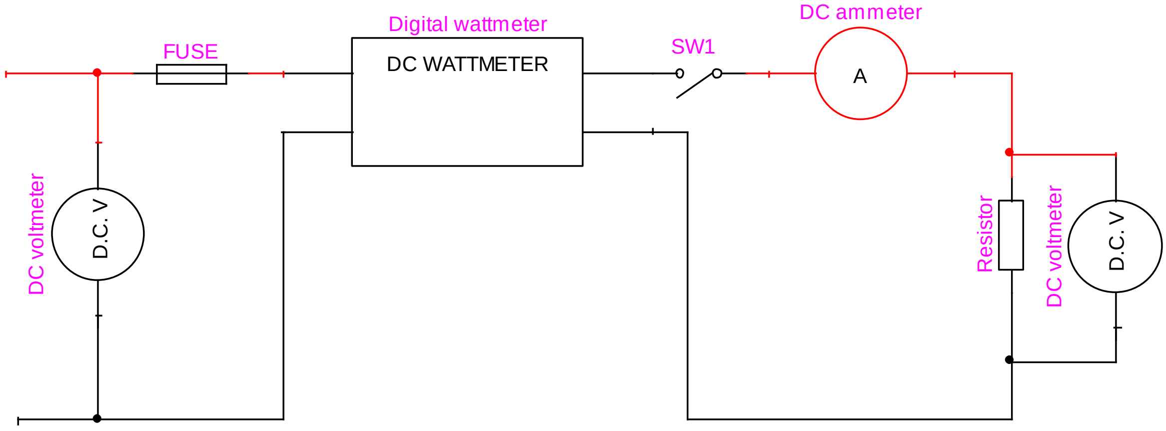
Equipment

Basic electrical circuit components consisting of:

An extra-low voltage variable DC supply (set to approx.12 volts).
A single-pole single-throw switch (SPST)
A fuse
A D C Wattmeter
A DC ammeter
A suitable load resistor (approx. 6 - 12 ohms)
A digital multimeter

Danger Tag (Danger - Do Not Operate)

Circuit Diagram



Procedure

DANGER TAG PROCEDURE REQUIRED – READ ALL INSTRUCTIONS BEFORE PROCEEDING

1. Occupation Safety and Health must be adhered to at all times with reference to the Laboratory Safety procedure, Danger Tag procedure and JHA risk analysis procedure.
2. Using your voltage and resistance values, calculate the expected line current that will flow in the circuit and the power dissipated by the load resistor.
3. Select the appropriate ammeter and wattmeter based on your calculations being aware of the range and its effect on the accuracy of your reading.
4. Connect the components according to the circuit diagram given above. Mark each connection off on the diagram as you go. Do **NOT** connect the circuit to the supply, at this stage.

5. Measure the resistance of the circuit at the terminals to which the voltage source is to be connected (with the switch closed) to ensure there is no short circuit condition present. The resistance should measure slightly higher than the load resistance. Record the resistance:

Resistance: ______________________________

6. Have your circuit wiring and resistance measurements checked by your Lecturer.

7. Remove your danger tag and plug in the power supply with the leads supplying the load disconnected. Use your multimeter and the adjustment knob to set the variable power supply to 12V

8. Disconnect the power supply and replace your danger tag. Once isolated connect the leads going to the load to the power supply.

9. When your lecturer agrees, remove your danger tag and connect your circuit to the 12 volt supply. Energise the circuit and take all readings necessary to complete Results Table 1 & 2.

Table 1 - Meter Reading Results

Meter Readings	**Switch On**	**Switch Off**
Voltage reading across the supply terminals		
Voltage reading across load		
Ammeter reading		
Wattmeter reading		

10. Switch the DC supply off and remove the plug from the outlet. Attach your danger tag to the plug top.

11. Submit your work to your Lecturer for comment and assessment.

12. Work site is cleaned and made safe in accordance with established procedures and return all equipment to its proper place.

Questions

1. What was the voltage across the load resistor when the switch was open?

   Voltage: ________________

2. Calculate the power dissipated in the circuit using the readings from Table 2 and compare with the wattmeter reading.

3. What fault would be indicated (if any) if the supply voltage was 12 volts, the switch was closed, the ammeter indicated 0 amps and the voltmeter across the fuse indicated 12 volts?

   ____

Table 2 - Meter Reading Results & Calculations

Meter Readings		Calculation	Result
V	A	(VxI)	W
V	Ω	(V^2/R)	W
A	Ω	(I^2xR)	W
Wattmeter		Not required, transfer reading from Table 1	W

4. Compare your results and discuss which method of measuring electrical power, do you consider to be the most accurate.

____

____

Satisfactory:		Not Satisfactory:	

Lecturer: ________________________________ Date: ______________

Effects of Electrical Current

Task:
Demonstrate an understanding of the effects of an electrical current flow.

Why:
When an emf causes an electric current to flow in a material it can have several effects. Sometimes the effects are beneficial and sometimes they are not. You need to be able to describe the effects so that you can predict the behaviour of a device and take appropriate precautions to minimise undesirable effects when necessary.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.

2. You must satisfactorily complete the set activities and laboratory tasks.

3. You must achieve 100% in a final practical competency test.

References

* Electrical Principles for Electrical Trades (6th ed.), J Jenneson, B. Harper & B. Moore.
* Electrical Wiring Practices (7th ed.), K. Pethebridge & I. Neeson.
* AS/NZS 3000:2018 Wiring Rules, Standards Australia.

Effects of Electrical Current
Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Wiring Practices

Chapter 2	Workplace and Electrical Safety	Page 40 – 43

Electrical Principles for Electrical Trades

Chapter 1	Elementary Electricity Effects of Electricity	 Page 25 – 26

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion and assessment.

Effects of Electrical Current

1. Physiological Effect

When electric current flows through the human body it can cause abnormal muscular contractions or heating of body tissue and it is known as an electric shock.

A small electric shock can cause a mild tingling sensation in the muscles of the arm, but a severe shock causes a sudden contraction of the heart muscles which can stun the victim and may have one or more of the following effects:

a. The victim stops breathing.

b. The victim's heart stops, or quivers rapidly without pumping blood a condition known as ventricular fibrillation.

c. The victim suffers severe burns.

d. The victim suffers traumatic shock to the nervous system.

e. The victim suffers muscular paralysis and may be unable to release his/her grip on a live machine.

2. Factors

The main factors which affect the seriousness of electrical shock are:

a. The amount of current passing through the body.

b. The path of the current through the body.

c. The voltage of the circuit.

d. The duration of contact with the live part.

e. The resistance of the body at the time of contact.

f. The surface area of the skin in contact with the live component.

g. The period of the cardiac (heartbeat) cycle during which the shock occurs.

h. The individual - some people are affected more than others.

It is not possible to define precisely the effects of a given current on the body, but the general effects of alternating current are shown in Figure 1.

```
Current in
 Amperes
           |
   0.5     |-    Severe burns
           |
           |
           |
           |     Breathing stops
   0.2     |-    Death usually occurs
           |
   0.1     | - - - - - - - - - - - - - - - - - -
(100 mA)   |     Extreme breathing difficulties
           |     Breathing upset and laboured
           |
           |     Severe shock
   0.05    |-    Muscular paralysis
 (50 mA)   |     Can not let go
           |
           |
           |     Painful
   0.01    | - - - - - - - - - - - - - - - - - -
 (10 mA)   |
           |     Mild sensation
           |
           |     Threshold of sensation
           |
  0.001    +------------------------------------------
  (1 mA)
```

Figure 1 - General effects of electric shock

Effects and Uses of Current Flow

3. Static Electricity

This is so called because it is electricity at rest. Static electricity is produced when two objects are rubbed together. Lightning is a form of static electricity.

The attractive force of static electricity is used in industry to clean air or smoke by electrostatic precipitation. Static electricity can be hazardous in areas containing flammable materials if equipment is not adequately earthed.

Adequate earthing is also required to prevent damage from static electricity when handling sensitive electronic components.

4. Electrical Heating

When electricity flows through a material heat is always produced. This is put to use in electric radiators, ovens, heating elements and so on.

In many cases such as cables, motors, generators and transformers the heating effect is unwanted and the devices must be designed or installed so that the heat cannot cause damage.

6. Light

The heating effect of an electric current passing through a conductor can be used to produce light, as in an incandescent lamp.

When electricity is passed through a gas both heat and light are produced. In many cases the light produced is invisible to the human eye and special chemicals are required to convert the invisible light to visible light, as in a fluorescent tube.

7. Magnetism

When electric current passes through any material a magnetic flux or field is produced.

If current is passed through a coil or wire wound around a steel core, an electromagnet is produced.

The electromagnetic effect is used to advantage in many electrical devices such as electric motors, transformers, generators, solenoids, relays, magnetic starters and so on.

The strength of the magnetic field produced depends largely on the current in the circuit, and in high current circuits the magnetic field produced can cause high mechanical stress on components, so components often need to be mechanically supported to avoid damage.

Some devices such as measuring instruments can be affected by strong magnetic fields, so they need to be kept away from components which produce such fields.

8. Chemical

When two dissimilar metals are immersed in a conducting liquid (an electrolyte), and a voltage is applied to the metals, one of the metals can be chemically decomposed and deposited on the other.

This effect is used to advantage in the electroplating process and for chemical refining.

9. Corrosion of Metals

The chemical effect occurs when two dissimilar metals are positioned so that they are touching (in a liquid or in air).

The resulting chemical decomposition of one of the metals is known as electrolytic corrosion or galvanic action.

Using zinc-plated (galvanized) saddles to fix bare copper sheathed cables, or bolting copper and aluminium together causes unwanted electrolytic corrosion if special precautions are not taken.

Principles of Protection

9. The Wiring Rules (Clause 1.5) provides fundamental principles for the protection against the effects of current flow.

Protection can be achieved by preventing a current from passing through the body of any person, or limiting the current which can pass through a body to a value lower than the shock current.

The Wiring Rules defines two types of contact - direct contact and indirect contact
(see Figures 1.2 and 1.3 on page 39 of AS/NZS 3000:2018)

Basic protection against direct contact with live parts can include:

a. The insulation of live parts.
b. The use of barriers or enclosures.
c. The use of obstacles.
d. The placing of live parts out of reach.

10. Methods of providing fault protection against indirect contact with exposed conductive parts which can become live under fault conditions can include **(see AS/NZS 3000:2018 Clause 1.5.5):**

a. Automatic disconnection of the supply on the occurrence of a fault likely to cause a current flow passing through the body.
b. Preventing a fault current passing through a body by the use of Class II equipment (double insulation).
c. Preventing a fault current passing through a body by electrical separation systems
d. Limit the fault current that can pass through a body to a value lower than the shock current.

11. Protection against the dangers that may arise from contact with exposed conductive parts may be provided by means including the following:

a. The automatic disconnection of the supply.
b. The use of double insulation.
c. The suitable location of exposed conductive parts.
d. The use of equipotential bonding.
e. The electrical separation of exposed conductive parts.

Effects of Electrical Current

1. List four physiological effects of current flow on the human body.

2. List four factors which affect the severity of an electric shock.

3. State four common effects of electric current flow and give one beneficial example and one non-beneficial example of each.

4. What conditions are necessary for 'electrolytic corrosion' to occur?

5. Give two examples each for measures that can be taken to prevent the “Direct contact” and “Indirect contact” with live parts.

Sources of Electromotive Force (EMF)

Task:

Describe the most common methods of producing an electromotive force.

Why:

There are several methods of producing an electromotive force and each method has applications in the electrical industry. You need to know the most common methods so that you can predict the behaviour of electrical devices.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.

2. You must satisfactorily complete the set activities and laboratory tasks.

3. You must achieve 100% in a final practical competency test.

Equipment:

Laboratory equipment to produce an emf
Samples of electrical devices

References:

* Electrical Principles for the Electrical Trades (6th ed.), J Jenneson, B Harper & B. Moore.
* Electrical Wiring Practice (7th ed.). K. Pethebridge & I. Neeson..

Sources of Electromotive Force (EMF)

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades – Vol. 1

Chapter 1 Elementary Electricity 1.5 Dynamic Electricity	Page 8 – 14
Chapter 2 Electrochemistry 2.2 Electrochemical energy sources	Page 34 – 36

Australian Electrical Wiring - Volume 1

Chapter 1 Electrical energy – past, present and future   page 2 - 17

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.
3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.
4. Complete the laboratory activities in this Section.
5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion and assessment.

Sources of Electromotive Force (EMF)

Methods of Producing Electricity

1. An Electromotive Force or EMF can be produced in a variety of different ways and each has different applications in industry. The methods of producing an EMF broadly fall into the five different categories as listed below.

Magnetic
Heat
Light
Pressure
Chemical
Friction

Magnetic/Mechanical - If relative motion is achieved between a conductor and a magnetic field and EMF will be produced.

This can be either a conductor being moved through a stationary magnetic field or a changing magnetic field cutting a conductor.

This is the principle on which an electric **generator** operates.

The voltage output produced depends on the strength of the magnetic field, the speed at which the conductor passes through it and the angle at which the conductor is passing through the magnetic field.

In general, **"Base-Load"** power comes from this source by burning fossil fuels or using a nuclear reaction to heat water that produces high-pressure steam, the steam is then forced through a turbine causing it to rotate which in turn provides the mechanical rotation required for a generator to produce its output.

Wind and wave energy, tidal energy and hydro-electric systems also use this generation method.

Heat - If the junction of two dissimilar metals is heated, a small amount of electricity is produced.

The voltage depends on the types of metal and the temperature of the junction.

Thermocouples are classed by the operating temperature and sensitivity of the metals used and given a letter designation.

For example a K-Type Thermocouple is a combination of Chromel and Alumel alloys.

The typical application for thermocouples is temperature sensing where the voltage produced is displayed on a voltmeter calibrated to read degrees Celsius.

Light - When light falls on certain materials a voltage is produced.

This is known as the 'photovoltaic effect'.

The use of P-type and N-type silicon creates electron movement when exposed to visible light.

Photovoltaic (PV) cells or solar panels (as they are more commonly known) are used to take advantage of this electron movement and are now used extensively to power our homes and businesses. They have reduced our reliance on burning fossil fuels which helps the environment. They also power space satellites, electronic devices and are used as a source of electricity in remote areas.

Pressure (Piezo Electric) - A voltage is produced when pressure is applied to or taken off certain substances such as crystals or quartz.

The voltage produced depends on the type of crystal and the amount of pressure applied. Push-button igniters for hot water systems and barbeques are common uses for piezoelectricity in a domestic situation. Industry incorporates the use piezoelectricity in load cells for measuring force.

Chemical - If two dissimilar metals called electrodes are placed in a suitable conducting liquid (an electrolyte) a voltage is produced.

The voltage depends on the types of metal and the type of conducting liquid - typically between 1 and 2 volts.

This is then called an electric CELL or they can be connected together to form a 'battery'. There are two main types of cell - primary cells and secondary cells, and there are several different variations. **In primary cells the negative electrode is 'consumed' and the cell cannot be recharged.**

In secondary cells the process can be reversed so they can be re-charged.

Another type of cell used to produce electricity via chemical means is the fuel cell. A fuel cell is a device which converts chemical energy from a fuel, like hydrogen, into electricity through a chemical reaction.Fuel cells can produce electricity indefinitely as long as the fuel is continually supplied.

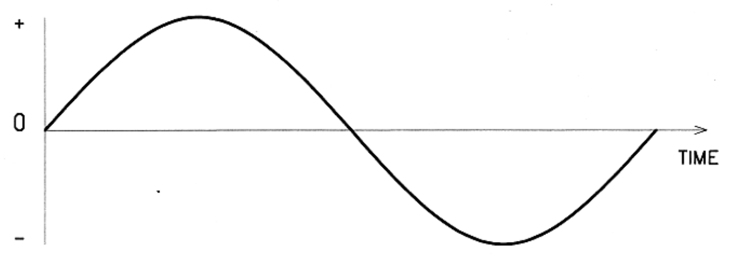
Friction - By rubbing (friction) you can create charges which are responsible for generating electricity. ... Friction produces static electricity by initiating the transfer of electrons between two or more objects. With regards to electron transfers, objects are either conductors or insulators.

Types of Supply

2. Alternating Current (AC) changes its direction through a conductor each and every "half" cycle. AC is derived by mechanically rotating a conductor through or around a magnetic field.

All generators produce sinusoidal AC as its prime current. The electricity provided by the Supply Authority is in alternating current form.

The voltage constantly changes in magnitude and polarity but it is symmetrical in form.

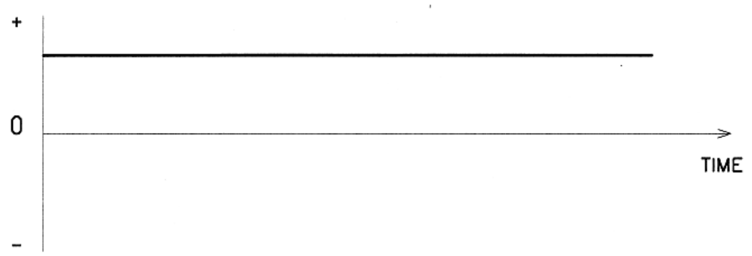


Alternating Current

Direct Current (DC) flows only in one direction as the polarity of the supply remains constant.

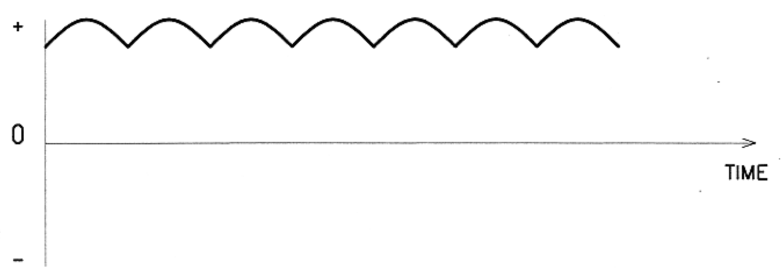
There are two general categories of DC; steady DC and rippled DC

a. Steady DC. is obtained from devices such as batteries, cells, fuel cells, thermocouples and solar cells.



Direct Current

b. Pulsating DC is obtained from a generator that uses "Commutation" to convert the prime AC into the pulsing DC shown below. The remaining "AC" after this conversion is called its "Ripple".



Rippled Direct Current

For practical purposes, the supply from a battery and that from a DC generator are both known as DC, however "Ripple-free" DC is only attainable from non-magnetic sources.

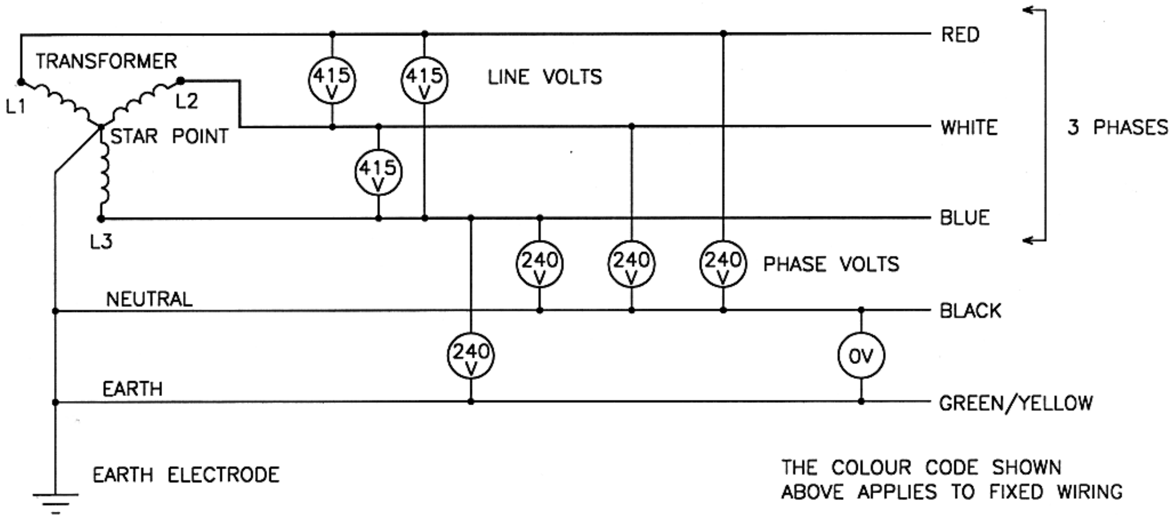
Distribution System

3. The main electrical supply system urbanised areas in WA is a **three-phase four-wire** system that comprises three active conductors and one neutral conductor.

This system can supply alternating current (a.c.) in two voltages to a consumer - 240 volts single phase and 415 volts three phase.

Both voltages are potentially lethal, so live terminals must not be touched under any circumstances.

Two basic rules must always be observed by electrical workers when carrying out isolation procedures: They are 'Test Before You Touch' and 'Always Check the Checker'. The supply must be isolated prior to commencing work on any live or potentially live circuits.



Note: Relevant parts of AS/NZS 3000 assume a nominal single phase voltage of 230 volts and a phase-to-phase voltage of 400 V as used in rest of Australia and in New Zealand.

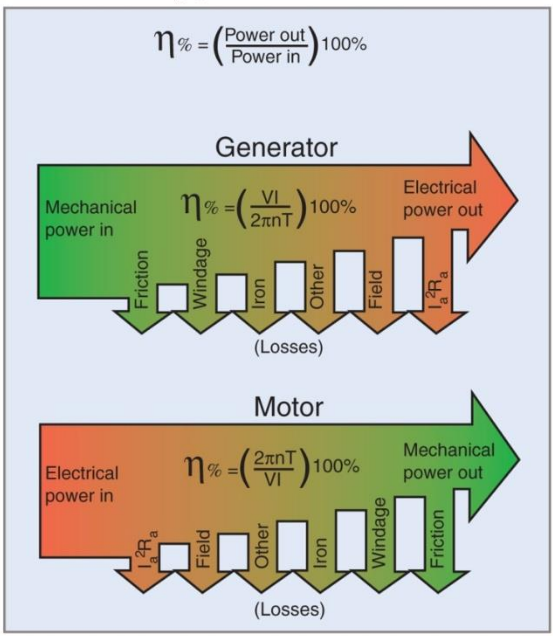
Efficiency of Electrical Systems and Machines

4. Efficiency of a machine is measuring input power against the output power which is the conversion of energy from one form to another. For example, an electrical generating unit converting mechanical power into electrical power will have losses.

The two principle mechanical losses in a generator are friction and windage. The two main electrical losses in a generator can be group as magnetic field losses and electrical resistance losses.

The formula to calculate machine losses is

$$\eta\% = (\frac{Power\ out}{Power\ in})100\%$$



Sources of EMF

1. Describe six different methods of producing electricity.

   Use diagrams where necessary.

   State how the voltage produced can be increased in each case.

2. Explain what is meant by the terms 'direct current' and 'alternating current'.

   Use diagrams for your explanation.

more…

3. What are the two nominal voltages available from the three phase electrical supply system in WA?

   Phase to Phase.

   Phase to Neutral

4. What is the main functional difference between a primary cell and a secondary cell and give an example and application for each type.

   Primary

   Secondary

5. Calculate the efficiency of an electric motor that produces 11.3 kW of mechanical power when it is supplied with 12.6 kW of electrical power.

Notes:

Sources of EMF

Objective

To identify six different sources of EMF and to briefly explain how that EMF is produced by each of those sources.

Equipment

Multimeter
Galvanometer
Glass rod and cat's fur
Hand wound demonstration generator
Major magnet and prepared coils of winding wire
Piezo electric spark gun
Prepared solar cell
Prepared thermocouple, LP gas bottle, flint gun
Prepared metal plates, beaker, container of dilute sulphuric acid
Safety glasses
Plastic tray
Clip board and writing equipment.

Procedure

1. Produce a measurable voltage using six different methods.
   Note: that the voltage produced in some cases will be extremely small so it may be necessary to use the galvanometer to detect it.

2. Write down the principle involved in each of the methods you used to produce an emf (on a separate sheet), and record how the voltage can be increased in each case. Give one or more practical examples of how each method is used to produce electricity in industry. See the example below.

3. Give one example of where the production of an emf is UNDESIRABLE where applicable.

4. Submit your work to your Lecturer for comment and assessment.

5. Return all of the equipment to its proper place.

Sources of EMF

Write down each of the five ***primary*** sources of EMF of which cause an electrical current to flow in a circuit, give a brief explanation of the process of how the EMF is produced and then list an application(s) how or where you would find the EMF sources being used in a practical way.

Source of the EMF	How the EMF is produced	Common Application(s)

Satisfactory:			Not Satisfactory:	

Lecturer: ______________________________ Date: ______________

Practical Resistors

Task:

To demonstrate an understanding of practical resistors used in industry and determine their resistance using measuring instruments, a resistor colour code and calculations.

Why:

Resistors are used in various forms throughout the electrical industry. You need to be able to recognise the types of resistors when you see them and determine their resistance using several methods, so that you can analyse the behaviour of the circuit.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set laboratory activities.
3. You must achieve 100% in a final competency test for each practical component.

Equipment

Samples of typical resistors
Samples of typical heating elements
Resistor colour codes
Digital and analogue multimeters

References

* Electrical Principles for the Electrical Trades (6th ed.). J. Jenneson, B. Harper & B. Moore.
* Video: Basic Electricity, Parts 1-14.

Practical Resistors

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) Volume 1

Chapter 5 Resistors

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the laboratory activities on:

    a. Identification of Practical Resistors
    b. Resistor Colour Code

5. Submit your answers to the Work Sheet and your completed Activity Sheets to your Lecturer for discussion.

Practical Resistors

Resistance

1. All materials have the property of resistance, and each material has a different value.

Devices which make use of the property of resistance are known as resistors, and when they are arranged in groups they are known as resistor networks or banks.

Figure 1a: shows the Australian standard symbol for a resistor.

Figure 1b: shows a superseded resistor symbol which is widely used in texts and other technical publications.

1a - Standard symbol

1b - Common symbol.

Figure 1 - Resistor symbols.

2. A conductor with a low resistance allows more current to flow than a conductor with a high resistance if the voltage remains constant, so current is inversely proportional to resistance.

This relationship can be expressed as a mathematical equation known as 'Ohm's Law':

$$I = \frac{V}{R}$$

Current = Voltage ÷ Resistance

3. The following examples show that current increases as resistance decreases.

4. Example 1

Calculate the current which would flow in a 6 ohm resistor if a voltage of 12 volts was applied to it.

$$I = \frac{V}{R}$$

$$= \frac{12}{6}$$

I = 2 amps
==========

1. **Example 2**

How much current would flow in the 12 volt circuit if the resistance was reduced to 3 ohms?

$$I = \frac{V}{R}$$

$$= \frac{12}{3}$$

I = 4 amps
==========

Types of Resistor

6. Most practical resistors can be classified in the following main groups:

a. Fixed or variable resistors which are used to control current or voltage in a circuit
b. Resistors used as heating elements
c. Resistive devices used as illuminating lamps
d. Temperature dependent resistors (thermistors)
e. Light dependent resistors (LDRs)
f. Voltage dependent resistors (VDRs)

7. Voltage Control - When several components are connected end-to-end they are said to be connected in series.

Under these conditions the voltage across each component depends on the resistance of the component (the higher the resistance the higher the voltage).
Connecting resistors in series is a method of obtaining a specified voltage between particular points in a circuit, and resistors are used in this way in most electronic circuits.

8. **Elements and Lamps** - When current is passed through any material, heat is produced. Some types of resistors are specifically designed to exploit this characteristic - they are known as heating elements or power resistors.

The trade name of a resistance wire specially intended for use in heating elements is Nichrome.

Other types of resistive devices are designed to produce enough heat to cause visible light to be emitted from a tungsten wire filament -these are known as incandescent lamps (or light globes).

A sustainable energy management principle is to always use the most efficient devices that are available. Incandescent lamps are very low in efficiency and their use should be avoided if possible.

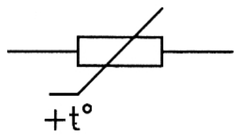
9. **Thermistors** - The resistance of a resistor depends on the temperature of the resistor.

The change in resistance for each degree change in temperature is called the 'temperature coefficient of resistance' - if the resistance increases as the temperature increases the material is said to have a POSITIVE temperature coefficient, if it decreases the material is said to have a NEGATIVE temperature coefficient.

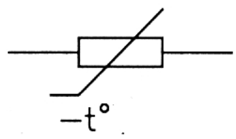
10. A family of small resistive devices is available which increase or decrease their resistance by a large amount for a comparatively small change in temperature - they are known as thermistors.

If their resistance increases as the temperature increases they are known as PTC (positive temperature coefficient) thermistors - if their resistance decreases as the temperature increases they are known as NTC thermistors.

Thermistors are used to sense temperature and operate temperature-sensing instruments or over-temperature protective devices. The symbols for PTC and NTC thermistors are shown in Figure 2.



PTC thermistor symbol.



NTC thermistor symbol.

Figure 2. - Thermistor symbols.

11. **LDRs** - Cadmium sulphide is a material which changes its resistance when it is exposed to light - it is said to be photo-conductive.

Cadmium sulphide is used to manufacture small light dependent resistors (LDRs). The passive component is basically a resistor whose resistance value decreases when the intensity of light decreases - the change in resistance is exploited to control other devices or processes.

The symbol for a LDR is shown in Figure 3.

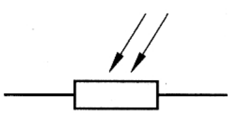


Figure 3. - Light dependent resistor symbol.

12. **VDRs** - A voltage dependent resistor (VDR) is a special resistive component in which the resistance falls quickly when the voltage across it increases to over a designed value.

They are also known as varistors. VDRs are used to protect other sensitive components from the effects of over-voltage, such as voltage surges in the supply system, lightning strike, or high induced voltages when large DC electromagnets are de-energised.

Each individual VDR has a specific designed 'break-over voltage' at which it allows enough current to flow to cause the circuit protection device to operate. The symbol for a VDR is shown in Figure 4.

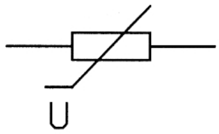


Figure 4. Voltage Dependent Resistor symbol - VDR.

Variable Resistors (Rheostats or Potentiometers)

13. It is frequently necessary to have a resistor in which the resistance can be altered manually - these are known as variable resistors. In a variable resistor a mechanical wiping or clamping mechanism is provided so that the resistance can be varied by positioning the wiping or clamping mechanism at the required place on the resistive portion of the device. Several variations are available, some with special names - including:

a. High power potentiometers (pots) - up to about 500 watts.
b. Low power potentiometers - up to about 2 watts.
c. Multi-turn potentiometers - up to about 1 watt.
d. Low power trimmers - up to about 1 watt.
e. Linear potentiometers - up to about 2 watts.
f. Logarithmic taper potentiometers - up to about 2 watts.
g. Wire wound variable resistors - up to about 200 watts.

As a rule, Rheostats are used to control current and have two connections in a circuit. Rheostats generally produce a fair amount of heat and require ventilation.

Potentiometers are most likely to be used to control voltage and normally have three connections to a circuit.

14. Most types of variable resistor have one of the two general shapes illustrated in Figure 5.

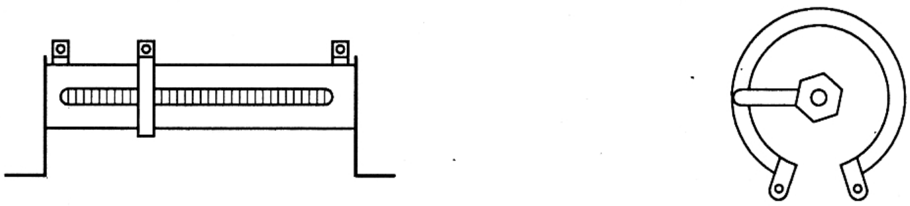


Figure 5 - Two common shapes of variable resistor.

Determining Resistance

15. Before attempting to measure the ohms of a resistor it is important to do the following beforehand to ensure your safety and to achieve an accurate reading;

a. Ensure the supply has been isolated from the circuit/s you will be working on.

b. Make sure your instrument is working properly and on the correct settings.

c. Disconnect at least one end of the resistor to ensure there are “No Parallel Paths”.

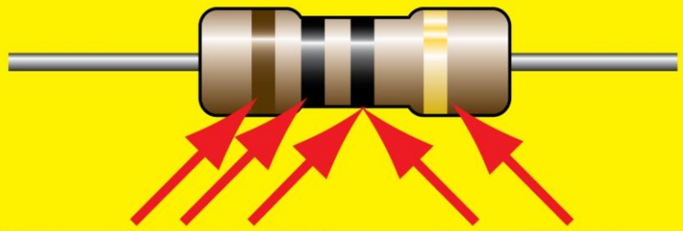
The resistance of a component can be measured directly using the following common instruments.

a. A multimeter selected to the 'ohms' range.
b. An Insulation Resistance selected to the appropriate 'ohms' range.
c. A Wheatstone bridge instrument.

Note: Some people refer to the instrument (b) as a “Megger”, this is the trade name for a manufacturer of electrical measuring instruments commonly used in the electrical trades.

16. In electronic circuits resistors can often be identified by the presence of between three and five bands of colour painted on the body of the resistor; these bands of colour are used to indicate the resistance of the resistor.

TABLE 5.3 RESISTOR COLOUR CODES



Colour	Value	Multiplier	Exp	Tolerance
black	0	1	E0	
brown	1	10	E1	1%
red	2	100	E2	2%
orange	3	1 000	E3 (kilo)	
yellow	4	10 000	E4	
green	5	100 000	E5	0.5%
blue	6	1 000 000	E6 (Mega)	
violet	7	—		
grey	8	—		
white	9	—		
gold		—	E–1	5%
silver		—	E–2	10%
none		—		20%

Some other components have bands of colour, so the presence of coloured bands is not a positive indication that the component is a resistor.

17. In order to determine the resistance of a colour coded resistor it is necessary to know the number which corresponds to the various colours.

This information is obtained from a Resistor Colour Code.

A simple version of the resistor colour code is shown in Table 5.3

18. Most colour coded resistors have three or four bands of colour.

Example: To determine the resistance of a resistor, that has the following colours:

Yellow Violet Red Gold

a. Position the resistor so that the band closest to the edge of the resistor is to your left.

b. Note the colours of each band reading left to right.

c. Determine the numbers that correspond to colours given in the chart above for the first two bands; in this case it is 47

d. Note the colour of the third band.
Write down the number of zeros corresponding to the number of the colour after the first two numbers. Should read; 4700

The resistor has a resistance of 4700 ohms (or 4.7kΩ). Note the letter "k" is "kilo" shortened prefix for "kilo-ohms" .This can also be expressed as "4k7".

Tolerance

19. The fourth band of colour is the 'tolerance band'.

Manufacturers of colour coded resistors do not usually attempt to make the resistors to the exact resistance indicated by the colour code; they specify upper and lower limits between which the actual resistance will be.
The percentage above or below the marked value is known as the 'tolerance. **If there is no fourth band of colour the tolerance is plus or minus 20%**; if there is a fourth band the indicated tolerance can be obtained from the colour code. In the case of the example above, the colour GOLD corresponds to a tolerance of 5%, so the actual resistance of the resistor would be somewhere between 4700 - 5% and 4700 + 5% ohms.

/ +5% = 4700+235 Ω = 4935 Ω (Maximum)
4700 Ω
\ -5% = 4700-235 Ω = 4465 Ω (Minimum)

21. **Exercise** Refer to a Resistor Colour Code and complete the following table.

Coloured Bands				Resistance In Ohms	Tolerance %
First	**Second**	**Third**	**Fourth**		
Green	Yellow	Yellow	Silver		
				56 000	
			Gold	39 MΩ	
Blue	Grey	Orange			2%
Brown	Yellow	Gold	Gold		
				2k2Ω	5%

Note: The letters R, k or M are sometimes used in place of a decimal point & prefix.

Power Rating

22. All resistors are given a maximum power rating. This is the maximum value at which the resistor can safely operate and it must not be exceeded.

If the power rating is exceeded it means that the resistor is producing too much heat and it can burn out or it can damage other components nearby.

Typical power ratings for colour coded resistors range from 0.125 watts to 5 watts, while large fixed or variable resistors can have a power rating in the order of kilowatts.

23. The power rating is not usually indicated on colour coded resistors; it has to be determined from information supplied by the manufacturer or by experience.

However it can be stated that, as the physical size is of the resistor is increased, then the higher its power rating or **dissipation** rate will become.

24. For large power resistors, the power rating is usually marked on the component. These resistors are often wound on porcelain grooved cylinders or fully enclosed in metal-sheathed elements.

For motor starting units, the resistors can take the form of large grid-type resistors made from cast-iron or pressed sheet-metal.

25. Since the power dissipated by a resistor is critical to safe operation, it is often necessary to calculate the actual power dissipation for a given fixed or variable resistor to ensure that it is not exceeded.

The actual power dissipation can be calculated using any one of the three basic power equations:

$$P = V \times I \qquad P = I^2 \times R \qquad P = \frac{V^2}{R}$$

26. The method involving voltage and resistance is particularly useful in cases where the resistor is connected in an operational circuit because it is not necessary to disconnect the resistor to measure the current in the circuit.

27. It is important to be aware that the power dissipated by a resistor increases in proportion to the SQUARE of the current - i.e. **if the current is doubled the power dissipated is quadrupled.**

28. **Exercise:** A 120 ohm 1 watt carbon composition resistor has a voltage of 10 volts across it when it is operating normally.

Determine the power dissipated with 10 volts across it, and the power which would be dissipated if the voltage was doubled to 20 volts.

Practical Resistors

1. What is a potentiometer?

____

2. What is a rheostat?

____

3. What is the special characteristic of a VDR or Varistor?

____

4. What is the special characteristic of an LDR?

____

5. What is the special characteristic of a negative temperature coefficient thermistor?

____

6. What is the resistance of a colour coded carbon composition resistor which has the following bands of colour: RED VIOLET ORANGE SILVER

____

7. What is the tolerance of a colour coded carbon composition resistor which has a SILVER tolerance band?

____

8. What is the tolerance of a colour coded carbon composition resistor which has a GOLD tolerance band?

____

9. What effect does it have on the power dissipated by a resistor if the applied voltage is doubled?

____

10. What is the nominal resistance of a resistor marked '2k2'.

____

11. What is the nominal resistance of a resistor marked '1R8'.

____

12. What is a non-linear PTC resistor (thermistor)?

____

13. What type of resistor is often wound on a grooved porcelain cylinder?

____

14. What two types of resistor are commonly embedded into motor windings to monitor their temperature and offer thermal protection of the motor?

________________________________ _________________________________

15. Determine if a “2k7” - ½ watt colour-coded resistor a 'preferred value'?

YES / NO

16. List three probable causes of a resistor overheating in service?

____

____

____

Identification of Practical Resistors

Objective

To identify examples of practical resistors

Equipment
Analogue Multimeter
Digital Multimeter
Resistor samples project board, including:
- Wire wound ceramic resistors
- Variable resistors
- Potentiometers
- Rheostats
- Temperature dependent resistors
- Light dependent resistors
- Voltage dependent resistors
- Trimmer resistors
- Encapsulated heating elements
- Wire wound heating elements > 100 W

Procedure

1. Identify each of the resistors supplied and enter your results in the Table below.

2. Measure the resistance of each type of resistor with an analogue multimeter and a digital multimeter and enter the results in the Table.

3. Submit your work to your Lecturer for comment.

4. Return all of the equipment to its proper place.

Type of Resistor	R (Analogue)	R (Digital)	Application

Satisfactory:			Not Satisfactory:	

Lecturer: ______________________________ Date: ______________

Resistor Colour Code

Objective

To determine the resistance and power rating of common colour coded resistors using a resistor colour code and manufacturers' information.

Equipment

Sample colour coded resistors
Resistor Colour Code
Multimeter
Manufacturers' power rating information
Clip board and writing equipment

Procedure

1. Examine each of the resistors provided and determine its resistance and tolerance according to the Resistor Colour Code and verify the resistance using a multimeter. Estimate the power rating of each of the resistors. Record the values in the Results Table.

2. Submit your work to your Lecturer for comment.

3. Return all of the equipment to its proper place.

Results Table

Colours						
First	**Second**	**Third**	**Fourth**	**Resistance**	**Tolerance**	**Power**

Satisfactory:		Not Satisfactory:	

Lecturer: ______________________________ Date: ______________

Analysis of Volt Drop in practical DC Circuits

Objective

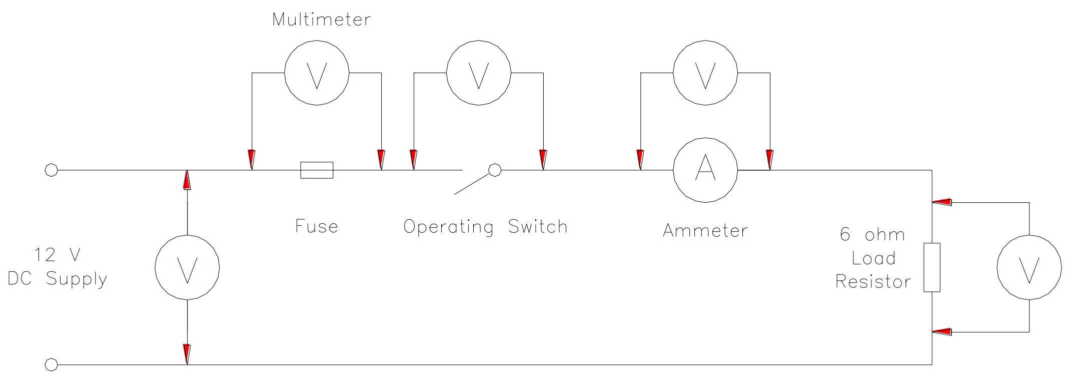
To connect the components of a basic electrical circuit and test it for correct operation

Equipment

Basic electrical circuit components consisting of:
- An extra-low voltage variable DC supply (set to 12 volts).
- A single pole single throw switch
- A fuse
- A DC ammeter
- A 6 ohm load resistor (at least 24 watts)

A digital multimeter
Danger Tag (Danger - Do Not Operate)

Circuit Diagram



Procedure

DANGER TAG PROCEDURE REQUIRED

1. Occupation Safety and Health must be adhered to at all times with reference to the Laboratory Safety procedure, Danger Tag procedure and JHA risk analysis procedure.

2. Using your voltage and resistance values, calculate the expected line current that will flow in the circuit
3. Select the appropriate ammeter based on your calculations being aware of the range and its effect on the accuracy of your reading.

4. Connect the components according to the circuit diagram given above. Mark each connection off on the diagram as you go. Do NOT connect the circuit to the supply.

5. Measure the resistance of the circuit at the terminals to which the voltage source is to be connected (with the switch closed) to ensure there is no short circuit condition present. The resistance should measure slightly higher than the load resistance. Record the resistance:

   Resistance: ______________________________

6. Have your circuit wiring and resistance measurements checked by your Lecturer.

7. Remove your danger tag and plug in the power supply with the leads supplying the load disconnected. Use your multimeter and the adjustment knob to set the variable power supply to 12V

8. Disconnect the power supply and replace your danger tag. Once isolated connect the leads going to the load to the power supply.

9. Remove your danger tag and connect your circuit to the 12 volt supply. Energise the circuit and take all readings necessary to complete Results Table 1.

Results Table 1

	Switch is On (Closed)	**Switch is Off (Open)**
Current Reading		
Voltage reading across the supply terminals		
Voltage reading across the fuse		
Voltage reading across the switch		
Voltage reading across the ammeter		
Voltage reading across the load		

10. Switch the DC supply off and remove the plug from the outlet. Attach your danger tag to the plug top.

11. Submit your work to your Lecturer for comment and assessment.

12. Work site is cleaned and made safe in accordance with established procedures and return all equipment to its proper place.

Summary Questions

1. With the supply connected and energised, what was the voltage drop across the switch in the “open” position?

   Voltage: ____

2. With the supply connected and energised, what was the voltage drop across the fuse while current was flowing in the load resistor?

   Voltage: ____

3. Using the values of voltage and current in your Results Table, calculate the resistance of the load resistor.

   Resistance: _______________________________________

4. What is the approximate resistance (in ohms) across the terminal of the switch when it is in the “closed” position?

   ____

5. What is the approximate resistance (in ohms) across the terminals of the switch in the “On” position?

   ____

6. What is the approximate resistance (in ohms) across the terminals of the switch in the “Open” position?

   ____

7. What is the approximate resistance (in ohms) across the terminals of the switch in the “Off” position?

   ____

8. What fault would be indicated when the supply voltage to a circuit is measured across the terminals of the fuse protecting it?

   ____

   ____

Satisfactory:			Not Satisfactory:	

Lecturer: _____________________________________ Date: _______________

Factors Effecting Resistance

Task:

To demonstrate an understanding of the factors effecting the resistance of electrical materials

Why:

Resistors are used in various forms throughout the electrical industry. You need to be able to determine their resistance using several methods, so that you can analyse the behaviour of the circuit.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.

2. You must satisfactorily complete the set laboratory activities.

3. You must achieve 100% in a final competency test for each practical component.

Equipment

Samples of typical resistance materials
Samples of typical heating elements
Digital and analogue multimeters

References

* Electrical Principles for the Electrical Trades (6^{th} ed.). J. Jenneson, B. Harper & B. Moore.
* Video: Basic Electricity, Parts 1-14.

Factors Effecting Resistance

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) Volume 1

Chapter 5 Resistors
Section 5.1 Factors effecting resistance

2. Read the Summary and practise answering the questions provided on the Work Sheet. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the laboratory activities on:

   a. Identification of Practical Resistors
   b. Resistor Colour Code

5. Submit your answers to the Work Sheet and your completed Activity Sheets to your Lecturer for discussion.

Factors Effecting Resistance

Resistance

1. All materials have the property of resistance, and each material has a different value.

2. There are four factors which govern the resistance of any material are:

a) Type of Material:

Different types of materials will have a unique value of resistance for a given specified quantity of material.

To compare different materials with how each conducts electricity its "resistivity" must be determined.

RESISTIVITY is determined by accurately measuring the resistance between two opposite sides of a cubic shape with each side being 1 square metre.

The lower the value recorded the better or easier the material can conduct electricity, pure solid copper has a resistivity of about 1.72×10^{-8} ohm-metres.

The quantity symbol used for Resistivity is the Greek letter "Rho" (ρ) which looks a bit like a cross between a "p" and an "r".

b) Cross Sectional Area:

As the cross-sectional area of a material INCREASES, its resistance DECREASES.
Thus a thicker conductor has LESS overall resistance than a thinner conductor of the same length, material and temperature.

The cross sectional area of a conductor can be determined by calculating the surface area of the end of the conductor if it has been very neatly cut. A bit like slicing bread with a knife to make a sandwich. The surface where you put the butter on would be the breads' cross-sectional area.

Most conductors are circular or rectangular and the cross-sectional area can be calculated using geometric formulae i.e.

For circular conductors; $A = \pi r^2$ or $A = \pi \frac{D}{4}$

Multi-stranded circular conductors; calculate the area of an individual strand and multiply by the no. of strands to find total area.

For rectangular conductors; $A = side\ A\ x\ side\ B$

Area should converted into square metres (m^2) $1mm^2 = 1 \times 10^{-6}\ m^2$

c) **Length:**

As the length of a material increases the resistance increases if all other factors remain the same i.e. the longer the cable the more resistance it will have from one end to another.

It is similar to trying to drink a thick shake through a straw, the longer or thinner the straw is, the more difficult it becomes to suck the liquid up through the straw.
Likewise with electrical current, the longer the cable is or the smaller the cross-sectional area becomes, then the more resistance there will be to current flow in the cable.

d) **Temperature:**

All materials change their resistance as their body temperature changes.

Pure elemental metals increase their resistance as their temperature increases, so they have what is called a "Positive Temperature Co-efficient" or PTC.

Some materials, such as carbon and silicon, decrease their resistance as their temperature increases and so they have a "Negative Temperature Co-efficient" or NTC.

Some specially formulated alloys of metals have very little increase in resistance over a wide temperature range and as such these alloys are useful in manufacturing high temperature resistors that can be used as heating elements and so on.

3. A useful way of remembering these four factors is by using the acronym "**M.A.L.T.**"

Material *with units expressed in ohm-metres (Ω-m)*

Area (Cross-sectional) *with units expressed in metre squared (m^2)*

Length *with units expressed in metres (m)*

Temperature *with units expressed in degrees Celsius (^oC)*

Calculating Resistance

4. The approximate resistivity of several common metals used in the electrical industry is given below:

Material	Resistivity (Ω.m) at 20˚C	Applications
Silver	1.63×10^{-8}	Contacts
Copper	1.72×10^{-8}	Conductors
Aluminium	2.83×10^{-8}	Conductors
Tungsten	5.51×10^{-8}	Lamp filaments
Brass	7.00×10^{-8}	General construction
Iron	10.00×10^{-8}	General construction
Manganin	45.00×10^{-8}	Ammeter shunts
Nichrome	110.00×10^{-8}	Heating elements
Kanthal	139.00×10^{-8}	Heating elements

5. To determine the value of resistance of any conductor we use the following equation.
* For the purposes of simplicity we assume the temperature of the conductor is at room temperature or 20^{o}C.

$$Resistance = \frac{Rho \quad x \quad Length}{Area} \quad \text{or} \quad R = \frac{\rho \ell}{A}$$

Where: **Resistance is in ohms**
Rho (ρ) is in ohm metres
Length (ℓ) is in metres
Area is the cross-sectional area in square metres (*m^2*)

Example. Calculate the resistance of 1000 metres of 2.5 square mm copper building wire given that the resistivity of copper is 1.72×10^{-8} ohm-metres.

$$R = \frac{\rho \ell}{A}$$ Note: convert mm^2 to m^2

$$= \frac{1.72 \quad x \quad 10^{-8} \quad x \quad 1000}{2.5 \quad x \quad 10^{-6}}$$

= 6.88 Ω

Exercise 1: Calculate the resistance of 500 metres of 4mm^2 copper building wire if the Resistivity of copper is 1.72×10^{-8} ohm metres.

Exercise 2: Calculate the length of 0.6mm^2 Kanthal resistance wire which would be required to make a heating element with a cold resistance of 60 ohms.

Effect of Temperature on Resistance

6. The resistance of all metallic conductors increases as the temperature increases, some by a lot and others very little. To compare how much change occurs we give each conductor a value by which the amount by which the resistance will change for every degree Celsius.

It is known as the Temperature Coefficient of Resistance and it is given the Greek letter Alpha (α).

7. Approximate values of the Temperature Coefficient of Resistance for different metals are shown below:

Material	**Temperature Coefficient of Resistance (Ohms per Ohm per degree C (0˚ - 100˚)**
Copper	+ 0.004 27
Aluminium	+0.003 88
Nichrome	+0.000 16 to 0.000 44
Silver	+0.003 77
Manganin	+0.000 011 to 0.000 039
Carbon	-0.000 5

17. To find the resistance after a given change in temperature in a metal conductor we use the following equation:

$$R_T = R_o\,(1+\alpha.t)$$

***** α.t means - α multiplied by t

Where: R_T = the resistance of the conductor after the temperature has changed
R_{ref} = the resistance at its referenced temperature before it changed
α = the Temperature Coefficient of Resistance
t = the temperature change in degrees Celsius

18. **Example:** A conductor has a resistance value of 100Ω when its body temperature is at 0ºC, calculate its resistance value if the body temperature of the conductor increases to 60ºC?

$R_T = R_o\,(1+\alpha t)$

= 100(1 + 0.004 27 x 60) BIMDAS Rule: Multiply before addition!

= 125.62 ohms (Ω)

19. The resistivity of copper cable increases as the temperature increases.

The resistivity of a typical copper cable at an operating temperature of 75 degrees C can be taken as 2.25 x 10^{-8} ohm metres.

Factors Effecting Resistance

1. Calculate the resistance of 500 metres of 2.5 square mm copper cable if the resistivity of copper is 1.72 x 10^{-8} ohm metres.

2. Calculate the length (m) required to make a heating element with a resistance of 40Ω if you were to use Nichrome wire with a cross-sectional area of $0.7mm^2$?
   Given the resistivity of Nichrome wire is 110 x 10^{-8} ohm metres.

3. A particular coil winding has a resistance of 50Ω when the temperature is 0^oC. Calculate the new resistance if the coil temperature increased to 60 degrees C. Assume the temperature coefficient of resistance to be 0.004 27 ohms per ohm per degree C. ($R_T = R_o(1+\alpha t)$).

4. What are the units of 'resistivity' are expressed in and give the symbol?

   ____

5. What are the four factors governing the resistance of any material?

   _______________ _______________ _______________ _______________

6. Which common electrical material has a negative temperature coefficient of resistance?

   ____

7. What effect does it have on the resistance of a metallic electrical conductor if the cross sectional area (CSA) is increased?

   ____

8. A particular coil winding has a resistance of 40Ω when the temperature is 20^0 C. Calculate the new resistance if the coil temperature increased to 85^0 C. Assume the temperature coefficient of resistance to be 0.004 27 ohms per ohm per degree C. (RT = Ro(1+αt)).

9. A length of aluminium conductor has a resistance of 65Ω when the temperature is 30^0 C. Calculate the new resistance if the coil temperature increased to 105^0 C. Assume the temperature coefficient of resistance to be 0.003 88 ohms per ohm per degree C. (RT = Ro(1+αt)).

10. A length of nichrome conductor has a resistance of 125Ω when the temperature is 10^0 C. Calculate the new resistance if the coil temperature increased to 130^0 C. Assume the temperature coefficient of resistance to be 0.000 44 ohms per ohm per degree C. (RT = Ro(1+αt)).

Notes:

End of Part A

Part B

Government of Western Australia North Metropolitan TAFE	**Solve problems in DC circuits**	Section 12 Introduction	TOG 12/2016 E104A

Series DC Circuit Analysis

Task:

To determine the resistance, voltage, current and power in any part of series DC circuits containing one voltage source and solve problems in these circuits.

Why:

You need to be able to determine the values of resistance, voltage, current and power so that you can analyse and accurately predict the behaviour of a series circuit when problems arise.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.

2. You must satisfactorily complete the set laboratory activities.

3. You must achieve 100% in a final competency test for each practical component.

Equipment

Sample series DC circuits
ELV DC power supplies
Digital and analogue multimeters
Fixed DC ammeters and voltmeters

References

* Electrical Principles for the Electrical Trades (6th ed.), J.Jenneson, B. Harper & B. Moore
* Australian Electrical Wiring - Volume 1 (7th Edition), K. Pethebridge & I. Neeson.
* Video: Basic Electricity, Parts 1-14.

Series DC Circuit Analysis

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades – Volume 1

Chapter 4 DC circuits
Section 4.4 Series circuit analysis

Chapter 11 Cell and Batteries
Section 11.1.8 Cells in series – strings (page 192)

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the laboratory activities in this Section.

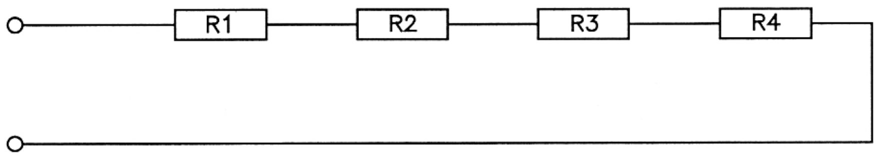
5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion.

Series Circuits

1. When resistors or other electrical components are connected 'end to end' as shown in the diagram below they are said to be connected in SERIES.

A simple test to determine whether or not the components are in series is to isolate the supply and disconnect any one component; if it is a series circuit then no current will flow in the circuit.

Only **ONE** current path exists in a series circuit. When connected there is only one wire connected to either end of the components.



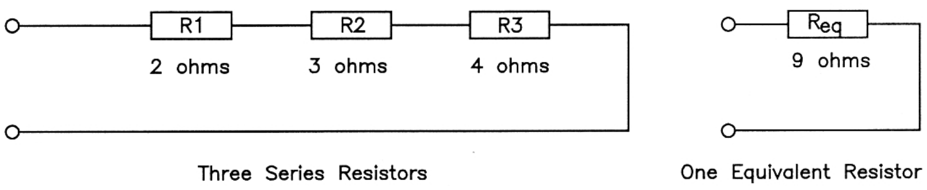
2. As more resistors are added to the circuit in series, then the total circuit or overall resistance will increase. Increasing the total resistance of any circuit will decrease the current flow through it - assuming the applied voltage remains the same (constant).

The total resistance must be greater than the resistance of any single resistor in the series circuit. In a series circuit the total resistance is the SUM of the individual resistors.

Total Resistance (R_T) = $R_1 + R_2 + R_3 \ldots\ldots + R_n$

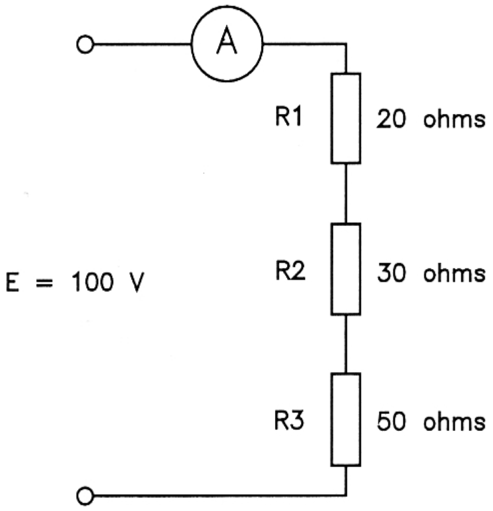
3. The total circuit resistance can also be expressed as the “equivalent” resistance (R_e or R_{eq})' of the circuit. If you were to replace every resistor in a circuit for just one single resistor, then this is the value it would need to be.

   Sometimes parts of circuits can also be described as an equivalent resistance for just those parts to help solve more complex circuits.



4. The current flowing in a series circuit is common to each and all components of the series circuit, thus the current flowing through each component of the circuit must share the same value.

5. When an electromotive force (E) is applied to a bank of resistors in series the total current in the circuit can be found by finding the total (or equivalent) resistance, then using Ohm's Law (I=E/R), as shown in the following example.



Total Resistance (R_T) = $R_1 + R_2 + R_3$

$= 20 + 30 + 50$

$= 100$ ohms
==========

$$I = \frac{E}{R_T}$$

$$= \frac{100}{100}$$

= 1 amp
=======

6. Consider a series circuit consisting of two or more resistors having different resistances.

Although the total current must be the same in all parts of a series circuit, the voltage required to cause that particular value of current to flow through each resistor would be different.

If the current is known and the resistance is known the voltage required for EACH resistor can be found by applying Ohm's Law (V = I.R) to each resistor.

The voltage which would be measured across each individual resistor is often described as the EFFECT of the flow of current in the circuit and is called 'potential difference (V)'.

Applying V = I.R to the circuit above, with a current of 1 amp, the potential differences across the resistors would be 20, 30 and 50 volts respectively.

7. Since the electromotive force (E) which causes the current to flow in the circuit can be considered as being different to the potential difference which appears across EACH resistor as a result of the current flow, electromotive force and potential difference have different quantity symbols (E and V respectively) but the same unit symbol (V in both cases).

8. Both E and V are expressed in volts (or any metric multiple or sub-multiple), and Ohm's Law applies in the same way to each, so Ohm's Law can be expressed as E = I.R or V = I.R, depending on the part of the circuit being considered, but care must be taken to make sure that the appropriate circuit values are used during any calculation.

In more modern times the symbol “V” has generally replaced the use of “E” when using Ohm’s Law.

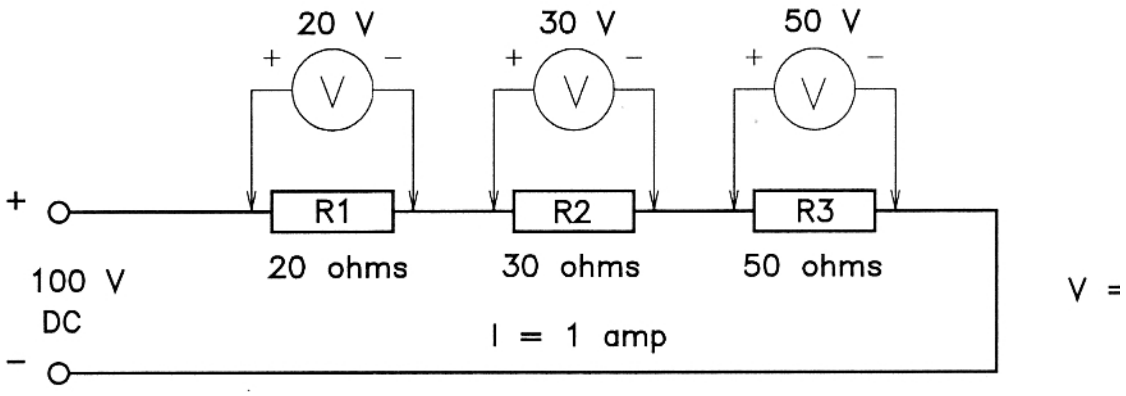
Thus electromotive force applies to an entire circuit, and potential difference applies to the individual parts of a circuit. Ohm's Law applies to any DC circuit and ANY PART of it.

9. Potential difference is also commonly known as 'volt drop', 'voltage drop' or 'fall in voltage' and is measured with a voltmeter or multimeter.

10. In any circuit consisting of series resistors, the potential difference across each resistor is proportional to the resistance of the resistor (because V=I.R), and the sum of the individual potential differences must be equal to the voltage applied to the circuit.

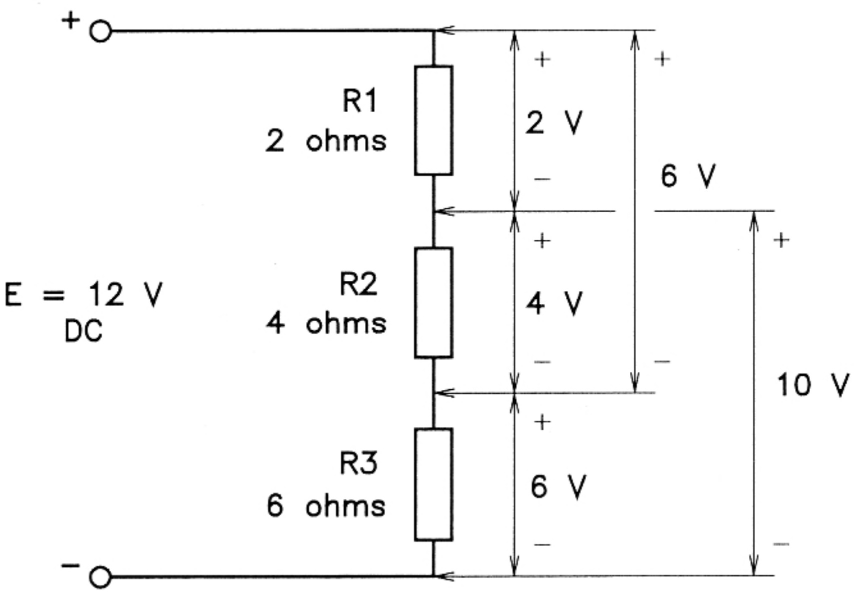
The potential difference across any individual resistor in a series circuit cannot be equal to or greater than the electromotive force applied to the circuit.

Resistors having the same value of resistance in a series circuit must have the same potential difference across them. If all resistors have the same value, then the applied voltage is equally divided across each resistor.



$$V_{R1} + V_{R2} + V_{R3} = \text{the applied voltage}$$

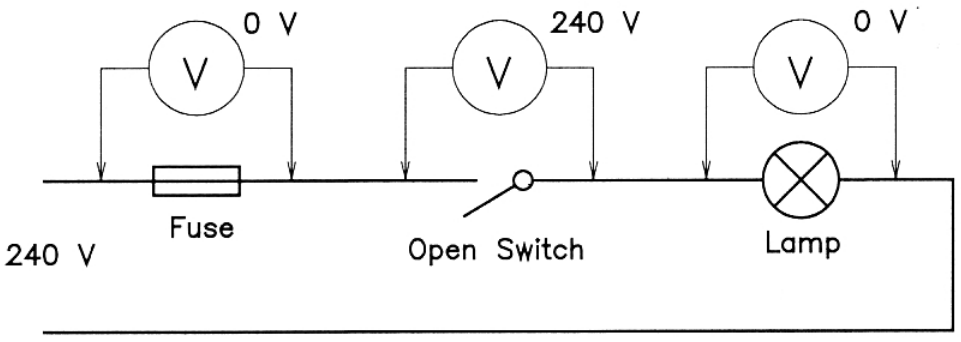
11. Series circuits are used in most electronic circuits to provide different voltages at different parts of a circuit. Resistors used in this way are referred to as 'voltage dividers'.



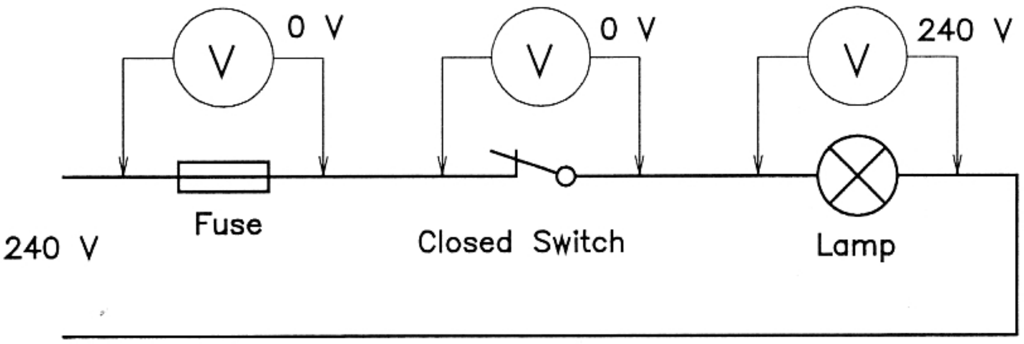
Voltage divider

12. If any component is **open circuited** in a series circuit in which the supply voltage is still connected, the **full supply voltage will be measured across the open component**.

This fact is very important when problem solving in a practical circuit.



13. The voltage across a closed switch or a short circuited component in a series circuit must be zero, regardless of the applied voltage.

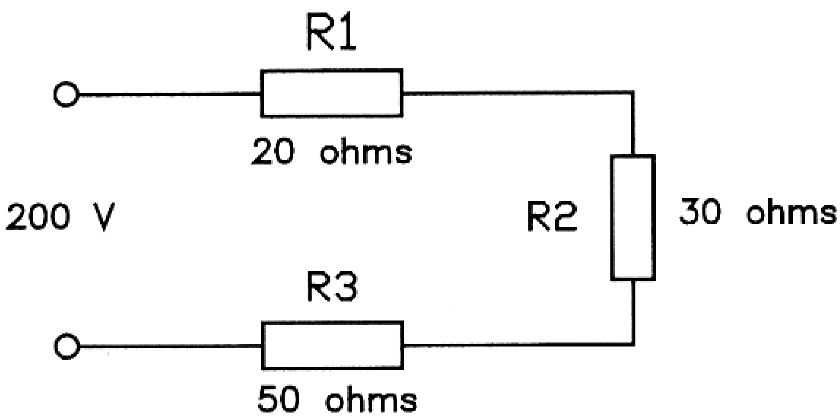


Calculations

14. A circuit consists of three resistors connected in series to a 200 volt supply; their resistances are 20, 30 and 50 ohms respectively.

Find the total resistance, total circuit current and the potential difference across each resistor. Note: ALWAYS draw the circuit first.

If there is more than one component of the same type, use subscripts to indicate which value is being considered in the equation.



Solutions

Resistance

$R_T = R_1 + R_2 + R_3$
$= 20 + 30 + 50$
$= 100$ ohms
==========

Current

$I = \frac{E}{R_T} = \frac{200}{100} = 2$ amps
======

Voltages

$V_{R1} = I \cdot R1 = 2 \cdot 20 = 40$ volts
==========

$V_{R2} = I \cdot R2 = 2 \cdot 30 = 60$ volts
==========

$V_{R3} = I \cdot R3 = 2 \cdot 50 = 100$ volts
===========

Voltage Check: 40 + 60 + 100 = **200 volts** (Correct)

15. The results of the calculation above, show that the potential difference is directly proportional to the resistance (V=I.R) - the highest voltage appears across the highest resistance and vice versa.

Power Calculations

16. Having calculated the current and voltages in the circuit the power being dissipated by each part of the circuit can be calculated by applying any one of the three power equations.

$$P_{R1} = V_{R1} . I$$
$$= 40 \times 2$$
$$= 80 \text{ watts}$$

==========

$$P_{R2} = I^2 . R2$$
$$= 2 \times 2 \times 30$$
$$= 120 \text{ watts}$$

==========

$$P_{R3} = \frac{V_{R3}^2}{R3}$$
$$= \frac{100 \times 100}{50}$$
$$= 200 \text{ watts}$$

============

Total Power = E x I
= 200 x 2
= 400 watts

===========

17. The total power in a circuit is the sum of the individual powers dissipated by each of the components, so the power calculations can be checked.

Total Power = $P_{R1} + P_{R2} + P_{R3}$

= 80 + 120 + 200
= 400 watts (Correct)

=========

18. In a resistive circuit all of power dissipated in the circuit results in heat being produced. In a series circuit, the resistor with the highest resistance produces the highest quantity of heat.

Problem Solving Exercises:

Note: You should always draw a diagram for calculation exercises.

1. Calculate the total resistance of four resistors in series, if their resistances are 5, 10, 15 and 20 ohms respectively.

2. The resistances of three resistors in a series circuit have a ratio of 1:3:4 respectively. If the line voltage to the circuit was 80 volts, work out what the potential difference is across each resistor?

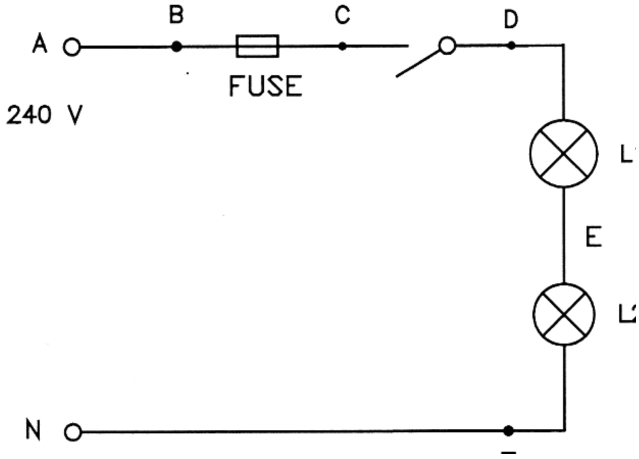
3. Three resistors in a series circuit have a resistance of 10Ω, 20Ω and 50Ω respectively. How much current would flow in the circuit if the applied voltage was 240 volts?

4. The resistances of the three resistors in a series circuit are 10Ω, 20Ω and 30Ω respectively. If the voltage drop across the 10Ω resistor was 20V, what would be the voltage applied to the circuit?

5. A switch is connected so that it can turn a 120 ohm load on and off. The voltage applied to the circuit is 240 volts. What voltage would be measured across the SWITCH when it is in the OFF position?

6. Consider **Circuit A**. What is the voltage between each of the following points, if L1 and L2 are identical lamps?

Circuit A



Between B and C _______

A and D _______

B and F _______

A and E _______

C and D _______

D and E _______

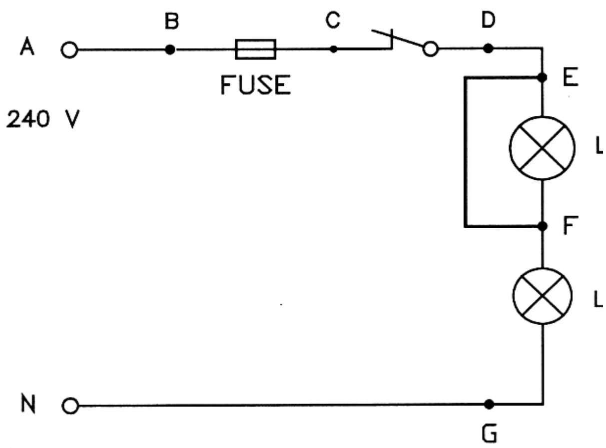
D and F _______

E and F _______

F and N _______

7. Consider **Circuit B**. What is the voltage between each of the following points, if L1 and L2 are identical lamps, but L1 is short circuited?

Circuit B



Between A and C _______

B and D _______

B and E _______

B and F _______

C and D _______

D and F _______

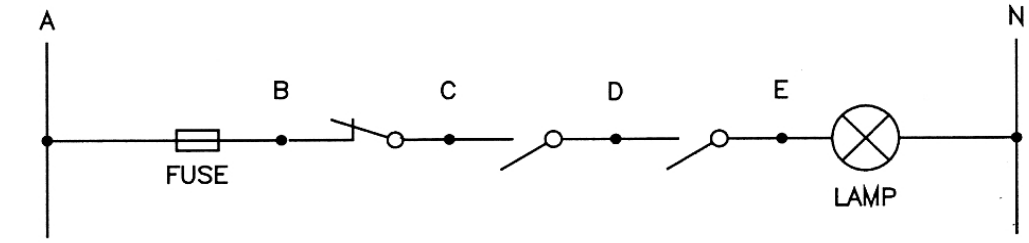
D and G _______

F and G _______

F and N _______

8. Consider **Circuit C**. What is the voltage between each of the following points if the voltage between A and N is 240 volts?

Circuit C



Between A and B _______

A and N _______

A and C _______

C and D _______

C and E _______

D and E _______

D and N _______

E and N _______

Practical Problem Solving

9 Problem solving or fault finding in practical circuits must always be carried out in such as way as to avoid damage to apparatus, circuits or the surrounding environment. If you encounter unexpected situations and you are not sure how to proceed, you should consult your supervisor immediately.

10. When you have completed the task and checked to see that all relevant requirements have been met you need to clean up your work area, make sure that it is safe, and report the completion to your supervisor.

Cells in Series – Strings

11. Read Section 11.1.8 in Electrical Principles Volume 1. (page 192)

Series Circuits

Note: Draw a neat circuit diagram for all calculation questions.

1. What simple test/s could be performed to determine if the resistors in a circuit are connected in series with one another?

2. What is the total resistance of a circuit which has four resistors connected in series given their values are 10, 20, 30 and 40 ohms respectively.

3. If a circuit consists of a 6 ohm, 4 ohm and 10 ohm resistor connected in series, what ohms value resistor would be required to replace all and substitute with just one single resistor?

4. What is unique about the current flowing through each component in a series circuit?

5. What can be said about the algebraic sum of the voltages (potential differences) across each component in a series circuit?

6. What can be said about the voltage measured across any one of any resistor in a series resistor circuit in relation to its voltage supply?

7. What can be said about the total circuit resistance of a series circuit in relation to the resistance of any single resistor in that circuit?

8. If the resistances values of three resistors in a series circuit have a ratio of 1:2:3 respectively and given that the potential difference across the first resistor is 10 volts, what is the applied voltage to the circuit?

9. A circuit contains resistances three resistors in series. They are 20 ohms, 30 ohms and 50 ohms respectively. If a current of 2 amps is flowing in the 20 ohm resistor, what is the total power being dissipated in that circuit?

10. What are two other common terms which are used to describe the 'potential difference' across resistors in a series circuit?

11. The resistances of the three resistors in a series circuit are 2 ohms, 4 ohms and 6 ohms respectively. If the applied voltage was 24 volts, calculate the expected current?

12. The resistances of the three resistors in a series circuit are 2 ohms, 4 ohms and 6 ohms respectively, and the applied voltage is 24 volts. What are the expected voltage drops across each resistor in the circuit?

13. A 10 volt supply is connected to a circuit containing three resistors in series, what voltage would be expected across any one of those resistors should “it” become open circuited?

14. A circuit contains two incandescent lamps in series connected to a 240 volt supply, a fault develops that causes one lamp to stay on and the other to go out. What is the most likely cause of this fault?

15. A circuit containing two lamps in series supplied by 24 volts is controlled through a single-pole switch. What voltage would be expected across the SWITCH when the lamps are ON?

16. How many current paths are there in a series circuit?

17. In a series circuit, if its applied voltage was halved, what influence would that have on its circuit current?

18. What is the "equivalent" resistance of a circuit that contains 5 identical 10 ohm resistors connected in series when one of those resistors has become "open" circuited?

19. Two incandescent lamps are connected in series to a 240 volt supply. A fault develops that results in both lamps going out, but the voltage measured at one of the lamps is 240 volts, and the voltage across the other is 0 volts. What is the most likely fault?

20. An appliance is drawing 10 amps from a 240 volt supply. It is connected to the supply via a two-core cable of which each core has a resistance of 2 ohms, Taking into account the voltage drop experienced in the supply cable, what voltage is the appliance actually operating at?

21. In question 20, what action could be taken to improve the operating voltage of the appliance without needing to increase the supply voltage?

22. What name is given to the potential difference which occurs across the cables supplying any electrical device when the device is connected to the supply?

23. Draw a neat circuit diagram of a circuit consisting of three resistors connected in series. Include measuring instruments to measure the line voltage and line current in the circuit, and indicate whether the resistance of the measuring instrument would be high or low.

24. What is the major disadvantage of using a voltmeter that has a low sensitivity (internal resistance) when attempting to measure the potential differences across components in extra-low voltage electronic circuits?

25. What is the major advantage of using a clip-on ammeter (tong-tester) to measure the current in a series circuit?

26. Consider the following, you have been asked to carry out problem solving or fault finding activities in the workplace.

a. What are the necessary precautions you should take prior to you commencing your work?

b. What you must do if you encounter an unexpected situation?

c. Who must you ask if you are unsure of what to do next?

27. When you have completed a given task at your workplace, what actions should you take before moving on to your next task?

28. A hand-held torch requires six volt to operate effectively, its battery is made up of a number of identical cells and each cell has a voltage of 1.5v, if only using the minimum number of cells necessary, how many cells would be required to make up the 6 volts required?

Draw a circuit diagram below of how the cells would need to be connected to gain the required output voltage.

Series Circuits

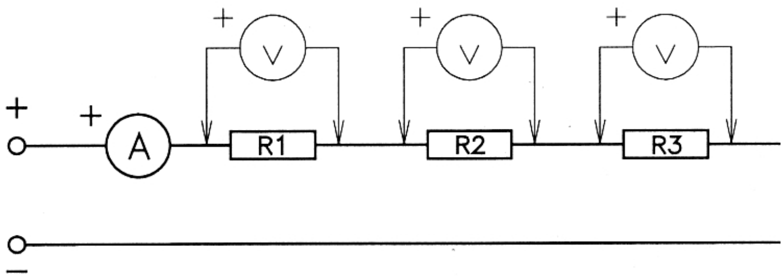
Objective

To connect the given resistors in series to a suitable DC supply and verify the readings by calculation.

Equipment

Series resistor project board
Connecting leads
Ammeters and voltmeters as required
Multimeter
ELV direct current supply

Circuit



Danger Tag Procedure Danger Tag procedure will be followed during this activity

Task Procedure

1. Check to see that the project board is isolated from the supply. **Measure the resistance of each of the resistors on the project board with a multimeter before connecting** them. Record the resistances in the Results Table.

2. Use "Ohm's Law" to calculate the voltage and current using the **measured values** of resistance, **not the nominal values.** Compile your results in the Results Table.

3. Connect the circuit according to the circuit diagram given above. **Do not connect** your circuit to the supply yet.

4. Ensure your multimeter is working correctly, set it to read ohms and then set it on the lowest ohms range to **record the total resistance of the circuit**. Record the amount here.

   ____

5. Connect your circuit to the supply but do not energise it until you have the Lecturer's approval.

   Lecturer Initials. Safe to energise? YES/NO

6. Take all voltage and current readings, enter the values where appropriate in the results table and compare your measured values with that of your calculated values.

7. Switch the circuit off and remove the plug from the outlet. **Do not disconnect/ dismantle** your circuit until the lecturer says you can.

8. Submit your results to your Lecturer for comment and discussion. The lecturer will advise if you can pack away your equipment and return it to its proper place.

Results Table - Series Circuit

	Resistance (Ω)		**Volts (V)**		**Current (A)**	
	Nominal	Measured	Calculated	Measured	Calculated	Measured
R1						
R2						
R3						
Total (Calculated)		$R_1 + R_2 + R_3$	$V_{R1} + V_{R2} + V_{R3}$	Supply V	Supply V / Measured R	
Total (Measured)		Multimeter reading	Supply V			Ammeter Reading

Questions

1. What general statement can be made about the current in each component in a series circuit?

   Answer: ______________________________

2. What general statement can be made about the algebraic sum of the potential differences across each component in a series circuit?

   Answer: ______________________________

3. How much current would flow in this circuit if R1 became short circuited?

   Answer: ______________________________

4. What general statement can be made about the total resistance in a series circuit in relation to the resistance of any single resistor in the circuit?

   Answer: ______________________________

5. If ONE of the components in a series circuit is open circuited, what effect would it have on the current in the other components in the circuit?

   Answer: ______________________________

6. What was the importance of measuring the circuit resistance before connecting it to the supply?
   Answer: ______________________________

Satisfactory:			Not Satisfactory:	

Lecturer: ______________________________ Date: ________________

Parallel DC Circuit Analysis

Task:

To determine the resistance, voltage, current and power in any part of parallel DC circuits containing one voltage source and solve problems in these circuits.

Why:

You need to be able to determine the values of resistance, voltage, current and power so that you can analyse and accurately predict the behaviour of a parallel circuit when problems arise.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set laboratory activities.
3. You must achieve 100% in a final competency test for each practical component.

Equipment

Sample parallel DC circuits
ELV DC power supplies
Digital and analogue multimeters
Fixed DC ammeters and voltmeters

References

* Electrical Principles for the Electrical Trades (6th ed.), J.Jenneson, B. Harper & B. Moore
* Australian Electrical Wiring - Volume 1 (7th Edition), K. Pethebridge & I. Neeson.
* Video: Basic Electricity, Parts 1-14.

Parallel DC Circuit Analysis

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades – Volume 1

Chapter 4 DC circuits
Sections 4.5 Parallel circuit analysis

Chapter 11 Cells and Batteries
Section 11.1.9 Cells in parallel – banks (page 192)

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet.

   Note: that you are required to answer ALL questions correctly, although not necessarily at the same time.

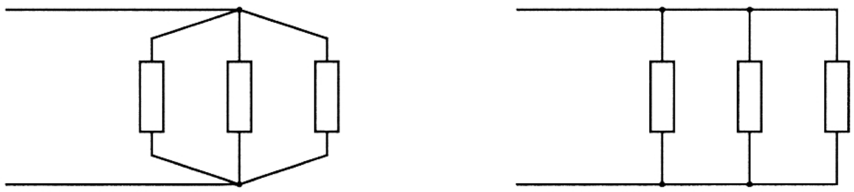
4. Complete the laboratory activities in this Section.

5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion.

Parallel Circuits

1. When two or more components are effectively connected to the same two points as shown in the diagram below they are said to be connected in parallel.

A simple test to determine whether or not the components are in parallel is to isolate the supply and disconnect one component; if it is a parallel circuit the other components in the circuit will not be effected.



2. Connecting resistors in parallel decreases the total resistance of the circuit and increases the current drawn by the circuit (if the voltage remains constant).

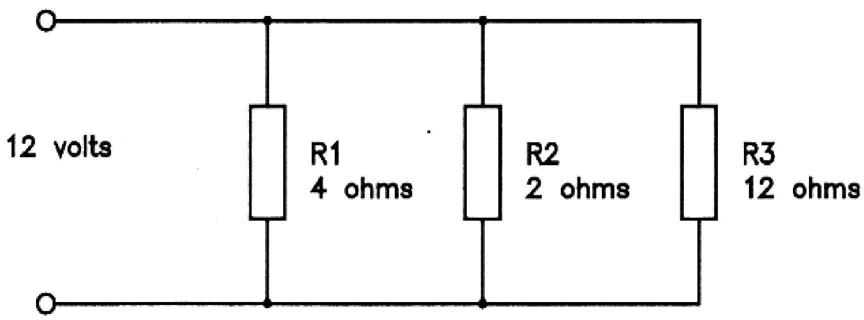
The total resistance must always be less than the resistance of any single resistor in the parallel circuit.

3. The voltage must be the same across all resistors connected in parallel (E and V are the same value).

The current through each resistor is inversely proportional to the resistance - the higher the resistance the lower the current (I=V/R).

4. There are several methods of calculating the equivalent resistance of a bank of parallel resistors.

Each of the methods shown below is based on the following parallel circuit:



Method 1

5. Use Ohm's Law to determine the total current in the circuit, then find the total circuit resistance. i.e.

$$I_{R1} = \frac{E}{R_1} = \frac{12}{4} = 3\text{ A}$$

$$I_{R2} = \frac{E}{R_2} = \frac{12}{2} = 6\text{ A}$$

$$I_{R3} = \frac{E}{R_3} = \frac{12}{12} = 1\text{ A}$$

6. The total circuit current is equal to the sum of each of the currents in the parallel branches:

$$I_{RT} = I_{R1} + I_{R2} + I_{R3}$$

$$= 3 + 6 + 1$$

$$= 10\text{ A}$$

======

7. Now apply Ohm's Law, using the total circuit current:

$$\text{Total Resistance } (R_T) = \frac{E}{I_T}$$

$$= \frac{12}{10}$$

= 1.2 ohms (Also known as the equivalent resistance - **Re**)

=========

Method 2

8. Derive a universal equation using Ohm's Law, as follows:

$$\text{Total } I\ (I_T) = I_1 + I_2 + I_3$$

$$\text{But: } I = \frac{V}{R} \quad \text{(Ohm's Law)}$$

So substitute V/R for each I, using the appropriate value of R:

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

But V is common to both sides of the equation, and to all of the parallel resistors, so divide both sides of the equation by V, giving:

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

9. The known values are substituted for the symbols in the equation, then the answer is found by arithmetic addition of fractions:

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

$$= \frac{1}{4} + \frac{1}{2} + \frac{1}{12}$$

$$= \frac{3 + 6 + 1}{12} \quad \text{(Addition of fractions)}$$

$$\frac{1}{R_T} = \frac{10}{12} \quad \textbf{(This is } \mathbf{1/R_T} \textbf{ not } \mathbf{R_T}\textbf{)}$$

$$\text{So: } R_T = \frac{12}{10} \quad \text{(By inverting both sides of the equation)}$$

= 1.2 ohms (Total resistance or EQUIVALENT resistance)
========

10. This method can be used to find the total circuit resistance for any number of resistors in parallel.
It is not necessary to know the line voltage to use this method.

Method 3

11. Add the reciprocal of each of the resistors together and then find the reciprocal of the result (the reciprocal of any number is 1 over that number):

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

$$= \frac{1}{4} + \frac{1}{2} + \frac{1}{12}$$

= 0.25 + 0.5 + 0.0833 (Add the reciprocals together)

= 0.83 (This is the reciprocal of the total resistance)

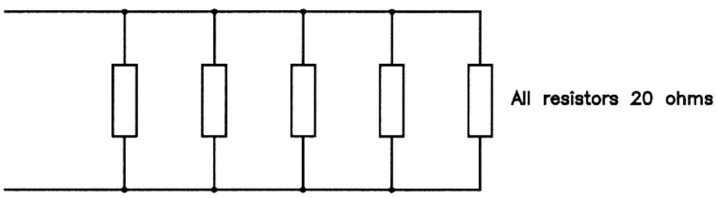
The reciprocal of 0.83 is 1.2, so the answer is 1.2 ohms.

12. The above method can be done using a calculator $\mathbf{x^{-1}}$ function

Eg. R_T **= (4 $^{x-1}$ +2 $^{x-1}$ +12 $^{x-1}$) $^{x-1}$**
=1.2 ohms
or
R_T = **1 ÷ (1 ÷ 4 + 1 ÷ 2 + 1 ÷ 12)**
= **1.2 ohms**

Method 4 (Special Case 1)

12. If several resistors in parallel bank have the same resistance, the total resistance may be found by dividing the resistance of one resistor by the number of resistors in parallel. Consider the case of five 20 ohm resistors in parallel.



$$R_T = \frac{R_1}{n}$$

R_1 (The resistance of one resistor)

n (The number of resistors)

$$= \frac{20}{5}$$

= 4 ohms

Method 5 (Special Case 2)

13. If there are only two resistors a special equation may be used. For example, if a 3 ohm resistor was connected in parallel with a 6 ohm resistor:

$$R_T = \frac{R_1 \times R_2}{R_1 + R_2} \quad \text{(Two resistors ONLY)}$$

$$R_T = \frac{3 \times 6}{3 + 6}$$

$$= \frac{18}{9}$$

$$= 2 \text{ ohms}$$

Choice of Method

14. The method of calculating the total resistance of resistors in parallel depends on the values involved. Method 1 could only be used if the line voltage was known. Method 2 would not usually be convenient if fractional resistances were involved (Method 3 would be more appropriate). Method 4 can only be used when all resistors have the same resistance. Method 5 can only be used for two resistors (including those with fractional resistances).

Power Calculations

15. It the voltage and resistances are known, the power in each branch of the circuit can be calculated by applying any one of the three power equations; the total power is then the sum of the powers in each resistor. The resistor with the highest resistance must dissipate the lowest power. Using the 4, 6, 12 ohm parallel circuit:

$$P_{R1} = V_{R1}.I = 12 \times 3 = 36 \text{ watts}$$

$$P_{R2} = I^2.R_2 = 6 \times 6 \times 2 = 72 \text{ watts}$$

$$P_{R3} = \frac{V^2}{R_3} = \frac{12 \times 12}{12} = 12 \text{ watts}$$

$$\text{Total Power} = E \times I = 12 \times 10 = 120 \text{ watts}$$

Power Check: 36 + 24 + 72 = 120 watts (Correct)

Fault Finding

16. In practical circuits components are often connected in parallel. For fault finding purposes it is necessary to be able to predict the behaviour of a circuit under fault conditions. If one branch circuit in a parallel bank becomes OPEN circuited, the result is:

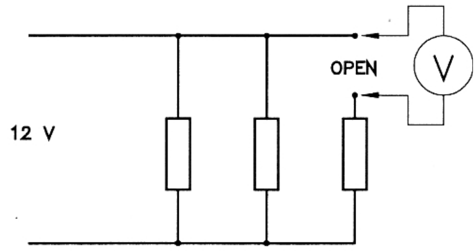
a. The total circuit resistance increases.

b. The total circuit current decreases.

c. The voltage across the remaining branches remains the same.

d. The voltage drop across the open circuit is equal to the applied voltage.

e. The voltage across the open circuited component falls to zero.



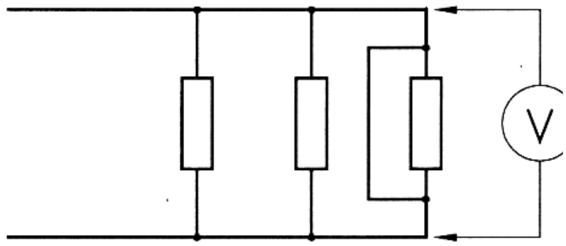
17. If one branch circuit in a parallel bank is SHORT circuited, the result is:

a. The total circuit resistance decreases to zero.

b. The total circuit current increases to a value limited only by the current available from the power supply. (The circuit protection device should operate).

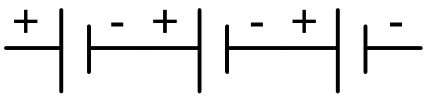
c. The voltage across the remaining branches falls to zero.

d. The voltage across the short circuited component falls to zero.

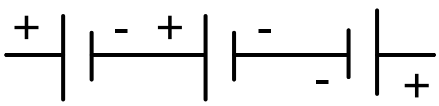


Batteries in series and parallel -

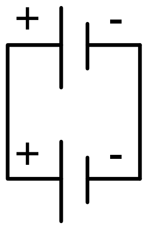
When cells are connected in series the voltage of each cell is cumulatively added depending on the orientation of the individual cells.



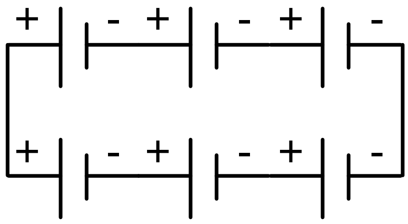
3 x 1.5V cells in series aiding. ie. 1.5 + 1.5 +1.5 = 4.5V



3 x 1.5V cells connected in series aiding/opposing i.e 1.5 + 1.5 + (-1.5) = 3.0V



When two cells are connected in parallel the voltage remains the same as either cell but the current capacity is doubled as both cells can supply the load simultaneously.



When connected in this series/parallel configuration each string of three cells in series will provide 4.5V and the two strings together in parallel still provide 4.5V but the current capacity is doubled as both sets of cells can supply the load simultaneously.

WARNING* When connecting cells or series strings in parallel they must be of the same voltage .**

18. Problem Solving Exercises

Note: Always draw a diagram with any calculation.

a. Find the total resistance of two resistors connected in parallel if their values are 1Ω and 1MΩ respectively.

b. Find the total resistance of two resistors connected in parallel if their values are 36.25Ω and 79.68Ω respectively.

c. Find the total resistance of three resistors connected in parallel if their values are 0.25Ω, 1.6Ω and 0.01Ω respectively.

d. Find the total resistance of ten identical resistors connected in parallel if the resistance of each is 500Ω.

e. Three resistors are connected in parallel to a 240V supply; the line current is 4A. If one of the resistors was safely disconnected, would the line current increase or decrease?

f. Three resistors are connected in parallel. One resistor is dissipating 48W, another has a resistance of 2Ω, and the third has a current of 2A flowing through it and the voltage across it is 24V.
What is the total resistance of the circuit?
What is the total power dissipated by the entire circuit?

19. Cells in Parallel – Banks

Read Electrical Principles for the Electrical Trades
Volume 1 Chapter 11, section 11.1.9 (page 192)

Parallel Circuits

Note: Draw a neat circuit diagram for all calculation questions.

1. Calculate the total resistance of four resistors in parallel if their resistances are 4, 8, 12 and 24 Ω respectively.

2. What simple test/s could be performed to determine if the resistors in a circuit are connected in parallel with one another?

3. A circuit contains of 6, 3 and 2Ω resistor connected in parallel. If the resistors needed to be replaced with just a single resistor equivalent to the circuit's total resistance, what value resistor is required?

4. In all parallel circuits, what general statement can be made about the voltage present across each component in a parallel circuit in relation to its supply voltage?

5. What general statement can be made about the sum of the individual currents in the components in a parallel resistor circuit in relation to the line current supplying the circuit?

6. Is it possible for the current through any one resistor in a parallel circuit to be greater than the overall line current?

7. With regards to the total resistance of a parallel circuit, what can be stated in terms of the resistance of any one resistor?

8. The values of three resistors in a parallel circuit have a ratio of 1:2:3 respectively. If the current through the first resistor was 12 amps, determine the total current flowing in the circuit?

9. Three resistors in a parallel circuit are 24 ohms, 30 ohms and 60 ohms respectively. If a current of 10 amps is flowing in the 24 ohm resistor, what is the power being dissipated by the entire circuit?

10. Three resistors in a parallel circuit are 3 ohms, 6 ohms and 12 ohms respectively. How much current would flow in the circuit if the applied voltage was 24 volts?

11. An electrically operated forklift requires a battery capable of providing 120 volts at a current of 40 amps. Calculate the number of lead–acid cells required if one cell has an output voltage of 2v with a current rating of 10 amps. Use a diagram to explain how the cells would need to be connected to achieve the desired output.

Government of Western Australia North Metropolitan TAFE	**Solve problems in DC circuits**	Section 13 Activity 13 - 1	TOG 12/2016 E104A

Parallel Circuits

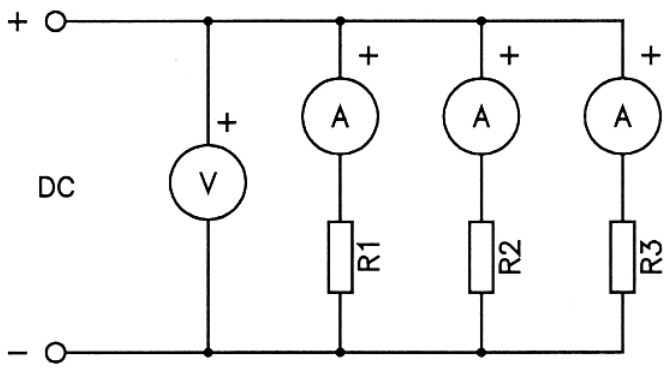
Objective

To connect the given resistors in parallel to a suitable DC supply and verify the readings by calculation.

Equipment

Parallel resistor project board
Connecting leads
Ammeters and voltmeters as required
Multimeter
ELV direct current supply

Circuit



Danger Tag Procedure Danger Tag procedure will be followed during this activity

Task Procedure

1. 1. Check to see that the project board is isolated from the supply. **Measure the resistance of each of the resistors on the project board with a multimeter before connecting** them. Record the resistances in the Results Table.

2. Use "Ohm's Law" to calculate the voltage and current using the **measured values** of resistance, **not the nominal values.** Compile your results in the Results Table.

3. Connect the circuit according to the circuit diagram given above. **Do not connect** your circuit to the supply yet.

4. Ensure your multimeter is working correctly, set it to read ohms and then set it on the lowest ohms range to **record the total resistance of the circuit**. Record the amount here.

   ____

5. Connect your circuit to the supply but do not energise it until you have the Lecturer's approval.

   Lecturer Initials. Safe to energise? YES/NO

6. Take all voltage and current readings, enter the values where appropriate in the results table and compare your measured values with that of your calculated values.

7. Switch the circuit off and remove the plug from the outlet. **Do not disconnect/ dismantle** your circuit until the lecturer says you can.

8. Submit your results to your Lecturer for comment and discussion. The lecturer will advise if you can pack away your equipment and return it to its proper place.

Results Table – Parallel Circuit

	Resistance (Ω)		**Volts (V)**		**Current (A)**	
	Nominal	Measured	Calculated	Measured	Calculated	Measured

R1						
R2						
R3						
Total (Calculated)		$R_1 \parallel R_2 \parallel R_3$	Supply V		$I_{R1} + I_{R2} + I_{R3}$	
Total (Measured)		Multimeter reading		Supply V		Ammeter Reading

Questions

1. What general statement can be made about the current through each component in a PARALLEL circuit in relation to line current?

Answer: ______________________________

2. What general statement can be made about the voltage across each component in a parallel circuit in relation to the line voltage?

Answer: ______________________________

3. Is it possible for the current in any one of the resistors in a parallel circuit to exceed the line current?

Answer: ______________________________

4. What general statement can be made about the total resistance in a parallel circuit in relation to the resistance of any single resistor in the circuit?

Answer: ______________________________

5. If ONE of the components in a parallel circuit is disconnected, what effect would it have on the current flowing through the other resistors of the circuit?

Answer: ______________________________

6. What is the general relationship between the resistance of each resistor and the expected current flowing through it?

Answer: ______________________________

Satisfactory:	

Not Satisfactory:	

Lecturer: ____ Date: ________________

Series/Parallel DC Circuit Analysis

Task:

To determine the resistance, voltage, current and power in any part of series/parallel DC circuits containing one voltage source and solve problems in these circuits.

Why:

You need to be able to determine the values of resistance, voltage, current and power so that you can analyse and accurately predict the behaviour of a series/parallel circuit when problems arise.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set laboratory activities.
3. You must achieve 100% in a final competency test for each practical component.

Equipment

Sample series/parallel DC circuits
ELV DC power supplies
Digital and analogue multimeters
Fixed DC ammeters and voltmeters

References

* Electrical Principles for the Electrical Trades (6th ed.), J.Jenneson, B. Harper & B. Moore
* Australian Electrical Wiring - Volume 1 (7th Edition), K. Pethebridge & I. Neeson.
* Video: Basic Electricity, Parts 1-14.

Series/Parallel DC Circuit Analysis

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades - Volume 1

Chapter 4 DC circuits

Sections 4.6 Compound circuit analysis

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

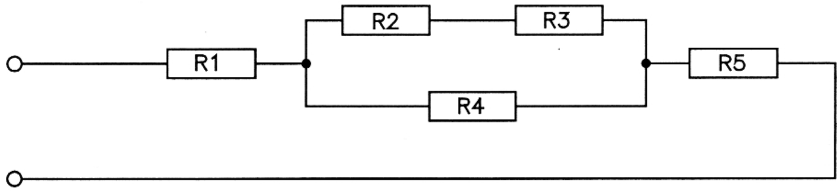
3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the laboratory activities in this Section.

5. Submit your answers to the Work Sheets and your completed activity sheets to your Lecturer for discussion.

Series/Parallel Circuits

1. A series/parallel circuit is a circuit in which some components are connected in series and some are connected in parallel. The principles used to determine the values in series and parallel resistive circuits apply in the same way to relevant parts of a series/parallel resistive circuit, but care must be taken to use the appropriate values for each calculation. A resistive series/parallel circuit is shown below:



2. The circuit shown could be drawn in numerous different ways, while still retaining the same electrical characteristics. It is important to be able to analyse such circuits and determine which components are in series with each other and which ones are in parallel.

Series/Parallel Calculations

3. Ohm's Law can be applied to an entire DC circuit or to any part of the circuit. If an entire circuit is being considered the TOTAL values of current, voltage and resistance must be used. If part of a circuit is being considered, only values of current, voltage and resistance for THAT PART must be used.

4. A typical sequence for resolving series/parallel circuits which involve a single voltage source is:

   a. Draw a circuit diagram and indicate the given values.
   Sections of the circuit should be identified with letters or number as required.

   b. Calculate the equivalent resistance of the parallel resistors.

   c. Find the total resistance of the circuit by adding the equivalent resistance of the parallel banks to the series resistors.

   d. Calculate the total circuit current using Ohm's Law (I = V/R).

   e. Calculate the potential difference (or volt drop) across each resistor using
   Ohm's Law (V = I.R). **Note** that the potential difference across resistors in parallel is common to all resistors in the parallel bank.

f. Add the potential differences together; the result should be the voltage applied to the circuit.

g. Calculate the current through each resistor in the parallel banks using Ohm's Law (I = V/R). The voltage value to use must be the value calculated in **Step e**. It is not the line voltage unless the resistors are connected directly across the supply.

h. Calculate the power dissipated by applying any one of the three power equations to each component or group of components.

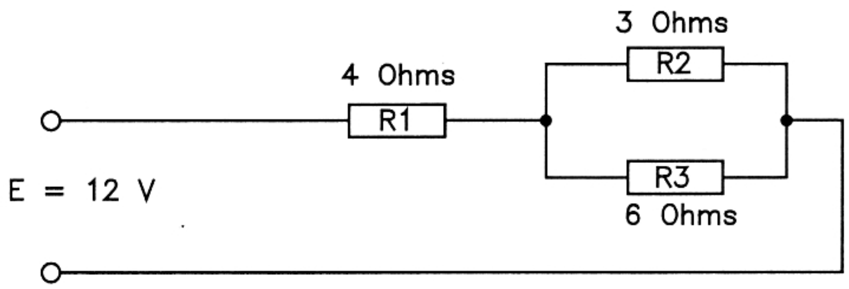
5. It is often useful to summarise the results in the form of a table such as:

	Resistance (Ω)	Volts (V)	Current (A)	Power (W)
R1				
R2				
R3				
R eq				
Totals				

Sample Calculation

6. The following sample calculation shows a typical sequence for calculating the values in a series/parallel circuit. Decimals are rounded to two places where applicable.

Circuit Diagram



Calculate: The total resistance of the circuit
The total current in the circuit
The voltage drop across each component
The power dissipated by each component
The total power dissipated by the entire circuit.

7. **Typical Solution Sequence**

a. Find the equivalent resistance of the parallel resistors:

$$\frac{1}{R_E} = \frac{1}{R_2} + \frac{1}{R_3}$$ (Other methods could have been used)

$$= \frac{1}{3} + \frac{1}{6}$$

$$= \frac{2 + 1}{6}$$ (Addition of fractions)

$$\frac{1}{R_e} = \frac{3}{6}$$ **(This is $1/R_e$, not R_e)**

So: $$R_e = \frac{6}{3}$$

= 2 ohms (EQUIVALENT resistance)

========

b. Find the total resistance of the circuit:

$R_T = R_1 + R_e$

= 4 + 2

= 6 ohms

========

c. Find the total circuit current:

$$I_T = \frac{E}{R_T}$$

$$= \frac{12}{6}$$

= 2 amps

========

d. Find the potential difference (volt drop) across each resistor:

$V_{R1} = I_T \times R_1$

= 2 x 4

= 8 volts

=========

$V_{RE} = I_T \times R_e$

= 2 x 2

= 4 volts (For R_2 and R_3)

=========

e. Check the potential difference calculations:

$$E = V_{R1} + V_{Re}$$

$$= 8 + 4$$

$$= 12 \text{ volts (Which is correct)}$$

========

f. Calculate the circuit currents:

$I_{R1} = 2$ amps

$$I_{R2} = \frac{V_{Re}}{R_2} = \frac{4}{3} = 1.33 \text{ amps}$$

$$I_{R3} = \frac{V_{Re}}{R_3} = \frac{4}{6} = 0.67 \text{ amps}$$

======== ========

g. Check the currents in the parallel resistors:

$$I = I_{R2} + I_{R3}$$

$$= 1.33 + 0.67$$

$$= 2 \text{ amps (Which is correct)}$$

======

h. Calculate the power dissipated by each resistor:

$$P_{R1} = V_{R1} \times I_{R1} = 8 \times 2 = 16 \text{ watts}$$

========

$$P_{R2} = I^2.R_2 = 1.33 \times 1.33 \times 3 = 5.33 \text{ watts}$$

==========

$$P_{R3} = \frac{V_{Re}^2}{R_3} = \frac{4 \times 4}{6} = 2.67 \text{ watts}$$

==========

i. Check the power calculations:

$$P_T = P_{R1} + P_{R2} + P_{R3} \quad \text{(Total power)}$$

$$= 16 + 5.33 + 2.67$$

$$= 24 \text{ watts (Which is correct)}$$

========

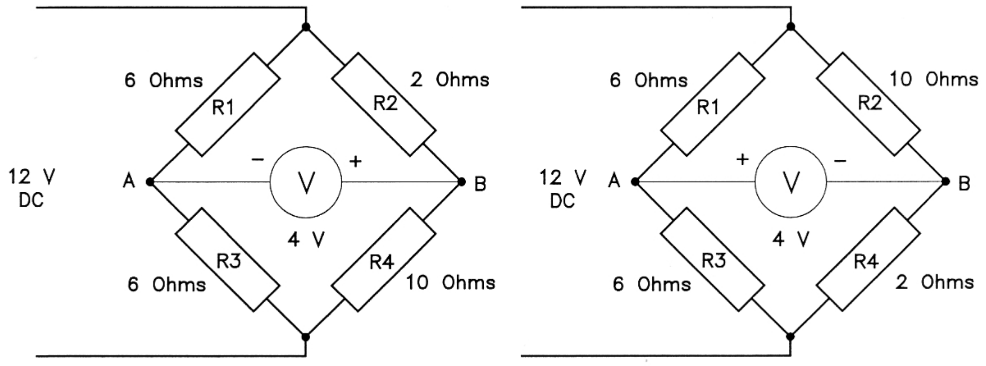
Summary of Results

	Resistance	Voltage	Current	Power
R1	4Ω	8V	2A	16W
R2	3Ω	4V	1.33A	5.33W
R3	6Ω	4V	0.67A	2.67W
Re	2Ω	4V	2A	8W
Totals	6Ω	12V	2A	24W

(These are not the COLUMN totals)

Bridge Configuration

8. If a series/parallel circuit is arranged a shown below (known as a BRIDGE configuration), the voltage between the points A and B will be the difference between the voltages across R3 and R4. If the voltages across R3 and R4 are the same, the voltage between A and B will be zero (because there is no DIFFERENCE of potential between A and B).



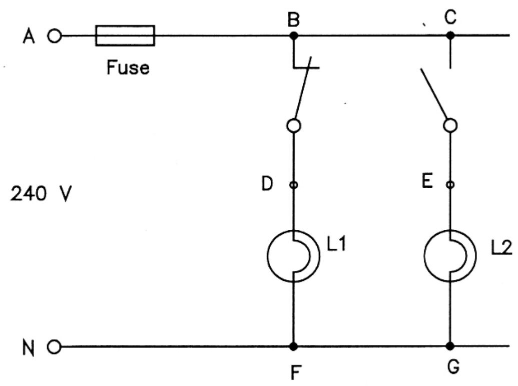
Note the polarity of the voltmeters shown between A and B.

Lecturer to demonstrate bridge megger here (see storeman) and refer to section 13 paragraph 14

Circuit Analysis

9. Consider Circuit A. What is the voltage between each of the following points if L1 and L2 are identical lamps?

Between A and B _______
A and G _______
B and D _______
D and F _______
D and E _______
C and E _______
E and G _______
G and N _______



10. **Exercises** Calculate the following for each of the circuits shown in Figure 1, if the circuit values are as indicated below:

The total resistance of the circuit
The total current in the circuit
The voltage drop across each component
The power dissipated by each component
The total power dissipated by the entire circuit

a. For Circuit 1:
R1 = 10 ohms R3 = 30 ohms
R2 = 20 ohms R4 = 40 ohms
E = 100 volts

b. For Circuit 2:
R1 = 2 ohms R3 = 4 ohms
R2 = 3 ohms R4 = 6 ohms
E = 24 volts

c. For Circuit 3:
R1 = 3 ohms R3 = 3 ohms
R2 = 6 ohms R4 = 7 ohms
E = 72 volts

d. For Circuit 4:
R1 = 6 ohms R3 = 24 ohms
R2 = 40 ohms R4 = 10 ohms
E =100 volts

e. For Circuit 5:
R1 = 40 ohms R3 = 20 ohms
R2 = 10 ohms R4 = 5 ohms
E = 240 volts

f. For Circuit 6:
R1 = 2 ohms R3 = 5 ohms
R2 = 18 ohms R4 = 45 ohms
E =100 volts
Find potential difference across X-Y

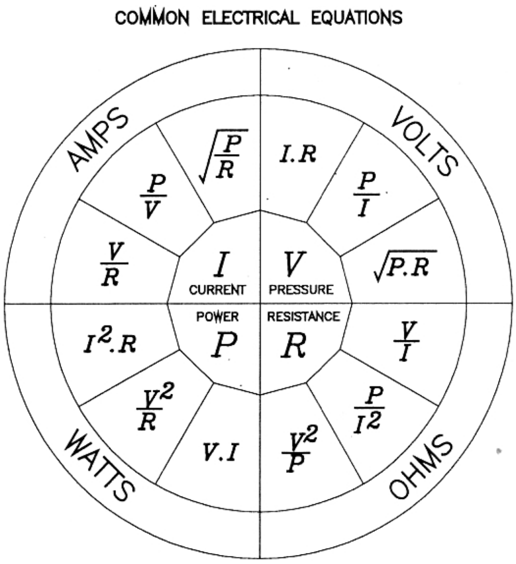
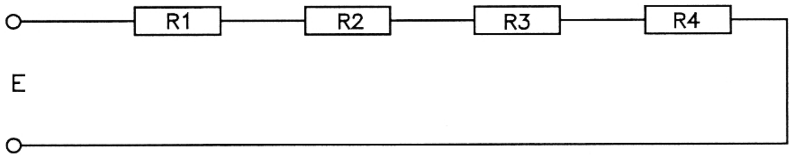
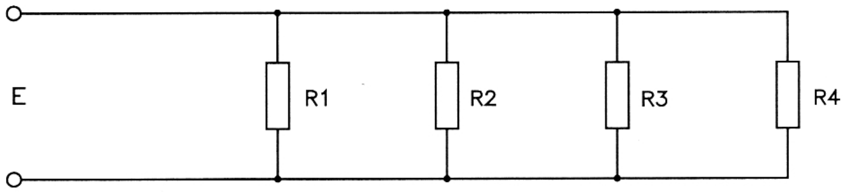


Figure 1 — Circuit Configurations

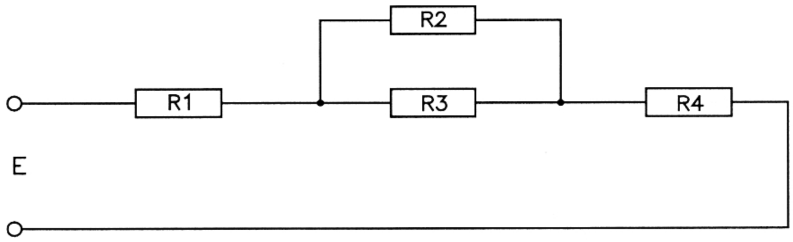
Circuit 1



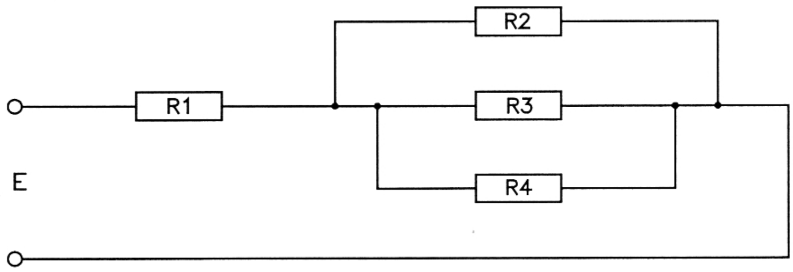
Circuit 2



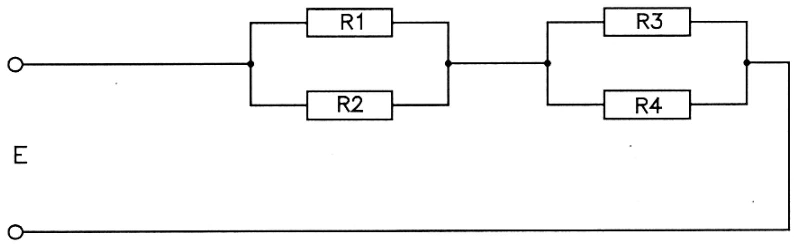
Circuit 3



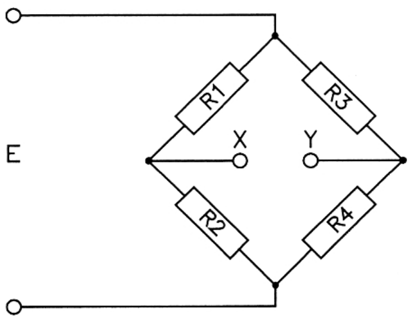
Circuit 4



Circuit 5



Circuit 6

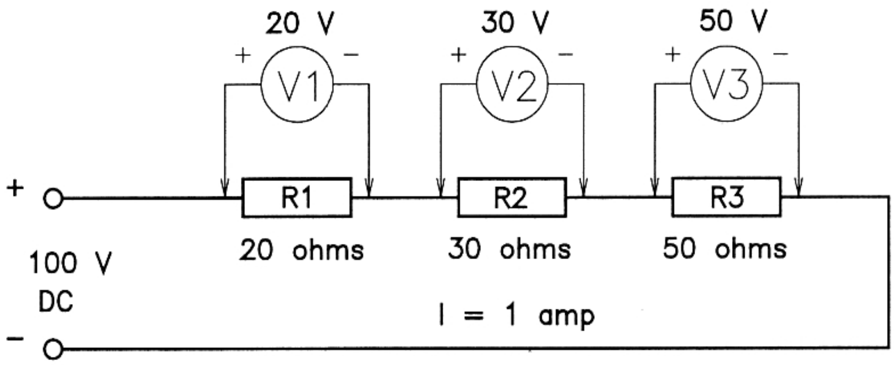


Kirchhoff's Laws

11. There are two other important relationships which enable current and voltages to be determined in circuits; they are known as Kirchhoff's Laws after another German physicist. The relationships are known as Kirchhoff's voltage law and Kirchhoff's current law.

12. Kirchhoff's voltage law states that the algebraic sum of the voltage drops in a circuit is equal to the applied voltage.

13. The circuit below shows three resistors connected in series to a DC supply. According to Kirchhoff's voltage law the applied voltage (E) is equal to the sum of the voltages across each series component



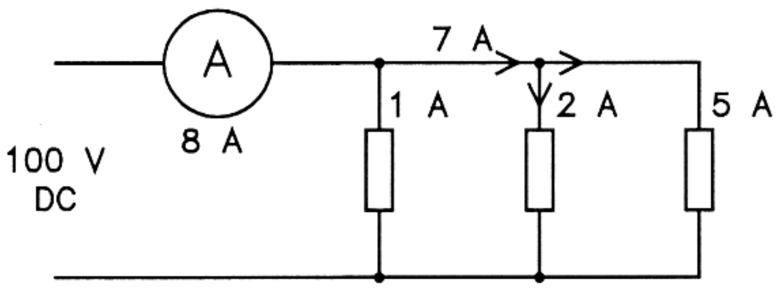
Voltages in a series circuit

$E = V_1 + V_2 + V_3$

14. Thus if any three of the four of the voltages in the circuit are known the fourth can be calculated.

15. Kirchhoff's current law states that in a parallel circuit, the algebraic sum of the currents entering a junction is equal to the algebraic sum of the currents leaving the junction.

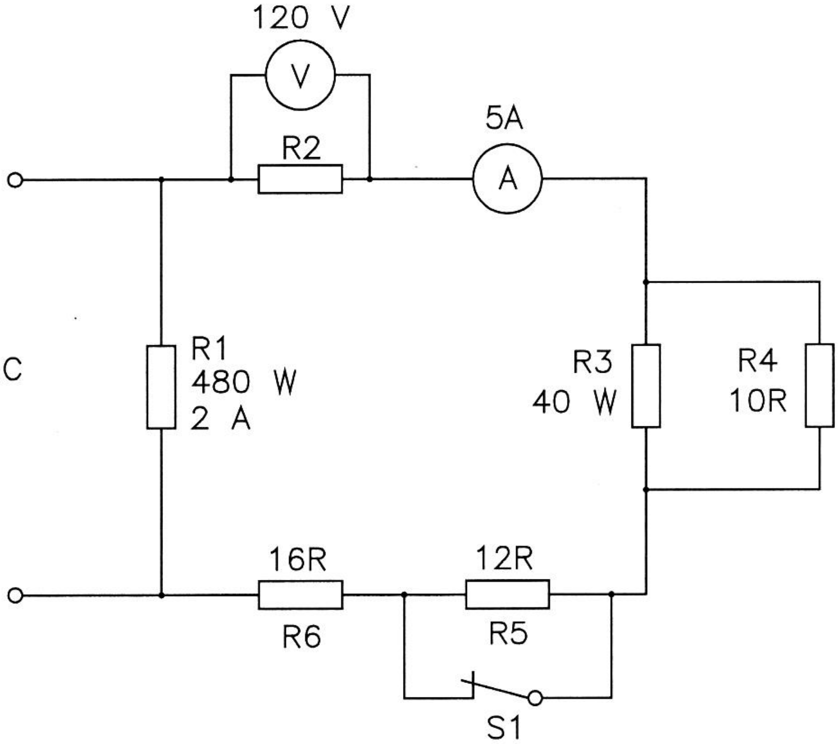
16. The circuit below shows three resistors connected in parallel to a DC supply. According to Kirchhoff's current law the sum of the currents entering each junction of conductors is equal to the sum of the currents leaving the junction.



Currents in a parallel circuit

17. Thus if any the current in each of the three resistors is known, the total (line) current can be found by adding the three currents together.

18. **Composite Circuit**



Complete the following table

	V	I	P	R
R1		2	480	
R2	120			
R3			40	
R4				10
R5				12
R6				16
Total				
	VOLTS	AMPS	WATTS	OHMS

Series/Parallel Circuits

Note: Draw a neat circuit diagram for all calculation questions.

1. A 12 ohm resistor is connected in parallel with a 6 ohm resistor and the pair are connected in series with another resistor of 20 ohms. What is the equivalent resistance of the entire circuit?

2. One of the resistors in a particular series/parallel circuit becomes short circuited. Does the total resistance of the circuit increase or decrease?

3. What are 'Kirchhoff's Laws'?

4. Calculate the hot resistance of a 1200 watt 240 volt heating element.

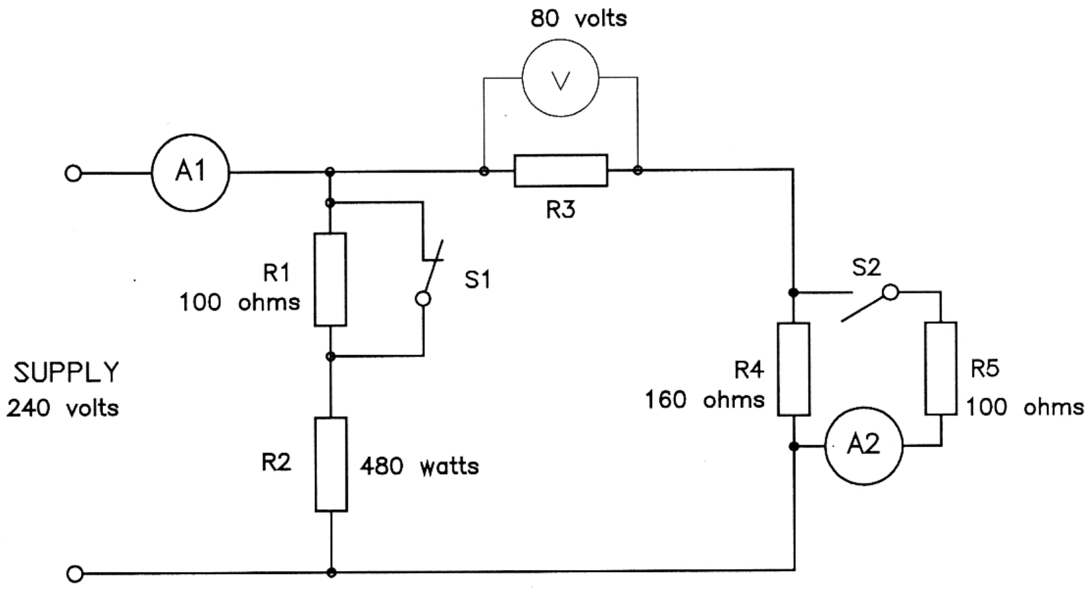
5. Refer to Circuit 1. Complete the table of values for the circuit for the following operating conditions (show all working on a separate sheet):

   The line voltage is 240 volts
   R2 is dissipating 480 watts
   The voltmeter V is indicating 80 volts
   R4 has a resistance of 160 ohms
   S1 is closed and S2 is open
   R1 and R5 each have a resistance of 100 ohms

Table of Values – Circuit 1

	Resistance (Ω)	**Current (A)**	**Volts (V)**	**Power (W)**
R1				
R2				
R3				
R4				
R5				
Totals				

Circuit 1



Notes:

Series/Parallel Circuits

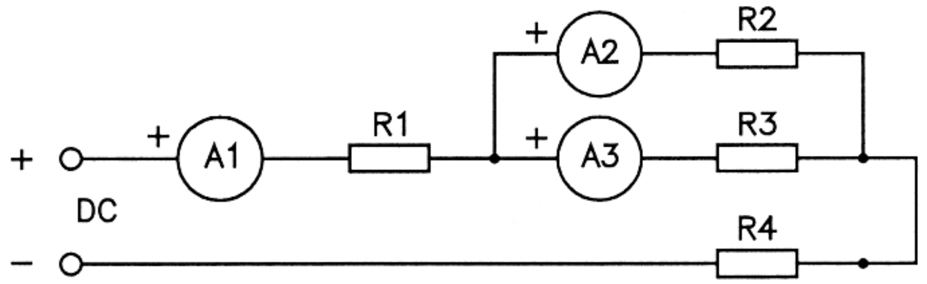
Objective

To connect the given resistors in series/parallel to a suitable DC supply and verify the readings by calculation.

Equipment

Series/Parallel resistor project board
Connecting leads
Ammeters and voltmeters as required
Multimeter
ELV direct current supply

Circuit



Danger Tag Procedure: Danger Tag Procedure will be followed during this activity.

Task Procedure

1. Check to see that the project board is isolated from the supply. Measure the resistance of each of the resistors on the project board with a multimeter. Record the resistances in the Results Table.

2. Calculate the values required to complete the Calculations (Calc.) section of the Results Table. (The Line values are the TOTAL values, but not necessarily the total of the values in that column).

3. Connect the circuit according to the circuit diagram given above.

4. Set your multimeter to the ohms x 1 range and check for short circuits between the two incoming line terminals. Check the checker before and after the test, and switch it off when you have finished using it.

5. Have your wiring checked by your Lecturer.

6. Ask your Lecturer for permission to switch the circuit on, then check it for correct operation. Record the instrument readings in the Results Table. Take all voltmeter readings with a multimeter set to an appropriate voltage scale.

7. Switch the circuit off and remove the plug from the outlet.

8. Submit your results to your Lecturer for comment and discussion.

9. Disconnect your wiring and return all of the equipment to its proper place.

Results Table – Series/Parallel Circuit

	Resistance (Ω)		**Volts (V)**		**Current (A)**	
	Nominal	**Measured**	**Calculated**	**Measured**	**Calculated**	**Measured**
R1						
R2						
R3						
R4						
Re						
Line values						

Questions

1. Calculate the total POWER dissipated by the series/parallel circuit.

----

2. Calculate the total POWER which would be dissipated in the circuit if the line voltage was doubled. What would be the percentage increase in power?

----

3. If the resistor R2 became open circuited due to a circuit fault, would the line current increase or decrease? Show your calculations.

Satisfactory:			Not Satisfactory:	

Lecturer: ____ Date: ________________

Notes:

Capacitors and Capacitance

Task:

To identify typical capacitors and describe their behaviour when connected to a DC supply.

Why:

Resistors, inductors and capacitors are the three general forms of electrical device. A sound knowledge of the principles of storing electricity in the form of an electrostatic field is important in the understanding of the behaviour of alternating current and alternating current devices.

To Pass:

1. You must correctly answer the questions on the Work Sheets provided and achieve a mark of 75% or more in a competency test for each Required Skills and Knowledge (RSAK) topic.
2. You must satisfactorily complete the set laboratory activities.
3. You must achieve 100% in a final competency test for each practical component.

Equipment

Sample capacitors
Prepared capacitor connection laboratory projects
Prepared time constant laboratory projects
Ammeters, voltmeters, multimeters

References

* Electrical Principles for the Electrical Trades (6th ed.). J. Jenneson, B. Harper, B. Moore.
* Video: Basic Electricity, Parts 1-14.
* AS/NZS 3000:2018 Wiring Rules - Clause 4.15 Capacitors

Capacitors and Capacitance

Suggested Self-Study Guide

1. Study the following sections in the recommended references:

Electrical Principles for the Electrical Trades (6th ed.) Volume 1

Chapter 7: Capacitors

2. Read the Summaries and practise answering the questions provided on the Work Sheets. Refer to other relevant texts if you feel it is necessary.

3. Answer the questions given on the Work Sheets. Use a separate answer sheet or sheets for each Work Sheet. Note that you are required to answer ALL questions correctly, although not necessarily at the same time.

4. Complete the laboratory activities in this Section.

5. Submit your answers to the Work Sheet and your completed Activity Sheets to your Lecturer for discussion.

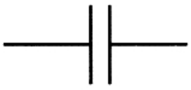
Capacitors and Capacitance

Capacitors

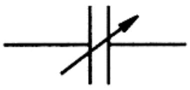
1. A capacitor is a device which stores an electrical charge in the form of an electrostatic field. They consist of two conductive plates separated by an insulating material known as a dielectric.

The property of capacitors exists in all electrical devices to some extent.

The general drawing symbols for capacitors are:



Fixed Capacitor



Variable Capacitor

2. The basic unit of capacity is the farad, but the farad is too large a unit to be useful.

Most capacitors are in the microfarad (uF), nanofarad (nF) or picofarad (pF) range.

Capacitors have a voltage rating which must not be exceeded.

The voltage rating is usually shown on the outer casing of the capacitor (e.g. 25 VDCW - 25 volts DC working).

Remove the supply and ideally, the charge remains, but in practice, leakage will slowly discharge the capacitor

3. The capacity of a capacitor depends on the area of the conductive plates, the distance between the plates and the type of insulating material used as the dielectric.

Capacitance increases as the area of the plates is increased, and decreases as the distance between the plates increases.

$$C = \frac{\mathrm{A}k}{\mathrm{d}}$$

Where: C = Capacitance in farads
A = area of plates
k = dielectric constant
d = distance between the plates

4. The basic unit of charge is the coulomb. The quantity symbol for charge is Q and the basic unit symbol is C (for coulombs).

   - When a potential is applied across the plates, electron charges flow away from the positive plate and on to the negative plate, creating an electrostatic field across the dielectric.
   - The valence electrons in the dielectric insulator are attracted to the +ve plate, distorting their orbits and storing energy.
   - The capacitor will charge to the supply voltage.

Remove the supply and ideally, the charge remains, but in practice, leakage will slowly discharge the capacitor.

The equation for determining the charge on a given capacitor is:

$$Q = VC$$

Where: Q is in coulombs
V is in volts
C is in farads

A coulomb can also be defined as a charge that passes a point in one second when a current of one ampere flows

$$Q = It$$

Where: Q is in coulombs
I is in amperes
t is in seconds

5. If the voltage and charge on a capacitor is known the capacitance can be calculated using the equation:

$$C = \frac{Q}{V}$$

6. **Example:** Calculate the capacitance of the capacitor if the applied voltage is 10 volts and the charge is 8×10^{-6} coulombs.

$$C = \frac{Q}{V}$$

7. **Solution**

$$C = \frac{8 \times 10^{-6}}{10}$$

= 0.000 000 8 (farads)

= 0.8 microfarads

8. **Energy Stored in a Capacitor**

When a capacitor is charged, a static electric field exists between the plates. The effect of this static field is stored energy. This stored energy depends on the capacity of the capacitor and the applied voltage on the capacitor.

$$W = \frac{1}{2} CV^2$$

Where: W is in Joules
C is in farads
V is in volts

9. Example: A 3.5µF is charged from a 250 V d.c. supply. Find the energy stored in the capacitor.

$$W = \frac{1}{2} CV^2$$

$W = 3.5E^{-6} X 250^2 \div 2$
$= 109mJ$

10. Capacitors (sometimes known as condensers) are usually classified according to the type of material used as the dielectric.

Typical types and applications include:

a. Paper - power applications such as fluorescent capacitors
b. Air - variable radio tuning capacitors
c. Tantalum - electronic circuits (they must be polarised)
d. Mica - electronic circuits
e. Electrolytic - electronic circuits (they must be polarised)
f. Electrolytic - a.c. motor starting capacitors
g. Ceramic - electronic circuits
h. Polycarbonate - small high stability capacitors

Capacitor Connections

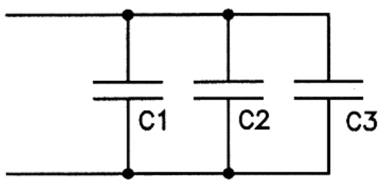
11. Capacitors can be connected in series and parallel to decrease or increase the total capacitance of the circuit.

The method of calculating total capacitance is similar to the method used for series and parallel resistors, but the general form of the equations is reversed.

12. **Parallel** Connecting capacitors in parallel has the effect of increasing the area of the plates, so the total capacity is increased.

The general equation is:

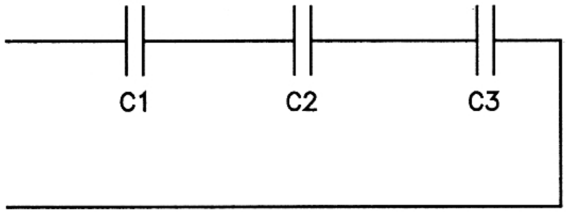
$C_T = C1 + C2 + C3 ......$



13. **Series:** Connecting capacitors in series has the effect of increasing the distance between the plates, so the total capacity is decreased.

The basic procedure applied to calculating the total (or equivalent) resistance of resistors in parallel can be applied to series capacitors - so a general equation is:

$$\frac{1}{C_T} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

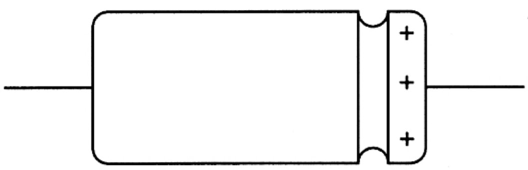


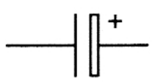
14. **Exercise:** Calculate the total capacitance of a bank of three paper capacitors connected in parallel if the capacities are 12, 6 and 2 microfarads respectively.

What is the total capacitance if the capacitors were re-connected in series?

15. **Polarisation:** Some types of capacitors must be polarised - the positive terminal of the capacitor must be connected to the positive terminal of the supply.

Electrolytic capacitors in electronic circuits need to be polarised, and a marking on the device indicates the terminal which must be connected to the positive terminal of the supply.





16. Electrolytic capacitors used in a.c. motor starting circuits do not need to be polarised.

Capacitors on DC

17. When a capacitor is connected to a DC supply it charges up.

Current flows in the external circuit (not through the capacitor), creating an excess of electrons on the negative plate, but when the capacitor is fully charged no further current flows.

If the voltage source is then removed the capacitor will remain charged until it is discharged by connecting a conductor across its terminals, or until the charge 'leaks away' through the imperfect dielectric.

18. The time taken for a capacitor to charge and discharge is governed by the same mathematical rise and decay laws that governed the behaviour of an inductor when it is switched on and off.

A capacitor is regarded as being fully charged or fully discharged after five time constants, where one time constant is the time required for the capacitor to charge to 63% of the applied voltage or to discharge to 37% of its initial voltage.

19. The time constant for a resistor/capacitor (RC) circuit can be calculated using the equation:

$$\mathcal{T} = R.C$$

Where $\mathcal{T}$ = the time constant in seconds ($\mathcal{T}$ is the Greek letter Tau)
R = the resistance in ohms
C = the capacity in farads

20. Figure 1 (A Capacitor on DC) shows a circuit of a resistor connected in series with a capacitor and to a battery via a two-way switch.

When the switch is placed in the CHARGE position, current flows to charge the capacitor. When the switch is placed in the DISCHARGE position the capacitor discharges through the resistor.

21. The 'charging' section of the graph in Figure 1 shows the rate of increase of voltage across the capacitor and the corresponding decrease in current as it charges up when the switch is placed in the CHARGE position. When the capacitor is fully charged, current flow in the circuit ceases.

(The curve showing the decreasing current is also the shape of the curve of voltage across the resistor when the switch is in the CHARGE position. Since it is a series circuit, the sum of the voltage across the capacitor and the voltage across the resistor must equal the applied voltage.)

22. The 'discharging' section of the graph in Figure 1 shows the rate of decrease of voltage across the capacitor as it discharges when the switch is placed in the DISCHARGE position.

The current which flows as the capacitor charges is in the opposite direction to the initial charging current from the battery.

23. If a DC voltage of 20 volts was applied to an RC series circuit, the voltage across the capacitor at any instant corresponding to a multiple of the time constant (up to 5) can be found using the charging percentage figures shown in Figure 1., i.e:

After 1 time constant: Vc = 63% of 20 = 12.6 volts
After 2 time constants: Vc = 86% of 20 = 17.2 volts

After 3 time constants: Vc = 95% of 20 = 19.0 volts
After 4 time constants: Vc = 98% of 20 = 19.6 volts
After 5 time constants: Vc = 99% of 20 = 19.8 volts (Charged)

24. If the capacitor was 2 uF and the resistor was 1 meg-ohm, giving a time constant of 2 sec. the voltage after 2 seconds would be 12.6 volts, after 4 seconds it would be 17.2 volts and so on until after five time constants, when the capacitor would be regarded as fully charged.

25. RC circuits are widely used in electronic circuits where precise and repeatable timing is required down to thousandths of a second.

Capacitor Faults

26. The main faults which occur in capacitors are:

a. Short circuits.
b. Open circuits.
c Dielectric breakdown.
d. Earth faults (in metal-cased capacitors)

Testing Capacitors

27. A power capacitor can be tested for short circuits or open circuits using an analogue multimeter.

The capacitor must be disconnected from the supply and it must be discharged by short circuiting the capacitor terminals for several seconds.

28. The multimeter is set to a high ohms range and connected across the two capacitor terminals.

The pointer on the multimeter should move up-scale (towards the 0 ohms marking), then it should gradually fall towards infinity.

If this occurs the capacitor can be regarded as serviceable.

29. If the multimeter indicates zero ohms and does not move it indicates that the capacitor is short circuited and should be replaced with another of the same size and type. If the multimeter remains on infinity without moving it indicates that it is open circuited and should be replaced with another of the same size and type.

30. A power capacitor can also be tested for serviceability using a digital multimeter, with a capacitance test function.

The capacitor must be disconnected from the supply and it must be discharged by short circuiting the capacitor terminals for several seconds.

31. The multimeter is set to the capacitance test function and connected across the two capacitor terminals.

The digital reading on the multimeter should indicate the correct capacitance of the capacitor.

If this occurs the capacitor can be regarded as serviceable.

32. If the digital multimeter reads OL, then the capacitor is short circuited and should be replaced with another of the same size and type. If the digital multimeter reads zero farads, then the capacitor is open circuited and should be replaced with another of the same size and type

Safety Precautions

33. Power capacitors can retain their charge for some time after the voltage has been removed. AS/NZS 3000 (Wiring Rules) requires that power capacitors greater than 0.5 microfarads be provided with a discharge path, either through the winding of an associated device or by connecting a ‘bleed’ resistor (typically 1 meg-ohm) in parallel with the capacitor. See AS/NZS 3000 Clause 4.15.3.1.

34. Always short circuit the terminals of a capacitor (after it has been disconnected) for several seconds before you work on it.

It must be treated as if it was alive until you have discharged it.

35. A capacitor must never be connected to a voltage higher than that for which it has been designed - the maximum voltage is usually marked on the casing of the capacitor.

A CAPACITOR ON DC

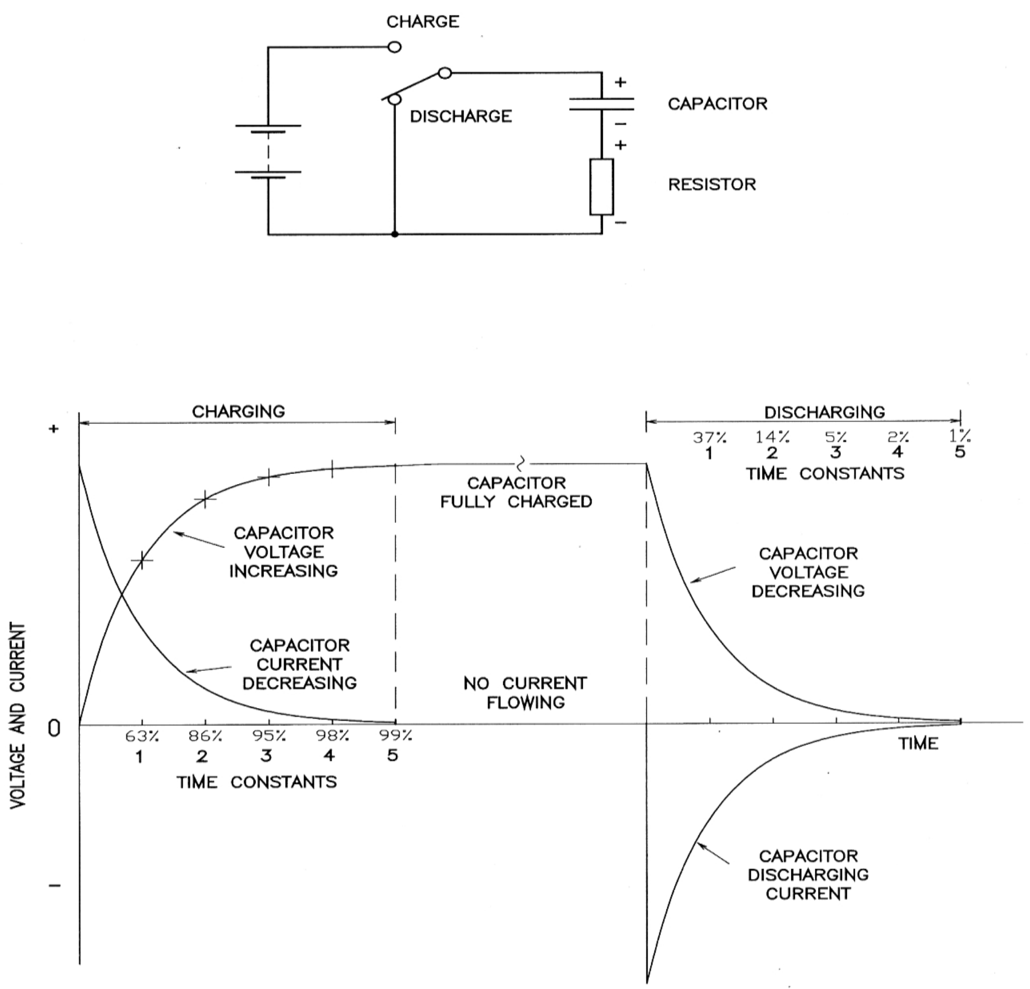


FIGURE 1

Notes

Capacitors and Capacitance

1. What is the special electrical characteristic of a capacitor?

2. What is the special name given to the insulating material in a capacitor?

3. In what basic unit is capacitance expressed?

4. What is the most common practical unit in which capacitance is expressed?

5. What is the quantity symbol for capacitance?

6. What is the unit symbol for the most common practical unit of capacitance?

7. Name five materials commonly used as the dielectric in capacitors.

8. What are three factors which govern the capacitance of a capacitor?

9. What effect would it have on the capacitance of a capacitor if the distance between the conducting plates was increased?

10. What effect would it have on the capacitance of a capacitor if the area of the conducting plates was increased?

11. What is another (non-standard) name for a capacitor?

12. Draw a graph showing the relationship, between line current and time, when a DC circuit is switched ON if it consists of a resistor and a capacitor in series.

13. Draw a graph showing the relationship between line current and time when a DC circuit is switched OFF if it consists of a resistor and a capacitor in series.

14. Calculate the total capacitance in a circuit in which a 3 uF capacitor is connected in **parallel** with a 6 uF capacitor.

15. Calculate the total capacitance in a circuit in which a 3 uF capacitor is connected in **series** with a 6 uF capacitor.

16. A 1.2 uF capacitor is connected in series with a 2 MΩ resistor. What is the time constant of the circuit?

17. A 3.3 uF capacitor is connected in series with a 2 MΩ resistor. If the voltage applied to the circuit is 10 volts DC, what voltage would there be across the capacitor 6.6 seconds after the circuit was energised?

18. Name six different types of capacitor and give one application for each.

19. What common type of measuring instrument can be used to check a 3.5 microfarad 240 volt paper power capacitor for serviceability?

20. What basic safety precaution must be taken before working on a large power capacitor?

21. Describe how a disconnected 240 volt 4 microfarad paper capacitor can be tested for serviceability with an analogue multimeter. Which multimeter range should be selected?

22. What are two common faults which can occur in a paper capacitor while it is in service?

Capacitor Identification

Objective

To identify various common types of capacitor and determine the capacity and voltage rating of each

Equipment

Capacitor identification board (with visible capacity and voltage markings)
Manufacturers' data sheets

Procedure

1. Examine the capacitor project board and record the type, capacity and voltage rating for each component.

Results Table

Component	Type	Capacity	V Rating
Capacitor 1			
Capacitor 2			
Capacitor 3			
Capacitor 4			
Capacitor 5			
Capacitor 6			
Capacitor 7			
Capacitor 8			

2. Submit your results to your Lecturer for comment.

3. Return all of the equipment to its proper place.

Satisfactory:		Not Satisfactory:	

Lecturer: ______________________________ Date: ______________

Capacitor Testing

Objective

To test power capacitors for serviceability.

Equipment

Sample power capacitors (with and without bleed resistors)
Connecting leads
Digital multimeter (Capacitance test function)
Analogue Multimeter

Procedure

1. Test the given power capacitors for serviceability and record your results in the Results Table.

Results Table

	Analogue Multimeter on the highest ohm setting		Digital Multimeter on the capacitance test function	
Component	**Resistance Reading**	**Servicable, Short or Open**	**Capacitance Reading**	**Servicable, Short or Open**
Capacitor 1				
Capacitor 2				
Capacitor 3				

2. Submit your results to your Lecturer for comment and assessment.

3. Return all of the equipment to its proper place.

Questions

1. Calculate the charge which would be stored in a capacitor which has 5µf capacitance at the full rated voltage of 20v?

____

2. What is the resistance of the bleed resistor across a typical 3.5 microfarad capacitor in a 36 watt fluorescent lighting fitting?

____

3. What is the capacitance of the largest power capacitor which may be installed without a discharge path according to the Wiring Rules? (State the clause)

____

4. What are the three most common faults which can occur in typical power capacitors?

____

5. What problem is indicated if a typical 5 microfarad 240 volt power capacitor gives a reading of zero ohms between the terminals when measured with an analogue multimeter set to the 'ohms times 1' range ?

____

Satisfactory:			Not Satisfactory:	

Lecturer: ____ Date: ________________

RC Time Constants

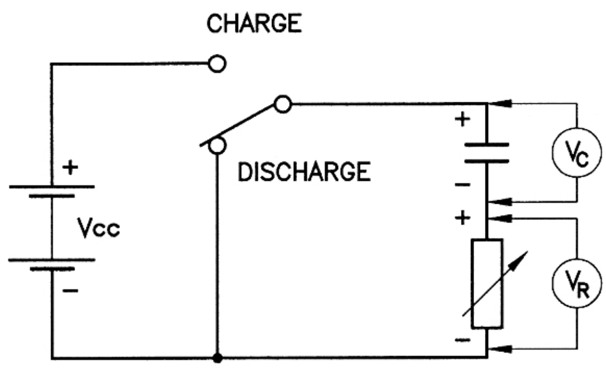
Objective

To observe the effects of the time constant in DC circuits consisting of resistance and capacitance in series.

Equipment

Capacitor time constant project board
Connecting leads
Multimeter (with a high DC voltage sensitivity)
Direct current supply (0-12 volt or similar)
Stopwatch

General Circuit



Procedure

1. Check to see that the project board is isolated from the supply. Examine the RC time constant project board and record the values of R and C in the Results Table.

2. Calculate the time constant for each RC circuit and record the results in the Results Table.

3. Set the applied DC voltage (Vcc) to about 10 volts and confirm the voltage by measurement. Record the value of Vcc and calculate the value of 63% of Vcc. Switch the power supply off at the selected setting.

4. Discharge all capacitors on the project board by temporarily short circuiting the capacitor terminals (do not leave the short circuit connected).

5. Connect the multimeter across the capacitor.

6. Have your connections checked by your Lecturer.

6. Energise the circuit and start the stopwatch at the same instant. Observe the voltage rise across the capacitor and stop the stopwatch at 63% of the measured value of Vcc and record the time in the results table below.

8. Switch the circuit off and repeat Step 7 with the remaining RC circuits on the project board.

9. Have your results checked by your Lecturer.

10. Return all of the equipment to its proper place.

Results Table

Applied Voltage (Vcc) ________________ 63% of Vcc _______

			Time (in Seconds)		
Circuit	**R**	**C**	**𝒯(Calc)**	**𝒯 (Measured)**	**Fully Charged**
Circuit A					
Circuit B					
Circuit C					
Circuit D					
Circuit E					

Questions

1. Calculate the time which would be required for the capacitor to be fully charged for each of the RC combinations in the Results Table & write your results in the full charged column.

____

2. Why was 63% of Vcc used as the value of one time constant?

____

3. How many time constants must elapse before the capacitor is regarded as fully charged?

____

4. Draw a neat freehand pencil sketch showing the approximate shape of curves for the voltage across the capacitor (Vc) and the voltage across the resistor (Vr) for a time equivalent to 5 time constants after switch on and switch off any RC time constant circuit.

Satisfactory:	

Not Satisfactory:	

Lecturer: ________________________________ Date: ________________

This is the end
of this resource book.

We hope you
enjoyed it.