Design and Technology

Year 12 Engineering Studies

ATAR Units 3 and 4

2018

MECHATRONICS

Booklet 2: Electronics and electrical

Student: ____________________________

Teacher: Mr Čečins and Mr Tilley

1. Safety

When working on electronic circuits, personal safety (both yours and of those around you) should be paramount in everything that you do. Hazards can exist within many circuits—even those that, on the face of it, may appear to be totally safe. Inadvertent misconnection of a supply, incorrect earthing, reverse connection of a high-value electrolytic capacitor, and incorrect component substitution can all result in serious hazards to personal safety as a consequence of fire, explosion or the generation of toxic fumes.

Potential hazards can be easily recognized and it is well worth making yourself familiar with them but perhaps the most important point to make is that electricity acts very quickly and you should always think carefully before working on circuits where mains or high voltages (i.e. those over 50 V, or so) are present. Failure to observe this simple precaution can result in the very real risk of electric shock.

Voltages in many items of electronic equipment, including all items which derive their power from the a.c. mains supply, are at a level which can cause sufficient current flow in the body to disrupt normal operation of the heart. The threshold will be even lower for anyone with a defective heart. Bodily contact with mains or high-voltage circuits can thus be lethal. The most critical path for electric current within the body (i.e. the one that is most likely to stop the heart) is that which exists from one hand to the other. The hand-to-foot path is also dangerous but somewhat less dangerous than the hand-to-hand path.

So, before you start to work on an item of electronic equipment, it is essential not only to switch off but to disconnect the equipment at the mains by removing the mains plug. If you have to make measurements or carry out adjustments on a piece of working (or 'live') equipment, a useful precaution is that of using one hand only to perform the adjustment or to make the measurement. Your 'spare' hand should be placed safely away from contact with anything metal (including the chassis of the equipment which may, or may not, be earthed).

The severity of electric shock depends upon several factors including the magnitude of the current, whether it is alternating or direct current, and its precise path through the body. The magnitude of the current depends upon the voltage which is applied and the resistance of the body. The electrical energy developed in the body will depend upon the time for which the current flows. The duration of contact is also crucial in determining the eventual physiological effects of the shock. As a rough guide, and assuming that the voltage applied is from the 250 V 50 Hz a.c. mains supply, the following effects are typical:

Current	***Physiological effect***
Less than 1 mA	Not usually noticeable
1 mA to 2 mA	Threshold of perception (a slight tingle may be felt)
2 mA to 4 mA	Mild shock (effects of current flow are felt)
4 mA to 10 mA	Serious shock (shock is felt as pain)
10 mA to 20 mA	Motor nerve paralysis may occur (unable to let go)
20 mA to 50 mA	Respiratory control inhibited (breathing may stop)
More than 50 mA	Ventricular fibrillation of heart muscle (heart failure)

It is important to note that the figures are quoted as a guide—there have been cases of lethal shocks resulting from contact with much lower voltages and at relatively small values of current. The upshot of all this is simply that **any potential in excess of 50 V should be considered dangerous.** Lesser potentials may, under unusual circumstances, also be dangerous. As such, it is wise to **get into the habit of treating all electrical and electronic circuits with great care.**

The above notes on *Safety* have been sourced from Electronic Circuits Fundamentals and Applications Third Edition 2006 by Michael Tooley page ix.

There are many safety hazards in the Engineering room. These include hand tools, power tools (especially drills – both fixed and portable), power points, electrical cables, chemicals, soldering irons and the laser cutting machine.

Do you know how to use these? If you inspect a piece of equipment and discover that it is unsafe what should you do? Are you wearing the appropriate personal protective equipment?

If you are unable to answer any of these questions correctly, then **DO NOT** use the equipment. See the teacher for more information and/or instruction.

2. Electrical quantities

Throughout this course of study there will be references to electrical quantities like volts, amperes (more commonly called ‘amps’), ohms and others. Most people have some familiarity with these terms but when studying Engineering Studies there is a need to be more precise.

The table shown below summarizes the key electrical quantities required for this subject.

Derived quantity	**Unit**	**Abbreviation**	**Symbol**	**Expression in terms of other SI units**
Voltage	volt	V	V	$W\ A^{-1}$
Current	ampere	A	I	$W\ V^{-1}$
Resistance	ohm	Ω	R	$V\ A^{-1}$
Charge	coulomb	C	Q	A s
Capacitance	farad	F	C	$A\ s\ V^{-1}$
Power	watt	W	P	$J\ s^{-1}$
Energy	joule	J	W	N m
Frequency	hertz	Hz	f	s^{-1}

Often the quantities are much smaller or much larger than the units and so the following multiples and sub-multiples are used.

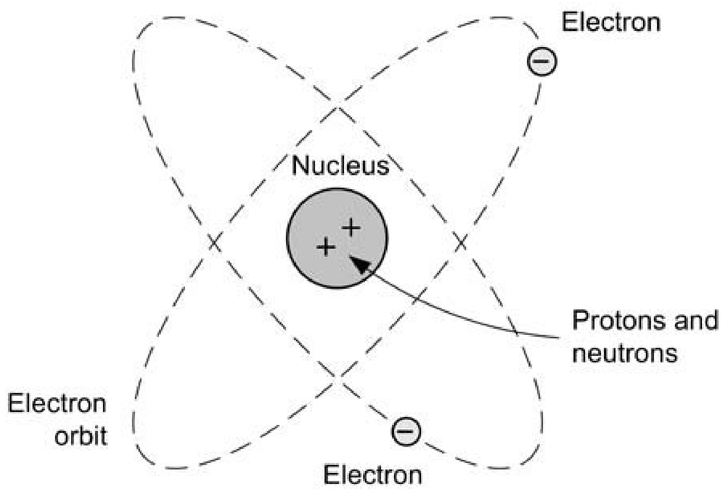
Prefix	Abbreviation	Multiplier
tetra	T	10^{12} = 1 000 000 000 000
giga	G	10^{9} = 1 000 000 000
mega	M	10^{6} = 1000 000
kilo	k	10^{3} = 1000
(none)	(none)	10^{0} = 1
milli	m	10^{-3} = 0.001
micro	µ	10^{-6} = 0.000 001
nano	n	10^{-9} = 0.000 000 001
pico	p	10^{-12} = 0.000 000 000 001

3. Electrical fundamentals

Conductors and insulators[1]

Electric current is the name given to the flow of **electrons** (or negative charge carriers). Electrons orbit around the nucleus of atoms just as the earth orbits around the sun (see Fig. 1.3). Electrons are held in one or more **shells,** constrained to their orbital paths by virtue of a force of attraction towards the nucleus which contains an equal number of **protons** (positive charge carriers). Since like charges repel and unlike charges attract, negatively charged electrons are attracted to the positively charged nucleus. A similar principle can be demonstrated by observing the attraction between two permanent magnets; the two North poles of the magnets will repel each other, while a North and South pole will attract. In the same way, the unlike charges of the negative electron and the positive proton experience a force of mutual attraction.

The outer shell electrons of a **conductor** can be reasonably easily interchanged between adjacent atoms within the **lattice** of atoms of which the substance is composed. This makes it possible for the material to conduct electricity. Typical examples of conductors are metals such as copper, silver, iron and aluminium. By contrast, the outer shell electrons of an **insulator** are firmly bound to their parent atoms and virtually no interchange of electrons is possible. Typical examples of insulators are plastics, rubber and ceramic materials.



Illustrated above is a single atom of helium (He) showing its two electrons in orbit around its nucleus.

1. Notes on *Conductors and insulators* are taken from Electronic Circuits Fundamentals and Applications Third Edition 2006 by Michael Tooley pages 5 – 6.

Voltage and resistance[2]

The ability of an energy source (e.g. a battery) to produce a current within a conductor may be expressed in terms of **electromotive force** (e.m.f.). Whenever an e.m.f. is applied to a circuit **a potential difference** (p.d.) exists. Both e.m.f. and p.d. are measured in volts (V). In many practical circuits there is only one e.m.f. present (the battery or supply) whereas a p.d. will be developed across each component present in the circuit.

The **conventional flow** of current in a circuit is from the point of more positive potential to the point of greatest negative potential (note that electrons move in the *opposite* direction!). **Direct current** results from the application of a direct e.m.f. (derived from batteries or a d.c. power supply). An essential characteristic of these supplies is that the applied e.m.f. does not change its polarity (even though its value might be subject to some fluctuation).

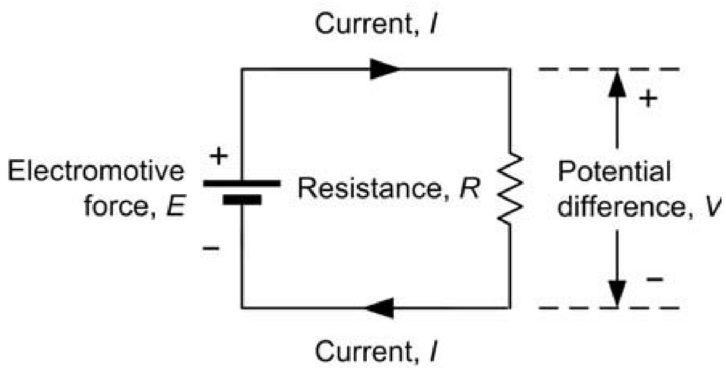
For any conductor, the current flowing is directly proportional to the e.m.f. applied. The current flowing will also be dependent on the physical dimensions (length and cross-sectional area) and material of which the conductor is composed.

The amount of current that will flow in a conductor when a given e.m.f. is applied is inversely proportional to its **resistance.** Resistance, therefore, may be thought of as an opposition to current flow; the higher the resistance the lower the current that will flow (assuming that the applied e.m.f. remains constant).

2. Notes on *Voltage and resistance* are taken from Electronic Circuits Fundamentals and Applications Third Edition 2006 by Michael Tooley page 6.

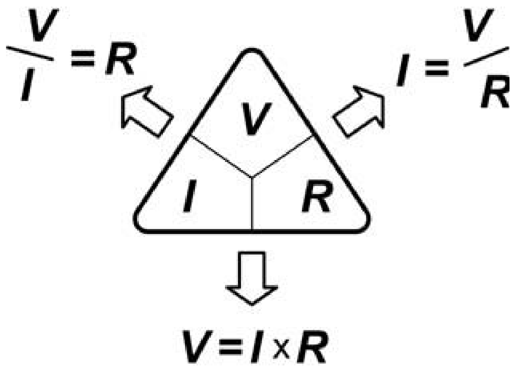
Ohm's Law[3]

Provided that temperature does not vary, the ratio of p.d. across the ends of a conductor to the current flowing in the conductor is a constant. This relationship is known as Ohm's Law and it leads to the relationship: V / I = a constant = R where V is the potential difference (or voltage drop) in Volts (V), I is the current in Amperes (A), and R is the resistance in Ohms (Ω).



Simple circuit to illustrate the relationship between voltage (V), current (I) and resistance (R). Note that the direction of conventional current flow is from positive to negative.

The formula may be arranged to make V, I or R the subject, as follows: $V = I \times R$, $I = V / R$ and $R = V / I$. These are illustrated in the diagram below.



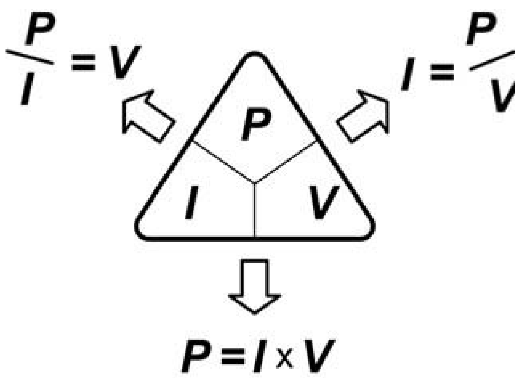
3. Notes on *Ohm's Law* are largely taken from Electronic Circuits Fundamentals and Applications Third Edition 2006 by Michael Tooley pages 6 – 7.

Energy and power[4]

At first you may be a little confused about the difference between energy and power. Put simply, energy is the ability to do work while power is the rate at which work is done. In electrical circuits, energy is supplied by batteries or generators. It may also be stored in components such as capacitors and inductors. Electrical energy is converted into various other forms of energy by components such as resistors (producing heat), loudspeakers (producing sound energy) and light emitting diodes (producing light).

The unit of energy is the Joule (J). Power is the rate of use of energy and it is measured in Watts (W). A power of 1 W results from energy being used at the rate of 1 J per second. Thus: $P = W / t$ where P is the power in Watts (W), W is the energy in Joules (J), and t is the time in seconds (s).

The power in a circuit is equivalent to the product of voltage and current. Hence: $P = I \times V$ where P is the power in Watts (W), I is the current. The formula may be arranged to make P, I or V the subject, as follows: $P = I \times P$, $I = P / V$ and $V = P / I$. These are illustrated in the diagram below.



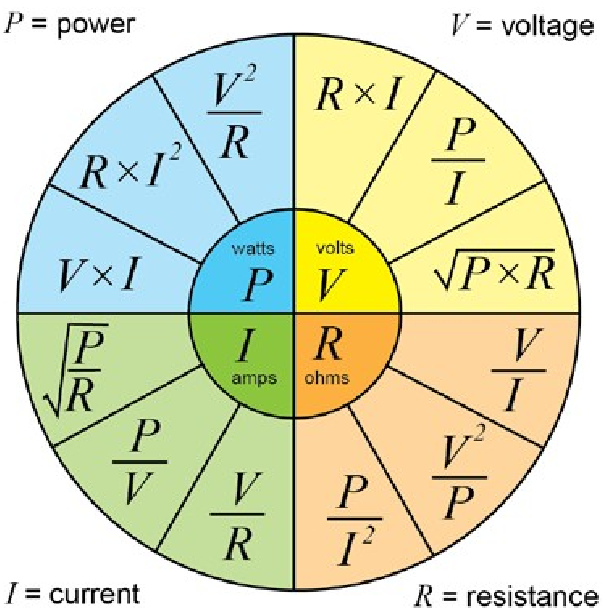
4. Notes on *Energy and power* are largely taken from Electronic Circuits Fundamentals and Applications Third Edition 2006 by Michael Tooley pages 8 – 9.

The relationship, $P = I \times V$, may be combined with that which results from Ohm's Law ($V = I \times R$) to produce two further relationships.

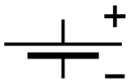
First, substituting for V gives: $P = I \times (I \times R) = I^2 R$.

Secondly, substituting for I gives: $P = (V / R) \times V = V^2 / R$

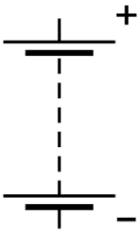
These and other relationships are given in the following diagram:



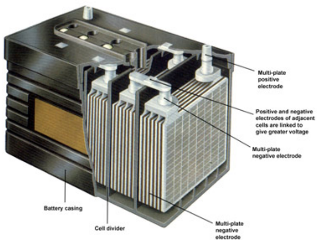
4. Components and associated equipment



Cell. Sometimes referred to as a battery cell. Voltage will vary depending on the type.



Battery. A collection of cells joined in series. Output voltage is the sum of the individual cells.

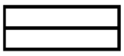


V_S or 9 V or + O———

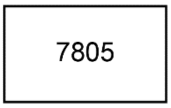
Positive terminal of a battery or D.C. power supply unit. Often a voltage is specified e.g. 9 V.

Gnd or 0 V or – O———

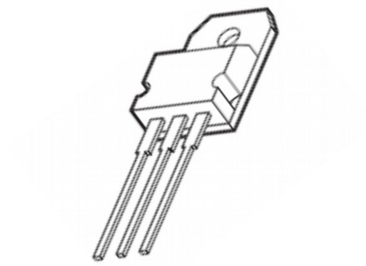
Negative terminal of battery or ground of D.C. power supply unit.



Fuse. Essentially a fine wire that will conduct current. However, if the current becomes excessive or dangerous then it will overheat and melt and thus produce a break in the circuit and the current will stop flowing.



Voltage regulator. In this case a 7805 where the output voltage is 5 V. Note: 7806 = 6 V, 7809 = 9 V, 7812 = 12 V etc. There are also variable and negative voltage versions.



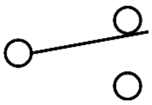
Input 0 V Output

Single pole single throw switch i.e. SPST

Toggle

Rocker

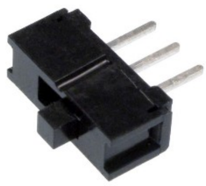
Slide



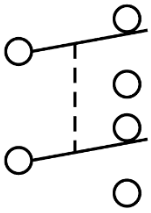
Single pole double throw switch i.e. SPDT

Toggle

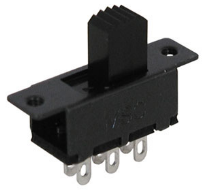
Rocker



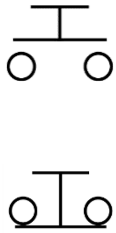
Slide



Double pole double throw switch i.e. DPDT

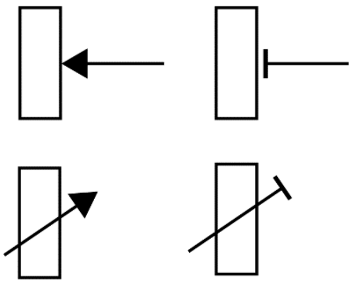


Toggle Rocker Slide

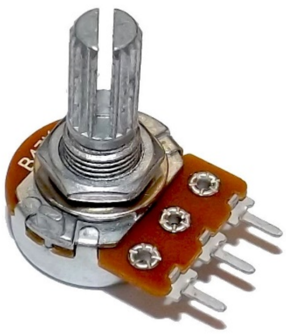


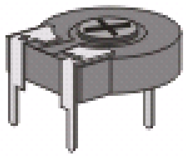
Push to make and push to break switches.

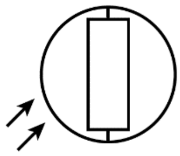
Resistor, fixed value.



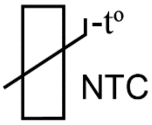
Potentiometer. Adjusted by twisting a spindle using fingers or rotating a slot using a screwdriver. The lower symbols represent a potentiometer connected as a **variable resistor**.



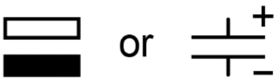




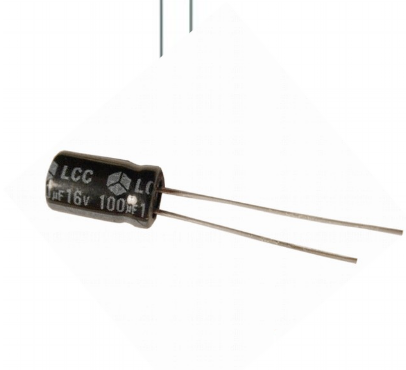
Light dependent resistor i.e. LDR. As the intensity of light increases then the resistance of the LDR decreases and vice-versa.

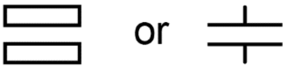


Thermistor, usually a negative thermal co-efficient type i.e. NTC. As temperature increases then the resistance of the NTC thermistor deceases and vice-versa.

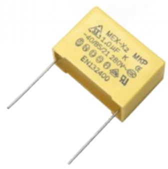


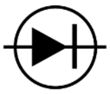
Capacitor, polarized



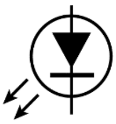


Capacitor, non-polarized

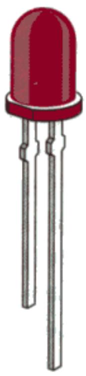


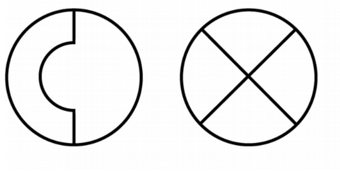


Diode – rectifier or signal.

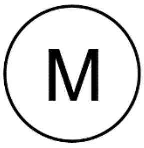


Light emitting diode i.e. LED.

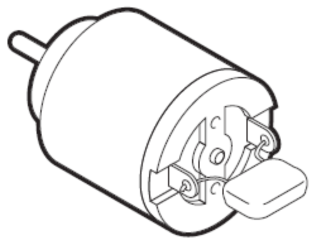


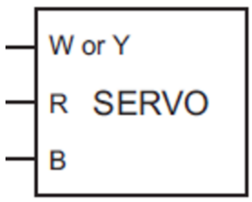


Bulb or lamp. The former indicates that it is used to produce light for illumination of an area whilst the latter is acting as a visual signal e.g. on a control panel.

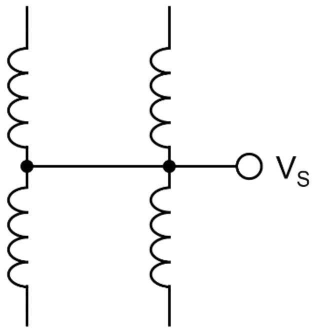


Electric motor. D.C. is the usual type used for this course of study. Direction of rotation is controlled by changing the polarity of its power supply. Speed can be varied using pulse width modulation (p.w.m.).

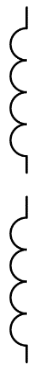




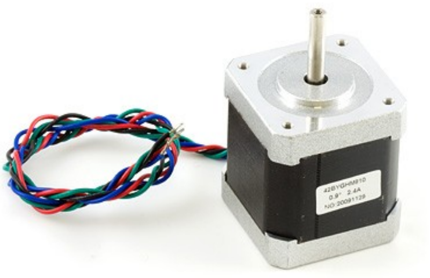
Servo motors can rotate continuously like a DC motor or can rotate sharply between positions on an arc. Inside the servo is a DC motor, gears, a potentiometer and control circuitry.

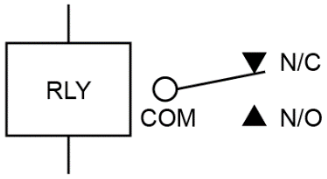


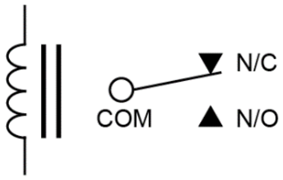
Stepper motors (unipolar). These rotate in distinct steps and are a means for obtaining precise and repeatable positional control. Steps for a unipolar stepper motor are typically 48 (7.5º). There are five wires: one for the positive power supply and 4 for the coils that are switched on and off in specific sequences.

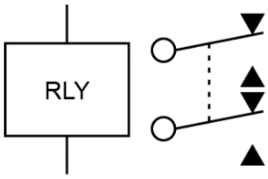


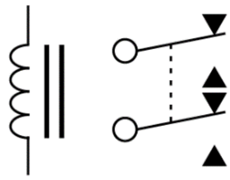
Stepper motors (bipolar). Typically these have much higher torque than unipolar stepper motors and the steps are much finer with 200 (1.8º) being the norm for school projects. Another difference is that bipolar stepper motors only have 4 wires. These are used to reverse the polarity of the coils and hence the name – bipolar.



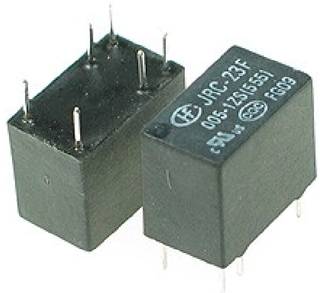


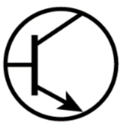


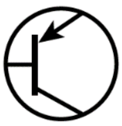




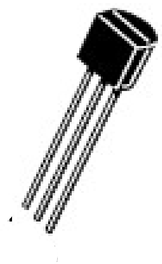
Relay. SPDT and DPDT changeovers. A relay enables a low voltage control circuit to activate high voltage/high power circuits. The output circuit may even be an A.C. circuit.

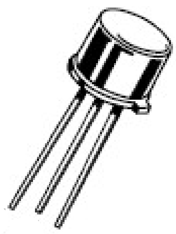


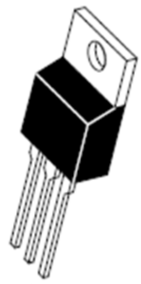


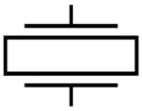


NPN and PNP transistors. These belong to the group known as bipolar junction transistors i.e. BJT. NPN transistors are the type listed in the syllabus but it is useful to be aware of PNP transistors and it may be the case that you might use these for project work.

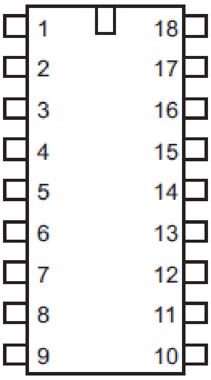




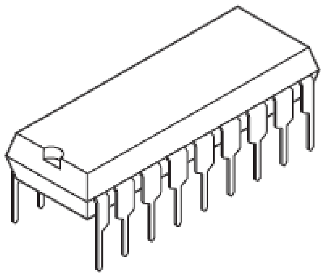


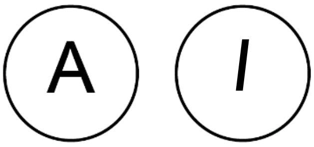


Piezo sounder



Integrated circuit (IC). It is usual to show an IC as a rectangular box. This example has 16 pins. On the actual component #1 pin is located at the top left corner and the rest follow in an anti-clockwise direction.





Ammeter. Used to measure current. Must be placed in series with the part of the circuit being measured. Typically this is achieved in this subject by selecting the appropriate setting of a **digital multimeter.**

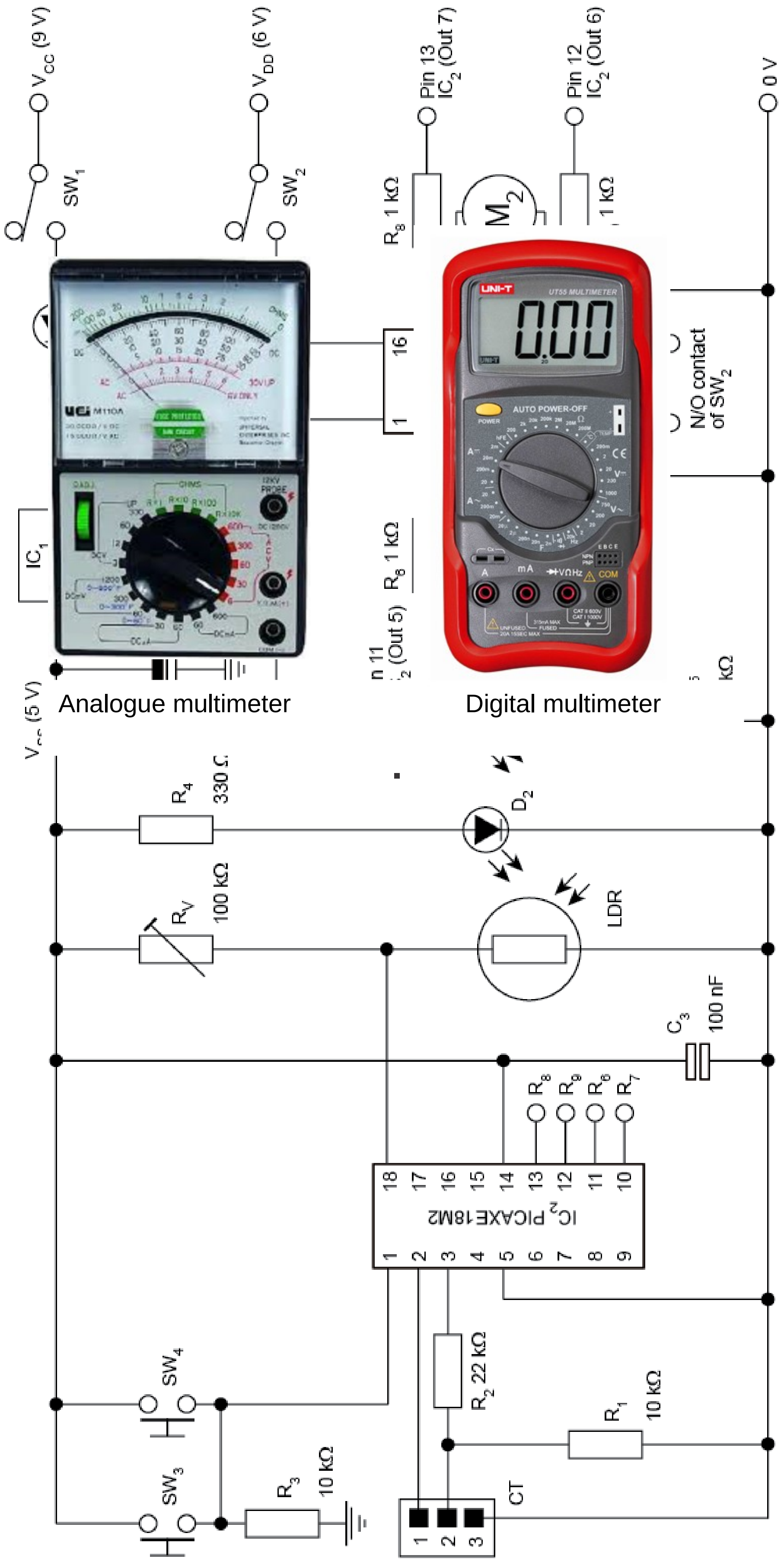
Voltmeter. Used to measure voltage. Must be placed in parallel with the part of the circuit being measured. Again, this will usually be done by selecting the appropriate setting of a digital multimeter.

Ohmmeter. Used to measure resistance. Must be placed in parallel with the component being measured. Ideally the measurement is made before installing the component in a circuit otherwise a false reading may result due to interaction with other circuit elements. It is normal practice to select the ohmmeter setting on a digital multimeter when measuring resistance.

Multimeter

As the name suggests, this piece of equipment is used to measure a number of different factors. A multimeter will typically be used instead of discrete meters like voltmeters and ammeters.

As has b[illegible] the norm. These a[illegible] be taken. Howeve[illegible] to be the usual fo[illegible]d' but are easily da[illegible]



Analogue multimeter

Digital multimeter

List the names of the components that appear in the circuit diagram on page 17.

SW_1 & SW_2

SW_3 & SW_4

D_1

D_2 & D_3

C_1 & C_2

C_3

IC_1

IC_2

IC_3

R_1 & R_3

R_2

R_4

R_5 – R_9

R_V

CT 3.5 mm stereo socket

LDR

M_1 & M_2

More questions

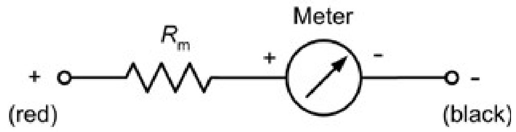
WACE 2009 multiple-choice question 9 (relay)

WACE 2016 multiple-choice questions 32, 35, 37; question 43 (a), (b), (c)(i), (c)(ii) and (d)

WACE 2017 multiple-choice questions 31, 32, 35 and 37; question 42 (b), (c), (d), (e) and (f); question 44 (d), (f), (h) and (i); and question 45 (b).

5. Measuring voltage, resistance and current

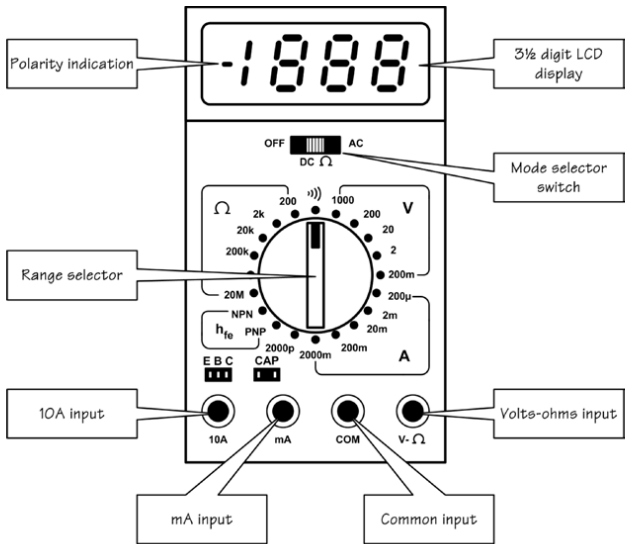
Voltage



Voltmeter circuit

1. Sketch the circuit symbol for a voltmeter.

How to measure voltage using a digital multimeter.



(a) Plug the black lead into the COM socket and the red lead into the V – Ω socket.

(b) Turn the range selector to the appropriate voltage (for most projects this will be the 20 V setting). Check that the range is for the correct type of voltage i.e. DC or AC. On the example illustrated above there is a mode switch but on many multimeters there are separate ranges that are clearly indicated.

(c) Connect the circuit to its power supply.

(d) Place the red probe and black probe on either side of the component or place the red probe on the test point and the black probe on 0 V (negative power rail).

(e) Record the reading.

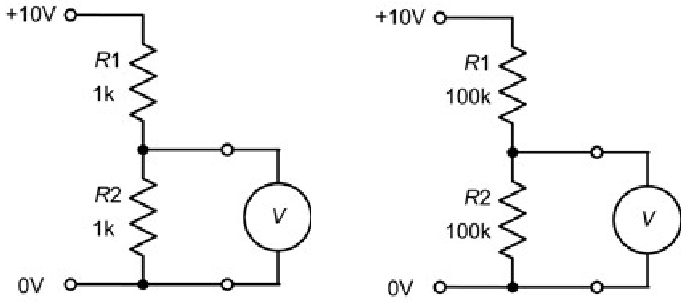
Voltmeter loading

If the resistance of the load being measured is very high then the reading will not be accurate due to **voltmeter loading**. This is *less likely* to be significant with modern digital meters due to their very high internal resistance but is a problem with analogue meters which usually have relatively low internal resistance.

Essentially, this is due to the fact that the voltmeter is connected in parallel to the circuit element being measured. The internal multiplier resistor (R_m) is meant to reduce to a minimum the current that is diverted through the meter. However, if the load has a very high resistance then, obeying Kirchhoff's Current Law, increased current will flow into the meter.

Also, by having two resistances in parallel then the net resistance will be effected and thus the voltage held across that part of the circuit. The effect of this is illustrated in the diagram and chart shown below.

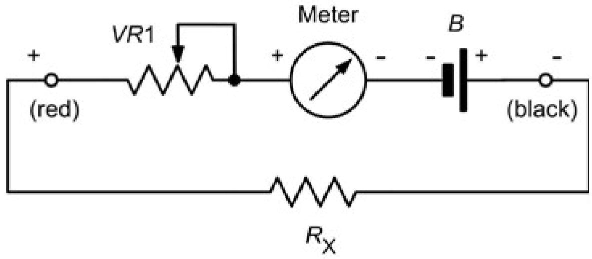
In both scenarios the expected readings for an ideal voltmeter would be 5.0 V. However, as the resistance of the load, R_2, becomes greater then it has an increased impact on the accuracy of the reading. The most dramatic effect occurs when the load resistance is high and the internal resistance of the meter is low.



(a) (b)

	V_{CC}	R_1	R_2	R_M	$R_2 \| \| R_m$	V_O
(a)	10 V	1000 Ω	1000 Ω	100 000 Ω	990.01 Ω	4.975 V
(b)	10 V	100 000 Ω	100 000 Ω	100 000 Ω	50 000 Ω	3.333 V
(a)	10 V	1000 Ω	1000 Ω	10 000 000 Ω	999.9 Ω	4.998 V
(b)	10 V	100 000 Ω	100 000 Ω	10 000 000 Ω	99010 Ω	4.975 V

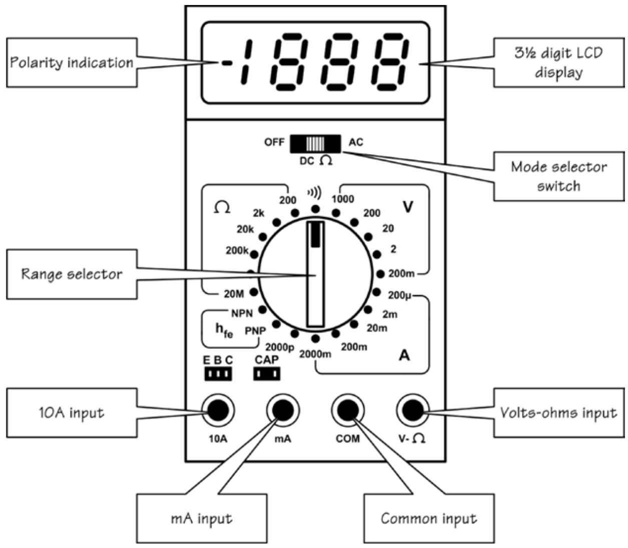
Resistance



Ohmmeter circuit

2. Sketch the circuit symbol for an ohmmeter.

How to measure resistance using a digital multimeter.



(a) Plug the black lead into the COM socket and the red lead into the V – Ω socket.

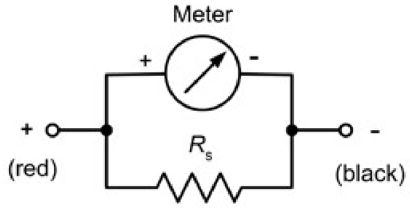
(b) Turn the range selector to the appropriate resistance setting. This should be the nearest setting that is larger than the anticipated value. If there is a mode switch then check that this is set to DC.

(c) Ideally the component should be removed from the circuit or have one leg disconnected so that no current can flow through the component other than that supplied by the multimeter. If this is not possible then disconnect the circuit's power supply (but even so, charged capacitors on the circuit might supply an unexpected current that will give a false reading or even damage the multimeter).

(d) Place the red probe and black probe on either side of the component.

(e) Record the reading.

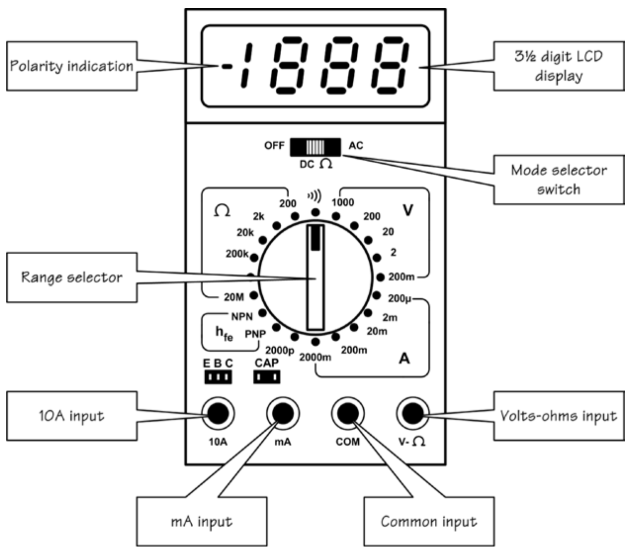
Current



Ammeter circuit

3. Sketch the circuit symbol for an ammeter.

How to measure current using a digital multimeter.



(a) Plug the black lead into the COM socket and the red lead into the mA socket for currents that are typically less than 200 mA or the 10 A socket for larger currents.

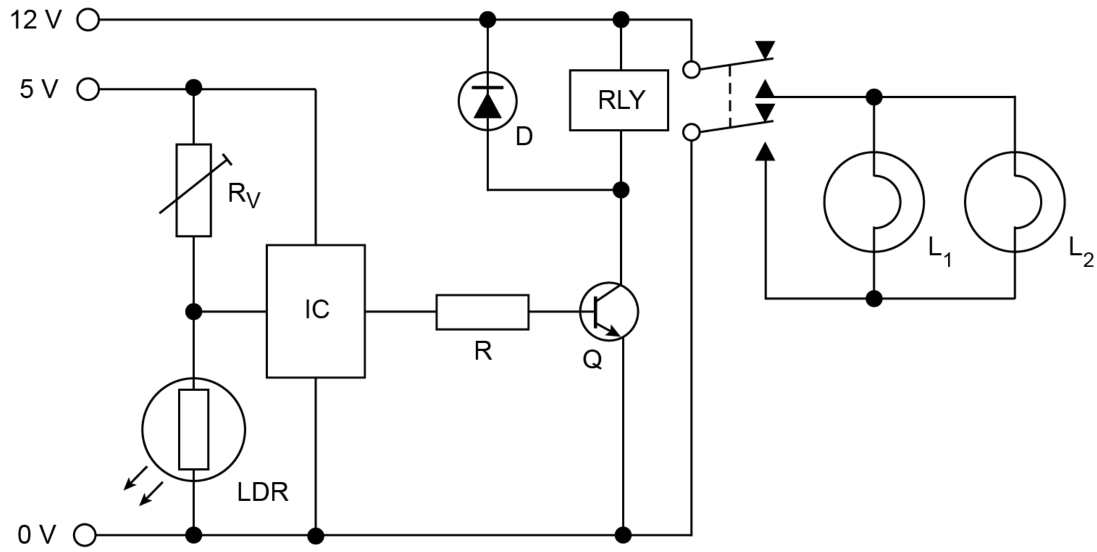
(b) Turn the range selector to the appropriate current setting. This should be the nearest setting that is larger than the anticipated value. Check that the range is for the correct type of current i.e. DC or AC. On the example illustrated above there is a mode switch but on many multimeters there are separate ranges that are clearly indicated.

(c) The meter must be connected in series in that part of the circuit being measured. This may involve making a deliberate break in the circuit by disconnecting one leg of an appropriate component so that it is in open circuit. On some circuits there are links that can be removed for the purpose of making readings of current.

(d) Place the red probe and black probe on either side of the open circuit.

(e) Record the reading.

Note: If the meter is set to measure current but used to measure voltage then it will create a short-circuit across the points where it is connected.



4. The circuit shown above uses IC, a microcontroller, to control two 12 V bulbs to turn on automatically when conditions become dark enough and to turn off when conditions becomes bright enough not to require the illumination of the bulbs. The light sensor is the potential divider shown to the left of the microcontroller.

(a) A series of voltage readings are required. These are listed in the table given below. On the diagram indicate where the probes of a voltmeter would be placed to measure by using a small labelled crosses e.g. x^{1}

Voltage reading	**Positive probe**	**Negative probe**
V_{RV}	1	2
IC output	3	4
V_R	5	6
V_{CE}	7	8
V_{RLY}	9	10

(b) Explain how to measure the resistance of R.

(c) In the space below redraw the circuit with the addition of the standard symbol for an ammeter to provide the following measurements:

I_{LDR}, I_{TOTAL}, I_B and I_{L1}.

Hint: It will be best to draw the diagram sideways along this page rather than across it. The 12 V and 5 V terminals have been supplied.

More questions

WACE 2015 question 57 (f).

WACE 2016 multiple-choice question 39.

6. Cells, batteries and power supplies

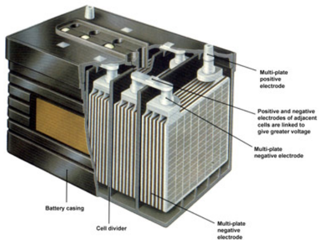
1. Sketch and label the symbol for a cell (sometimes known as a cell battery).

2. What are the typical voltages for the following cell types?

(a) Alkaline (primary) ________

(b) Ni-Cd (rechargeable) ________

(c) Lead acid (rechargeable) ________



(d) Silver oxide (primary) ________

(e) Lithium (primary) ________

(f) Li-ion (rechargeable) ________

3. In the space below sketch a labelled diagram of six 1.5 V cells in series.

4. What will be the total voltage across this arrangement? ___________

5. Sketch and label the symbol for a battery.

6. In the space below sketch a labelled diagram of two 6 V batteries in parallel.

7. What will be the total voltage across this arrangement? ___________

8. What advantage is gained by joining cells or batteries in parallel?

____

____

____

Markings on batteries

Note: These tend to appear on secondary (rechargeable) forms of batteries.

A

B

C

D

9. Using calculations, demonstrate that the Ah capacity of battery A is 2.1 Ah.

10. If battery A is fully charged then demonstrate by calculation that the current draw that would result in it being fully discharged over a period of 90 minutes is 1.4 A.

11. If battery B is fully charged then use calculations to demonstrate that the current draw that would result in it being fully discharged over a period of 45 minutes is 2 A.

12. Confirm, using calculations, that the energy transferred by fully discharging battery B is 0.0111 kWh.

13. Calculate the energy transferred by fully discharging battery C. Answer in units of joules. Show all workings.

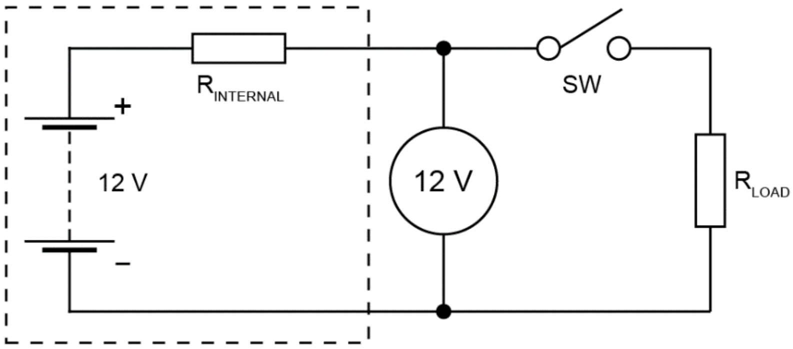
(Answer 23 043.6 J or 23 040 J)

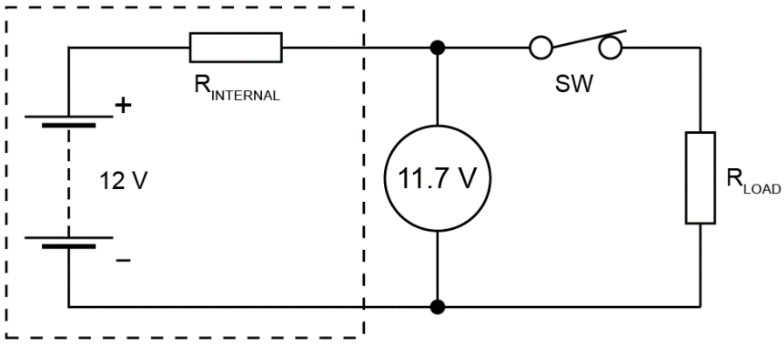
14. Assuming the load is consistent with the 20 hour rating, show that the current draw of battery D is 0.35 A.

15. Following on from question 14, demonstrate that the power being supplied by battery D is 4.2 W.

The batteries used in the previous examples are theoretical or ideal models. The terminal voltage is exactly as stated, there is no internal resistance and the current always remains constant depending on the draw of the circuit. Real or practical batteries are more complex.

There is always some internal resistance in a practical battery due to its chemistry and this will alter the terminal voltage and, over time as charge begins to fall, there will be a drop in cell voltage and therefore the current that can be drawn. Without going into too many of the complexities of how real batteries function, it is worthwhile to at least consider the effects of its internal resistance.





16. A battery is rated at 12 V. When a voltmeter is placed across its terminals the reading is 12 V. However, this reading is only true when there is no current draw. When the battery is connected to an external circuit a current of 10 A flows and the terminal voltage drops to 11.7 V. What is the internal resistance of the battery?

Internal resistance =______________

17. A flashlight has 4 AA 1.5 V battery cells connected in series as its power supply. When switched on its bulb, rated at 1.2 W, glows at full brightness.

(a) Calculate the current draw of the bulb when glowing.

____

____

____

Current draw = _______________

(b) Calculate the resistance of the bulb when glowing.

____

____

Resistance of bulb = _______________

(c) Would the bulb's resistance be the same when it is not glowing?

____

____

____

____

(d) Calculate the energy transferred by the batteries to the bulb in 15 minutes. Answer in units of joules.

Note: $E = P\,t$ *and* 1 J = 1 W × 1 second

____

Energy transferred =___________________

An alternative to cells and batteries is a PSU. What is a PSU?

A PSU is a power supply unit. PSU's are often used instead of cells or batteries to power an electronic/electrical circuit. A PSU is plugged into a wall socket (240 VAC) and the output is a much lower voltage. This lower voltage is achieved through the use of a transformer. The output voltage can be AC or DC – the latter will be the case if rectifying circuitry is incorporated in the PSU. High quality DC PSUs will also make use of voltage regulators.

18. Sketch the symbol for an alternating current supply e.g. 240 VAC.

19. An aquarium tank uses a 24 VAC PSU connected to a 150 W heating element to maintain optimum water temperature.

(a) Calculate the current draw of the heating element when switched on.

Current draw =___________________

(b) Calculate the energy transferred by the power supply to the heating element in 5 minutes. Answer in units of joules.

____

____

Energy transferred = ____________________

More questions

WACE 2015 question 56 (a)

7. Switches

1. Sketch the symbols for the following types of switches in the space to the right of each description.

   (a) Single pole single throw (SPST)

   (b) Single pole double throw (SPDT)

   (c) Double pole double throw (DPDT)

   (d) Push to make (momentary action)

   (e) Push to break (momentary action)

   (f) Magnetic reed (normally open and normally closed)

2. Sketch a circuit that meets the following specifications:

(a) Power supply is a 4.5 V alkaline battery.
(b) A SPST switch, SW, when closed will cause an LED, D, to glow and when open the LED will cease to glow.
(c) A series resistor, R, is required to control current through the LED.

3. Sketch a circuit that meets the following specifications:

(a) Power supply is a 6 VDC PSU.
(b) The circuit incorporates two LEDs, $D_1$and D_2, with current limiting resistors, R_1 and R_2.
(c) A SPDT switch, SW, when thrown to the normally closed (N/C) terminal will cause one of the LEDs to glow whilst the other is off.
(d) When the switch is thrown to the normally open (N/O) terminal then the LEDs will behave in the opposite manner.

4. Sketch and label a circuit diagram that meets the following specifications:

(a) Power supply is a 24 VDC PSU.

(b) The circuit incorporates a DPDT switch, SW_1, which controls the direction of rotation of an electric motor, M, which moves a roller door.

(c) The door can only be fully open (up) or closed (down). The open and closed positions are detected by **two** N/C push switches, SW_2 and SW_3. When the N/C switch at the top (door up) is pressed the motor stops but it can be reversed by the DPDT switch. Similarly, when the N/C switch at the bottom (door down) is pressed the motor will also stop but it can be reversed by the DPDT switch.

5. Sketch a circuit that meets the following specifications:

(a) Power supply is 240 VAC.

(b) Two SPDT switches, SW_1 and SW_2, control two bulbs connected in parallel, L_1 and L_2.

(c) Either switch can turn the bulbs on and off without having to adjust the other switch.

6. Sketch a circuit that meets the following specifications:

(a) Power supply is a 12 V battery.
(b) The circuit incorporates 4 push to break switches, SW_1- SW_4, and a bulb, L.
(c) Any single closed switch or combination of closed switches can turn the bulb on but all 4 must be pressed to the open position for the bulb to turn off.
(d) There is also a SPST switch, SW_5, which can turn the bulb on if all 4 push to break switches are in open circuit.

More questions

Note: Some of the following have a focus on completing a circuit diagram that may not include switches.

WACE 2010 question 53 (d).

WACE 2013 multiple-choice question 47 and question 55 (c).

WACE 2014 question 54 (d) and question 55 (e).

WACE 2015 multiple-choice question 44; question 57 (b) and (c); and question 53 (f).

WACE 2017 multiple-choice question 31; question 42 (e) and (f); and question 44 (i).

8. Fixed value resistors

Coloured bands

Most resistors used in this course are **carbon film or** possibly **carbon composition (**a mixture of carbon and ceramic material) and have **four coloured bands** used to identify value and tolerance.

The first two bands represent digits i.e. 0, 1, 2, 3, 4, 5, 6, 7, 8 or 9.

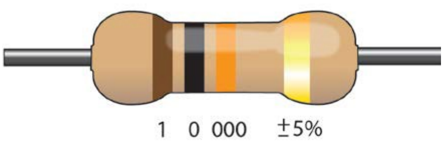
Note: 0 (black) is not used for the first band.

The third band is the multiplier. Normally these range from 10^0 (black) to 10^6 (blue). Two special multipliers for very small values are occasionally used. These are 10^{-1} (gold) and 10^{-2} (silver).

The last band is the tolerance band. This is a quality control guarantee from the manufacture and specifies the accuracy of the resistor. Carbon film resistors are usually ± 5% (gold) and sometimes ± 10% (silver).

Band colour	**1st band**	**2nd band**	**Multiplier**
Silver	not used	not used	0.01
Gold	not used	not used	0.1
Black	not used	0	1
Brown	1	1	10
Red	2	2	100
Orange	3	3	1000
Yellow	4	4	10 000
Green	5	5	100 000
Blue	6	6	1 000 000
Violet	7	7	not used
Grey	8	8	not used
White	9	9	not used

Tolerance band	
Brown	± 1%
Red	± 2%
Gold	± 5%
Silver	± 10%



Five band metal film resistors (nickel chromium) are also commonly used. The first three bands are digits, the fourth a multiplier and the fifth is for tolerance. As was the case for four band resistors, 0 (black) is not used for the first band. The tolerance band for this type of resistor usually specifies ± 1% (brown) or ± 2% (red).

Power rating

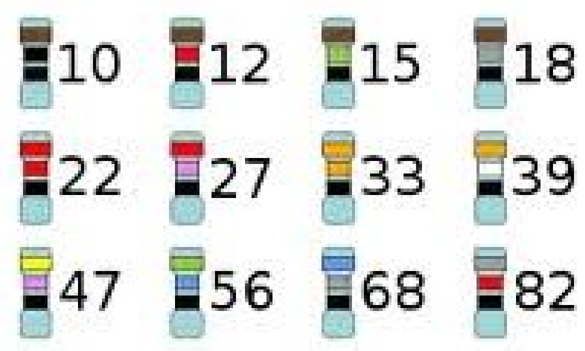
The most common power ratings for fixed value resistors are 0.125W, 0.25W, 0.5W, 0.6 W, 1 W and 2 W with 0.25 W being the predominate rating used for most school projects.

Note: When resistance values are very low (<10 Ω) and power requirements greater than 2 W then precision wire wound resistors are used.

Preferred values

Fixed value resistors are not available in an unlimited range of values – this would simply not be feasible for suppliers to stock. Therefore, a limited range of values is manufactured using what is known as **preferred values**. For this course of study E12 values are used.

These use 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68 and 82 as the base numbers.



Using the 4 band system, the first two bands determine the base number and the third band the multiplier. For example, if 47 is used as the base number then the values available are:

Value	Band 1	Band 2	Band 3 (multiplier)
0.47 Ω	Yellow	Violet	Silver
4.7 Ω or 4Ω7	Yellow	Violet	Gold
47 Ω	Yellow	Violet	Black
470 Ω	Yellow	Violet	Brown
4k7 Ω	Yellow	Violet	Red
47 kΩ	Yellow	Violet	Orange
470 kΩ	Yellow	Violet	Yellow
4M7 Ω	Yellow	Violet	Green

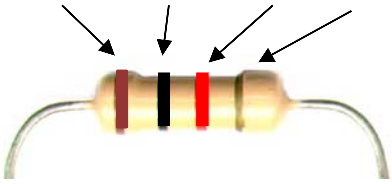
Note: The maximum value that is usually available from suppliers is 10 MΩ

4 band resistors

Complete the following -

e.g. brown black red gold

1 0 00 ± 5%

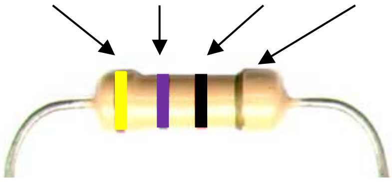


Ideal value = 1000 Ω or 1 kΩ

Maximum value = 1050 Ω

Minimum value = 950 Ω

1. yellow violet black gold

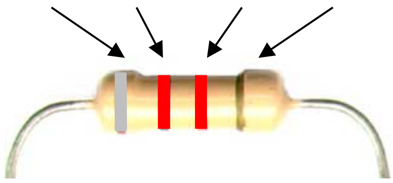


Ideal value = ____________________

Maximum value = ____________________

Minimum value = ____________________

2. grey red red gold

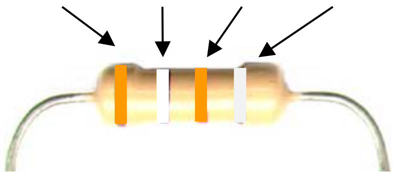


Ideal value = ____________________

Maximum value = ____________________

Minimum value = ____________________

3. orange white orange silver

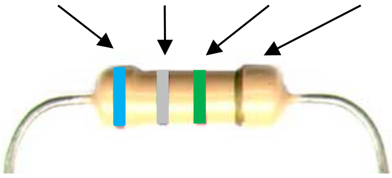


Ideal value = ____________________

Maximum value = ____________________

Minimum value = ____________________

4. blue grey green gold

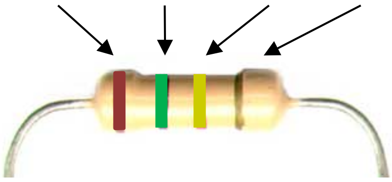


Ideal value = ____________________

Maximum value = ____________________

Minimum value = ____________________

5. brown green gold gold



Ideal value = ____________________

Maximum value = ____________________

Minimum value = ____________________

6. What are the colour codes for the following?

82 kΩ ±5% = 82 000 ±5% = 823 ±5%	**grey red orange gold**
22 Ω ±5%	
2.7 Ω ±5%	
390 kΩ ±5%	
5M6 Ω ±5%	
6k8 Ω ±10%	

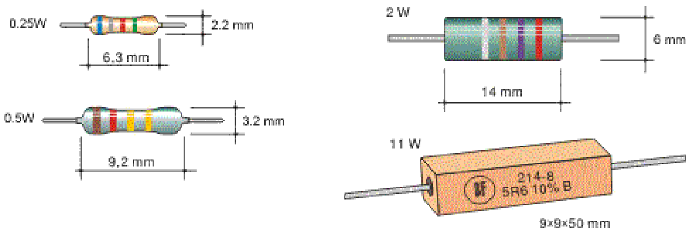
Preferred values

7. What values can be derived from the E12 value of 68 as a result of using the multiplier band? Assume that these resistors are marked with 4 coloured bands.

Value	Band 1	Band 2	Band 3 (multiplier)
0.68 Ω			

Note: The maximum value listed in most supplier's catalogues is 10 MΩ.

Power ratings



8. Given that the voltage held across a resistor is 2.35 V and its resistance is 270 Ω then which of the above power ratings for a fixed value resistor should be used? Use calculations to support your answer.

____

____

____

____

Power rating = ______________

More questions

WACE 2012 question 54 (a) (iv)

WACE 2013 question 59 (c)

WACE 2014 question 52 (d) and question 54 (e)

WACE 2015 questions 53 (e) and 56 (c)
.
WACE 2016 question 43 (b), (c)(i) and (c)(ii).

WACE 2017 multiple-choice question 39; and question 42 (g).

9. Resistor networks

The problems that follow require students to apply the following:

Ohm's Law	$V = IR$ and its variations	V = voltage (volts, V) I = current (amperes, A) R = resistance (ohms, Ω)
Power	$P = I\,V$ and its variations	P = power (watts, W) I = current (amperes, A) V = voltage (volts, V)
Resistors in series	$R_T = R_1 + R_2 + \ldots\ldots$	
Resistors in parallel	$R_T = \dfrac{R1\ R2}{R1 + R2}$	2 resistors only
	$\dfrac{1}{RT} = \dfrac{1}{R1} + \dfrac{1}{R2} + \dfrac{1}{R3} + \ldots..$	2 or more resistors

Kirchhoff's Current Law (Kirchhoff's First Law) $\sum I = 0$

This conforms with the principles of the **conservation of charge** in a system.

The sum of the currents entering a junction must equal the sum of the currents leaving that junction.

If the currents entering the junction are assigned positive values and those leaving the junction are negative, then the sum of all the currents will equal 0.

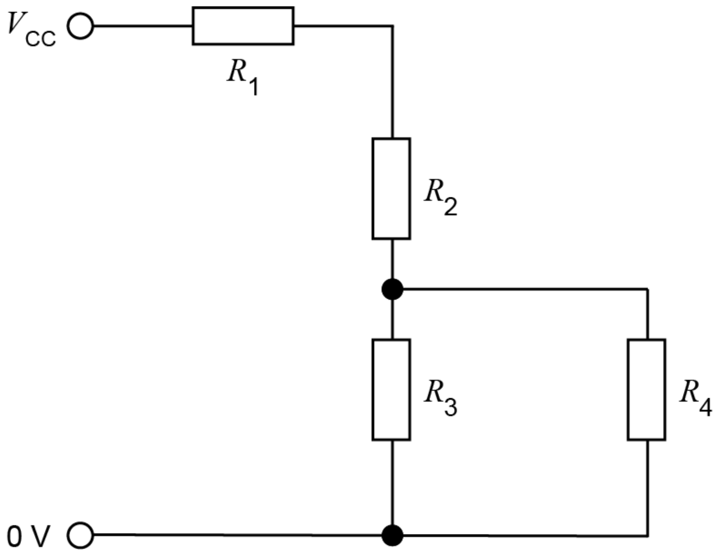
Kirchhoff's Voltage Law (Kirchhoff's Second Law) $\sum \Delta V = 0$

This conforms with the principles of the **conservation of energy** in a system.

The sum of the voltage drops in a loop will equal the total voltage held across that loop.

If the total voltage held across the loop is assigned a positive value and the individual voltage drops are considered to be negative, then the sum must equal 0.

Observations about voltage and current in resistor networks



Voltage

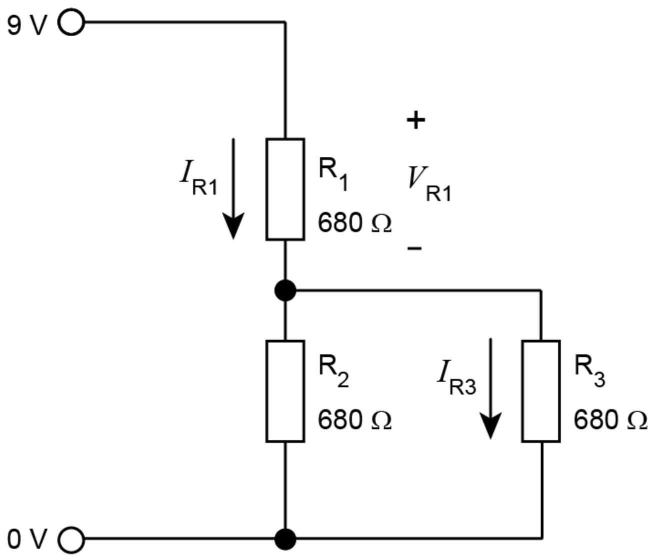
1. Voltage will be dropped across resistors in series in the same relative proportions as the individual resistances. For example, if R_1 has a higher resistance than R_2 then more voltage will be dropped across R_1 compared to R_2.

2. Resistors in parallel share the same voltage drop. R_3 and R_4 in the example above will have the same potential difference (Kirchhoff's Voltage Law). This voltage drop will be the same for an equivalent resistor that replaces the resistors that were in parallel.

Current

1. Current through resistors in series will be the same e.g. the current through R_1 is the same current that flows through R_2 (Kirchhoff's Current Law). In fact, for this circuit $I_{Total} = I_{R1} = I_{R2}$.

2. Current through resistors in parallel will be greater through the resistor(s) with lower resistance and less through the resistor(s) with higher resistance. Total current flowing into or out of a network of resistors in parallel will equal the sum of the currents flowing through each parallel arm (Kirchhoff's Current Law).



1. Examine the diagram and calculate the following:

(a) I_{R1}, the current through R_1.

I_{R1} = ____________________

(b) V_{R1}, the voltage across R_1.

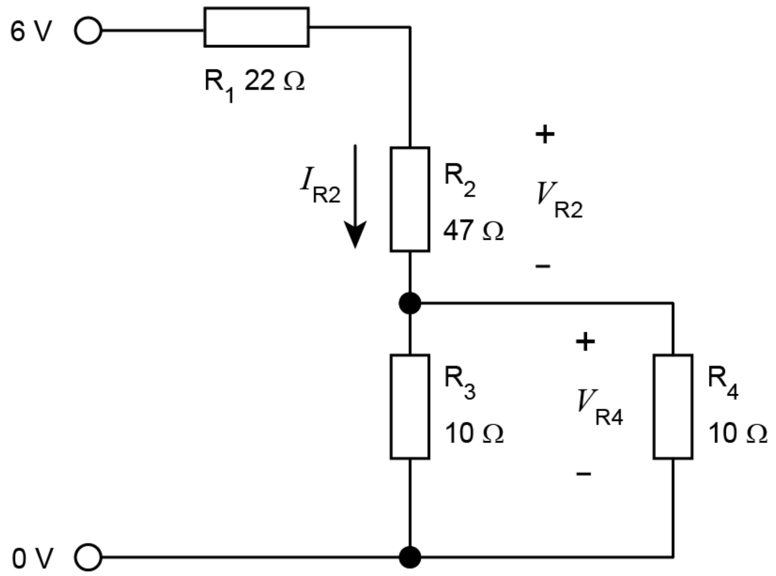
V_{R1} = ______________________

(c) I_{R3}, the current through R_3..

I_{R3} = ______________________

(d) P_{R2}, the power dissipated by R_2.

P_{R2} = ______________________



2. Examine the diagram and calculate the following:

(a) I_{R2}, the current through R_2

I_{R2} = ____________________

(b) V_{R2}, the voltage across R_2.

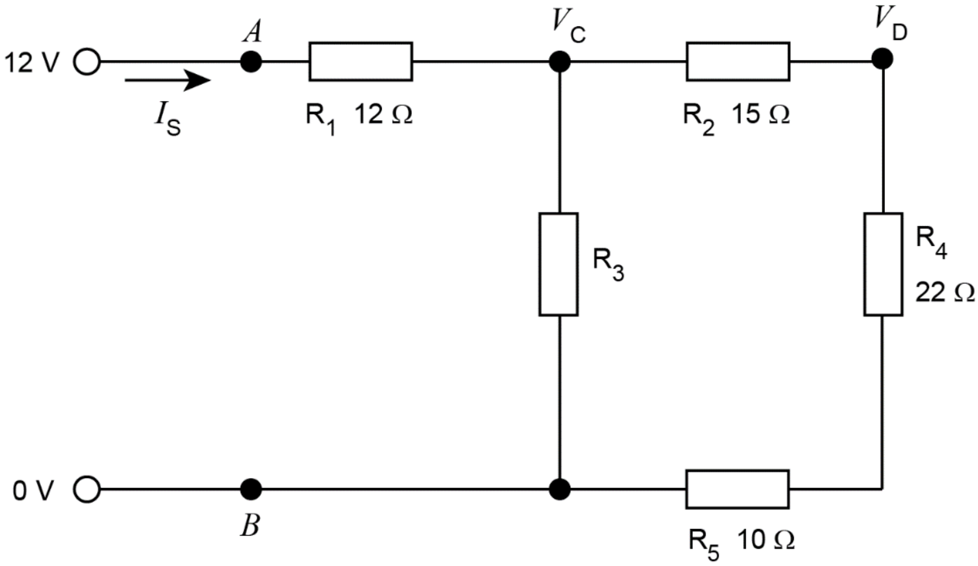
V_{R2} = ______________________

(c) V_{R4}, the voltage across R_4

V_{R4} = ____________________

(d) P_{R3}, the power dissipated by R_3.

P_{R3} = ____________________



Note: The node voltage V_C is the voltage drop from node C to 0 V; and node voltage V_D is the voltage drop from node D to 0 V.

3. Examine the diagram and answer the questions that follow.

(a) If R_3 = 100 Ω then determine:

(i) R_{AB}, the equivalent resistance between nodes *A* and *B*.

R_{AB} = ____________________

(ii) I_S, the supply current.

I_S = ______________________

(iii) P_S, the power delivered by the power supply to the circuit.

P_S = ______________________

(iv) Node voltage V_C.

V_C = ______________________

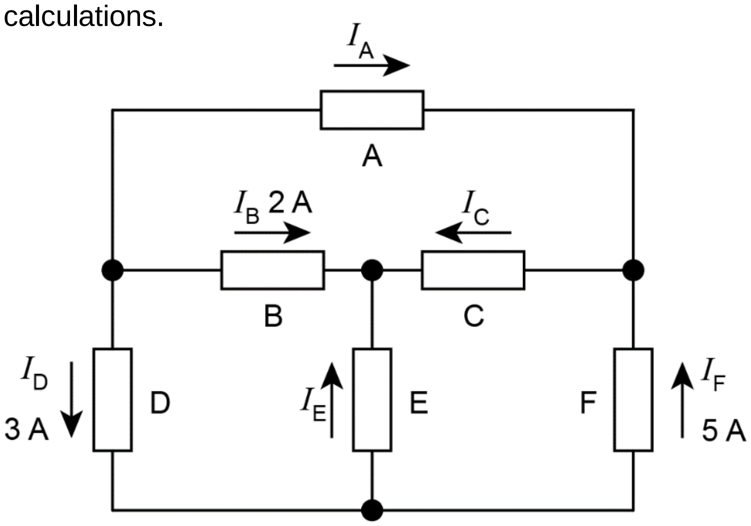
(v) Node voltage V_D.

V_D = ______________________________

(b) If node voltage V_D is now 6.4 V and the values of all circuit elements, with the exception of R_3, remain the same then calculate the new value for that resistor.

R_3 = ____________

4. Examine the diagram below and complete the table that follows it by applying Kirchhoff's Current Law. Use the space provided below the table for completing calculations.



Note: This example exceeds the expectation of the syllabus which limits examination network questions to 5 resistors or less.

I_A =	I_B = 2 A	I_C =
I_D = 3 A	I_E =	I_F = 5 A

I_A ______________________________

____

____

____

I_C ______________________________

____

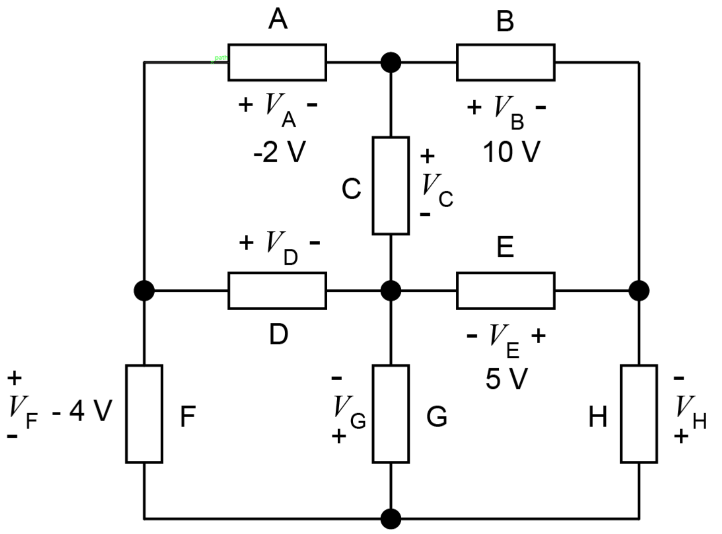
____

____

I_E ______________________________

____

5. Examine the diagram below and complete the table that follows it by applying Kirchhoff's Voltage Law. Use the space provided below the table for completing calculations.



Note: This example exceeds the expectation of the syllabus which limits examination network questions to 5 resistors or less.

V_A = -2 V	V_B = 10 V	V_C =	V_D =
V_E = 5 V	V_F = - 4 V	V_G =	V_H =

V_C ______________________________

____

____

V_D ______________________________

____

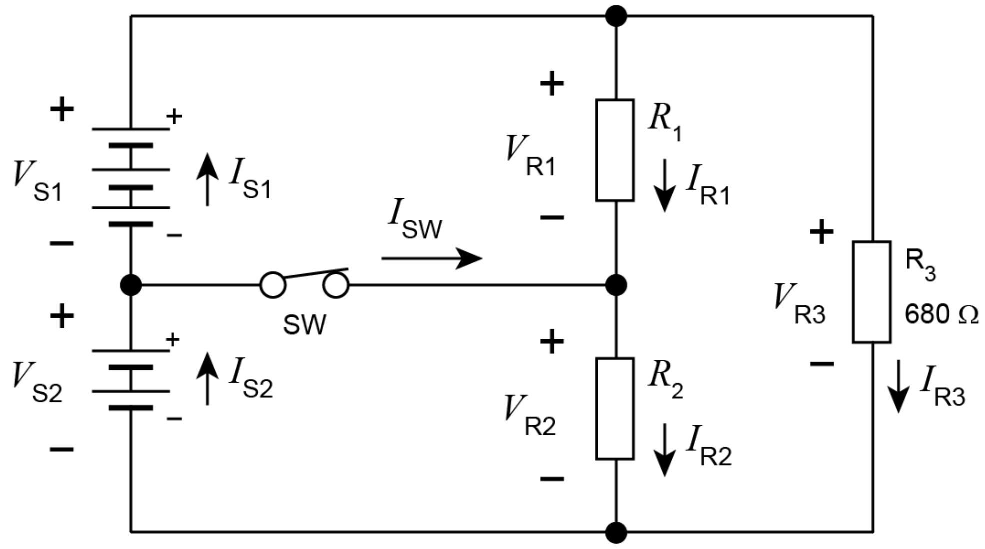
____

V_G ______________________________

____

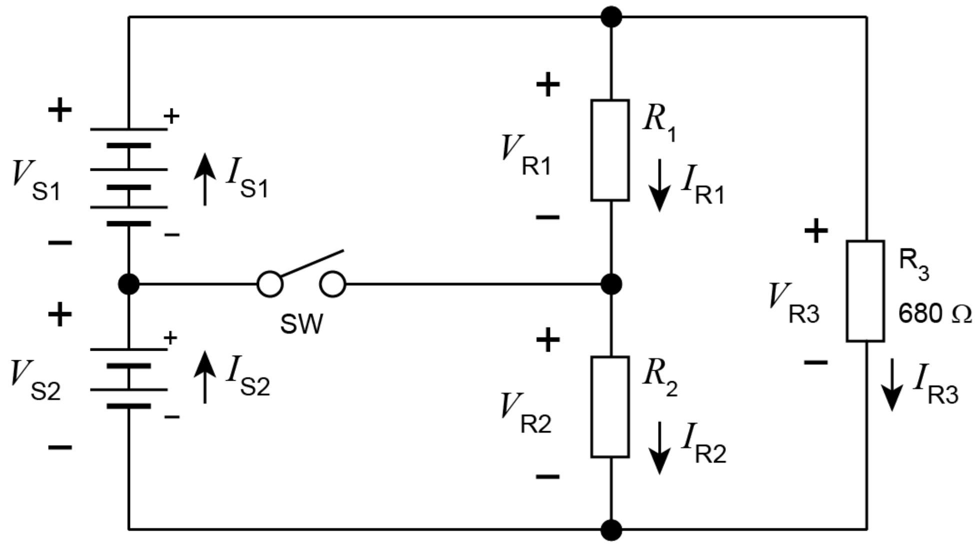
V_H

6. A circuit is constructed, as shown below, with three resistors R_1, R_2 and R_3, an ideal switch SW, and two batteries V_{S1} and V_{S2}. The diagram also specifies the direction of the current and the voltage polarity of each circuit element (excluding the switch).



(a) Using Kirchhoff's voltage law, Kirchhoff's current law, Ohm's law and the power law, complete the following tables, to show the voltage, current and power of each circuit element in the case when the switch SW is **closed**. Use the space inside the chart for calculations.

When the switch is closed			
Circuit Element	**Voltage (V)**	**Current (A)**	**Power (W)**
V_{S1}	V_{S1} = 4.5 V		P_{S1} = 0.09 W
V_{S2}	V_{S2} = 3.0 V		P_{S2} = 0.069 W
R_1			
R_2			
R_3			



(b) Using Kirchhoff's voltage law, Kirchhoff's current law, Ohm's law and the power law, complete the following tables, to show the voltage, current and power of each circuit element in the case when the switch SW is **open**. Use the space inside the chart for calculations.

When the switch is open			
Circuit Element	**Voltage (V)**	**Current (A)**	**Power (W)**
V_{S1}	V_{S1} = 4.5 V		P_{S1} = 0.0945 W
V_{S2}	V_{S2} = 3.0 V		
R_1			P_{R1} = 0.05 W
R_2			
R_3			

More questions

WACE 2009 multiple-choice question 6, and electronics/electrical extended question 1 (a), (b), (d) (i) - (iv), and (e) (i) - (iii).

WACE 2010 multiple-choice question 49, question 52 (b)(i), (ii), (iii) and (iv), and (c) (i) - (vi).

WACE 2011 multiple-choice question 41, question 51 (a) (i) - (iv), and question 52 (d) (i) and (ii).
Note: Question 51 (c) and (d) have been used as examples 4 and 5 on pages 51 and 52 of this workbook)

WACE 2012 multiple choice questions 43 and 49, question 53 (a), (b)(i) - (iii) and (c) (i) and (ii), and question 56 (a), (b), (c), (d) and (e) (i) and (ii).

WACE 2013 question 54 (a), (b), (c), and (d) (i) - (iii), and question 58 (a) and (b).

WACE 2014 question 54 (f).

WACE 2015 question 54(b), (c) and (e).

WACE 2016 question 45 (a), (b), (c), (d), (e), (f) and (g).

WACE 2017 question multiple-choice questions 34 and 39; question 40 (a) – (g).