Defence School of
Aeronautical Engineering

AEROSYSTEMS ENGINEER &
MANAGEMENT TRAINING SCHOOL

ACADEMIC PRINCIPLES ORGANISATION

CN 1236 and 3853

Electronic and Further Electrical Fundamentals

Book 1 – Direct Current

WARNING

These course notes are produced solely for the purpose of training. They are not subject to formal amendment action after issue and they must NOT be used for operating and maintaining the equipment described. Operation and maintenance of equipment is governed by the limitations and procedures laid down in the authorized publications and manuals which must be complied with for these purposes

CHAPTER 1
INTRODUCTION TO ELECTRICITY

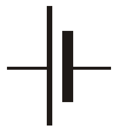
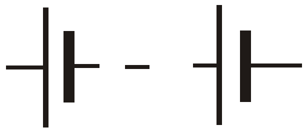
KLPs

Av01.01.01.01	Describe in simple terms the following: Conductors Insulators Current Voltage Resistance
Av01.01.02.01	Describe the properties and application of resistors.
C003.01.02.02	Describe the nature and state the hazards of static electricity.

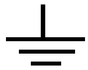
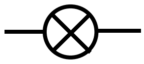
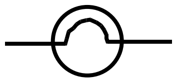
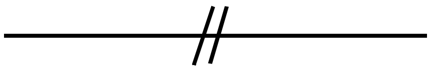
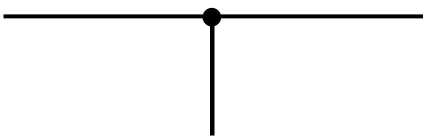
Notes:

GRAPHICAL SYMBOLS USED IN ELECTRICAL DIAGRAMS

The following graphical symbols are extracted from British Standard 3939. They should be used whenever an electrical or electronic diagram is drawn.

DESCRIPTION	SYMBOL
Primary or secondary cell	
Battery	 50V Alternative  50V

8224(01)

DESCRIPTION	SYMBOL
Earth	
Signal Lamp	
Filament Lamp	
Conductors:general symbol.	
2 Conductors: single line representation.	
Junction of conductor.	
Fuse: general symbol	 alternative 
Fixed resistor.	

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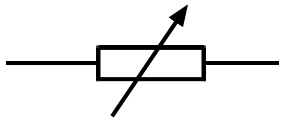
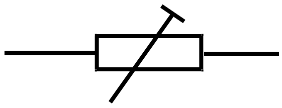
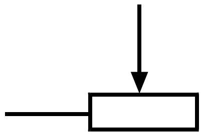
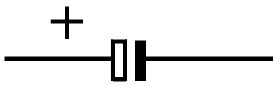
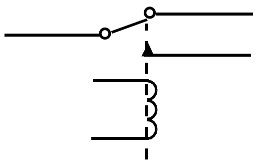
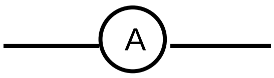
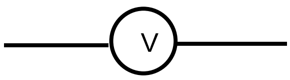
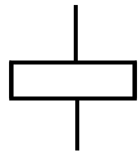
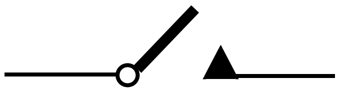
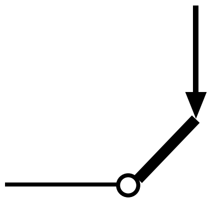
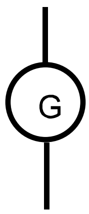
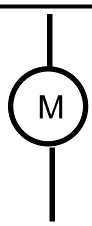
DESCRIPTION	SYMBOL
Variable resistor.	
Preset resistor.	
Resistor with moving contact.	
Capacitor:general symbol.	
Electrolytic capacitor.	
Inductor	
Relay	
Ammeter	
Voltmeter.	

8224(02)

DESCRIPTION	SYMBOL
Relay coil: general symbol	
Make contact-unit.	
Break contact-unit.	
Generator	
Motor.	

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The symbols listed above represent only a selection of the symbols used in electrical diagrams.

INTRODUCTION TO ELECTRICITY

ELECTRICAL PROPERTIES OF MATERIALS

Atoms And Electrons

1. To gain an understanding of the nature of electricity and the basic electrical properties of materials, let us start by looking at the structure of atoms, the most simple of which is the element hydrogen:

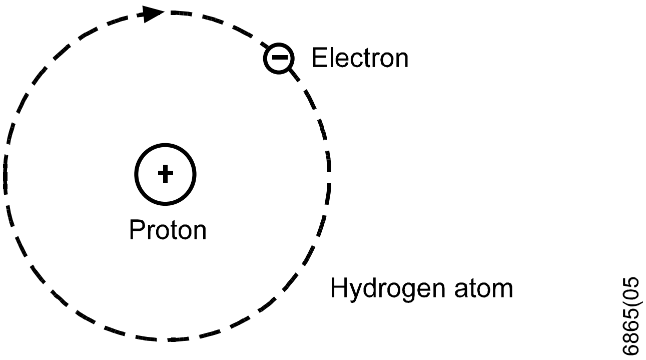


Figure 1

The nucleus of this atom is a tiny particle called a proton; an even smaller particle called an electron spins in orbit around the nucleus. The proton has a quantity of electricity (a charge) which is called positive and the electron has an equal but opposite (a negative) charge.

2. The atoms of other elements have larger number of protons and electrons. For example, the copper atom has 29 protons and its 29 electrons travel in quite distinct groups of orbits called shells.

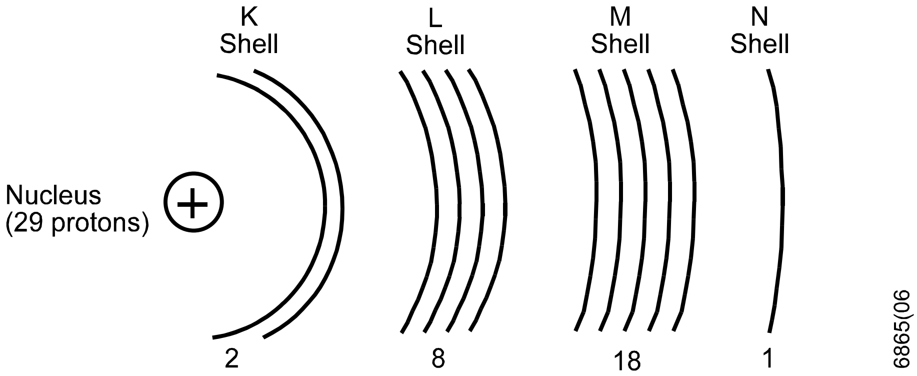


Figure 2 – Copper Atom: Electron Shells

The nuclei of atoms also contain neutrons, but these particles are uncharged.

Ions

3. Normally an atom has equal number of protons and electrons and is therefore electrically neutral. If the energy of an atom is increased, by heating for example, then electrons in the outer shells may gain sufficient energy to break free from the binding forces within the atom and become free electrons. This process is called ionisation and the atom, now with an overall positive charge, is called a positive ion.

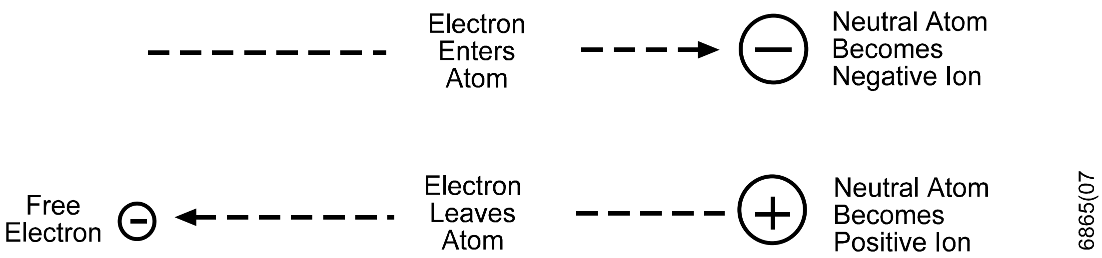


Figure 3

Sometimes a neutral atom may gain an electron and the atom, now with an overall negative charge, is called a negative ion.

Electric Current

4. A negative charge is a surplus of electrons, a positive charge is a deficiency of electrons and electrons tend to be repelled by negative charges but attracted towards positive charges. In more general terms:

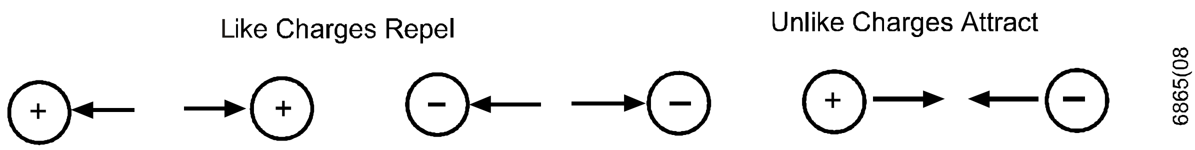


Figure 4

5. Electrical charges therefore have 'areas of influence' called electric fields, where other charges will be attracted or repelled according to their polarity. The movement of free electrons in an electric field in the same general direction from negative to positive is called an electric current.

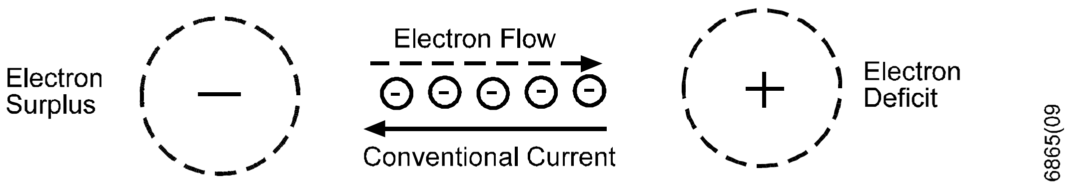


Figure 5

It is unfortunate that the convention was adopted that electrical current flows from positive to negative; this assumed that electrical current consisted of positive charges when, in fact, current consists of electrons flowing in the opposite direction.

Electrical Materials

6. The electrical properties of materials are a direct result of the behaviour of the electrons in the outer electron shells. These outer electrons also provide the forces that bind atoms together in an element or in a compound.

a. Insulators are materials in which all the outer electrons are committed to binding atoms together. Only extreme heat or intense electric fields will free outer electrons from their atoms.

Examples: Glass; mica; ceramics; rubber; plastics

b. Semiconductors are materials similar to insulators but having some outer electrons which can be freed at room temperature by moderate electrical fields, ie the number of free electrons can be varied.

Examples: Silicon and germanium.

c. Conductors are materials (including many metal elements) with outer electrons which are not committed to binding atoms together. Free electrons are easily produced.

Examples: Copper; chromium; magnesium; iron; nickel; zinc; aluminium; silver; gold; tungsten

PRINCIPLES OF ELECTRICAL CIRCUITS

Charges

7. Electrons in the outer shells of atoms, given a little extra energy, can break free of the atoms and become free electrons which are a source of electrical energy. The energy used to free them has been converted into electrical energy.

8. A body having a surplus of electrons will be negatively charged. A body which is deficient in electrons will be positively charged.

9. Amounts of charge are expressed in coulombs where:

1 coulomb = approx 6.3×10^{18} electrons.

Potential Difference

10. If two identical bodies are charged, the state of charge of one in comparison to the state of charge of the other is called potential difference (pd) and is measured in volts. Voltage is measured with an instrument called a voltmeter.

11. If an electrical energy source can produce a continuous stream of free electrons such that current can be maintained it is called an electro motive force (emf). Electro-motive force is measured in volts.

Current

12. If two charged bodies are connected by a conductor, electrons will flow along the conductor until there is no potential difference. A flow of electrons is current.

13. The unit of current is the ampere, which is an expression of the rate of flow of electrons.

1 ampere = 1 coulomb per second

Current is measured with an instrument called an ammeter.

14. The relationship of current, time and total charge is given by the formula:

$$I = \frac{Q}{t}$$

Where I is current in amperes and Q is total charge moved in t seconds.

Example: 200 Coulombs of charge pass a point in a wire in 10 seconds. What is the current in the wire ?

$$I = \frac{Q}{t} \qquad \therefore I = \frac{200}{10} = 20$$

current = 20 amps

CONNECTION OF METERS

15. An ammeter measures current along a wire and is connected in series. A voltmeter measures the potential difference between two points and is connected in parallel.

16. Both meters can be used to monitor a circuit where a source of electrical energy is being used to do work in a load.

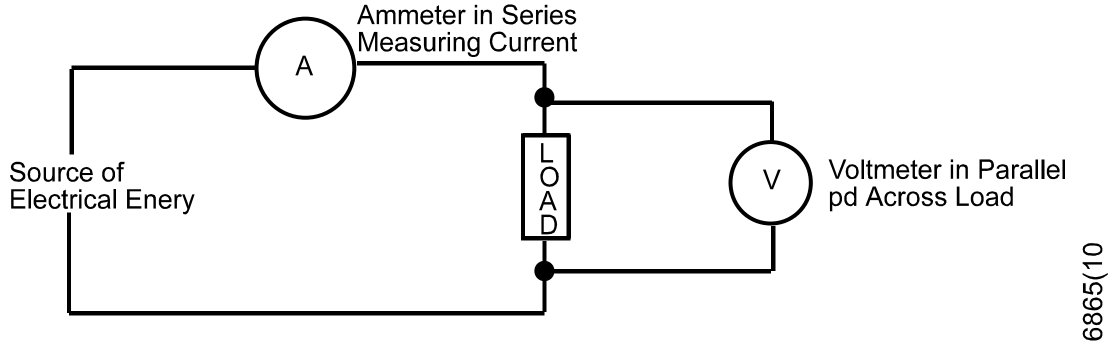


Figure 6

CIRCUITS

17. For current to flow there must be a continuous conducting path. Any break in that path, whether intentional (switch) or unintentional (fault) prevents current flow and is called an open circuit:

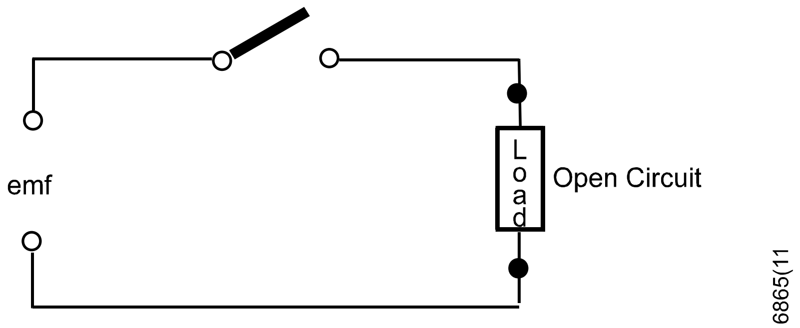


Figure 7

18. Work is done in the load when current flows through it. Current flows due to potential difference. If a wire is connected in parallel to the load there is no pd across the load, and therefore no current through it. This is called a short circuit:

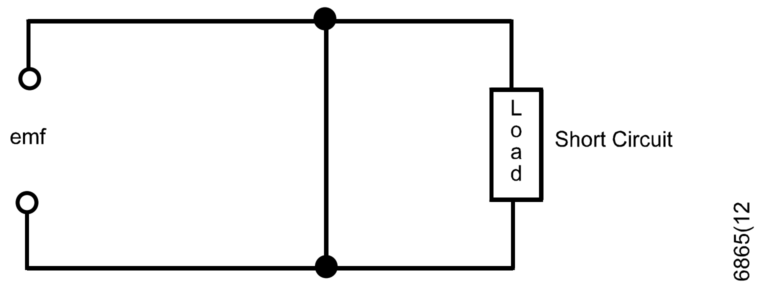


Figure 8

MULTIPLES AND SUB-MULTIPLES OF UNITS

19. There are many instances where the basic unit is unsuitable as a statement of quantity. It is often necessary to express quantities in multiples and sub-multiples of the basic units. The following are the most common quantities with their significances and symbols:

Unit	Significance	Index	Symbol	Examples
kilo	× 1000	10^3	k	kV, kΩ
mega	× 1000 000	10^6	M	MV, MΩ
giga	× 1000 000 000	10^9	G	GV, GHz
milli	÷ 1000	10^{-3}	m	mV, mA
micro	÷ 1000 000	10^{-6}	µ	µV, µA
nano	÷ 1000 000 000	10^{-9}	n	nV, nA
pico	÷ 1000 000 000 000	10^{-12}	p	pV, pA

20. Examples: Express the following electrical quantities into the appropriate multiples and sub-multiples.

a. 2500 milliamperes into amperes. ....

b. 775 kilovolts into megavolts. ....

c. 0.0012 kilohms into ohms. ....

d. 14820 microhms into milliohms. ....

e. 0.008 megavolts into kilovolts. ....

f. 0.0012 millicoulombs into microcoulombs ....

g. 0.0000128 amperes into microamperes ....

h. 4151 millivolts into volts ....

RESISTANCE

21. Resistance is the opposition to current flow.

EFFECT OF RESISTANCE ON CURRENT

22. With a constant voltage applied to a circuit, the larger the resistance of the material in the circuit, the smaller is the current. Using the same voltage, the lower the resistance the greater is the current.

RESISTANCE SYMBOLS

23.

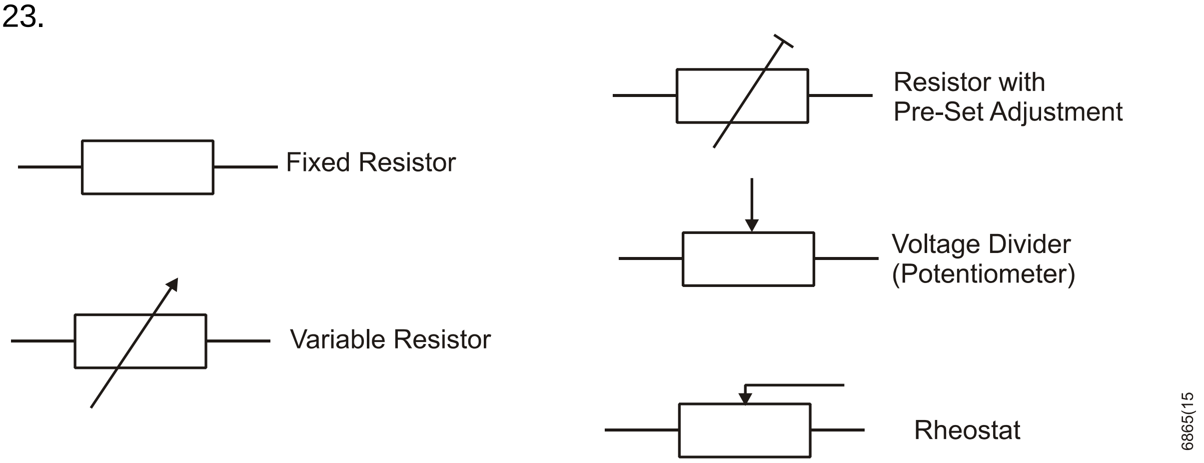


Figure 9

UNIT OF RESISTANCE

24. The unit of resistance is the ohm (symbol Ω). A circuit has a resistance of 1 ohm if an applied voltage of 1 volt produces a current of 1 ampere in the circuit.

RESISTIVITY

Specific Resistance or Resistivity

25. The factors affecting the resistance of a conductor of given material at constant temperature, are:

a. Material. Resistance depends upon conductor material.

b. Length. (ℓ) Resistance is directly proportional to ℓ.

c. Cross Sectional Area (A). Resistance is inversely proportional to A.

26. At steady temperature $R \propto \frac{\ell}{A}$. Different materials have different values of resistance per given volume. This property is called specific resistance or resistivity and has the symbol ρ. Hence:

$$R = \frac{\rho\ell}{A}\text{ohms}$$

27. If ρ, ℓ and A are measured in SI units, then R will be calculated in ohms. The SI unit for ρ is the Ω-m.

TYPICAL VALUES OF SPECIFIC RESISTANCE

28. Typical values of ρ at 0°C are:

Silver	1.5	10^{-8}	Ω-m
Copper	1.6	"	"
Aluminium	2.5	"	"
Manganin	41	"	"
Carbon	7000	"	"

29. **Examples**:

Calculate the resistance of 2 metres of copper wire with 1 mm^2 cross-sectional area.
(Ans. 0.032 ohms).

RESISTIVITY EXAMPLES

EXAMPLES

Find the resistance of 8 km of copper wire if its area of cross section is 0.032 sq cm and its specific resistance is $1.6 \times 10^{-8}\ \Omega m$.

A length of wire has a resistance of 23 ohms. Find the resistance of a piece of wire of the same material having twice the length and half the cross sectional area.

A piece of cable 120 metres long has a cross sectional area of 0.15 cm^2. Find the resistance of the cable. Assume the resistivity to be $2.5 \times 10^{-8}\ \Omega m$.

A coil is made from 300m of insulated copper wire. If the resistance is 2.4 ohms, calculate the cross sectional area of the wire. The resistivity of copper may be taken as $1.6 \times 10^{-8}\ \Omega m$.

TEMPERATURE COEFFICIENT OF RESISTANCE

Effect of Temperature on Materials

30. a. The resistance of a material depends upon its temperature.

b. For most metallic conductors there is an increase in resistance for an increase in temperature.

c. There are certain materials that have a decrease in resistance with increase in temperature. For example: carbon, electrolyte, semi-conductors and insulators.

31. Typical graphs of resistance against temperature for different materials:

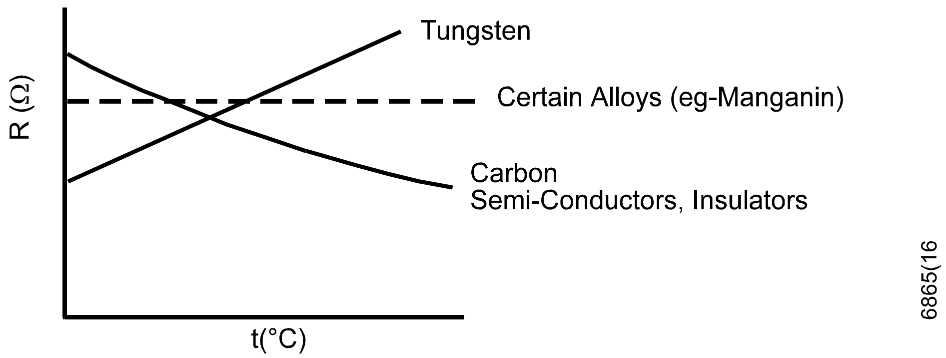


Figure 10

RESISTORS

Resistor Construction (For Reference only)

32. The most common resistor types are:

a. **Carbon Composition**. A mixture of powdered carbon and an insulating filler material are bound together by resin and moulded into shape. The resistor value depends upon the proportion of carbon in the mixture. Resistance values range from two or three ohms to about one hundred megohms and wattage ratings from about $^{1}/_{10}$W to 3 W. It is the cheapest and most widely used resistor type. The temperature stability can be improved by encasing the resistor in ceramic.

b. **Carbon Film.** A hard carbon film is deposited on a ceramic rod and the required resistance obtained by cutting a spiral track through the film; the rod is then varnished or encased in another ceramic tube. They have a higher stability than the carbon composition type, but are only suitable for use at fairly low working voltages (less than about 350 V).

c. **Metal Oxide.** A coating of tin oxide is deposited on a glass or ceramic rod. The required resistance is then cut and protective coating applied. These have higher stability than the carbon types and are now often used in military quality equipments.

d. **Thick Film.** These miniature resistors are made by printing a special resistive ink on a ceramic substrate. The result is a highly stable resistor which can be made to very close 'tolerances'. Although slightly dearer than the other types they are used in high quality equipments.

e. **Wirewound.** A resistive wire element, usually of nichrome, is wound on a ceramic former. Service types of resistor are coated with vitreous enamel to protect the wire from oxidation and to increase the surface area to improve heat dissipation. These resistors have high stability and can be made to very close tolerances. Their disadvantages are high cost and large size and they can become very hot.

33. Due to these various methods of construction, the actual size of a resistor is no indication of its resistance value. The actual sizes of resistors (all ½ w rated) are shown below:

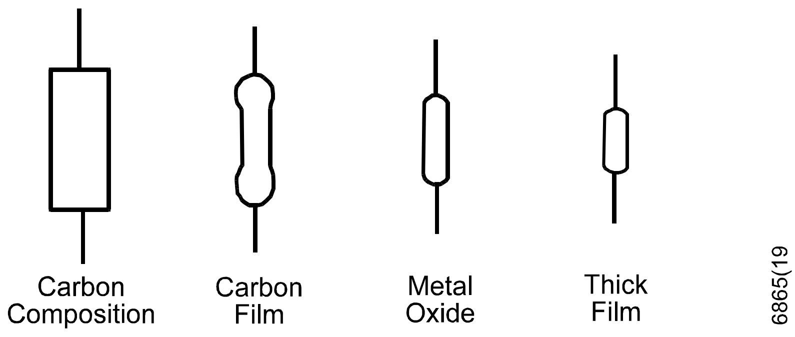


Figure 11

Resistor Codes

34. Because resistor size does not give any clue to its resistance value, this value must be marked on individual components. This is often accomplished by using, for convenience, a form of coding. Two codes are currently used to indicate resistor values; a colour code and a numerical code. The following codes are reproduced from British Standards Institution BS 1852: 1975 and 1EC 62: 1974.

Resistor Colour Code

35. The colour code method of marking resistor values is shown at figure 13.

Alpha Numeric Code-Resistors

36. In this code the numbers are printed on the body of the resistor to indicate its value. In addition, letters are used to indicate the multiplying factor (eg MΩ) and the tolerance, as shown below:

Multiplying Factor			Tolerance%	
$\times 1$	R	Ω	0.1 - B	5 - J
$\times 10^3$	K	kΩ	0.25 - C	10 - K
$\times 10^6$	M	MΩ	0.5 - D	20 - M
$\times 10^9$	G	GΩ	1.0 - F	30 - N
$\times 10^{12}$	T	TΩ	2 - G	

The position of the multiplying letter is also used to indicate the decimal point position:

eg: 470 R = 470 Ω

4R7 = 4.7 Ω

4K7 = 4.7 kΩ

R47 = 0.47 Ω

The tolerance letter is added on the end:

eg: 1M5 B = 1.5 MΩ ± 0.1%

2K2 N = 2.2 kΩ ± 30%

Preferred Value Resistors

37. In practical electrical circuits the precise value required for a resistor is not critical. It is more economic to produce large tolerance resistors than low tolerance ones. The number of resistor values required to cover a given range of resistance depends on the tolerance of the resistors being used. An example of resistor Preferred Values for 10% is given at figure 12.

38. Notice that the upper and lower tolerance resistance limits of each preferred value cover the complete range:

eg: 2.2 k ± 10% = 1.98 to 2.42

2.7 k ± 10% = 2.43 k to 2.97 k

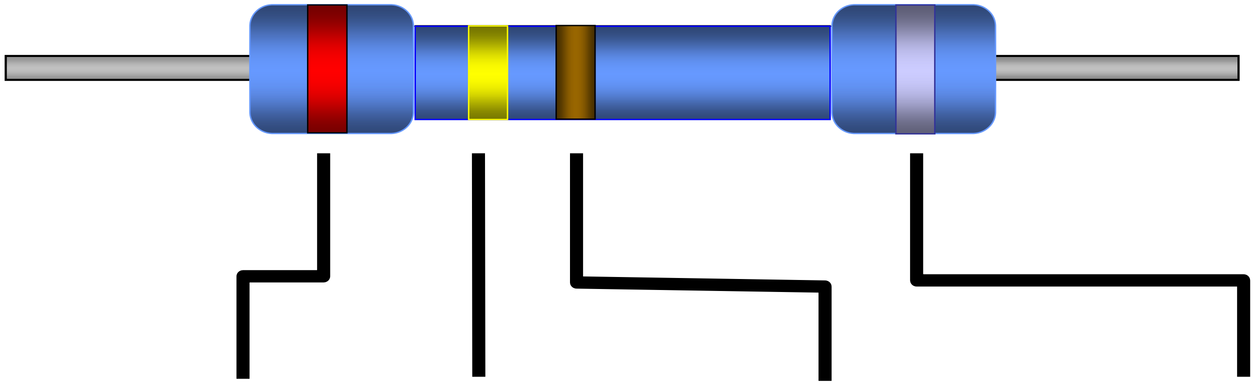
3.3 k ± 10% = 2.97 k to 3.63 k

1	10	100
1.2	12	120
1.5	15	150
1.8	18	180
2.2	22	220
2.7	27	270
3.3	33	330
3.9	39	390
4.7	47	470
5.6	56	560
6.8	68	680
8.2	82	820

Figure 12 - Nominal Resistance Values (10% Tolerance)

Resistor Colour Code

4 band resistor **240 Ω** *+/- 10%*



Colour	1st Band	2nd Band	Multiplier	Tolerance
Black	0	0	x 1 Ω	
Brown	1	1	x 10 Ω	+/- 1%
Red	2	2	x 100 Ω	+/- 2%
Orange	3	3	x 1K Ω	
Yellow	4	4	x 10K Ω	
Green	5	5	x 100K Ω	+/- 5%
Blue	6	6	x 1M Ω	+/- 25%
Violet	7	7	x 10M Ω	+/- .1%
Grey	8	8		+/- .05%
White	9	9		
Gold			x .1 Ω	+/- 5%
Silver			x .01 Ω	+/- 10%

RESISTOR CODES

CLASSWORK EXAMPLES

Determine the value and tolerance of the following coded resistors:

Colour Code

Bands	**1st**	**2nd**	**3rd**	**4th**	
1	Red	Red	Red	None	
2	Yellow	Violet	Silver	Silver	
3	Brown	Black	Green	Red	± %
4	Grey	Red	Brown	Gold	± %
5	Orange	Orange	Orange	None	± %
6	Green	Blue	Black	Gold	± %
7	Blue	Grey	Yellow	Brown	± %
8	Red	Violet	Gold	Silver	± %
9	Brown	Black	Red	None	± %
10	Red	Green	Yellow	Red	± %

SELF-ASSESSMENT QUESTIONS

1. What is a:

   a. positive ion?

   b. negative ion?

2. If the nucleus of an atom has 10 protons and 10 neutrons, how many electrons will it have?

3. How does electron current differ from conventional current?

4. What is the unit of potential difference and what instrument is used to measure it?

5. A current of 4 amperes is maintained for 2 seconds. How much charge is transferred?

6. An ammeter and voltmeter are to be used to monitor a load. How are they connected?

7. Express:

   a. 250 µA in mA.

   b. 1 kHz in Hz.

   c. 5000 MV in µV.

8. What is the effect on current in a load of:

   a. An open circuit in the supply line?

   b. A short circuit across the load?

9. What factors affect resistance?

10. A length of wire has a resistance of 100 ohms. Find the resistance of a piece of wire of the same material having half the length and twice the cross sectional area.

11. What is the effect of an increase in temperature on the resistance of carbon?

12. What is the symbol for a variable resistor?

13. A resistor is marked 3k3 M. What does this mean?

14. A resistor is colour coded green/blue/orange/red. What does this mean?

Notes:

CHAPTER 2
RESISTIVE CIRCUITS

KLPs

Av01.01.02.02 Describe the relationship between voltage, current and resistance.

Av01.01.02.03 Describe Kirchoff's laws of current and voltage.

Notes:

OHM’S LAW

1. At constant temperature the current (I) in a conductor is directly proportional to the applied voltage (V).

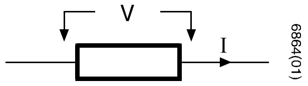


Figure 1

$I \propto V$
or $I = \text{constant} \times V$

2. The constant is $\frac{I}{R}$:

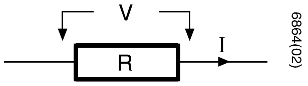


Figure 2

Current (I) = $\frac{I}{R}$ x voltage (v) or……
Volts = amps × ohms

3. Ohm’s Law may be expressed in three forms:

$V = IR$

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

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

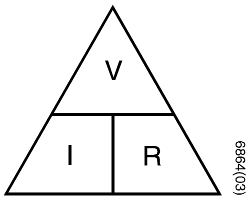


Figure 3

Notes:

1. Ohm’s Law and all the work in this module apply equally to dc or ac circuits.

EXAMPLES - OHM'S LAW

a. A conductor has a resistance of 60 ohms. The voltage across it is 12 V. Calculate the current in mA.

b. A 12 V battery produces a current of 2 A in a lamp. Calculate the resistance of the lamp.

c. The pd across a resistor of 5 kΩ is 250 V. Calculate the current in mA.

d. Calculate the voltage required to produce a current of 10 mA in a resistance of 5 kΩ.

e. An electric fire for use with a 240 V supply takes a current of 8 A. Calculate the resistance of the element.

f. A voltage of 4000 V produces a current of 2 mA in a circuit. Calculate the resistance of the circuit in MΩ .

g. A lamp of resistance 625 Ω is connected to a 250 V rms supply. Calculate the current in mA.

h. A pd of 12 V is connected to a circuit. If the pd is increased to 18 V, the circuit current increases by 2 A. Calculate the circuit resistance.

PRACTICAL – INVESTIGATING OHM'S LAW

Objectives

4. To find the relationship between the voltage and current, in a dc circuit, with constant resistance.

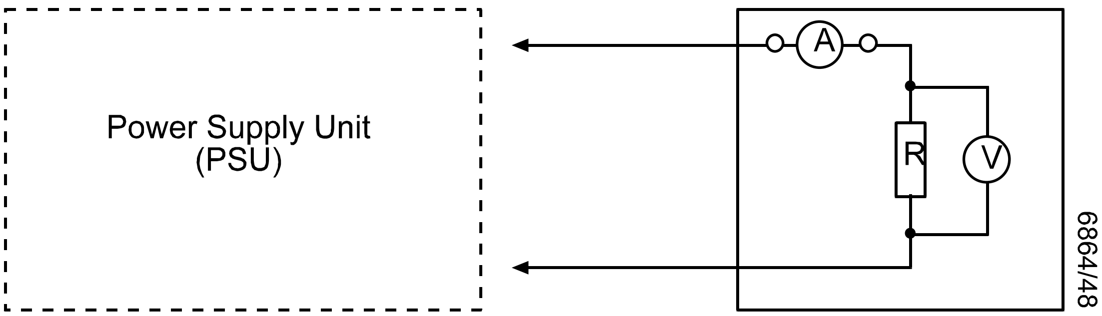
5. To plot a graph of the variation of current with voltage.

6. To study the significance of the slope of the graph.

Apparatus

Item	Rating	Description
Resistor	1 kΩ ± 1%	Loctronics
Resistor	2.2 kΩ ± 1%	} Equipment
Voltmeter	V dc	Fluke Multimeter
Ammeter	mA dc	Fluke Multimeter

Table 1



Laboratory Supply Panel **Loctronics Board**

Figure 4

7. **Method**

a. Check that the supply panel is 'OFF'.

b. Turn the PSU voltage control anti-clockwise.

c. Connect the circuit as shown, in figure 4, using the 1 kΩ resistor.

d. Switch 'ON'.

e. Slowly rotate the PSU voltage control clockwise until ammeter reads 2 mA and then record the voltage, across the 1 kΩ resistor, in Table 2.

f. Take a voltage reading at each current value indicated in Table 2.

g. Reduce current to zero and switch ‘OFF’.

h. Disconnect the 1k resistor and replace it with the 2.2 kΩ resistor.

i. Repeat items e and f above, then switch ‘OFF’.

j. Plot voltage against current, on the graph provided in figure 5, for both resistors.

k. Calculate the resistance of each resistor by using $R = \frac{V}{I}$ and record the results in Table 2.

	1 kΩ					2.2 kΩ				
I (mA)	2	4	6	8	10	2	4	6	8	10
V (volts)										
$\frac{V}{I}$ (Ω)										

Table 2

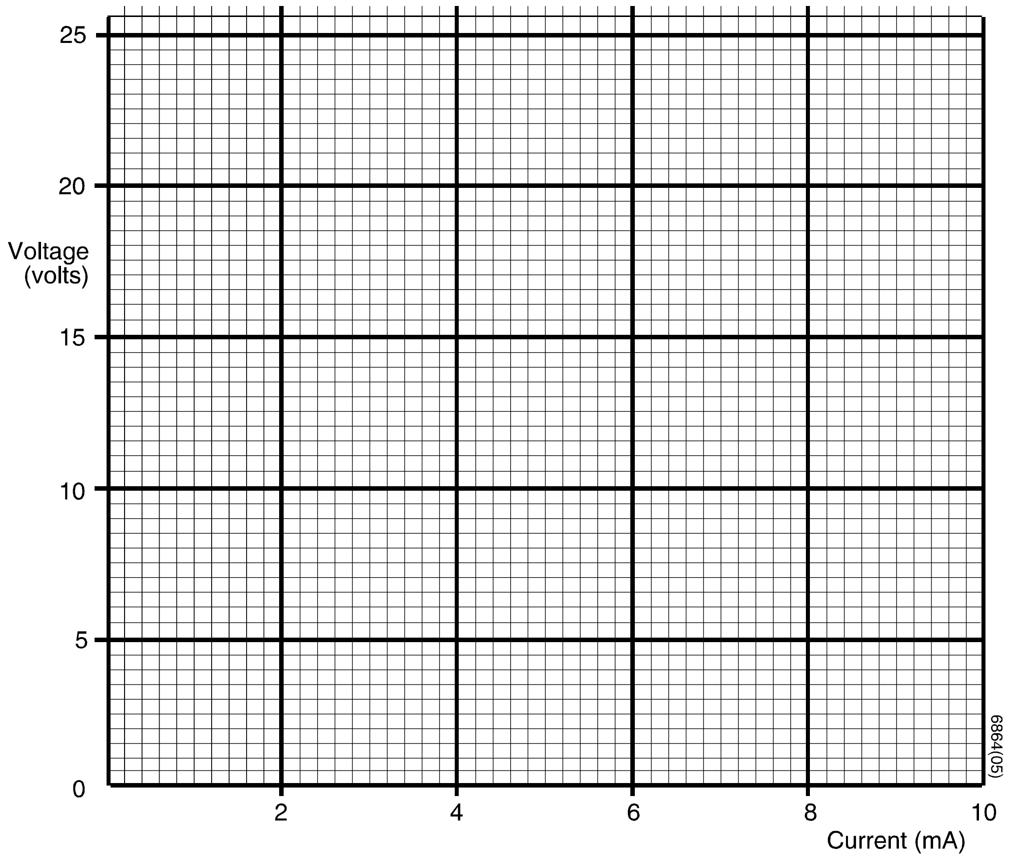


Figure 5

CONCLUSIONS

8. Calculate the slopes of the graphs, eg:

$$\text{Slope} = \frac{\text{change of V}}{\text{change of I}}$$

Comment upon the significance of the results, compared with calculated values of resistance:

____

____

9. State the relationship between V and I ________________________________

SERIES CIRCUITS

10. In a series circuit the same current flows through each resistor. The voltage drop across each resistor is directly proportional to its resistance. The resistance between the ends of the circuit, R_T, is the sum of the individual resistances.

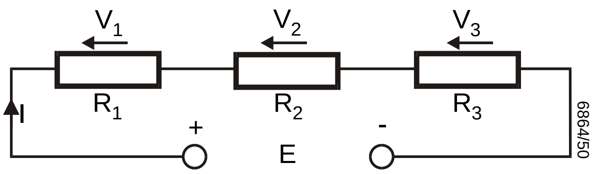


Figure 6

$E = V_1 + V_2 + V_3$

$IR_t = IR_1 + IR_2 + IR_3$

$R_t = R_1 + R_2 + R_3$

11. Example. Calculate the supply current I and the voltage drop across each resistor:

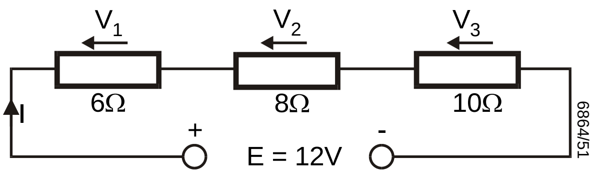


Figure 7

$I = \frac{V}{R_T}$ and $R_T = 6 + 8 + 10 = 24\ \Omega$

$E = 12\text{ V} \therefore\ I = \frac{12\text{ V}}{24\,\Omega} = 0{\cdot}5\text{A}$

$V_1 = I \times R_1$

$V_1 = 0.5 \times 6 = 3\text{ V}$

$V_2 = I \times R_2$

$V_2 = 0.5 \times 8 = 4\text{ V}$

$V_3 = I \times R_3$

$V_3 = 0.5 \times 10 = 5\text{ V}$

Check $E = V_1 + V_2 + V_3 = 12\text{ V}$ (the supply voltage)

12. **Examples - Series Circuits**. For the circuits below, calculate:

a. The total resistance across the supply terminals.

b. The supply current.

c. The voltage drop across each resistor.

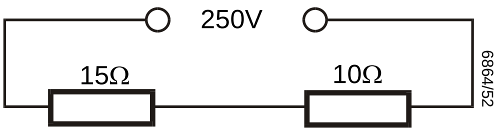


Figure 8

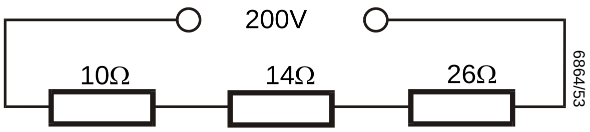


Figure 9

13. An ammeter of resistance 0·2 Ω is connected in series with a 1 Ω resistor across a 12 V supply:

a. Draw the circuit diagram.

b. What is the current taken from the supply?

c. What is the voltage drop across the ammeter?

d. What would be the current if the ammeter were short-circuited?

PRACTICAL - RESISTORS IN SERIES

Objectives

14. To use the resistor colour code.

15. To study the distribution of voltage in a series circuit.

16. To verify the expression for total resistance of resistors in series.

Apparatus

Item	Rating	Description
Fluke Multimeter Resistors	Resistance Various	Loctronics Equipment

Table 3

Method

17. a. Locate the resistors in Table 4 and confirm their stated value by the colour code.

Resistor Value (Stated)	R_1	R_2	R_3	R_4	R_5	R_6
	220 Ω	680 Ω	1 kΩ	2.2 K	6.8 K	10 K

Table 4

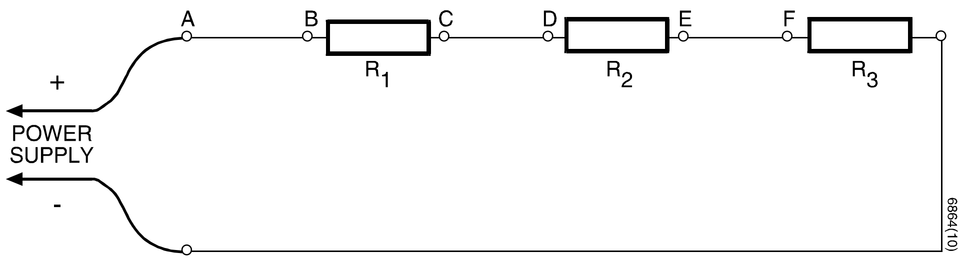


Figure 10

b. Construct the circuit using resistors R1, R2 and R3.

c. Calculate the total resistance and record the value into table 5.

d. Using the multimeter, measure the individual resistance values (R1, R2 and R3) and the total resistance of the circuit, then record your results in table 5.

e. Set the power supply to 12v and ensure the voltage is correct by checking with the multimeter.

f. Switch off the power supply.

g. Calculate the circuit current using the measured value of resistance from table 5.

h. Replace link A-B with the multimeter set to read mA.

i. Switch on the power supply and note the reading on the multimeter.

j. Repeat steps f to I for links C-D and E-F. What do you notice about the current readings?

k. Record the measured current value in table 5.

l. Calculate the voltage across each resistor using the values from table 5. Record the values in table 5.

m. Measure the voltage across each resistor and record your readings in table 5.

n. Add the three readings together. What do you notice about the answer?

o. Now add together the calculated values of voltage across any two adjacent resistors.

p. Measure the voltage across the two resistors. What do you notice about the result?

q. Switch off the power supply and replace R1, R2 and R3 with R4, R5 and R6.

r. Repeat the experiment, recording your results in table 6.

	R_1	R_2	R_3	R_{TOTAL}	I	V_1	V_2	V_3
Calculated Values	X	X	X					
Measured Values								

Table 5

	R_4	R_5	R_6	R_{TOTAL}	I	V_1	V_2	V_3
Calculated Values	X	X	X					
Measured Values								

Table 6

EARTHING

18. **Introduction**. Most (but not all) electrical systems incorporate an EARTH. An electrical earth may be the ground we stand on, or the metal skin of an aircraft, a conductor from a transformer or the bodywork of a car. Whatever the system, the earth voltage is taken as zero volts. The symbol for an earth is:

19. The purpose of earthing depends upon the electrical system. In particular, the use of earths is quite different in high-voltage ac and low-voltage dc systems. These notes are a brief introduction. Electrical earths in high-voltage ac systems will be covered in detail later in this course.

AC SYSTEMS

20. For lethal ac voltages, such as the domestic 230 V supply, an earth is provided for electrical safety. The earth is not part of the load circuit and will carry current only when there is an electrical fault.

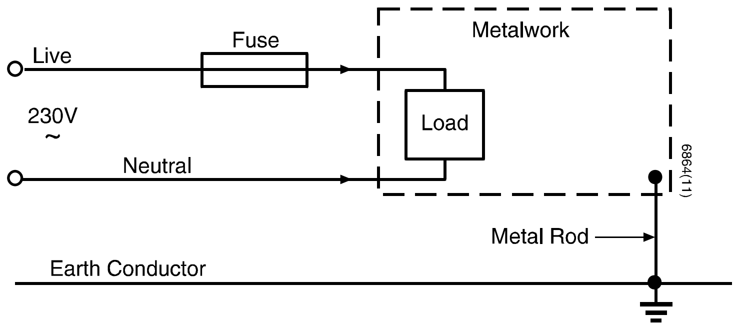


Figure 11

Figure 12 shows a typical domestic ac supply with the exposed metal work of electrical equipment (such as the metal frames of cookers, washing machines and heaters) bonded to the earth conductor. If there is an electrical fault and the metal work becomes ‘live’, the large fault current flowing to earth should ‘blow’ the fuse and disconnect the supply. The earth conductor should be literally at ‘earth potential’, being connected to the ground by a metal rod.

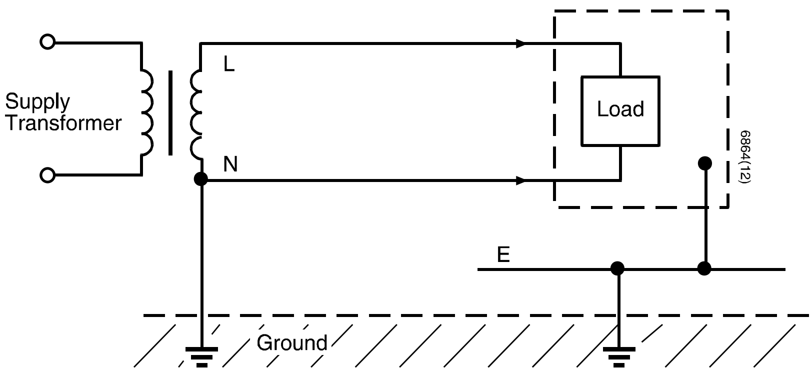


Figure 12

In many ac systems a separate earth conductor is used, the conductor being connected to the supply transformer.

DC SYSTEMS

21. Most dc electrical systems at low voltages, such as 12 V for cars and 28 V for most aircraft systems. An earth is not required for electrical safety. The metal skin of the aircraft or the car body can be used as part of the electrical load circuit, saving almost half of the electrical conductors.

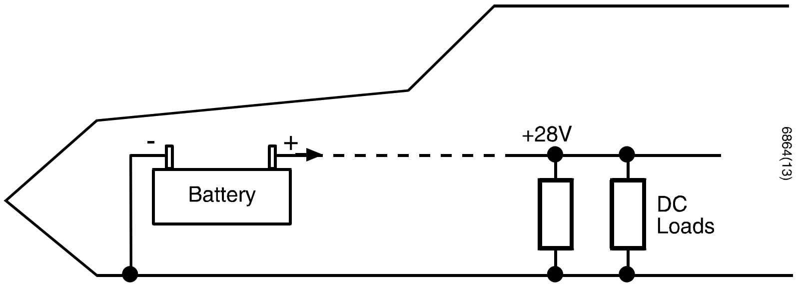


Figure 13

22. The metalwork is often called the 'earth return', though it may not be at local earth potential (and will certainly not be, in the case of an aircraft in flight). The so-called 'earth' is just part of the load circuit, its function is not electrical safety. It is normal practice to 'earth' the negative terminal of the supply.

AIRCRAFT

23. It should be stressed that electrical earthing practices differ between aircraft. The relevant documentation must be consulted for each aircraft type.

VOLTAGES WITH RESPECT TO EARTH

24. The examples below show resistor loads connected to supplies. Some circuits show voltages with respect to earth (wrt E), determine the other voltages wrt E as an exercise.

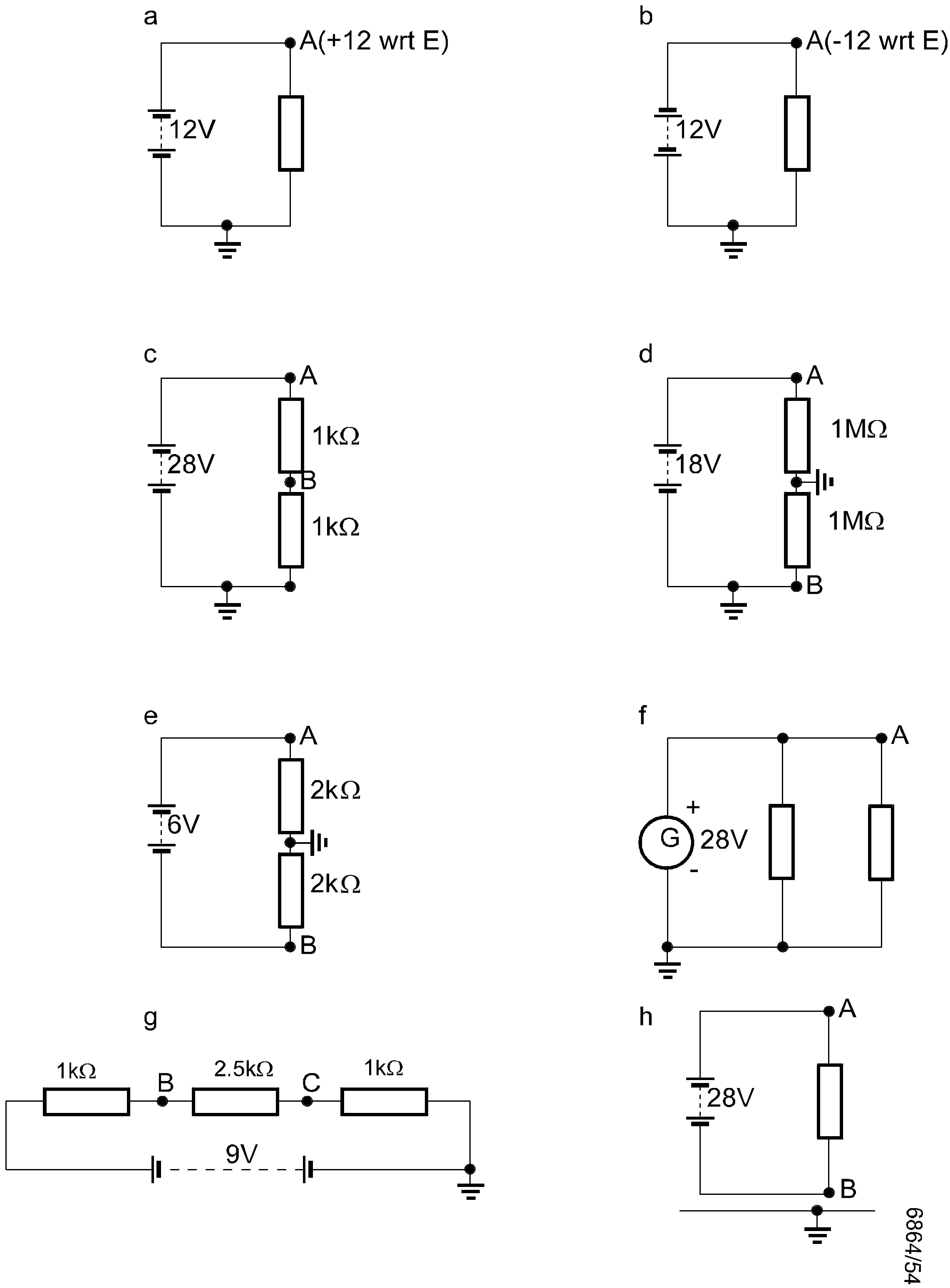


Figure 14

PRACTICAL – VOLTAGES WITH RESPECT TO EARTH

OBJECTIVE

25. To investigate the effects of an earth connection on the voltages within a potential divider network.

Apparatus.

Farnell dual power supply unit
Fluke multimeter
Locktronics board and components. (Links and resistors 2.2 k, 6.8 kΩ and 10 kΩ)

Method.

Record all results in the spaces provided

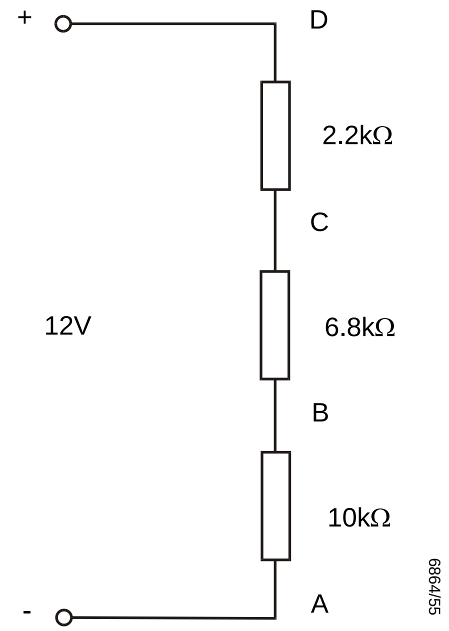


Fig. 15

a. Measure the resistance of each resistor:

2.2 kΩ = ... 6.8 kΩ = ... 10 kΩ = ...

b. Measure the total resistance of the resistors: R_T = ……………….

c. Calculate the circuit current: I = …………………

d. Calculate the voltage across each resistor:

$V_{2.2\,k\Omega}$ = ... $V_{6.8\,k\Omega}$ = ... $V_{10\,k\Omega}$ = ...

e. Set the power supply to 12V and verify the setting with the multimeter.

f. Construct the circuit as shown at fig. 15 above. Switch the power supply on and measure the voltage at points B, C and D with respect to point A. Comment on your results.

V_B = …………….. V_c = …………….. V_D = ……………..

Comments:

g. Switch off the power supply. Without disconnecting the circuit from the supply connect point A to the earth connection of the power supply. Repeat item f. Record your results and comment on them.

V_B = …………….. V_c = …………….. V_D = ……………..

Comments:

h. Switch off the power supply, move the earth connection to point B. Switch on the supply and measure the voltage at points A, C and D with respect to earth. Comment on your results.

V_A = …………….. V_C = …………….. V_D = ……………..

Comments:

i. Switch off the power supply, move the earth connection to point C. Switch on the supply and measure the voltage at points A, B and D with respect to earth. Comment on your results.

V_A = …………….. V_B = …………….. V_D = ……………..

Comments:

j. Switch off the power supply, move the earth connection to point D. Switch on the supply and measure the voltage at points A, B and C with respect to earth. Comment on your results.

V_A = …………….. V_B = …………….. V_C = ……………..

Comments:

k. Switch off the power supply, move the earth connection to any point on the Locktronics board that is not connected to the circuit. Switch on the supply and measure the voltage at points A, B, C and D with respect to earth. Comment on your results.

V_A = …………….. V_B = …………….. V_C = …………….. V_D = ……………..

Comments:

PARALLEL CIRCUITS

26. Parallel components connected across a voltage source have the same voltage applied to each component. The total supply current is the sum of the currents in each branch. The current in each branch is inversely proportional to the resistance in that branch, in accordance with Ohm's Law $\left(I = \frac{V}{R}\right)$.

$I = I_1 + I_2 + I_3$.

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\therefore \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

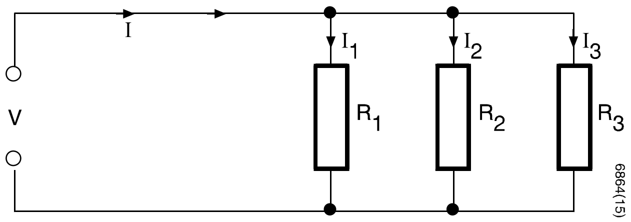


Figure 16

27. When just two resistors are connected in parallel the total equivalent resistance is given by:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 \times R_2}$$

$$\therefore \quad R_T = \frac{R_1 \times R_2}{R_1 + R_2}$$

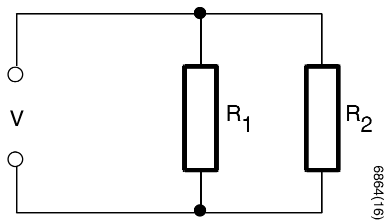


Figure 17

28. When two equal resistors are connected in parallel the equivalent resistance is one half of the value of one resistor.

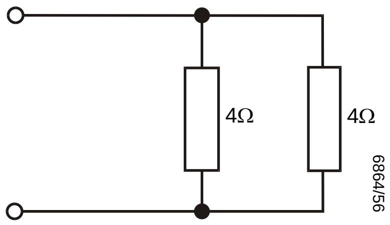


Figure 18

$R_T = 2\ \Omega$

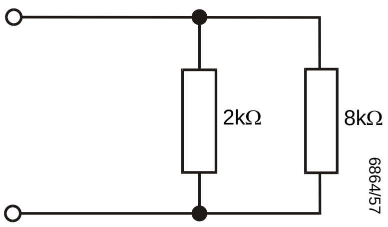


Figure 19

$$R_T = \frac{2x10^3 \times 8x10^3}{2x10^3 + 8x10^3} = \frac{16x10^6}{10x10^3} = 1.6K\Omega$$

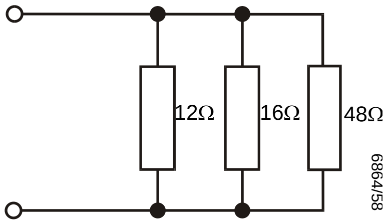


Figure 20

$$\frac{1}{R_T} = \frac{1}{12} + \frac{1}{16} + \frac{1}{48}$$

$$\frac{1}{R_T} = \frac{4+3+1}{48} = \frac{8}{48}$$

$$R_T = \frac{48}{8} = 6\,\Omega$$

CURRENT DIVISION

29. The current in each branch of a parallel circuit is INVERSELY proportional to the resistance in that branch.

Example. Determine the currents in the circuit below:

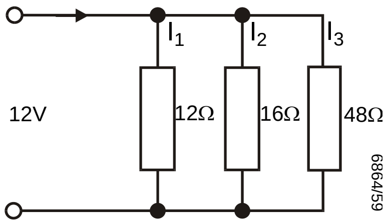


Figure 21

$$I_1 = \frac{12}{12} = 1\,\text{A}$$

$$I_2 = \frac{12}{16} = 0.75\,\text{A}$$

$$I_3 = \frac{12}{48} = 0.25\,\text{A}$$

$$I = I_1 + I_2 + I_3 = 2\,\text{A}$$

Check: in a previous example R_T was found to be 6 Ω, therefore:

$$I = \frac{V}{R_T} = \frac{12}{6} = 2\,\text{A}$$

EXAMPLES - PARALLEL CIRCUITS

a. Calculate the value of the equivalent resistance of the circuits below:

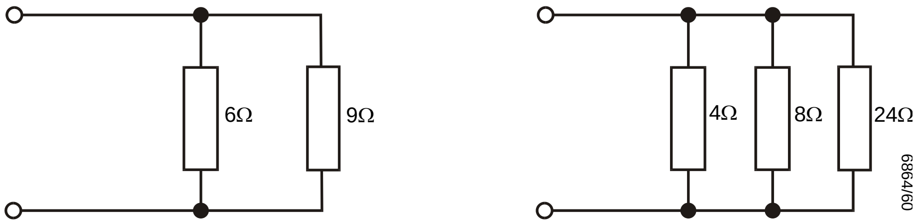


Figure 22

b. In the circuits shown below calculate:

(1) Total resistance.

(2) Current taken from the supply.

(3) Current in each resistor.

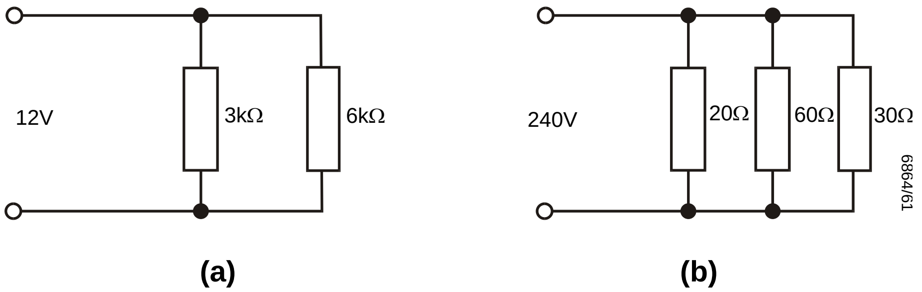


Figure 23

PRACTICAL - RESISTORS IN PARALLEL

Objectives

30. To study current division in a parallel circuit.

31. To prove the general formula for resistors in parallel:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} \text{ etc}$$

34. To confirm the $\frac{\text{product}}{\text{sum}}$ method of resistance calculation.

Apparatus

Item	Rating	Description
Fluke Multimeter	As required	
Resistors	As required	Loctronics

Table 7

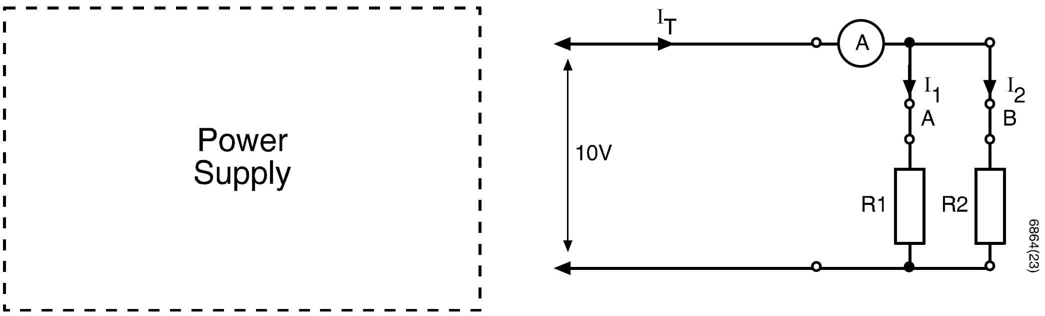


Figure 24

33. **Method**

a. Connect the circuit as shown in figure 24 and select 1 kΩ resistors for R_1 and R_2.

b. Switch ON power supply and adjust to 10 V.

c. Measure total current I_T and record in Table 8.

d. Switch OFF.

e. Disconnect the multimeter and replace it with a link.

f. Reconnect the multimeter in place of links A and B in turn to measure I_1 and I_2 and record in Table 8.

g. Disconnect the power supply and with the multimeter set to resistance range, measure and record the total resistance R_T in Table 8.

h. Replace R_1 and R_2 with 10k and 5k respectively and repeat b to g.

i. Complete calculations in Table 8:

	V	I_T measured	I_1	I_2	$I_T = I_1 + I_2$	R_T measured	$R_T = \frac{\text{product}}{\text{sum}}$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$
$R_1 = R_2 = 1\ k\Omega$	10 V							
$R_1 = 10\ k\Omega$ $R_2 = 5\ k\Omega$	10 V							

Table 8

Conclusions

34. Does the addition of I_1 and I_2 equal the supply current I_T? ________________

35. How do the calculated values of resistance compare with your Fluke measurements?

____

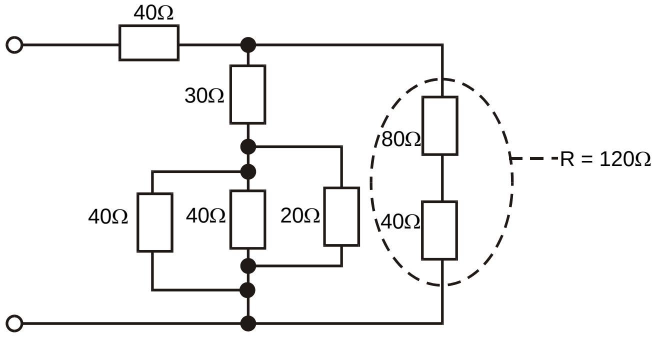
____

Select various other resistance combinations and carry out further experiments.

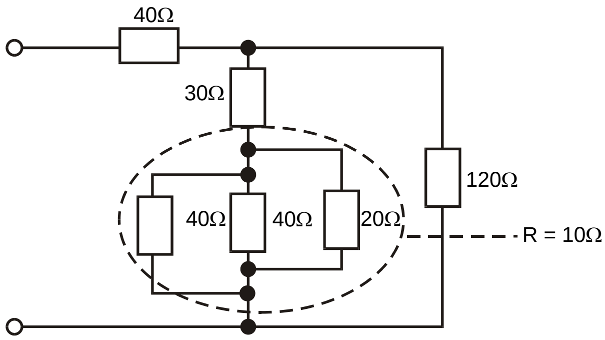
SERIES/PARALLEL CIRCUITS

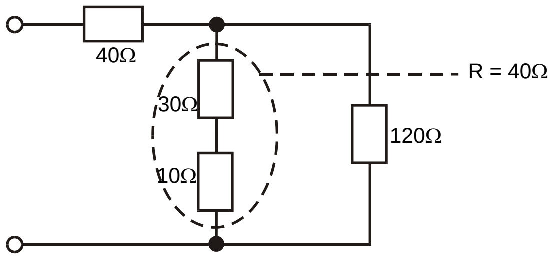
36. Complicated series/parallel circuits can be reduced to a single equivalent resistor by following a step-by-step sequence as shown in the example below:

Combine any series resistors

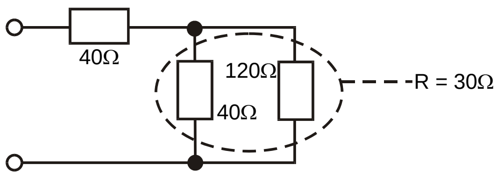


Then replace any parallel groups by single resistors





Continue the process of combining series groups then parallel groups . . . .



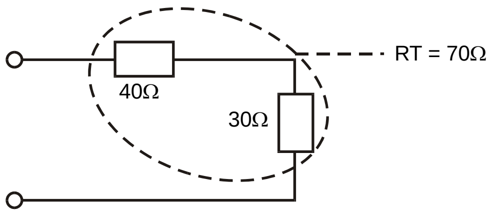


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Figure 25

EXAMPLES - SERIES/PARALLEL CIRCUITS

For each circuit below find the total equivalent resistance between the open terminals:

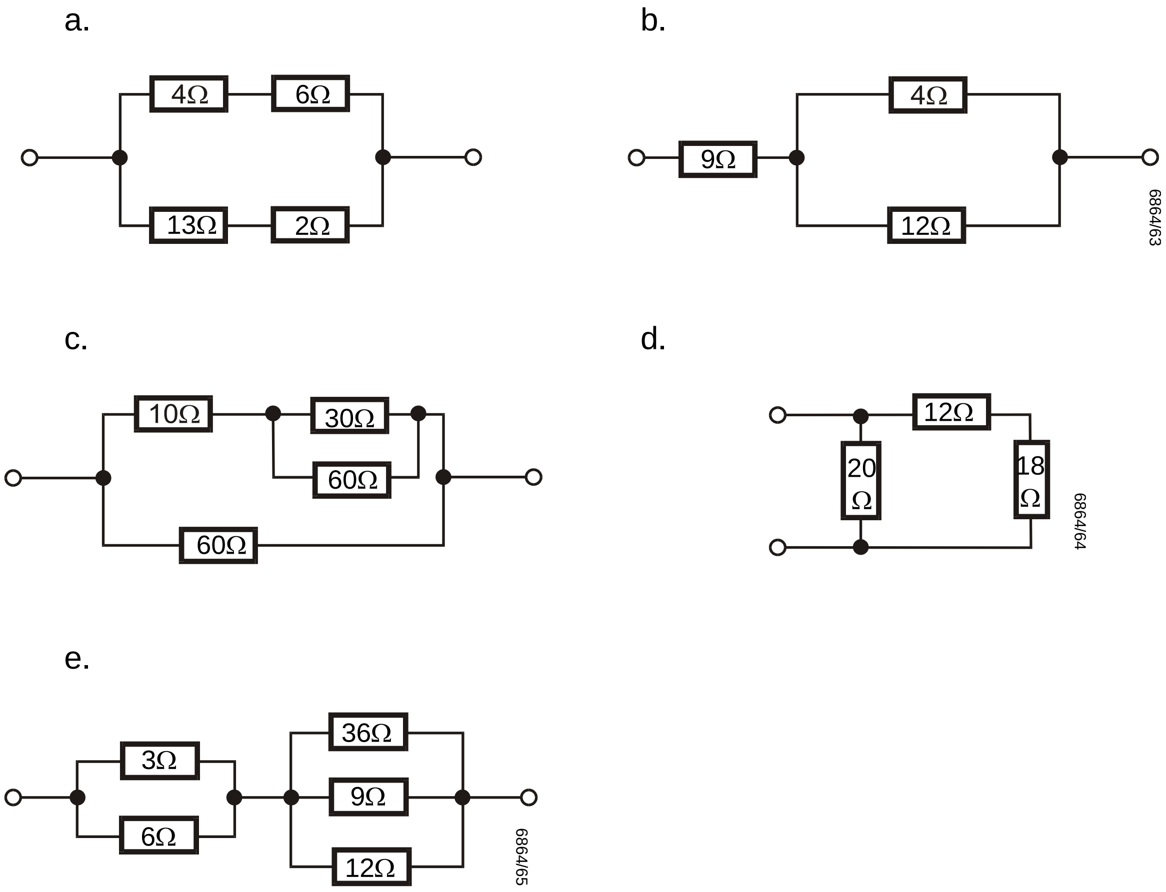


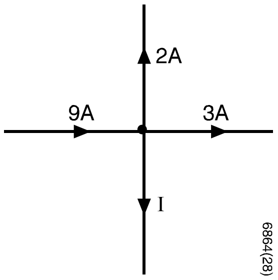
Figure 26

KIRCHHOFF'S LAWS

37. These two laws often assist in the solving of circuit problems. We have already used both laws in previous examples.

First Law: The total current flowing towards a circuit junction equals the total current flowing away from the junction.

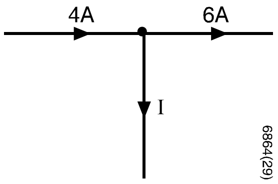
Example 1



$$\text{Current in} = \text{current out}$$
$$9 = 2 + 3 + I$$
$$\therefore \quad I = 4\text{ A}$$

Figure 27

Example 2

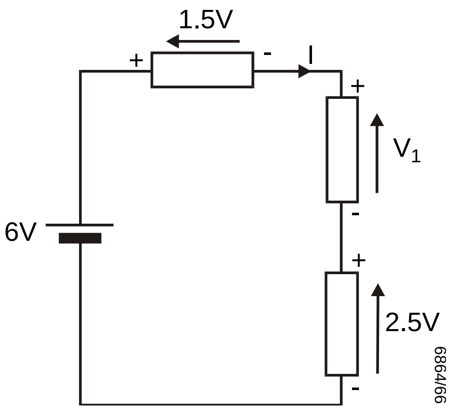


$$4 = 6 + I$$
$$\therefore \quad I = 4 - 6$$
$$I = -2\text{A}$$

Figure 28

Second Law: In any closed circuit, the algebraic sum of the applied voltages equals the algebraic sum of the voltage drops.

Example



$$\text{Applied voltages} = \text{voltage drops}$$
$$6\text{ V} = 1.5\text{ V} + V_1 + 2.5\text{ V}$$
$$\therefore \quad V_1 = 2\text{ V}$$

Figure 29

EXAMPLES OF KIRCHHOFF'S LAWS

Determine the current I in each circuit below:

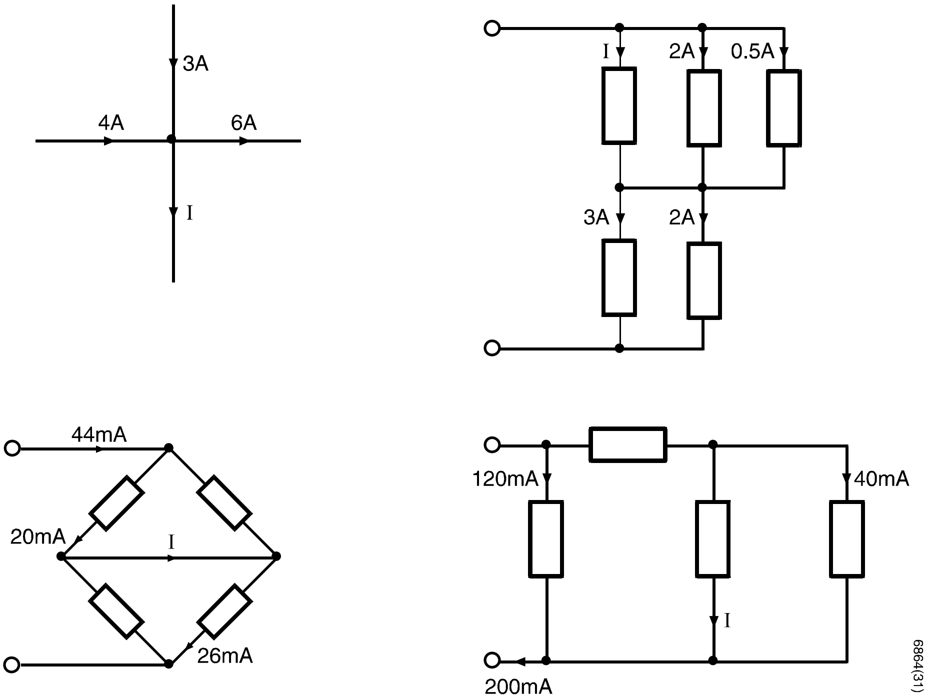


Figure 30

Use Kirchhoff's Laws to determine the voltage V in each circuit below:

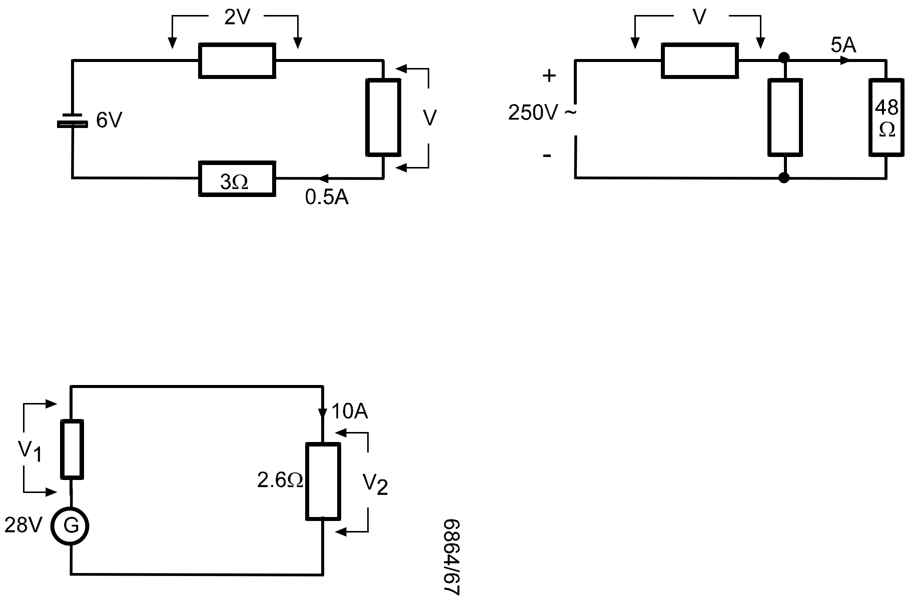


Figure 31

PRACTICAL- SERIES-PARALLEL RESISTOR COMBINATIONS

OBJECTIVES

38. To calculate and measure current and voltages in a series-parallel resistor circuit

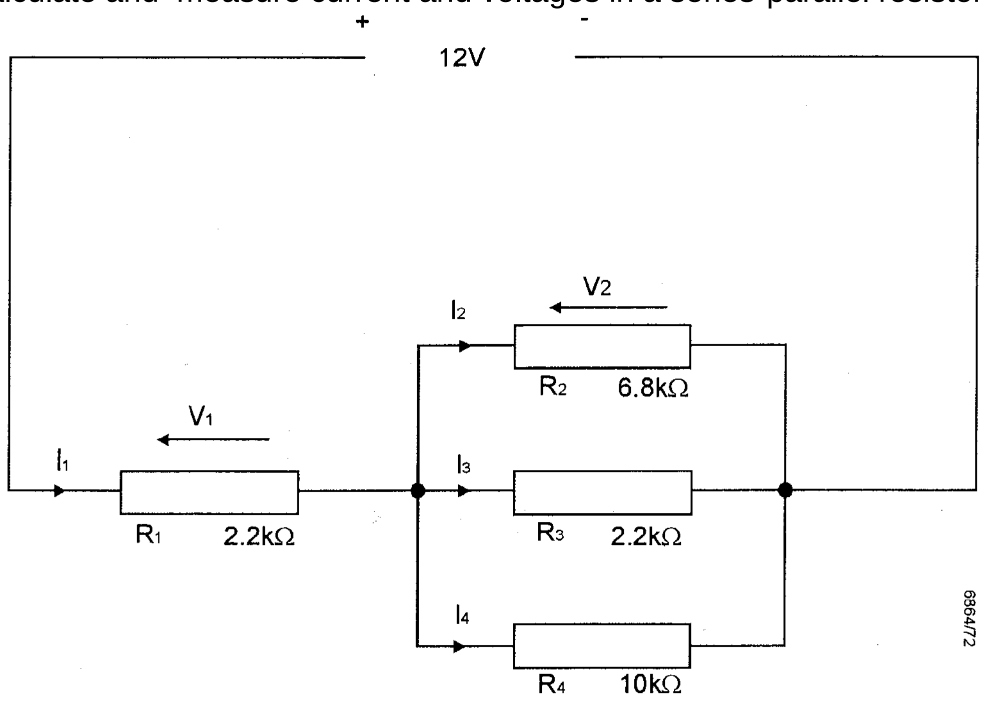


Fig. 32

39. **Method**

a. Measure the value of each resistor and record them in the table below.

b. Construct the circuit of Fig 32

c. Calculate currents I_1 to I_4 and voltages V_1 to V_4 and record your answers in table 9.

d. Switch the power supply on and adjust the output for 12V and verify the value with the multimeter.

e. Measure each of the currents in the circuit and record the values in table 9.

f. Measure each of the voltages in the circuit and record the values in table 9.

g. What do you notice about the currents in the parallel network and current I_1?

	R_1	R_2	R_3	R_4	I_1	I_2	I_3	I_4	V_1	V_2
Calculated Values	X	X	X	X						
Measured Values										

Table 9

VARIABLE RESISTORS

40. Variable resistors normally consist of a resistive element with a variable contact. The resistive element may be wire wound or consist of a track of carbon, high resistivity metal or conductive plastic.

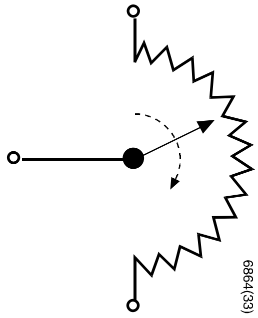


Figure 33

41. **Symbols**

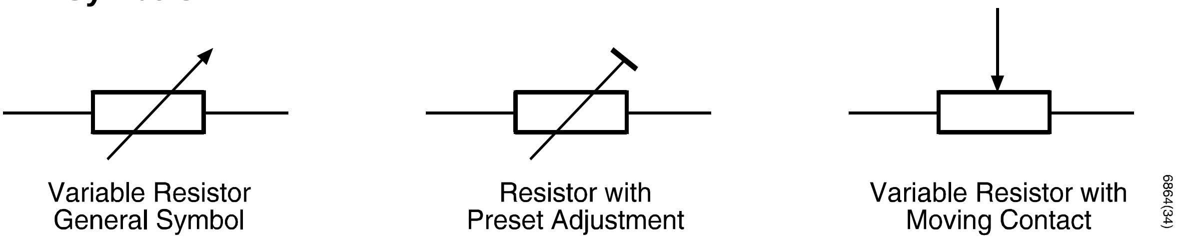


Figure 34

Variable resistors have many uses and are often known under alternative names according to how they are used in a circuit. The two main alternative names are explained below:

42. **Rheostat**. A variable resistor used as a two-terminal device to control the current in a load.

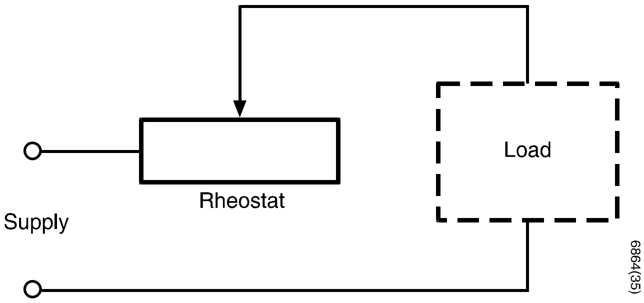


Figure 35

43. **Potentiometer.** A variable resistor used as a three-terminal device to control the voltage across a load.

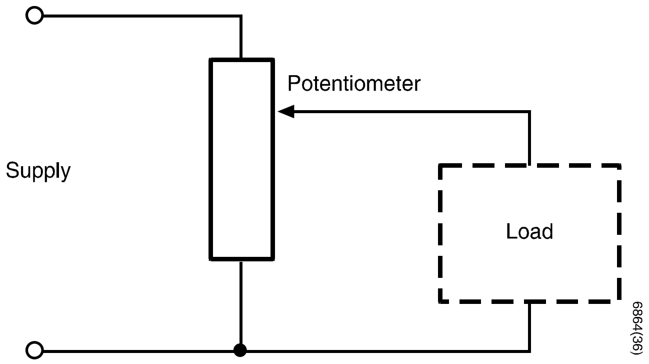
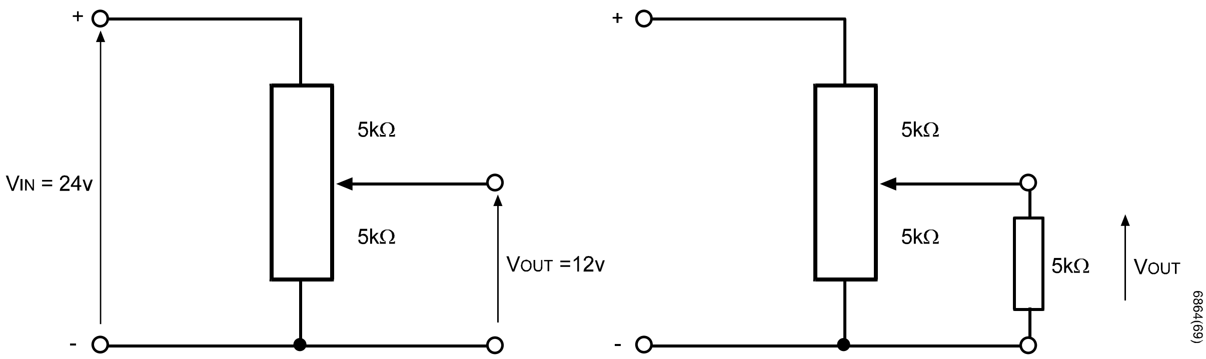


Figure 36

Note: When a load resistor is connected across a potentiometer (potential divider) the output voltage will tend to fall.

Consider:



(a) **(b)**

Figure 37

V_{out} will fall to 8 V because of the load paralleling with the lower part of the potentiometer and thereby reducing the output resistance.

In general we try to keep load resistance high to avoid loading effects.

EXAMPLES - VARIABLE RESISTORS

Calculate the maximum and minimum values of current **I** in the circuits shown below:

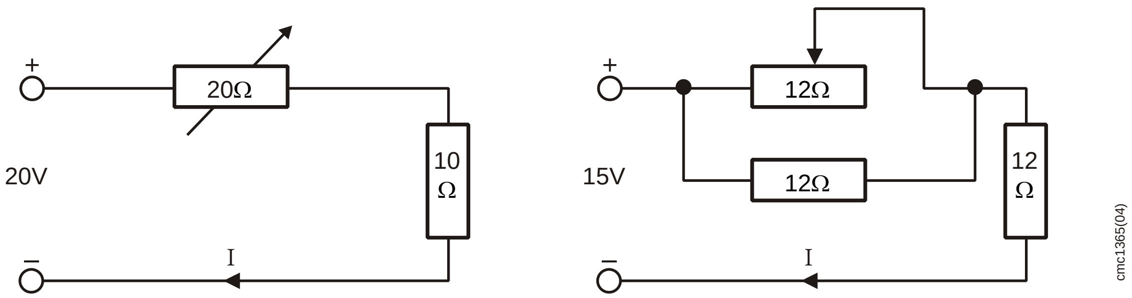


Figure 38

Calculate the maximum and minimum voltage across the 680 Ω resistors in the circuits below:

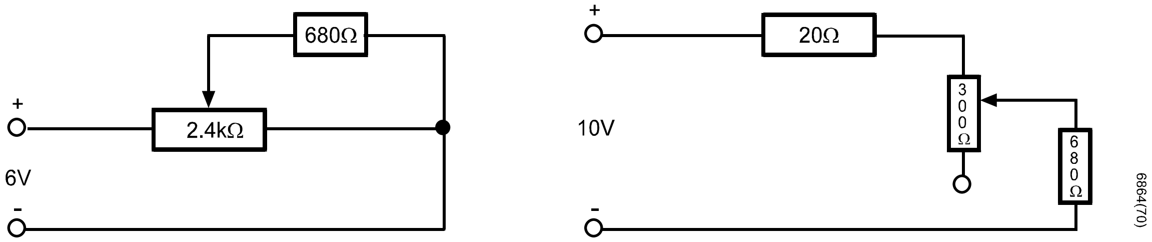


Figure 39

WHEATSTONE BRIDGE

44 The circuit below is known as a Wheatstone bridge. The bridge is said to be balanced when there is no voltage difference between the points X and Y.

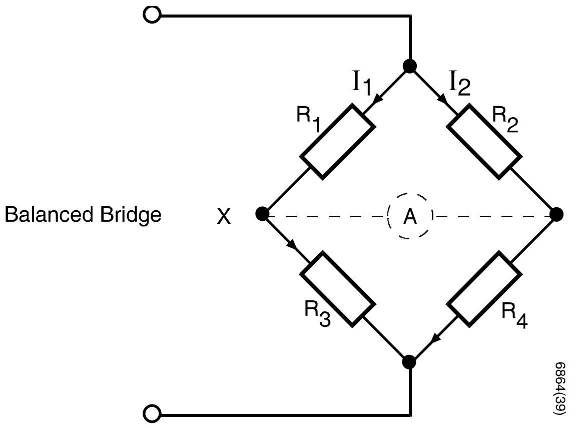


Figure 40

At balance:

$I_1 R_1 = I_2 R_2$, . . Eqn 1

and $I_1 R_3 = I_2 R_4$ . . Eqn 2

Divide Eqn 1 by Eqn 2.
(voltage ratio)
this gives:

$$\frac{R_1}{R_3} = \frac{R_2}{R_4}$$

45 A Wheatstone bridge may be used to determine the value of an unknown resistance. In the circuit below, R_X is the unknown resistance and R_2 is a variable resistor with a calibrated dial.

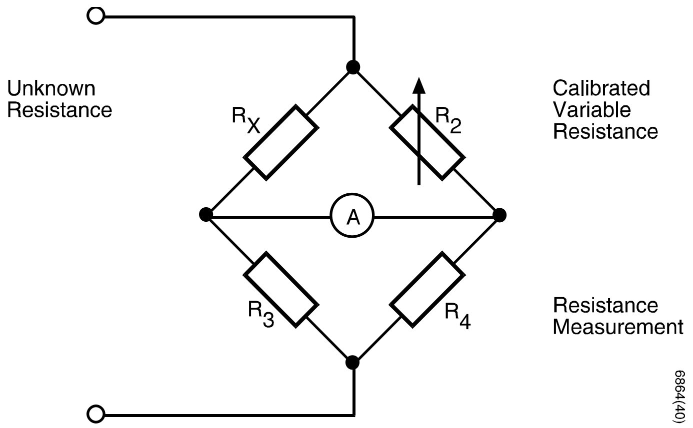


Figure 41

R_2 is adjusted until the bridge is balanced, then:

$$\frac{R_X}{R_3} = \frac{R_2}{R_4} \text{ or } R_X = R_3 \times \frac{R_2}{R_4}$$

The bridge may be used with dc or ac supplies.

46. A Wheatstone bridge may be used as a temperature sensor. The bridge is supplied with dc and has four resistors with the same value of resistance at 'normal' temperature. Three of the resistors are 'temperature stable' and the fourth is a thermistor (with a negative temperature coefficient). A thermistor's resistance changes linearly with temperature.

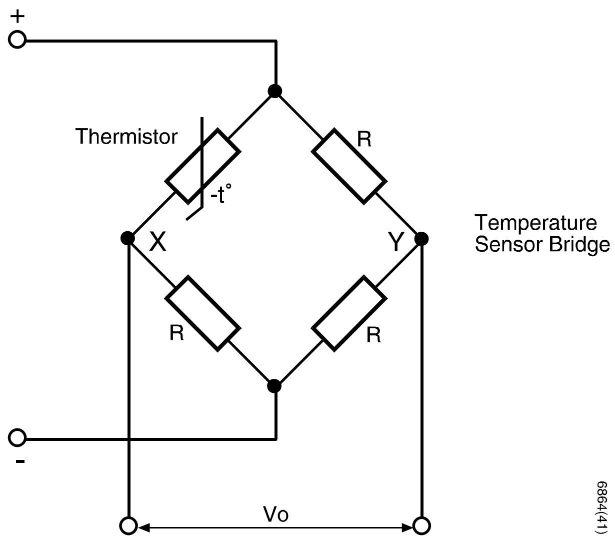


Figure 42

47. At 'normal' temperature the bridge is balanced, but if the temperature changes the bridge becomes unbalanced and there is an output voltage V_O. The amplitude of V_O is proportional to the change in temperature.

48. The polarity of the output voltage depends on whether the temperature has risen or fallen. If the temperature rises then X is positive with respect to Y; if the temperature falls then X is negative with respect to Y.

49. Wheatstone bridge circuits are used in many control circuits. Variations of the bridge have many other applications in electrical engineering.

PRACTICAL THE WHEATSTONE BRIDGE

Objectives

51. To investigate the relationship between the values of resistors in a balanced Wheatstone bridge network.

52. To demonstrate the use of an unbalanced Wheatstone bridge as a control mechanism.

Apparatus

Item
Locktronics board
Resistors various
Thermistor
Fluke multimeter

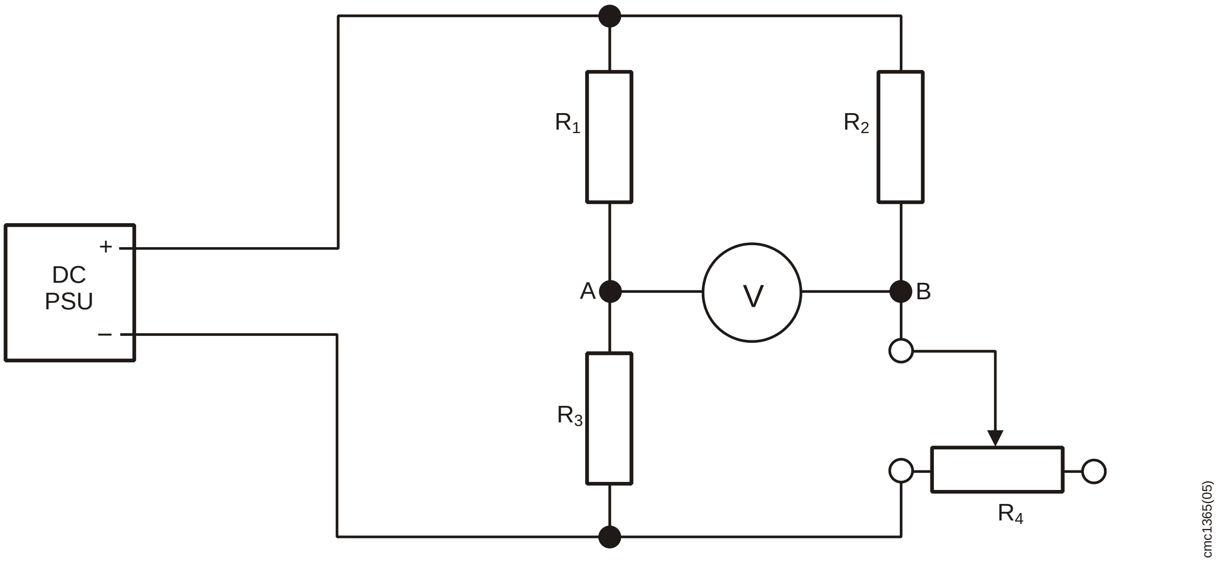


Figure 43

53. **Method**

a. Connect up the circuit as shown in figure 43, using the first line of resistors indicated in Table 10. R_4 is a 10kΩ potentiometer.

b. Set the dc power supply unit to 12V and switch 'on'.

c. Adjust R_4 to give minimum reading on the voltmeter connected between A and B.

d. Switch off, remove R_4 from the circuit taking care not to alter its setting. Measure the resistance value of R_4 with the Fluke set to resistance - ohms and enter the result in the appropriate column of Table 10.

e. Repeat items a to d for the other values of R_1, R_2 and R_3 shown in Table 10.

f. Calculate $R_4 = \frac{R_2 \times R_3}{R_1}$ and complete the last column in Table 10.

g. Obtain a balanced condition, with any of the resistor combinations and switch off the supply. Reverse the supply connections, and switch on again. Observe that the state of balance still exists.

h. Vary the supply voltage from zero to -20 volts and also observe if this has any effect upon the state of balance.

i. Return the supply connections to normal, set the supply to 12V and switch on.

j. Connect the voltmeter across points A and B and obtain balance.

k. Switch off and connect the circuits as follows:

R_1 = thermistor $R_2 = 1\ k\Omega$ $R_3 = 10\ k\Omega$ variable $R_4 = 500\Omega$

l. Warm up the thermistor with the fingers and observe the effect.

RESULTS

R_1	R_3	R_2	R_4 measured	$R_4 = \frac{R_2 \times R_3}{R_1}$
500Ω $1\ k\Omega$ $10k\Omega$	$1\ k\Omega$ $2.2k\Omega$ $5.6\ k\Omega$	$1.5\ k\Omega$ 500Ω $2.2\ k\Omega$		

Table 10

CONCLUSIONS

53. Are the calculated values of R_4 the same as the measured values? If not, why not?

54. Explain why the balance is unaffected by variation in supply voltage, or by reversing the polarity of the supply.

55. Briefly explain the effect produced by warming the thermistor and the reason for any change.

EXAMPLES - WHEATSTONE BRIDGE

In the following circuits, calculate the value of the unknown resistance when the ammeter reads zero:

a. b. c.

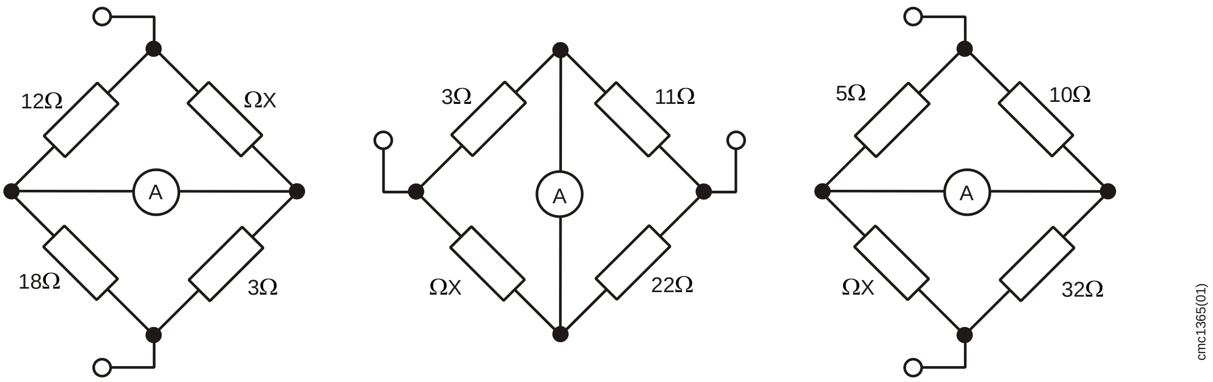


Figure 44

In the following unbalanced bridge circuits, determine whether point X is positive or negative wrt Y.

d. e.

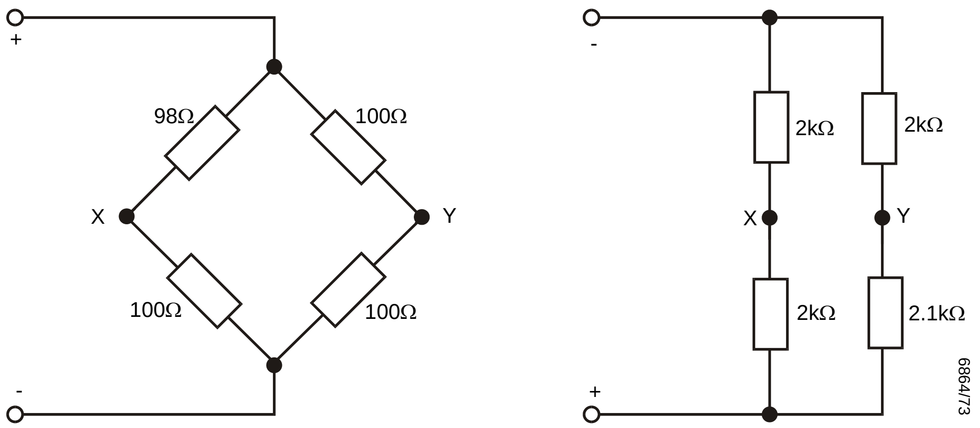


Figure 45

CONSOLIDATION QUESTIONS

1. Draw a diagram to show how you would measure the current and voltage of a lamp, in series with a resistor, connected to a dc power supply.

2. The current in a circuit is 4 amperes when the applied voltage is 240 volts. Calculate the resistance of the circuit.

3. Three resistors of 60, 80 and 100 ohms are connected in series across a supply of 200 volts. Calculate the total current flowing and the voltage across each resistor.

4. Find the effective circuit resistance when three 48 ohm resistors are connected in parallel.

5. a. In the circuit below, calculate the voltage at B with respect to earth.

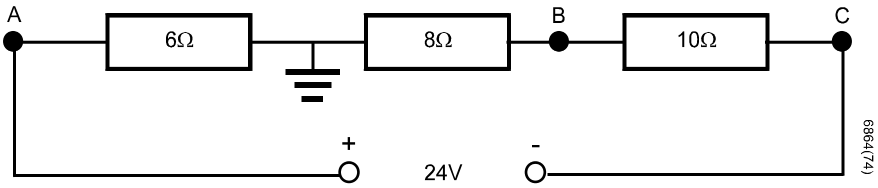


Figure 46

   b. If the earth point is moved to C, calculate the new value of voltage at B with respect to earth.

6. Calculate the value of R_1 and R_2

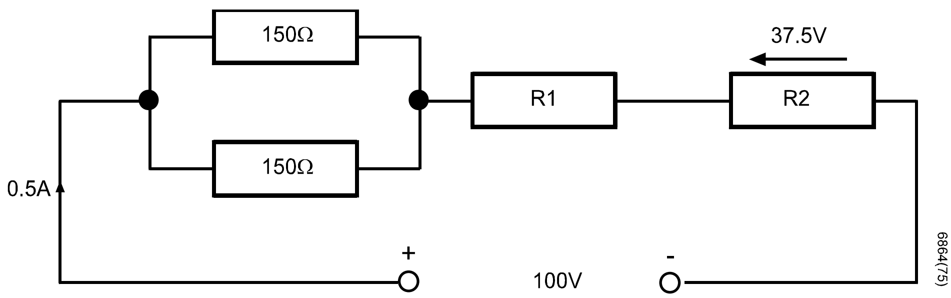


Figure 47

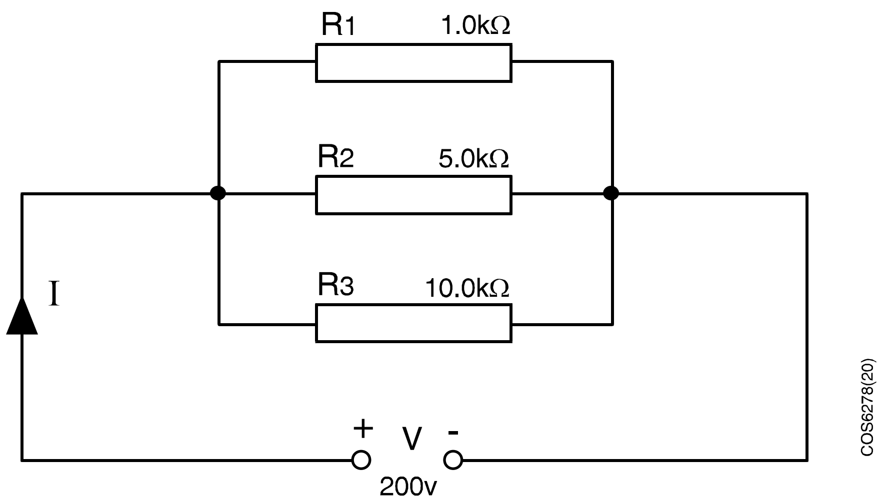


Figure 48

7. Given the information shown in Figure 48 above, calculate the supply current I).

8. Given the information shown in Figure 49 below, calculate the current in each resistor.

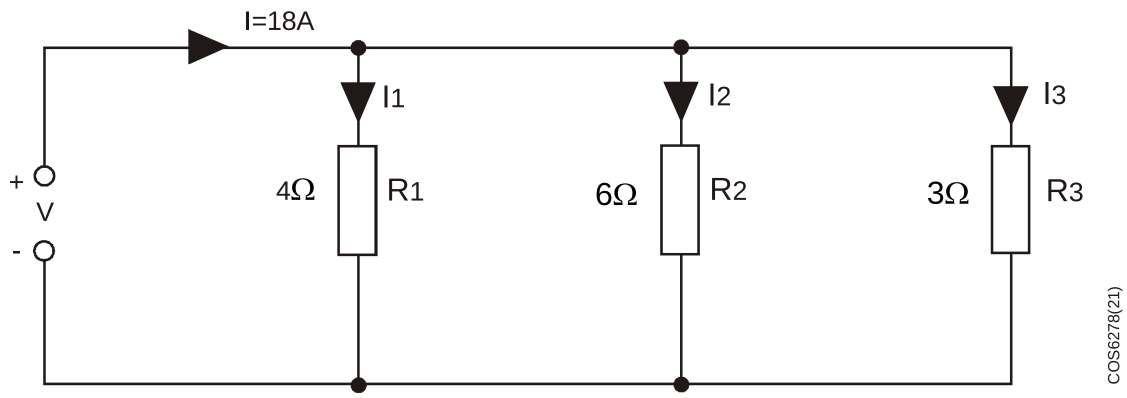


Figure 49

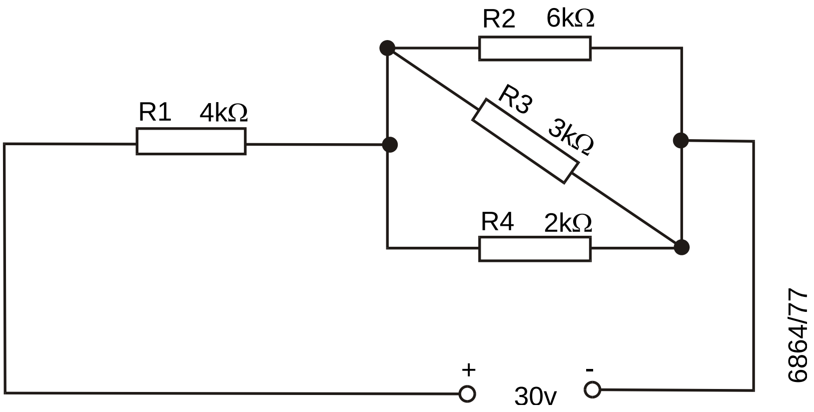


Figure 50

9. In Figure 50 above, calculate the current in:

   (i) R_1

   (ii) R_2

   (iii) R_3

   (iv) R_4

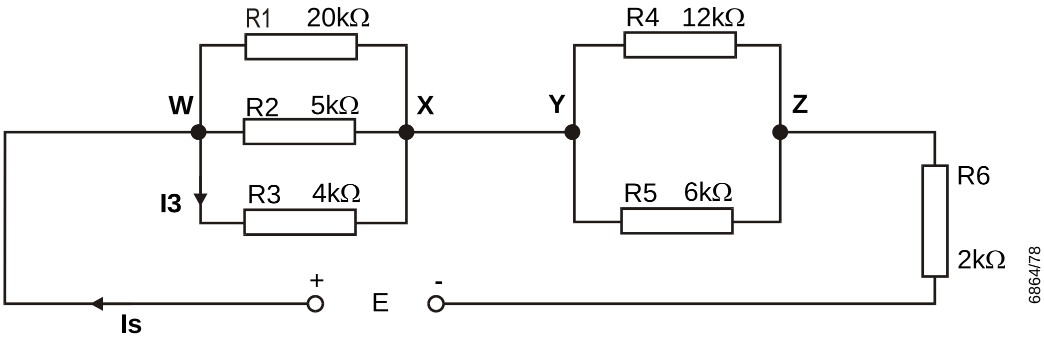


Figure 51

10. In Figure 51 above, the current in R_3 (I_3) is 5 mA. Calculate:

    (i) The resistance between W and X (R_{123}).

    (ii) The resistance between Y and Z (R_{45})

    (iii) The total resistance of the circuit (R_{total})

    (iv) The voltage between points W and X (V_{WX})

    (v) The supply current (I_S)

    (vi) The applied voltage (E)

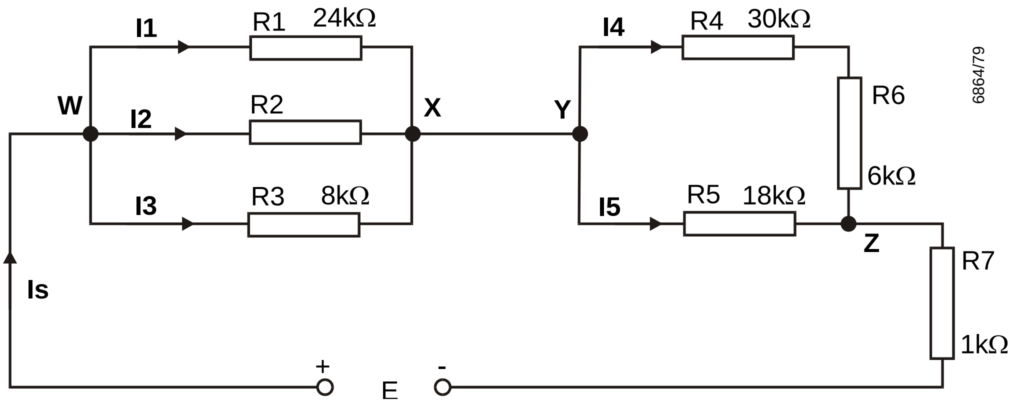


Figure 52

11. In Figure 52 above, the supply current (I_S) is 6 mA, I_3 is 3 mA and the voltage across R_4 is 60 V. Calculate:

(i) The voltage between points W and X (V_{WX}).

(ii) The resistance between W and X (R_{123})

(iii) The value of current I_5

(iv) The value of resistor R_2.

(v) The applied voltage E.

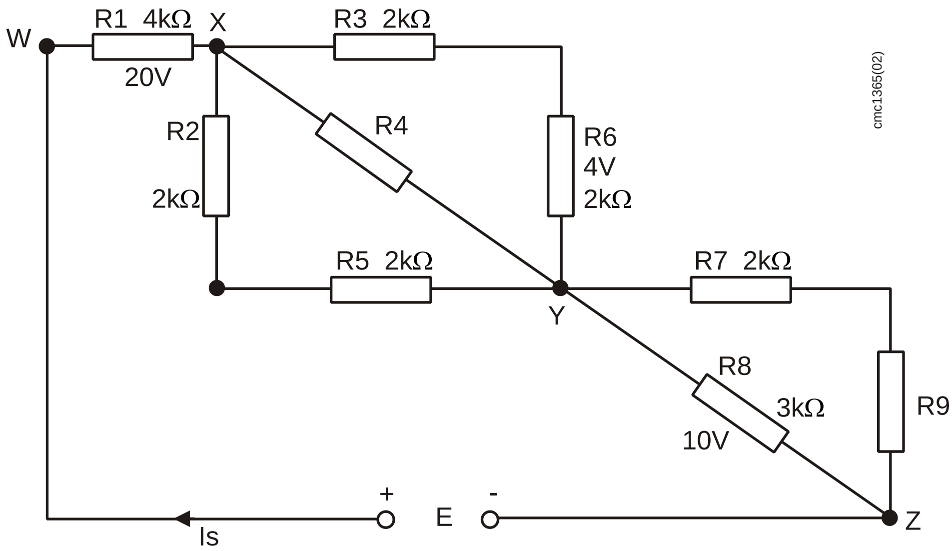


Figure 53

12. Values of resistance and voltage are as shown in Figure 53 above. Calculate:

(i) The supply current (I_S)
(ii) The voltage between X and Y (V_{XY})
(iii) The current in R_2 (I_2)
(iv) The current in R_7 (I_7)
(v) The current in R_4 (I_4)
(vi) The value of R_4
(vii) The value of R_9
(viii) The applied voltage (E)

Notes:

CHAPTER 3

ELECTRICAL ENERGY AND POWER

KLP

Av01.03.01.01 Explain how energy is dissipated in dc circuits.

Notes:

ELECTRICAL ENERGY

1. Electrical energy is the ability of an electrical system to do work. The SI unit of energy is the joule. One joule of work is done when one coulomb moves through a potential difference of one volt:

1 joule = 1 volt $\times$ 1 coulomb.

Since one coulomb is one ampere second:

1 joule = 1 volt $\times$ 1 ampere $\times$ 1 second.

ie, electrical energy = VIt joules

ELECTRICAL POWER

2. Electrical power is the rate at which an electrical system can perform work. The SI unit of power is the watt which is a rate of work of 1 joule per second:

1 watt = 1 joule per second.

= 1 volt $\times$ 1 ampere.

The symbol used for power is P:

$$P = VI \text{ watts}$$

3. By substituting V = IR in the above power formula, two other expressions for electrical power are obtained:

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

Example:

Calculate the power in a 40 Ω resistor connected to a 200 V supply.

$$P = V.I = 200 \times 5 = 1000 \text{ W}$$

or $P = I^2R = 5 \times 5 \times 40 = 1000$ W

or $P = \frac{V^2}{R} = \frac{200 \times 200}{40} = 1000\,\text{W}$

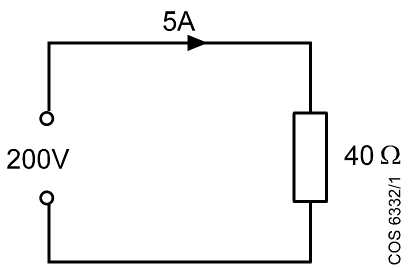


Figure 1

PRACTICAL UNITS

4. The watt is a rather small unit. In many circuits power is expressed in KILOWATTS:

$$1000 \text{ watts} = 1 \text{ kilowatt } (1 \text{ kW})$$

It is also normal to express domestic and industrial energy consumption in terms of kilowatts and hours:

$$1 \text{ kilowatt} \times 1 \text{ hour} = 1 \text{ kilowatt - hour } (1\text{kW})$$

Example:

An electric heater taking 6 A from a 250 V supply is switched ON for 8 hours.

power P	=	250 × 6	=	1500 W	=	1.5 kW
energy consumed	=	1.5 kW × 8 hours			=	12 kWh

EXAMPLES - ELECTRICAL ENERGY AND POWER

5. A 5 Ω resistor is connected to a 20 V supply. Calculate the power in the resistor, using all three expressions:

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

6. Calculate the power consumption in each of the circuits shown below in figure 2:

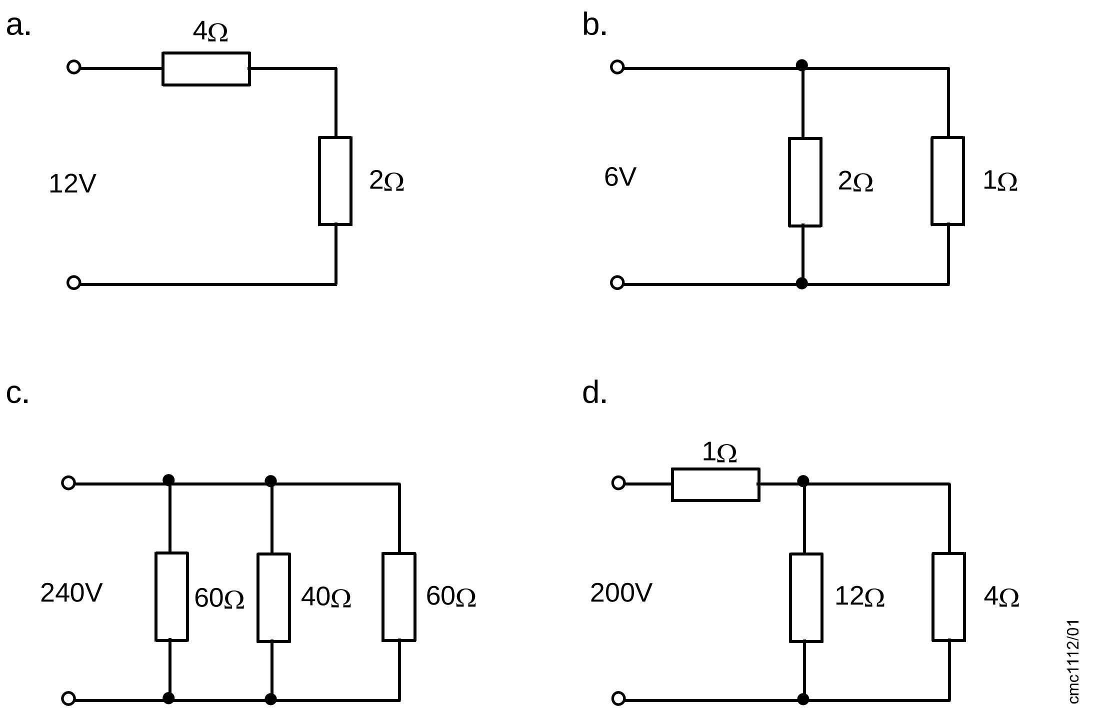


Figure 2

7. A lamp takes a current of 0.4 A from a 250 V supply. Calculate the power and the total electrical energy consumed in ten hours.

8. An emergency electrical generator supplies a steady 40 A at 250 V for 24 hours. Calculate the power and the electrical energy supplied.

9. Calculate the electrical energy of a fully charged 12 V, 40 A-h battery.

EQUIPMENT PROTECTION - POWER RATING AND FUSES

10. The limiting factor in the use of most electrical components and machines is the maximum temperature at which they can operate without damage. The power rating of a component or machine therefore indicates the maximum current or voltage at which it may operate without overheating.

Do not exceed the power rating of
any electrical component or machine

Example

A dc motor is rated at 2.2 kW, 200 V. The maximum current that may be taken by the motor without risk of damage due to overheating is:

$$\frac{2.2\,\text{kW}}{200\,\text{V}} = 11\,\text{A}$$

FUSES

11. Fuses are constructed of metals with a very low resistance but with a melting point which enables them to ‘blow’ and thus open the circuit when the current exceeds the rated value of the fuse. Fuses are used to protect the wiring and the circuits.

SYMBOL

12. A fuse is connected in SERIES with the circuit that it is designed to protect it. It is normal to select a fuse with a current rating SLIGHTLY HIGHER than the maximum current expected in the circuit (to avoid unnecessary circuit disconnection).

Examples:

The motor in paragraph 10 would be best protected by a 12 A fuse. A 3 kW, 240 V electrical fire (maximum rated current is therefore 12.5 A) would be best protected by a 13 A fuse.

EXAMPLES - POWER RATING AND FUSES

13. Calculate the current taken by each of the following components at rated working voltage:

a. 60 W, 240 V lamp.

b. 1.4 W, 4.5 V lamp.

c. 2 kW, 250 V electric fire.

d. 6 W, 24 V panel lamp.

e. 2.2k W, 200 V dc electric motor.

EMF, TERMINAL PD AND INTERNAL RESISTANCE

14. All electrical supplies have internal resistance. In batteries it is mainly due to the resistance of the plate connections and junctions between plates and electrolyte; in electrical generators it is mainly the resistance of the machines windings.

15. The voltage across the open-circuited terminals of a supply is equal to the emf. When a load is connected to the supply, the load current causes a volts drop across the internal resistance of the supply.

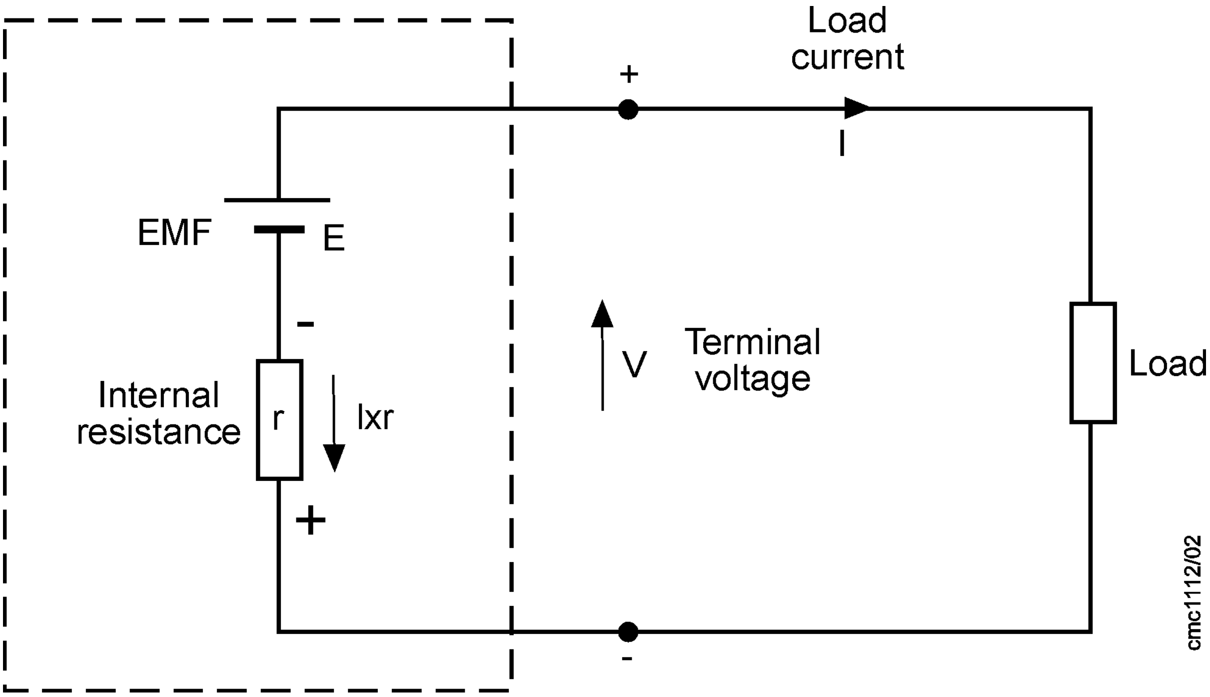


Figure 3

$$V = E - I \times r$$

The on-load terminal voltage V is equal to the emf minus the volts dropped across the internal resistance.

Thus as the current drawn from the supply increases the terminal voltage falls.

16. Assuming that the internal resistance remains constant, the fall in terminal voltage is directly proportional to the load current.

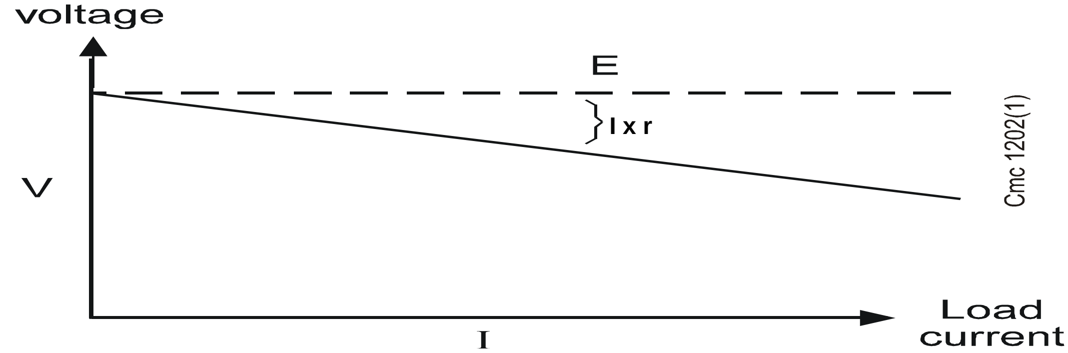


Figure 4

BATTERY CIRCUITS

17. **Primary Cells**

a. Primary cells cannot be recharged that is, the conversion of chemical energy to electrical energy is irreversible and the cell cannot be used once the chemicals are exhausted.

b. Typical Dry cells have an emf of about 1.5 V when new, but this falls rapidly due to polarization if in continuous use. The hydrogen film on the carbon electrode forms faster than can be dissipated by the depolarizer. The dry cell is suitable only for intermittent use, applications including torches, transistor radios, bells, indicator circuits, gas lighters, controlling switch-gear and so on. The cell is the most commonly used of primary cells, is cheap, requires little maintenance and has a self-life of about two years.

18. **Secondary Cells**

a. Secondary cells can be recharged after use, that is, the conversion of chemical energy to electrical energy is reversible and the cell may be used many times. Examples of secondary cells include the lead-acid cell and alkaline cells. Practical applications of such cells include car batteries, telephone circuits and for traction purposes, such as milk delivery vans and fork lift trucks.

b. Lead Acid Cells. A typical lead acid cell is constructed of:

(1) A container made of glass, ebonite or plastic.

(2) Lead Plates

(a) the negative plate (cathode) consists of spongy lead.

(b) the positive plate (anode) is formed by pressing lead peroxide into the lead grid. The plates are interleaved to increase their effective cross-sectional area and to minimize internal resistance.

(3) Separators made of glass, celluloid or wood.

(4) An electrolyte which is a mixture of sulphuric acid and distilled water.

The terminal pd of a lead acid cell is about 2 V.

19. The capacity of a cell is measured in ampere-hours (Ah). A fully charged 50 Ah battery rated for 10 h discharge can be discharged at a steady current of 5 A for 10 h, but if the load current is increased to 10 A, then the battery is discharged in 3-4 h, since the higher the discharge current the lower is the effective capacity of the battery.

20. Batteries are often combinations of smaller voltage cells. For example, an ordinary 12 V car battery consists of six 2 V cells in series and a transistor radio 6 V battery will be four 1.5 V cells in series.

21. Series combination of voltage cells gives increased output voltage and parallel combination gives greater current supply capacity.

22. The examples below show the effect of combining voltage cells and how internal resistance is affected. Since it is normal practice, to combine identical voltage cells we shall consider only that case.

SERIES COMBINATION

23.

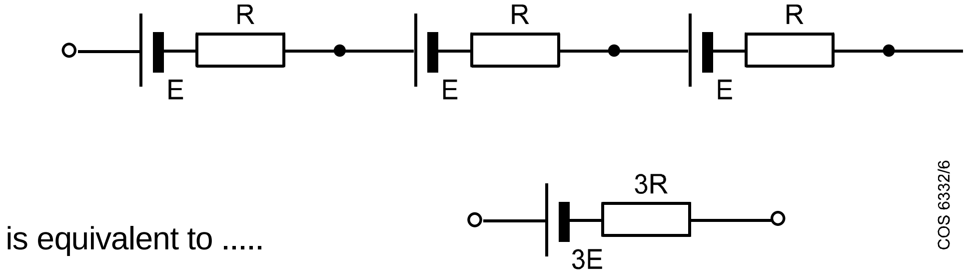


Figure 5

Conclusion

Series combination gives { increased emf
increased internal resistance

PARALLEL COMBINATION

24.

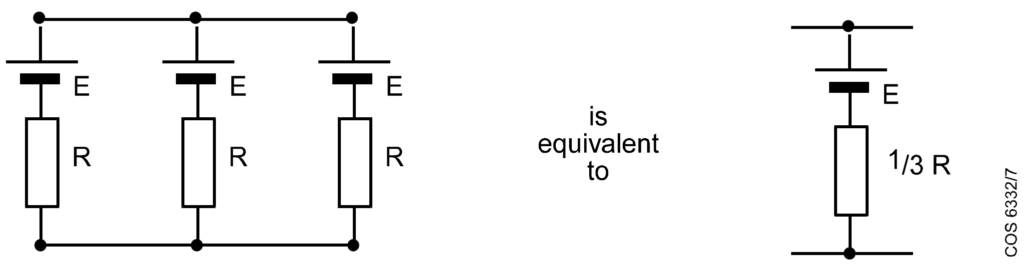


Figure 6

Conclusion

Parallel combination gives { same emf
reduced internal resistance
increased current supply capacity

EXAMPLES - INTERNAL RESISTANCE AND BATTERIES

25. A battery of internal resistance 0.1 Ω has an emf of 12 V. Calculate the battery terminal voltage when the load current is:

a. 5 A.

b. 10 A.

c. 20 A.

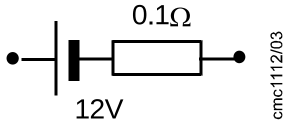


Figure 7

26. The internal resistance of an aircraft dc generator is 0.04 Ω. During an open-circuit test the output voltage was found to be 29 V. What would be the output voltage of the generator, under the same running conditions, but supplying a load of 50 A?

27. A voltage supply unit is set to an output of 6 V on open circuit. When a 550 Ω load is connected to the unit the output voltage falls to 5.5 V. Calculate:

a. The load current I.

b. The supply unit internal resistance r.

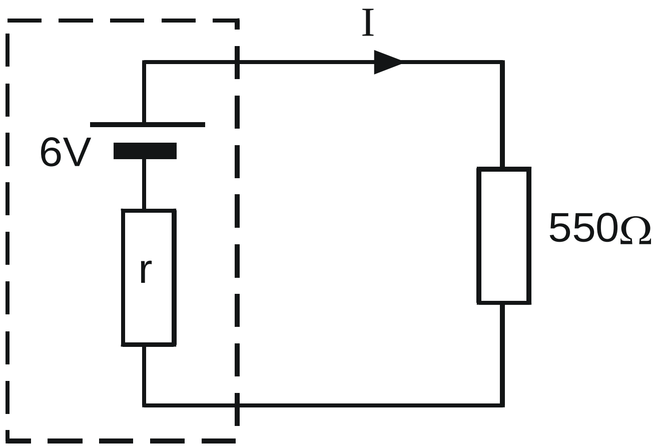


Figure 8

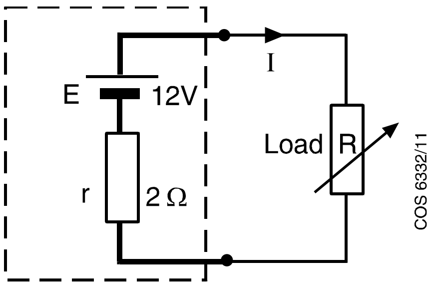
MAXIMUM POWER TRANSFER

28. The internal resistance of a voltage supply affects the power that can be developed in a load:

Maximum power is developed in a load when the load resistance is equal to the internal resistance of the supply

This statement is known as the 'Maximum Power Transfer Theorem'.

29. The example below shows a battery of emf 12 V and internal resistance 2 Ω supplying a load R.



$$I = \frac{E}{r+R} = \frac{12}{2+R}$$

power in load = I^2R

Figure 9

Choosing a few suitable values of R and calculating the load power:

R	I	Load Power
1 Ω 2 Ω 4 Ω 10 Ω	4 A 3 A 2 A 1 A	16 W 18 W 16 W 10 W

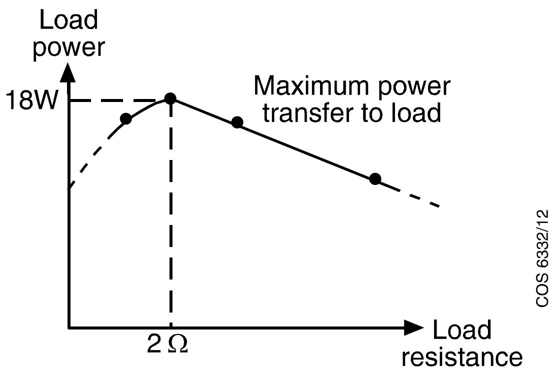


Figure 10

30. When the load resistance and supply internal resistance are equal, the load and supply are said to be 'matched'. The transference of maximum power from a supply to a load is often required in electronic circuits, a typical example being the matching of an audio amplifier to a loudspeaker.

EXAMPLE

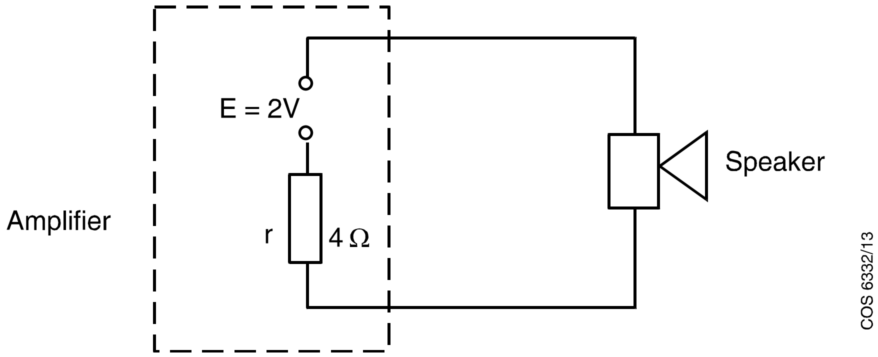


Figure 11

31. An audio amplifier with an output terminal resistance of 4 Ω has a no-load output of 2 V. Calculate the power supplied to loudspeakers of impedance:

a. 4 Ω

b. 12 Ω

32. Batteries, generators and other power supply systems are NOT operated under maximum power transfer conditions since this would involve the same amount of power being dissipated in the supply as in the load. Power supply systems are always designed to have the minimum possible internal resistance.

DETERMINATION OF INTERNAL RESISTANCE

OBJECTIVE

33. To determine the internal resistance of a MN 1604 (PP3) Cell.

EQUIPMENT

34.

Item		
PP3 cell 9V (Nominal) Crocodile clips	Locktronics Board Fluke Multimeter	500Ω, ¼ W resistor

METHOD

Note: Leave the cell connected for as short a time as possible when taking voltage readings in order to prolong the life of the cell.

35. a. Using the multimeter, accurately measure the value of the 500Ω resistor. Record this value in the space below:

....

b. Using the multimeter, accurately measure the open circuit voltage (E) of the cell. Record this value in the space below:

....

c. Connect the circuit as shown in Figure 12.

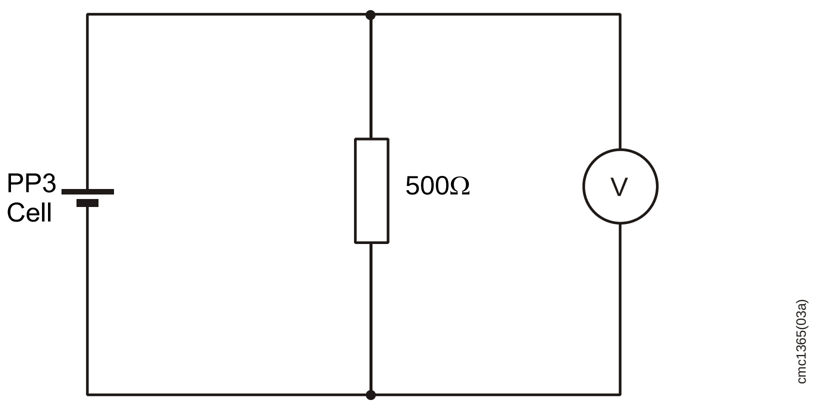


Figure 12

d. Using the multimeter, accurately measure the voltage (V) across the load resistor and then disconnect the cell. Use this value to calculate the current (I) in the load. Record your results below:

Load voltage (V) = ……………..V   Current (I) = ………….mA

e. Transpose the following formula and make r the subject of the equation:

$$V = E - Ir$$

f. Using the modified formula and values measured above calculate the internal resistance of the cell and record the value below:

Internal resistance = ……………………Ω

CHAPTER 4
MAGNETISM

KLPs

Av01.03.02.01	Describe the fundamental laws governing magnetism.
Av01.03.03.01	Describe the fundamental principles and laws governing electromagnetic induction.
Av01.03.04.02	Describe the properties and applications of inductors.

Notes:

MAGNETISM

1. The properties of magnets are as follows:

    a. Magnetism takes two forms:

    - Natural, eg, lodestone
    - Artificial, eg, magnets made electrically from steel and its alloys

    b. The poles of a magnet are where the magnetic field is the strongest and are called the North (seeking) pole N, and the South (seeking) pole S.

    c. Like poles repel, unlike poles attract.

MAGNETIC FIELD

2. A region where magnetic effects can be detected is called a magnetic field, and is said to be filled with lines of magnetic flux. These flux lines have the following properties:

    a. They are continuous from N to S outside the magnet, and from S to N inside the magnet.

    b. The flux is concentrated where the magnetic field is strongest (flux density = flux/unit area).

    c. The direction of the magnetic field is the direction of the flux line and is the direction an isolated north pole would tend to move if placed in the field at that point.

    d. They never cross.

    e. Lines of flux may be considered in tension (explains why unlike poles attract), and tend to follow the easiest magnetic path.

    f. Lines of flux repel each other sideways (explains the repulsion of like poles).

EXAMPLES OF MAGNETIC FIELD

3. Examples of magnetic fields are as follows:

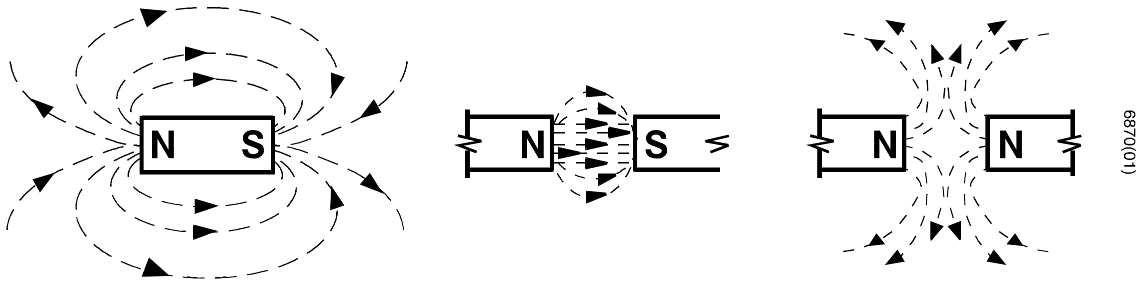


Figure 1

MAGNETIC TERMS

4. The following terms and symbols are used in magnetism:

a. Flux (ϕ). This is the total flux emitted from the poles of the magnet. It is measured in webers (Wb).

b. Flux Density (B). Flux Density is the flux per unit area and is measured in webers/metre^2 or tesla (T).

$$\text{Flux density} = \frac{\text{flux}}{\text{area}}$$

$$B = \frac{\phi}{a} \text{ tesla}$$

Typical values of B in the steel core of electrical machines are 1·2 to 1·8 tesla.

c. Reluctance (S). The reluctance of a magnetic circuit is the opposition of that circuit to the establishment of flux. Some materials (eg, soft iron) provide an easier path for the flux lines than other materials. They are said to have a low reluctance.

d. Magneto Motive Force (mmf). The magneto motive force is the force that establishes the flux and is measured in amperes. Sometimes ampere-turns are used but amperes is strictly correct.

e. Magnetic Field Strength (H) or Magnetising Force. This is the force that produces the magnetic field within the coil. It is the product of the current in the coil and the number of coil turns divided by the length of the magnetic path.

f. Residual Magnetism. When a magnetic material (such as soft iron) is removed from a magnetic field it does not lose all its magnetism. What remains is called residual magnetism or remanence.

g. Magnetic Saturation. The number of flux lines passing through a given material cannot increase indefinitely. Eventually magnetic saturation is reached.

h. Magnets. An iron compound called Magnetite forms natural magnets. Artificial magnets are formed from compounds of iron with elements such as cobalt and nickel. A ferromagnetic material is described as:

- SOFT if easily magnetised and demagnetised
- HARD if magnetised and demagnetised with difficulty

Non-ferrous metals such as copper and aluminium are not ferromagnetic.

ELECTROMAGNETS

5. Electromagnets can give stronger magnetic fields than permanent magnets and have the added advantage of having their magnetism easily controllable.

FIELD OF A CURRENT CARRYING CONDUCTOR

6. a. The direction of the field about a current carrying conductor can be found by the corkscrew rule: "A corkscrew advancing in the direction of the current turns in the direction of the magnetic field".

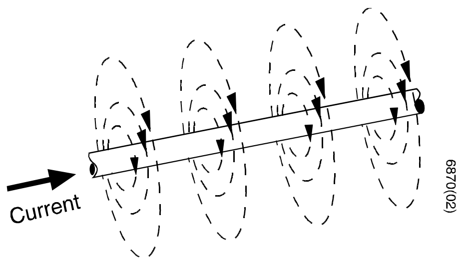


Figure 2

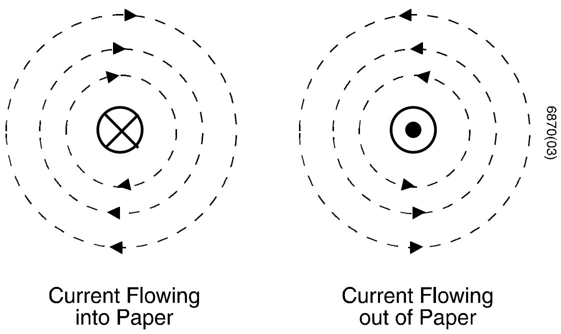


Figure 3

b. The field is proportional to the current flowing in the conductor.

FLUX PATTERNS OF PARALLEL CONDUCTORS

7. The flux patterns set up by parallel current carrying conductors have the following effects:

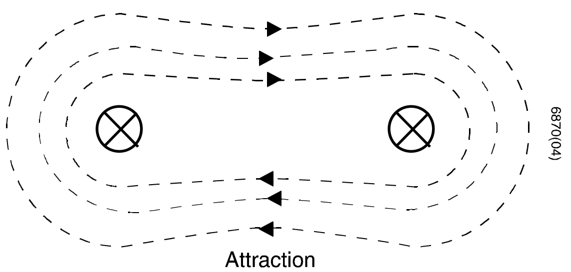


Figure 4

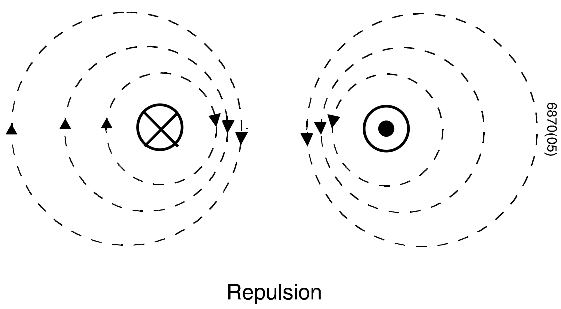


Figure 5

SOLENOID

8. A long coil of many turns forms a solenoid. The flux pattern is similar to that of a bar magnet. The magnetic field is only present when current flows.

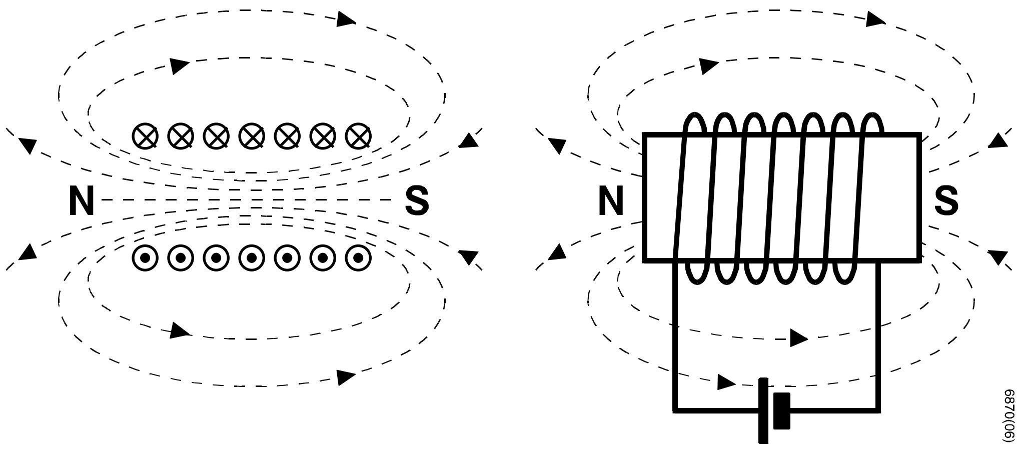


Figure 6

RIGHT HAND GRASP RULE

9. The direction of the magnetic field of a solenoid can be found by using the right hand grasp rule. If a solenoid is grasped in the right hand with the fingers indicating the direction of conventional current, then the extended thumb points to the North Pole.

MAGNETIZING FORCE (H) OR MAGNETIC FIELD STRENGTH

10. The factors affecting the magnetising force of a solenoid are:

a. Current (I) - amperes.

b. Number of turns (N).

c. Length of the magnetic (ℓ) path - metres.

In general:

$$H = \frac{IN}{\ell} \text{ amperes/metre}$$

PRACTICAL-MAGNETISM

11. **Method.**

a. Determine, with the aid of plotting compasses, the shape of the magnetic field surrounding the bar magnet.

b. From your observations, sketch the magnetic field on the diagram at figure 7.

c. Connect the solenoid to a 9V battery and place the solenoid on its side on the bench.

d. Determine, with the aid of plotting compasses, the shape of the magnetic field surrounding the solenoid.

e. From you observations, sketch the magnetic field on the diagram at figure 8.

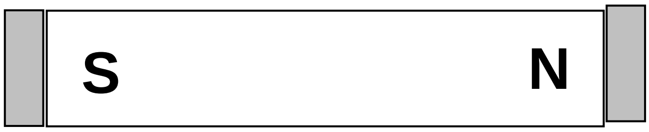


Figure 7

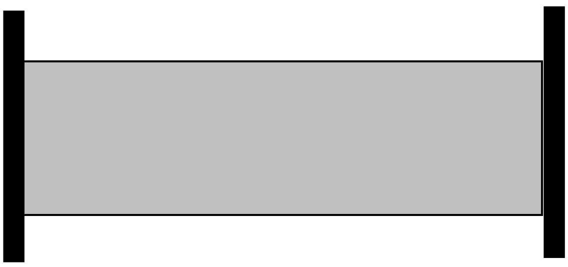


Figure 8

COMPARISON BETWEEN MAGNETIC CIRCUITS AND ELECTRICAL CIRCUITS

12. It is useful to compare various electric and magnetic quantities and their relationships. Consider the electric and magnetic circuits shown below.

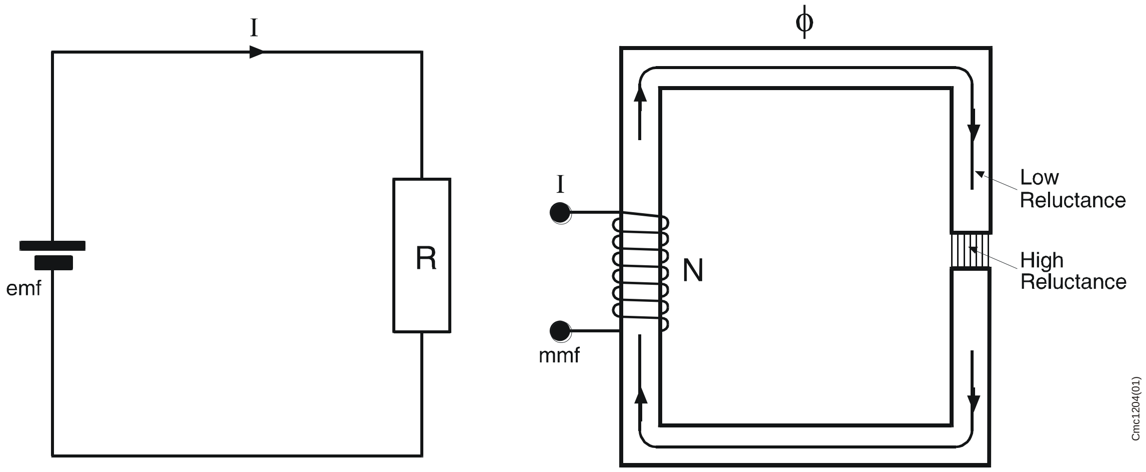


Figure 9

13. Tabulating the comparison gives:

Electric Circuit		**Magnetic Circuit**	
Quantity	**Unit**	**Quantity**	**Unit**
emf	volt	mmf	ampere
current	ampere	magnetic flux	weber
resistance	ohm	reluctance	amperes/weber

and

$$I = \frac{\text{emf}}{\text{resistance}} , \qquad \phi = \frac{\text{mmf}}{\text{reluctance}}$$

FERROMAGNETIC MATERIALS

14. The performance of electrical machines, transformers and many other components depends partly upon the ferromagnetic materials used in their construction.

DOMAINS

15. A ferromagnetic material contains microscopic magnetic areas called domains. If the material is unmagnetized the domains are orientated at random.

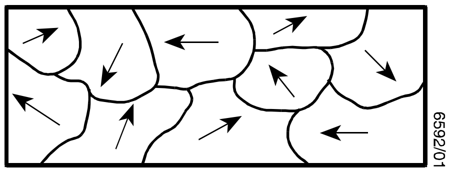


Figure 10

16. When a magnetic field is applied, the domains start to move in the direction of the field. The ferromagnetic material is now partially magnetised and assists the field of the coil.

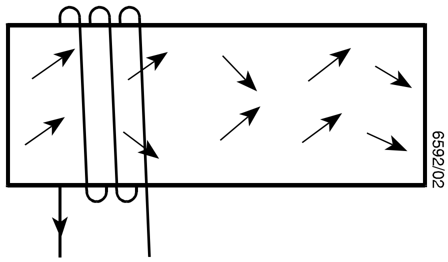


Figure11

17. When the applied field is sufficiently intense, all the domains will align in the field direction. The ferromagnetic material is completely magnetised and cannot contribute further to the production of flux; it is said to be saturated.

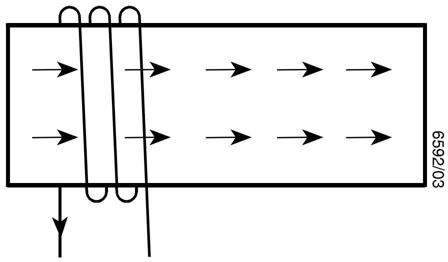


Figure 12

MAGNETISATION (B/H) CURVE

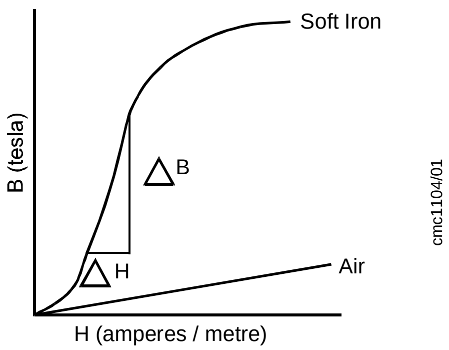
Permeability of Free Space

18. If an air cored solenoid had its magnetising force (H) varied and flux density (B) noted, the ratio is constant and is called the permeability of free space (μ_o). This has the value of $4\pi \times 10^{-7}$ (henrys/metre).

$$\frac{B}{H} = \mu_o$$

MAGNETIZATION CURVE (B/H CURVE)

19. The magnetic properties of a given material vary with the degree of magnetisation and a magnetisation curve is the usual way of comparing two magnetic materials. A graph of Flux Density (B) is plotted against Magnetising Force (H) and is as follows:



$$\text{Slope } \frac{\Delta B}{\Delta H} = \mu$$

Figure 13

ABSOLUTE PERMEABILITY (μ)

20. The slope of the magnetisation curve is the absolute permeability and is made up of two components:

a. Relative Permeability (μ_r). For air this is 1, and some nickel iron alloys it can be in excess of 100,000.

b. Permeability of Free Space (μ_o). The permeability of free space (or vacuum).

$$\mu = \mu_o \mu_r$$

RELATIVE PERMEABILITY/MAGNETIC FIELD STRENGTH

21. The value of relative permeability varies with the magnetizing force and can be obtained from the B/H curve.

22. The variation of μ_r and the property of saturation is important in the working of magnetic amplifiers.

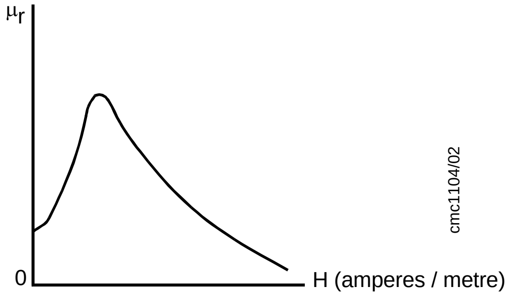


Figure 14

HYSTERESIS

Hysteresis Cycle

23. If a magnetic material is taken through a complete cycle of magnetisation and demagnetisation the graph of Flux Density (B) and Magnetic Field Strength (H) is as follows:

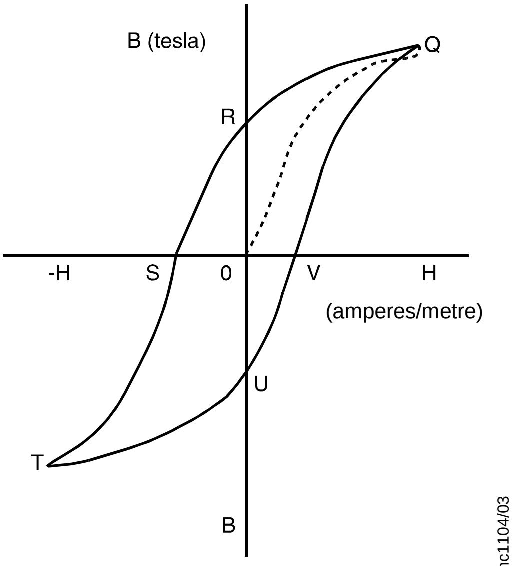


Figure 15

O - Q	Initial Magnetisation curve to Saturation
Q - R	Magnetising Force reduced to zero
O - R	Represents remanence or residual magnetism
R - S	To reduce flux density to zero magnetising force is reversed.
O - S	Represents coercive force
S - T	Further increase in reversed magnetising force causes magnetic material to reach saturation in the reverse direction.
T - Q	Reversal of magnetising force again eventually makes material saturated in original direction.

Hysteresis loss

24 Energy is needed to magnetise and demagnetise a piece of magnetic material and this energy is dissipated in the form of heat. The area of the loop represents the energy loss each cycle of magnetisation and demagnetisation.

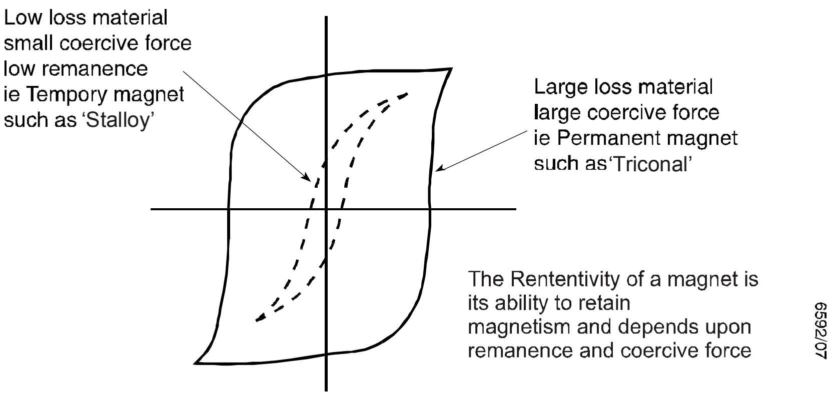


Figure 16

25. **Ferromagnetic Applications.** In the examples below the ferromagnetic material is soft, returning to the unmagnetized state when the coil field is not energized.

a. **Electric Bell.** Electrical bells may be designed for use with either dc or ac supplies.

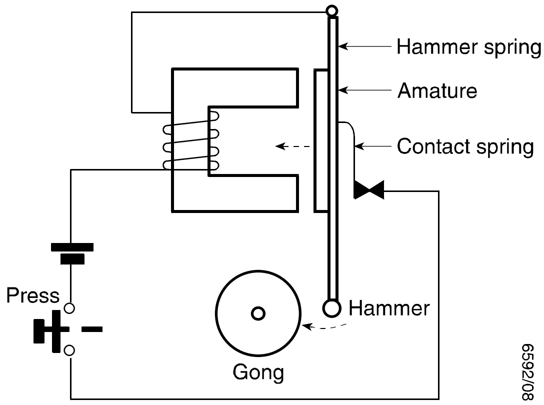


Figure 17

b. **Relay**. A relay enables a load current to be switched on or off using a relatively small current in the relay coil. A relay is particularly useful when the load is distant from the control panel as, for example, the heated rear window circuit in a car. Relays have numerous applications in aircraft.

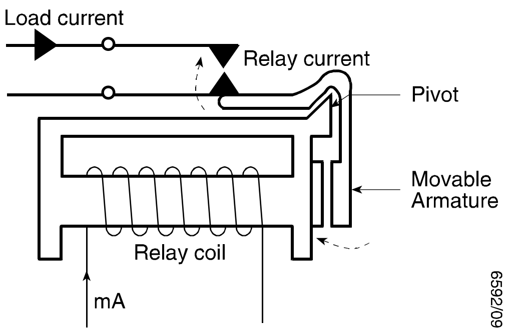


Figure 18

c. **Car Starter Motor Solenoid**. This component is a heavy duty relay for switching the high current of a starter motor. In an aircraft it would be referred to as a contactor. Aircraft solenoids are similar devices, used as fuel or hydraulic valves.

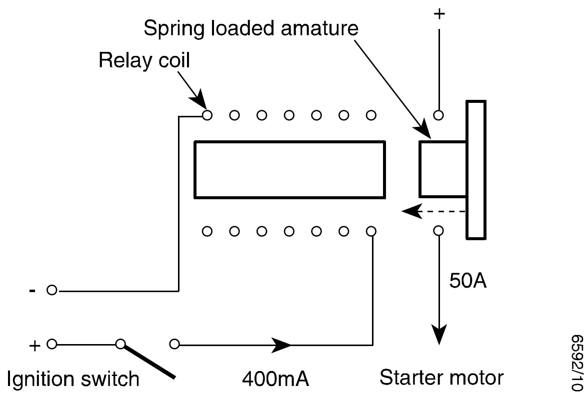


Figure 19

FORCE ON A CONDUCTOR

26. A current carrying conductor at right angles to a magnetic field has a force exerted on it.

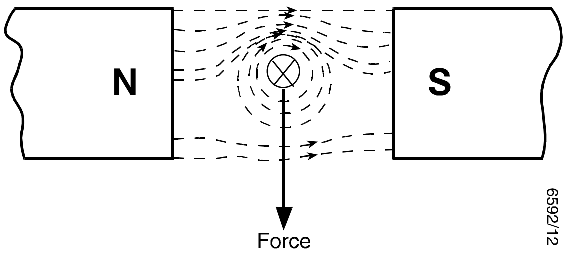


Figure 20

The value of the force depends upon:

- The flux density (B).
- The current (I).
- The length of the conductor in the field (ℓ).

$$F = BI\ell \text{ newtons}$$

FLEMING'S LEFT HAND RULE

27. The direction of the motion of the conductor is determined by Fleming's LEFT HAND RULE.

First finger	=	**Field**
seCond finger	=	**Current**
ThuMb	=	**Motion**

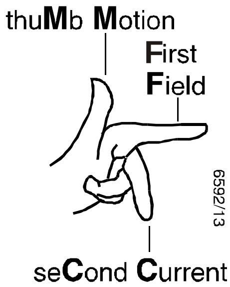


Figure 21

The three vectors are mutually at right angles.

FORCE ON A CONDUCTOR - EXAMPLES

28 Sketch the direction of the motion of the conductor in the diagram below:

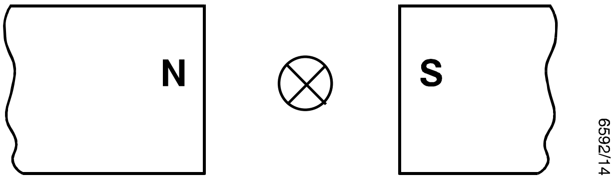


Figure 22

29. What is the direction of the magnetic field?

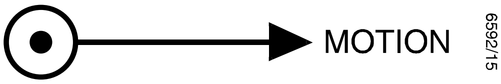


Figure 23

30. Mark the direction of current in the diagram below:

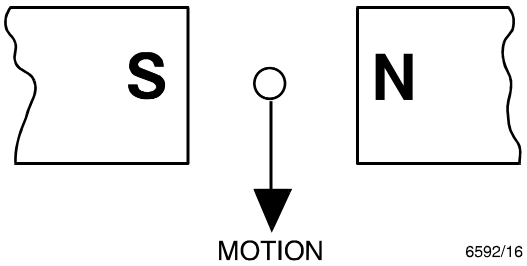


Figure 24

31. Sketch the motion of the current carrying coil below:

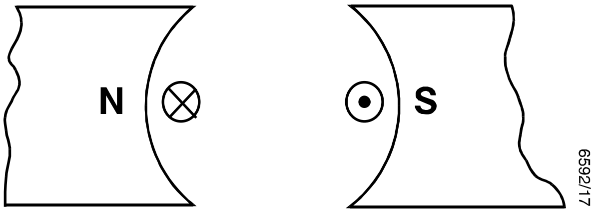


Figure 25

PRACTICAL APPLICATIONS

32. **Electric Motors.** The most obvious application of this force is in electric motors; all dc motors and most ac motors operate on this simple principle. In these motors, B, I and ℓ will normally be made as large as is possible (for the size of the machine) and the design will ensure that the motor conductors are always at right angles to the magnetic field.

33. **Moving-Coil Meter.** Many meters, have mechanisms which operate on the principle of a coil rotating in a magnetic field. The basic construction is shown in figure 26 where the current I passes through a pivoted coil and the resultant motor force, the deflecting force, is directly proportional to I. Flux is concentrated within the coil by a solid cylindrical ferromagnetic core.

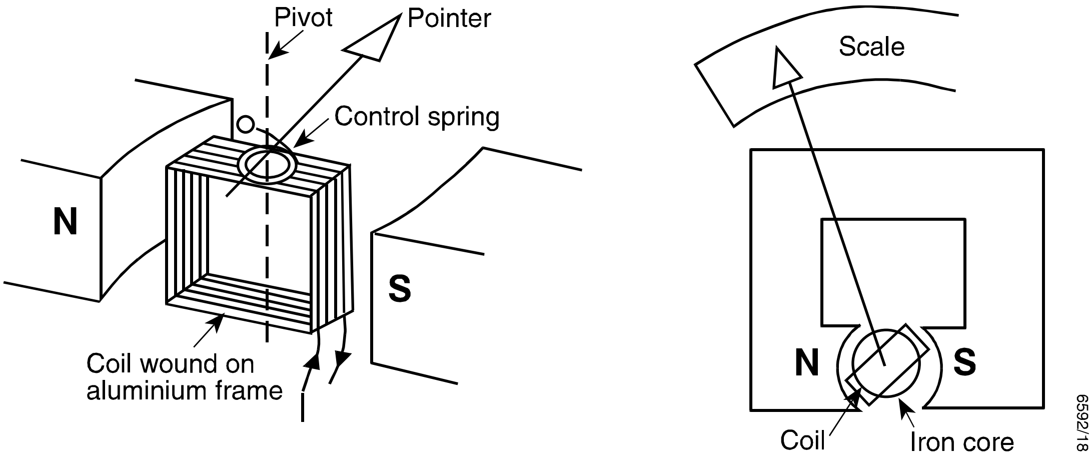


Figure 26 – Moving-Coil Meter

EXAMPLES - MOTOR FORCE

34. Mark the magnetic flux direction:

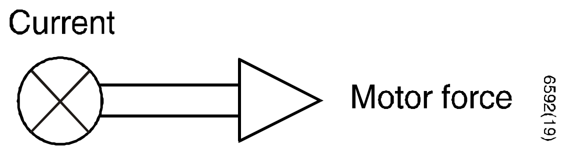


Figure 27

35. Mark the current direction in the conductor:

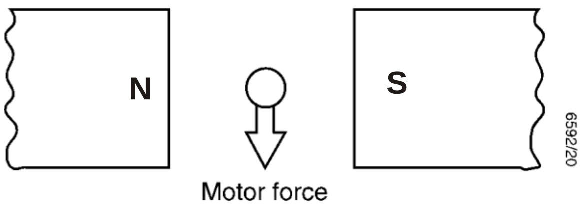


Figure 28

36. Sketch the direction of rotation of the conductor coil:

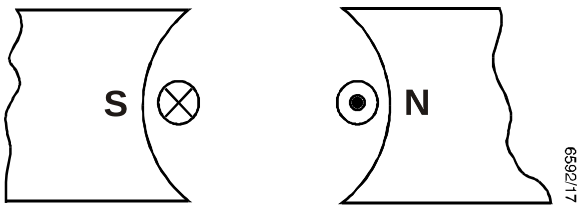


Figure 29

ELECTROMAGNETIC INDUCTION

37. **Magnet and Coil**. A simple demonstration with a coil, magnet and voltmeter shows that:

a. An emf is induced in the coil when (and only when) there is relative movement between the magnet and coil.

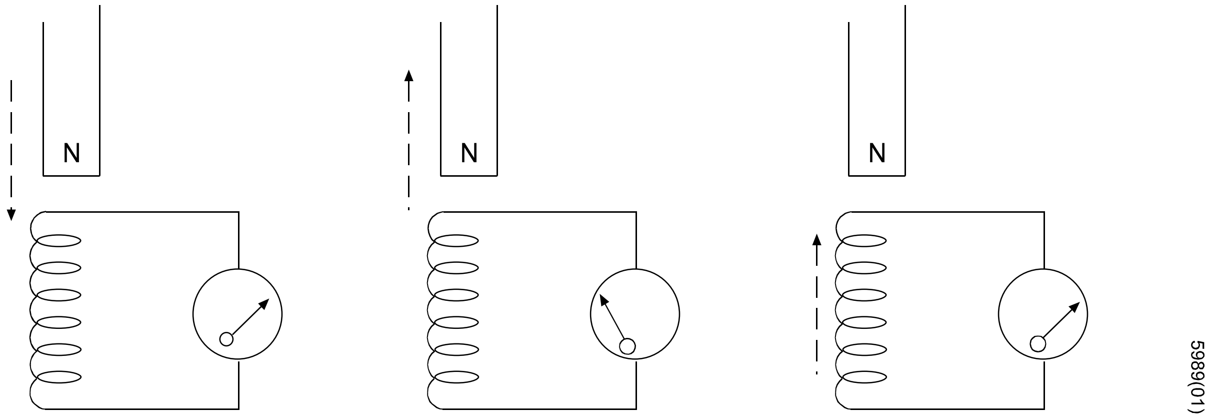


Figure 30

b. The magnitude of this induced emf is directly proportional to:

(1) The rate of relative movement.

(2) The strength of the magnet (ie, the flux density)

(3) The number of turns on the coil.

c. The polarity of the induced emf depends upon the direction of relative movement. The voltage induced in the coil produces a magnetic field which always opposes the relative movement.

Laws of Electromagnetic Induction

38. The two important laws of electromagnetic induction are:

a. **Faraday's Law.** When a magnetic flux through a coil is made to vary, an emf is induced. The magnitude of this emf is proportional to the rate of change of flux.

b. **Lenz's Law.** The induced voltage always acts in such a direction so as to oppose the change in flux producing the current.

39. **Induced emf in Conductor**. Voltages are induced in an electrical generator by moving a conductor through a magnetic field.

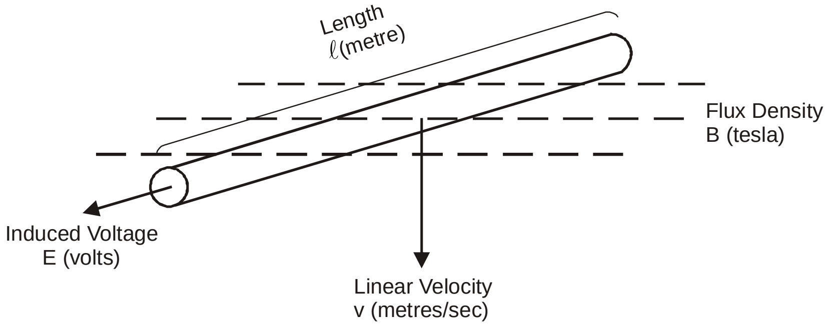


Figure 31

GENERATION OF ELECTRICITY

Magnitude of Generated emf

40. The magnitude of the generated emf depends upon:

a. Velocity of the conductor (v) - metres/sec.

b. Strength of the magnetic field (B) - tesla.

c. Length of the conductor (ℓ) - metres.

$$E = B\ell v \text{ volts}$$

DIRECTION OF THE GENERATED EMF

41. The direction of the generated emf can be found by Fleming's right-hand rule.

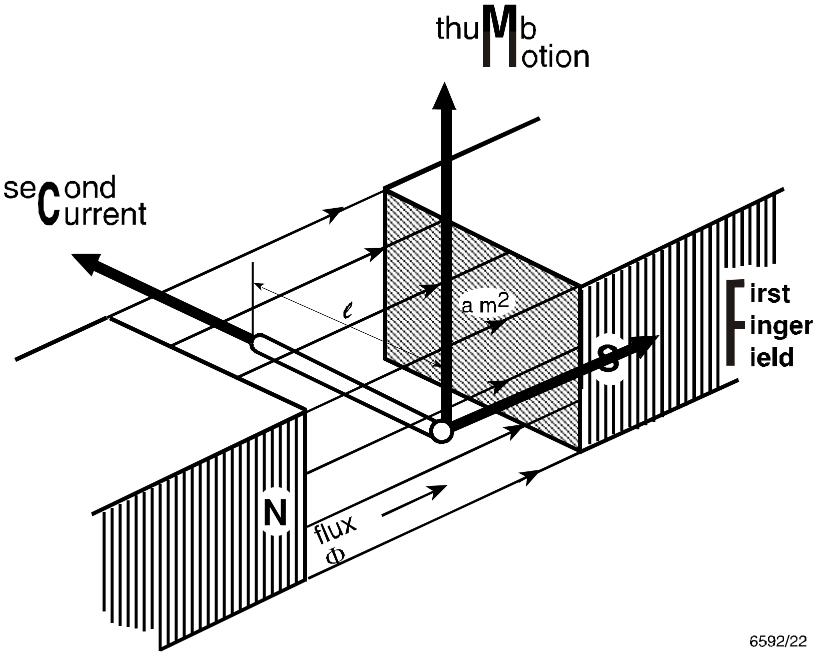


Figure 32

INDUCTANCE (FARADAY'S LAW)

42. a. Any circuit in which a change of current, and therefore flux, induces an emf in itself (self) or another circuit (mutual) is said to be inductive.

b. In the circuit shown, the current produces a magnetic field around the coil. This is, in fact, potential energy stored in the magnetic field. When the switch is broken, current and flux falls, cutting the coils and inducing an emf.

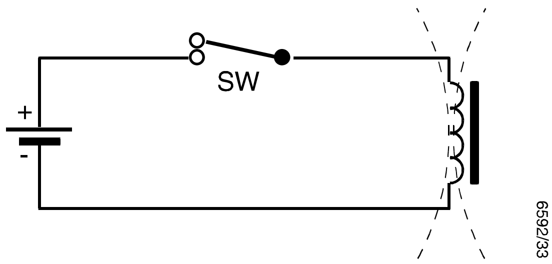


Figure 33

SELF INDUCTANCE (L)

43. The ability of a coil to produce back emf when there is a current change is a design factor and depends upon the:

- number of coil turns (N)
- cross-sectional area (a) square metres
- coil length (ℓ) metres
- permeability of core material (μ)

$$L = \frac{N^2 \mu a}{\ell} \text{ (H)}$$

44. The unit of inductance is the henry (H) and is the inductance possessed by a coil when one volt is induced when the current changes at a rate of one ampere/second.

45. When the magnetic flux linking a coil is made to vary, an emf is induced in the coil (E_b). The magnitude of this induced emf is proportional to the rate of change of flux. Hence:

$$E_b \propto \frac{d\phi}{dt}$$

where $d\phi$ = change of flux
and dt = time taken to change

46. Also the greater number of turns on the coil (N), the larger will be the induced emf (length of conductor in the magnetic field).

$$E_b = -N\frac{d\phi}{dt} \quad \text{volts}$$

Note: The negative sign indicates that, by Lenz's Law, the induced emf opposes the change responsible for inducing it. It is therefore often referred to as back emf.

CALCULATION OF INDUCED EMF

47. If the induced emf is produced by the changing flux, which in turn is produced by the changing current, then:

$$E \propto \frac{d\phi}{dt} \text{ or } \frac{di}{dt}$$

Thus the equation for induced emf E, can also be written as:

$$E = -L\frac{di}{dt}$$ volts where L is the inductance in henrys

EXAMPLES

48. If the current through a coil of 0·5 H is reduced from 5 A to 2 A in 0·05 sec, calculate the value of the back emf induced in the coil.

49. Calculate the inductance of a circuit in which 30 volts are induced when the current varies at a rate of 200 A/s.

50. Calculate the rate of current variation in a circuit of inductance 50 mH, if the induced emf is 8 volts.

51. Calculate the inductance of a 500 turn coil in which a flux of 200 µWb is produced when the current changes from zero to 0.5 amperes.

INDUCTANCE

Mutual Inductance

52. Back emf. Relative movement between a coil and a magnetic field induces an emf in the coil (E). The same effect occurs if two coils are in close proximity and a current in one of the coils is varied, as shown in figure 34.

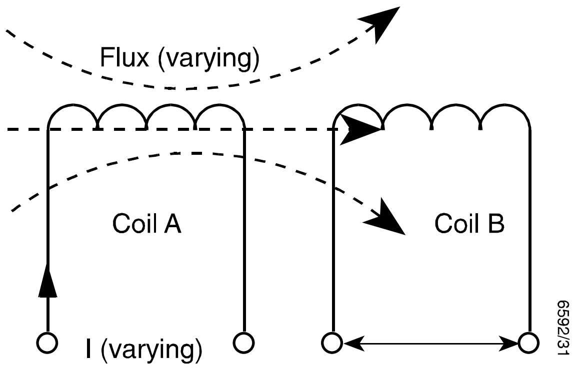


Figure 34 - Mutual Inductance

The polarity of E depends upon whether I is increasing or decreasing. It is called a BACK-EMF since, by Lenz's Law, E tends to oppose any change in I. In practice this means that, if the coil B circuit is closed, the current due to E flows in such a direction as to produce a flux which opposes any change in the coil A flux.

53. Mutual Inductance. The magnitude of E depends partly upon factors such as the angle and distance between the coils and the reluctance of the flux path but, for a given pair of coils, E is directly proportional to the rate of change of I. The ratio between E and rate of change of current is the mutual inductance of the coils, which has the symbol M.

$$M = \frac{-E}{\text{rate of change of current}}$$

The negative sign in the relationship indicates that E is a back emf. The unit of M is the henry (H). A circuit has M of one henry if one volt is induced by a rate of change of current of one ampere/second.

EXAMPLE

54. A current change rate of 200 A/sec in a coil induces 10 V in a nearby coil. Calculate the mutual inductance of the coils.

TRANSFORMERS

55. The main application of mutual inductance is in voltage transformers for ac power supply circuits; the basic construction is illustrated in figure 35.

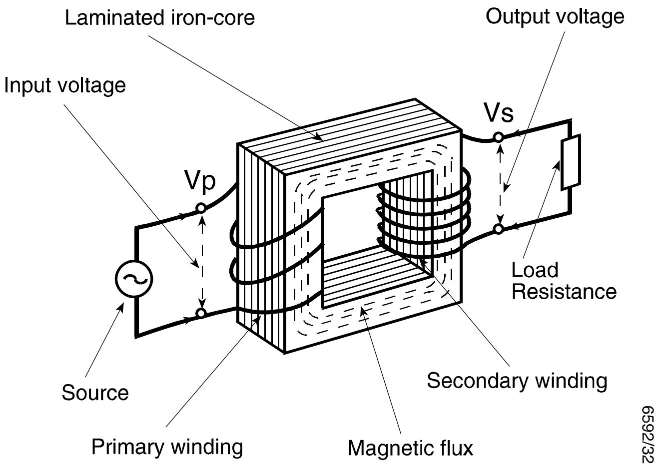


Figure 35 - Voltage Transformers

The input and output windings are called the primary and secondary respectively. The ferromagnetic core provides a low reluctance flux path.

EXAMPLES

56. Two coils have a mutual inductance of 100 mH. If the current in the primary is changed uniformly from 0-50 mA in 1ms what is the value of the induced emf?

57. Two coils have a mutual inductance of 0·3 H. If the current in one coil is varied uniformly from 5 A to 2 A in 0·4 s calculate the emf induced in the second coil.

58. If an emf of 5 V is induced in a coil when the current in an adjacent coil varies uniformly at the rate of 80 A/s what is the value of the mutual inductance of the coil?

PRACTICAL-ELECTROMAGNETIC INDUCTION

CIRCUIT DIAGRAMS

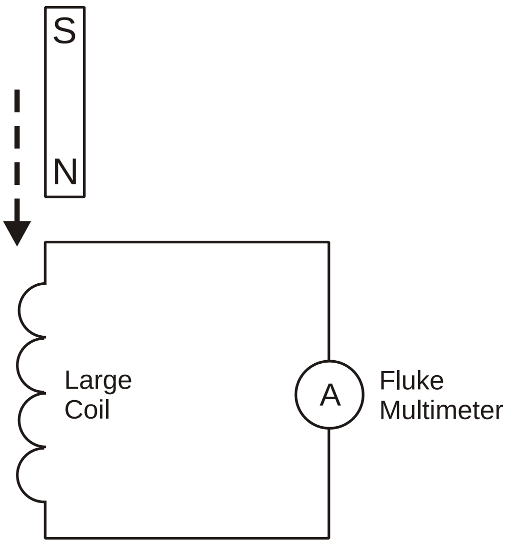


Figure 36

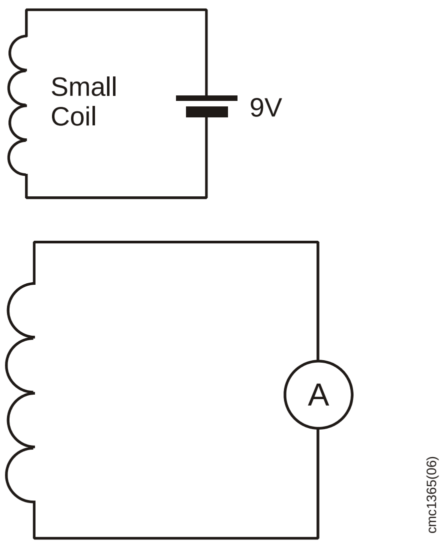


Figure 37

SELF INDUCTION

59. **Method**

a. Connect the large coil to the multimeter as figure 36.

b. Move the North pole of the magnet in and out of the coil and observe the relative magnitude and direction of the induced current.

c. Repeat item b using the South pole of the magnet.

Observations

a. How does the rate of movement of the magnet affect the induced current?

b. Is there an induced current when the magnet is inside the coil but stationary?

c. Upon what factors does the direction of the induced current depend?

MUTUAL INDUCTION

60. **Method**

a. Connect the small coil to the battery as in figure 37

b. Insert and withdraw the small coil in the large coil and observe the small induced current.

c. Repeat item b with an iron core inside the small coil.

Observation

a Is there any basic difference in how currents are induced by a magnetic or electromagnetic field?

b. Why does the iron core greatly increase the voltage induced in the stationary coil?

61. **Method**

a. Leaving the circuit connected as in figure 37, place the small coil inside the large coil. Insert and withdraw the iron core.

Observation.

b. Explain briefly why the iron core movement induces a voltage in the coil.

62. **Method**.

a. Leave the circuit connected as in figure 37 with the small coil and iron core inside the large coil. Switch the battery circuit on and off and observe the induced current.

Observations

a. Why does the direction of the current depend upon whether the battery current is switched on or off?

b. This test demonstrates the principle of a very widely used electrical component. What is that component?

63. **Method.**

a. Disconnect the battery from the small coil and reconnect with the Uni lab power supply. Connect the multimeter set to measure ac voltage and record the voltage induced in the large coil. Note the effect of removing the iron core. Set the output of the Unilab power supply to 2V rms (Do not exceed 2V)

Observations

a. By what ratio does this simple transformer step-up (increase) the voltage level?

b. Why does the iron core reduce the reluctance of the magnetic circuit?

c. Sketch a core design that would greatly reduce the reluctance of the magnetic circuit.

INDUCTIVE TIME CONSTANTS

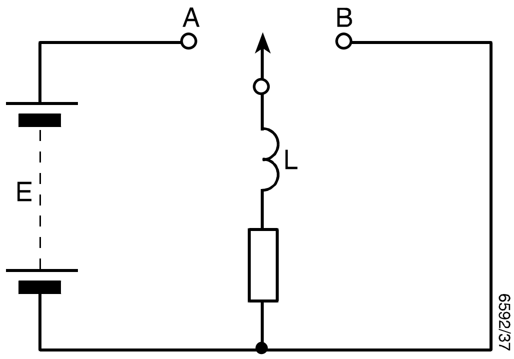


Figure 38

64. This circuit demonstrates the effect of an inductor when the current in a dc circuit is changed. When the switch is moved to A the current in the inductor rises, reaching a final steady value I = E/R. When the switch is moved to B the current decays to zero.

65. The emf induced in L opposes the change of current. The current change therefore cannot be instantaneous but is exponential, as indicated in the typical graphs below:

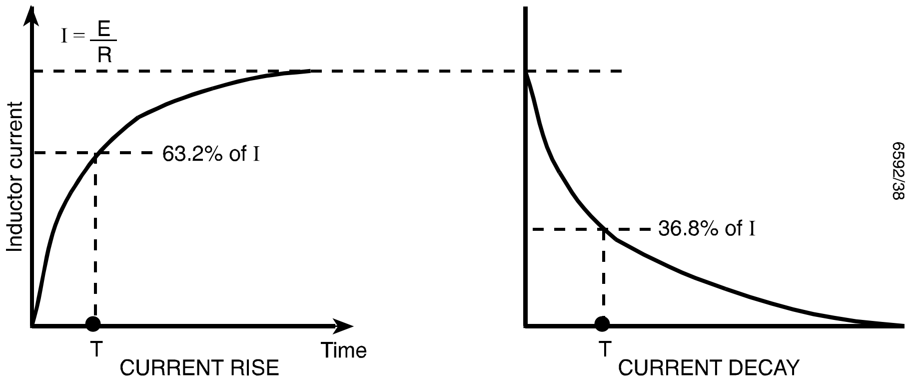


Figure 39

66. An indication of the delay in current change is given by the ratio of L to R, known as the time constant of the circuit.

$$\text{Time constant} \quad T = \frac{L}{R}$$

T is measured in seconds if L is in henrys and R in ohms.

EXAMPLE

67. An electromagnet coil has a self-inductance of 10 mH and resistance 4 Ω.

$$T = \frac{10\text{mH}}{4} = 25 \text{ msec}$$

68. T can be determined from the graphs of current change. At a time equal to T, the current will have:

risen to 63·2% of the final value when increasing or
decayed to 36·8% of the original value when decreasing.

The circuit current is considered to have reached a steady state after 5T seconds. Time constants and delays between signal and response are particularly important in servomechanisms and control circuits.

69. Example. The field coil of a dc motor has self-inductance 12H and resistance 20Ω. A dc voltage of 24 V is applied:

a. What is the time constant? $T = \frac{12}{20} = 0.6 \text{ sec}$

b. What is the current after T seconds?

The final current $I = \frac{24\,V}{20\,\Omega} = 1.2 \quad A$

After T seconds the current will be:

$0{\cdot}632 \times 1.2\text{ A} = 0{\cdot}748\text{ A}.$

c. How long elapses before the current reaches the final steady value of 1.2A?

After $5T = 5 \times 0.6 = 3$ sec.

Notes:

CHAPTER 5
CAPACITANCE AND CAPACITORS

KLP

Av01.03.04.01 Describe the properties and applications of capacitors.

Notes:

INTRODUCTION

1. **Capacitors** are electrical energy storage devices which have various applications in aircraft systems. For instance, to list but a few:

- Aircraft fuel contents systems
- Aircraft navigation lights flashing units
- Aircraft high energy igniter units
- MT ignition circuits
- Electro static microphones
- Photographic photo flash equipment

2. To appreciate how capacitors function in some of the above applications, it is necessary to study the basic principles of capacitors and to understand how they are able to store energy.

CAPACITOR

3. A basic capacitor consists of two metal plates separated by an insulator (called the dielectric).

ACTION OF A CAPACITOR

4. When connected to a supply voltage:

a. Free electrons are moved from plate A to plate B around the circuit, as shown in figure 1.

b. This imbalance of electrons produces an electrostatic field across the dielectric (similar to a magnetic field) the strength of which depends upon many factors, one of which is the type of material used for the dielectric.

c. The collection of electrons on plate B and reduction of electrons on plate A produces a pd across the plates which is equal in magnitude, but opposite in polarity, to the applied voltage (V).

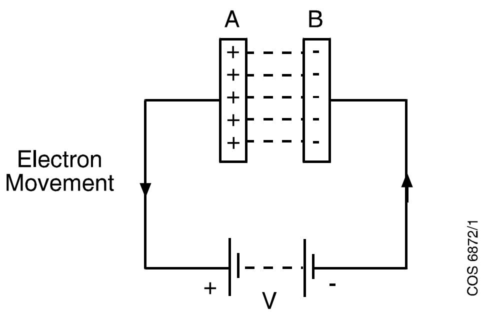


Figure 1

UNIT OF CAPACITANCE

5. The unit of capacitance is the farad, which is a measure of its ability to store charge

DEFINITION

6. A capacitor has a capacitance of one farad when a charging current of one ampere flowing for one second causes a change of 1 volt in the potential difference across the plates.

$$C = \frac{Q}{V} \qquad \text{where } Q \text{ is in coulombs and } C \text{ is in farads}$$

7. The farad is a very large and impractical unit, and practical capacitors have much smaller values eg, a microfarad (1μF) $= 1 \times 10^{-6}$ farads and a picofarad (1pF) $= 1 \times 10^{-12}$ farads

CAPACITOR SYMBOLS

8.

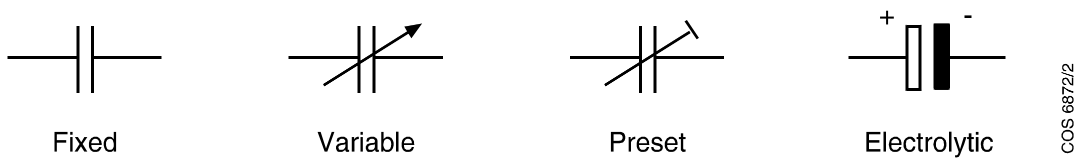


Figure 2

EXAMPLES

9. a. A 4 μF capacitor is connected to a 100 V dc supply and is fully charged. Calculate the charge on the capacitor in coulombs.

$$C = \frac{Q}{V} \quad \therefore \quad Q = VC$$

$$=$$

b. A capacitor has a charge of 0.25 coulombs when the pd across its plates is 2,500 volts. Calculate its capacitance .

c. A power supply is connected to a 600 pF capacitor and establishes a charge of 0.24 μC. Calculate the voltage of the power supply.

d. A capacitor charge current of 2 mA flowing for 2 sec causes a rise in voltage of 100 V. Calculate the capacitance.

FACTORS AFFECTING CAPACITANCE

10. The capacitance of a parallel plate capacitor depends upon:

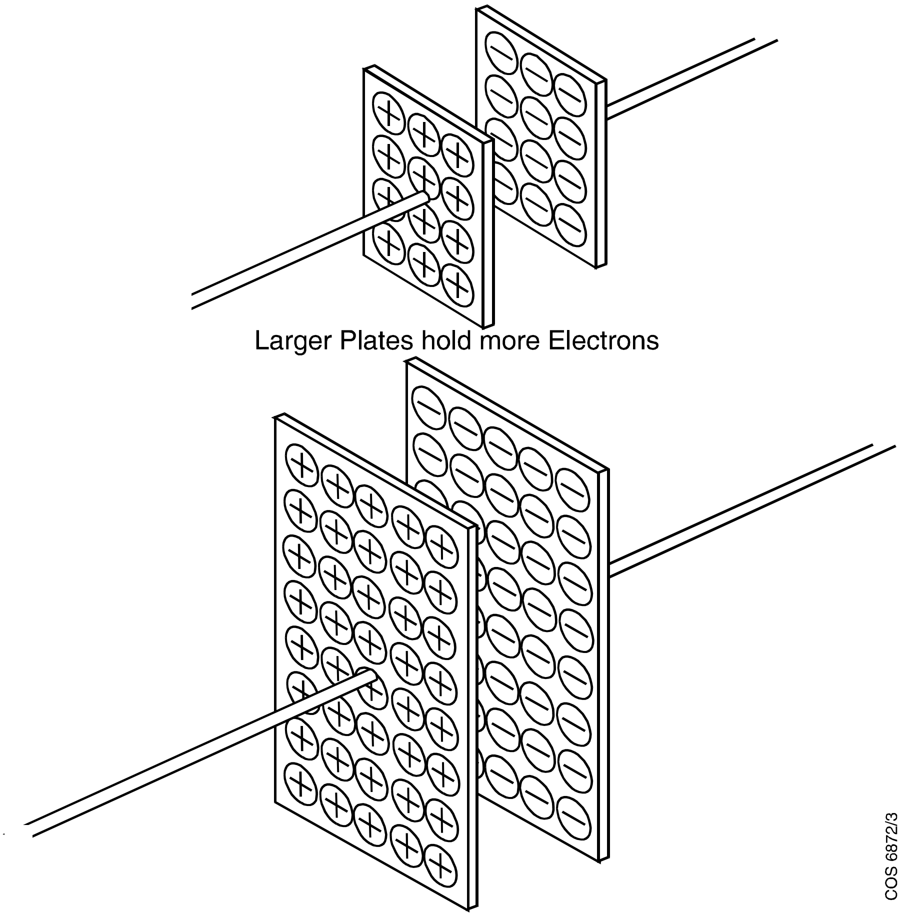
    a. The area for overlap of the plates (A) m^2

    b. The distance between the plates (d) m

    c. The type of insulating material between the plates (k) F/m

$\therefore \quad C = \dfrac{kA}{d}$ where A is in square metres
d is in metres
and k is a constant for the dielectric used

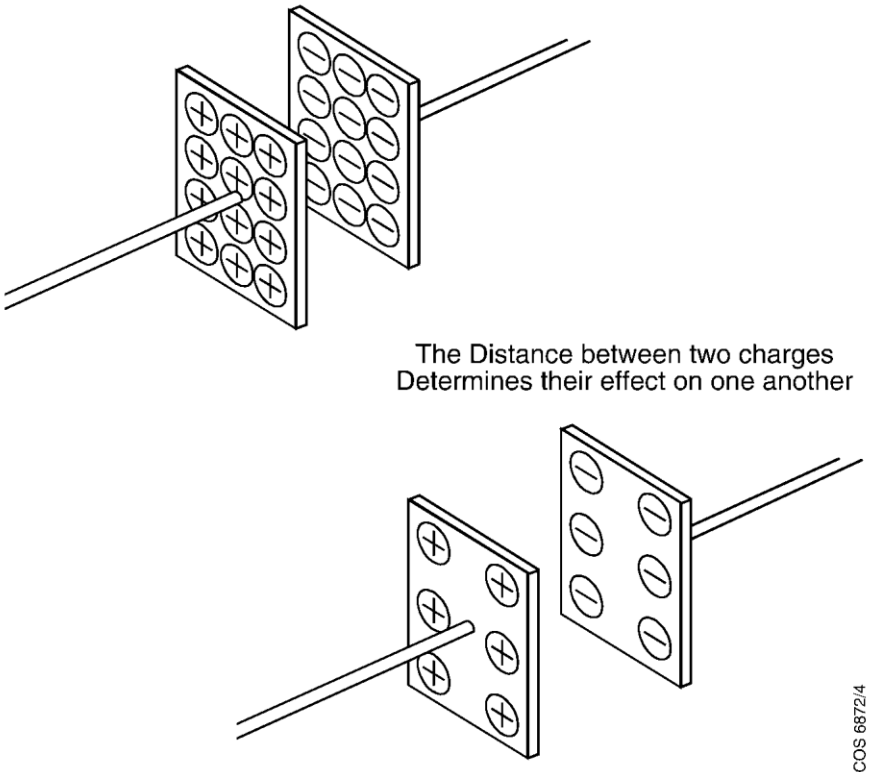
11. Referring to 10a above:



Increased plate area increases capacitance
Figure 3

A large plate area has room for more excess electrons than a small area and thus it can hold a greater charge.

12. Referring to 10b above.



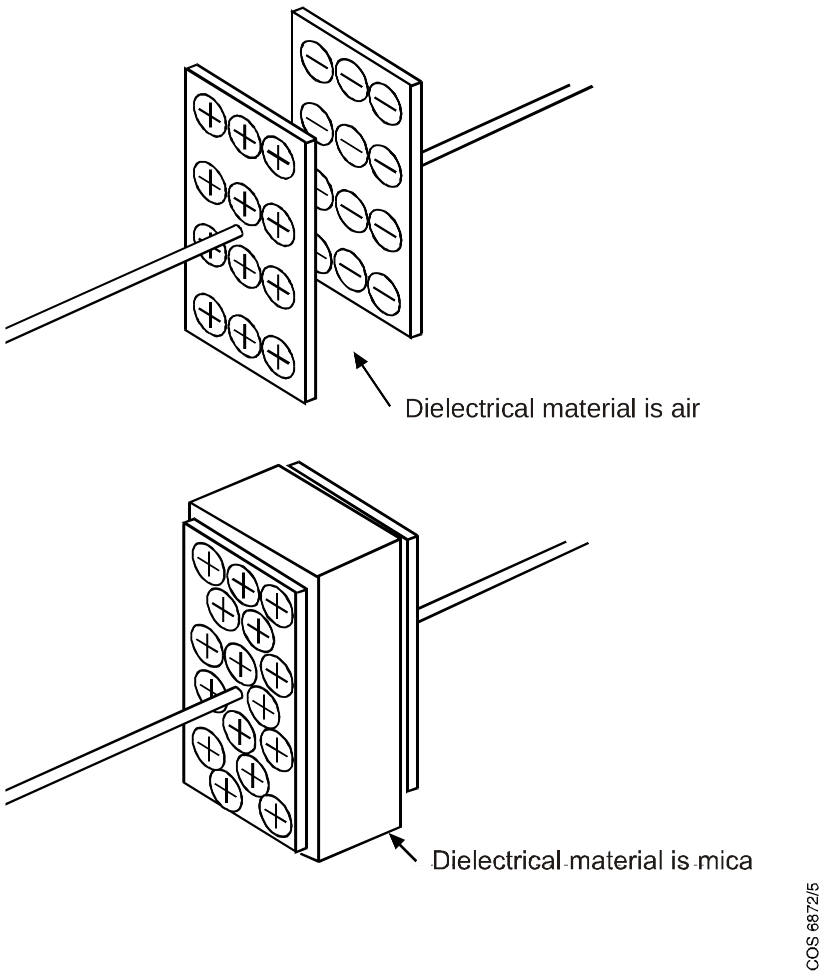
Increasing the distance between the plates decreases capacitance

Figure 4

An excess of electrons on one plate forces electrons off the opposite plate, leaving it positive. The closer the plates are to each other, the greater will be the effect of one charge on the other thus increasing the capacitance.

13. Referring to 10c above:

Changing the dielectric material changes the capacitance



Mica Dielectric increases the Capacitance
Figure 5

If the dielectric material used is other th an air, the capacitance will be increased by the approximate factors: Paper 3, Mica 5, Ceramics 100 to 1000. These coefficients are called relative permittivity.

SAFE WORKING VOLTAGE

14. The safe working voltage is the maximum dc voltage that can be applied to the capacitor without the dielectric breaking down. A large value capacitor with a thin dielectric, is suitable only for low voltages. A high voltage, high capacitance value is usually very bulky.

15. Capacitor values are stated in capacitance and maximum working voltages eg, 1 µF 750 V dcw (dc working). **This voltage must NOT be exceeded**.

16. A charged capacitor, especially a large one, can be dangerous. Always make sure it is discharged before handling it, by discharging it through a resistor..

17. An electrolytic capacitor is polarised. It can only be used in a dc circuit and must be connected to the correct polarity. This type of capacitor usually has the positive terminal marked with a red dot, a + sign, or sometimes both.

CAPACITOR TIME CONSTANT - CHARGE OF A CAPACITOR THROUGH A RESISTOR

18. When the switch is closed on the circuit shown in figure 6 the rate of flow of current is determined not only by the amount of resistance but also by the opposition of any charge which is stored by the capacitor.

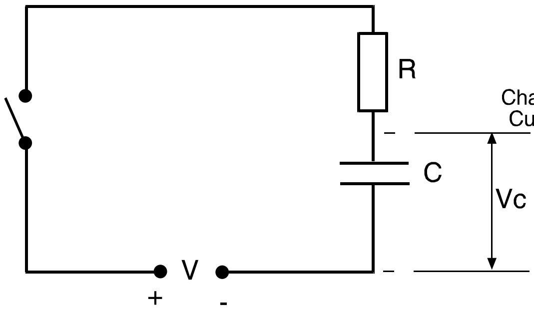


Figure 6

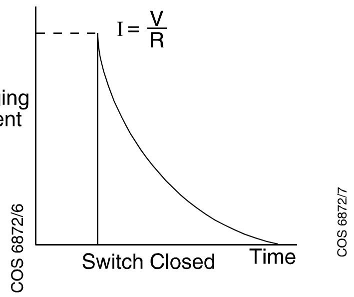


Figure 7

19. If the capacitor has no charge when the switch is closed the current will rise instantly to its maximum value, given by $\frac{V}{R}$ and the capacitor will begin to charge. The increasing charge will establish a potential difference, opposing the supply voltage V, which will cause the current to fall, see figure 7. When the voltage across the capacitor (Vc), is equal (and opposite) to the supply voltage the current will have fallen to zero, see figure 8.

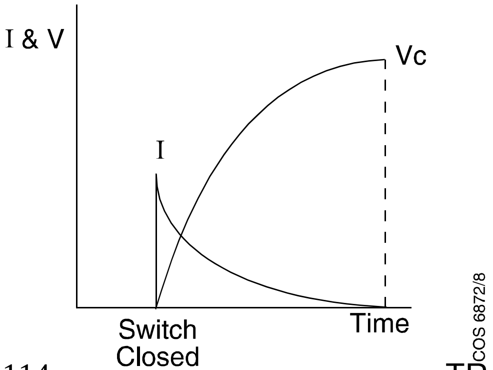


Figure 8

The time taken to fully charge the capacitor is given by $5 \times C \times R$ and is in seconds when C is farads and R in ohms.

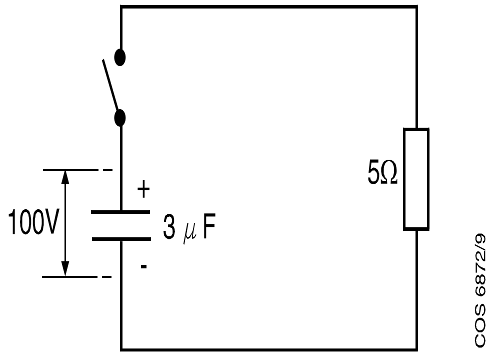
$$T = C \times R$$

TIME CONSTANT

20. The time constant is the time taken for the voltage to rise from zero to 63.2% of its maximum value and is given by C × R. The charging current will have fallen 63.2% of its maximum value in the same time.

Note: Whatever the value of the charge/discharge resistor the current will still fall 63.2% of its maximum value in CR seconds and take 5 × CR secs to either fully charge or discharge.

21. **Example.** A 3 μF capacitor charged to a PD of 100 V, is discharged through a 5 Ω resistor. Calculate the time constant and the voltage across the capacitor after the time constant has elapsed.



$T = C \times R$

$= \frac{3}{10^6} \times 5 = 15\ \mu s$

After 15 μs the voltage will have fallen 63.2% of its maximum value of 100 V.

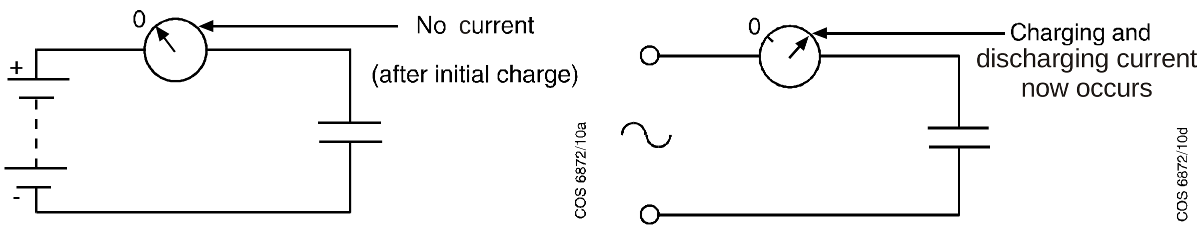
$\therefore$ Vc = 100 - 63.2 V = 36.8 V

Figure 9

Note: The voltage across the capacitor will fall to 0 V in 5 × 15 µs = 75 µs.

22. As can be seen in figure 10(a) when dc is applied to a capacitor, the current falls to zero when the capacitor is fully charged. Thus under normal circumstances, a capacitor effectively 'blocks' current flow in a dc circuit.

23. If alternating current is applied to a capacitor, figure 10(b), it will constantly be charging, first in one direction, and then in the other. This means that as far as the circuit is concerned, current exists. The higher the frequency of the ac, the more circuit current there will be flowing, as current is the rate of flow of electrons. (1 amp = 1 coulomb per second)



(a) dc supply **(b) ac supply**

Figure 10

EXAMPLES

24. A two parallel plate capacitor has an area of overlap of 2 cm^2 and an air gap of 1 mm between them. Calculate the capacity of the capacitor:

a. When air is the dielectric (k = 8.85 $\times$ 10^{-12} F/m)

b. When mica is the dielectric (k = 48 $\times$ 10^{-12} F/m)

25. An air dielectric tuning capacitor is made with seven overlapping plates as shown in the diagram. The distance between the plates is 0.15 mm and the area of one side of each plate is 500 cm^2. If k = 8.85 $\times$ 10^{-12} F/m calculate:

a. The capacitance is microfarads.

b. The charge taken when it is connected to a 240 volt supply.

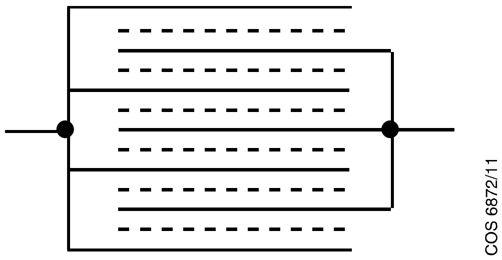


Figure 11

26. A 50 μF capacitor is fully charged to 200 V and then connected across a 5 k Ω resistor. Calculate:

a. The initial value of current.

b. The time constant of the circuit.

c. The value of current after 1 time constant.

d. The voltage across C after 1 time constant.

PRACTICAL - CHARGE AND DISCHARGE OF A CAPACITOR

Method for charge

27. **Caution: Ensure capacitors are discharged before handling.**

a. Construct the circuit shown in figure 12 below.

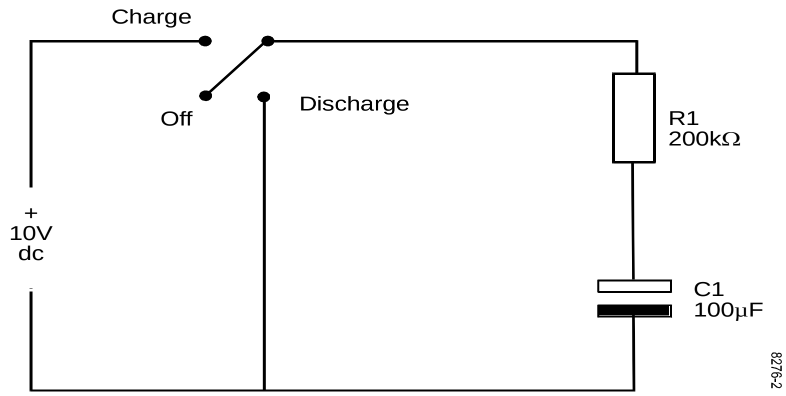


Figure 12

b. Calculate and record the time constant (CR) and 5 CR time for the circuit.

CR time = ______________ 5 CR time = _______________

c. Calculate and record I_{max}. I_{max} = ___________________

d. Set the output of the dc power supply unit to 10 V. **Do not switch the output on**.

e. Place the link in the **charge** position.

f. Switch the power supply output to on and concurrently start the stopwatch.

g. Record V_C at the time intervals detailed in table 1.

Time (Seconds)										
Time	0	5	10	20	30	40	60	80	100	120
V_C										

Table 1

h. Switch off the power supply unit.

i. Place the link in the **discharge** position and concurrently start the stop watch.

j. Record V_C at the time intervals detailed in Table 2.

Time (Seconds)										
Time	0	5	10	20	30	40	60	80	100	120
V_C										

Table 2

Method for discharge

28.

a Reconfigure the circuit to remove the voltmeter and insert an ammeter in series with the capacitor and resistor.

b. Set the output of the dc power supply unit to 10 V. **Do not switch the output on**.

c. Place the link in the **charge** position.

d. Switch the power supply output to on and concurrently start the stopwatch.

e. Record I_S at the time intervals details in table 3.

Time (Seconds)										
Time	0	5	10	20	30	40	60	80	100	120
I_S										

Table 3

f. Switch off the power supply unit.

g. Place the link in the **discharge** position and concurrently start the stopwatch.

h. Record I_S at the time intervals detailed in table 4.

Time (Seconds)										
Time	0	5	10	20	30	40	60	80	100	120
I_S										

Table 4

TYPES OF CAPACITORS

29. Some typical types of capacitor are shown below:

a. Paper (High voltage)

- Aluminium foil strips separated by waxed paper.
- 250pF to 10 µF range.
- Working voltage up to 150 kV dc (above 600 volts oil filled).

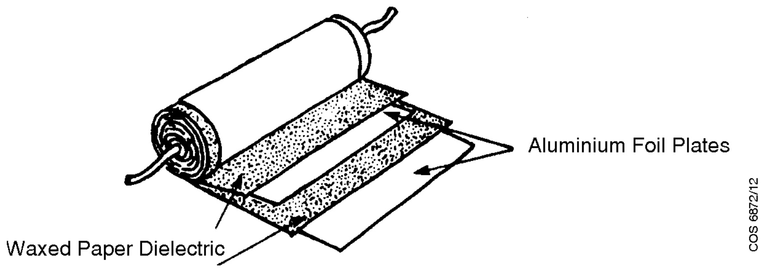


Figure 13

b. Mica (High quality/high temperature)

- Mica and foil interleaved.
- 25 pF to 0.25 µF.
- Up to 2 kV dc working voltage.

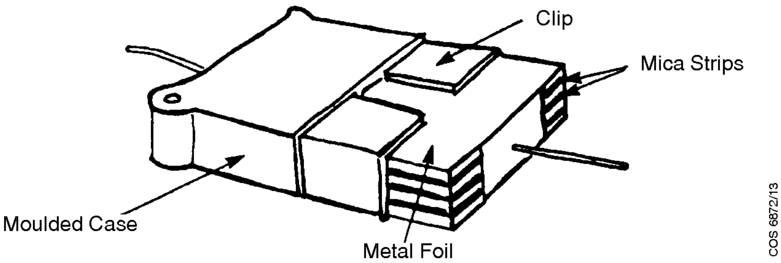


Figure 14

c. Ceramic (Very Small Capacitance)

- Two silver films on ceramic rod.
- 0.5pF to 0.01µF.
- Working voltage up to 500 V dc.

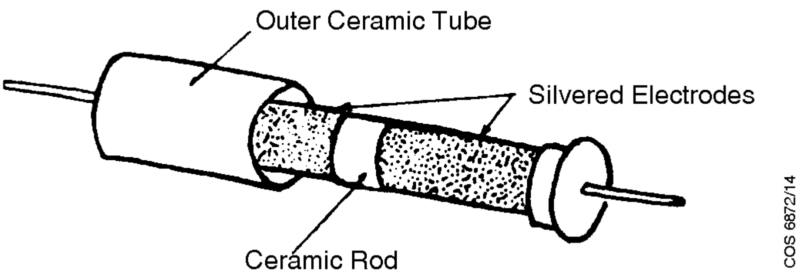


Figure 15

d. Electrolytic (large capacitance small size).

- The dielectric is very thin chemical film.
- dc is essential with polarity of connection.
- 1 µF to 1000 µF capacitance.
- about 600 V maximum (decrease as capacitance increases).

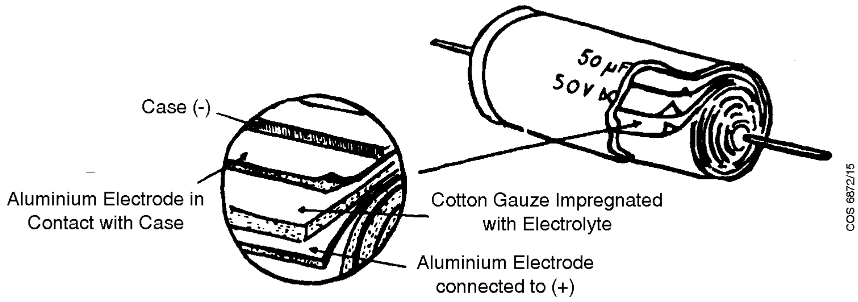


Figure 16

e. Variable

- Fixed and moveable vanes are overlapping.
- Usually an air dielectric.
- Typical values 50 pF to 500 pF.

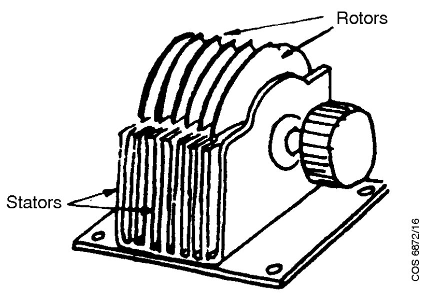


Figure 17

f. Pre-set (Trimmers)

- Smaller versions of variable air dielectric types.
- Mica compression or variable ceramic types available.
- Typical values 2 pF to 50 pF.

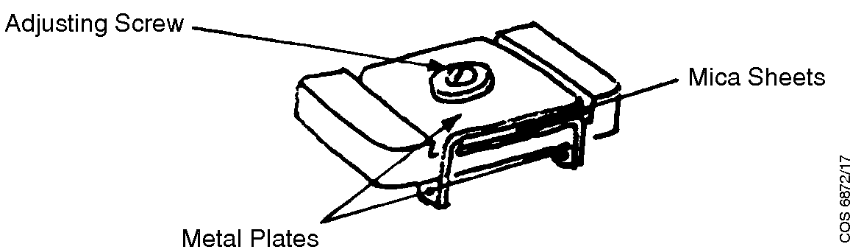


Figure 18

GROUPING OF CAPACITORS

30. It is sometimes useful to connect capacitors in parallel and the effect of this is to increase the capacitance by increasing the plate area, and hence the total charge drawn from the supply eg:

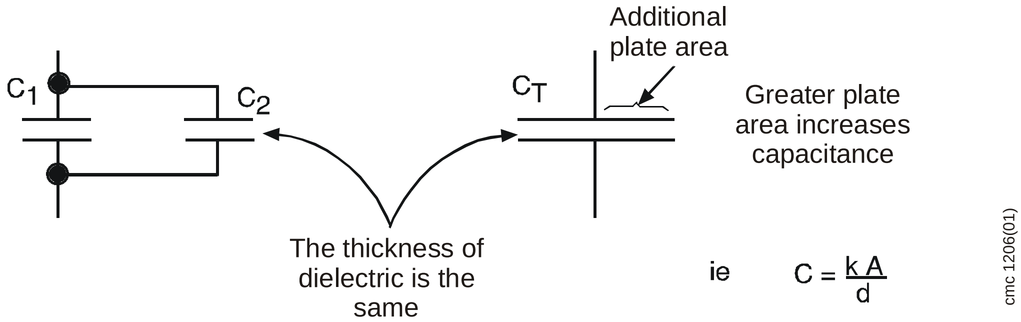


Figure 19

31. The total capacitance for parallel connected capacitors is found by adding the values of the various capacitors together.

$$C_T = C_1 + C_2 \text{ ... etc}$$

32. Connecting capacitors in series is a method of grouping rarely used because it has the effect of reducing the effective capacitance.

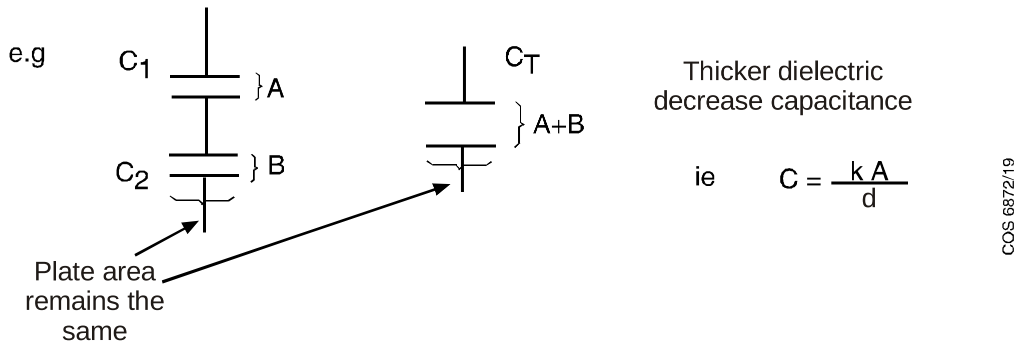


Figure 20

33. Total capacitance for series connected capacitors is therefore found by:

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} \text{....etc}$$

ENERGY STORED IN A CAPACITOR

34. The energy stored in the electric field of a capacitor is given by the formula:

$$W = \frac{1}{2}CV^2 \text{ joules}$$

EXAMPLE

Calculate the energy stored in a 10μF capacitor charged to 100V.

$$W = \frac{1}{2}CV^2 \text{ joules} = 0.5 \times 10 \times 10^{-6} \times 100^2 = 0.05 \text{ joules}$$

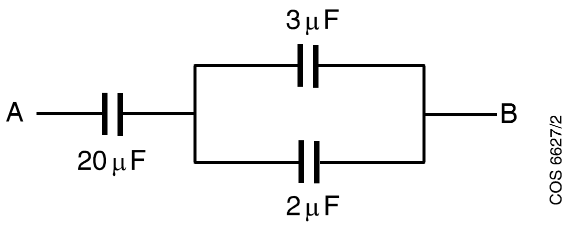
Notes:

CAPACITORS IN SERIES AND PARALLEL

EXAMPLES

35. Capacitors of 4 µF and 16 µF are connected in series across a 250 volt supply. Find the total capacitance and the voltage across each capacitor.

36. Calculate the capacitance between A and B for the circuit shown below:



37. Two capacitors having capacitances of 10 µF and 15 µF respectively, are connected in series across a 200 volt dc supply. Calculate:

a. The charge on each capacitor.

b. The pd across each capacitor.

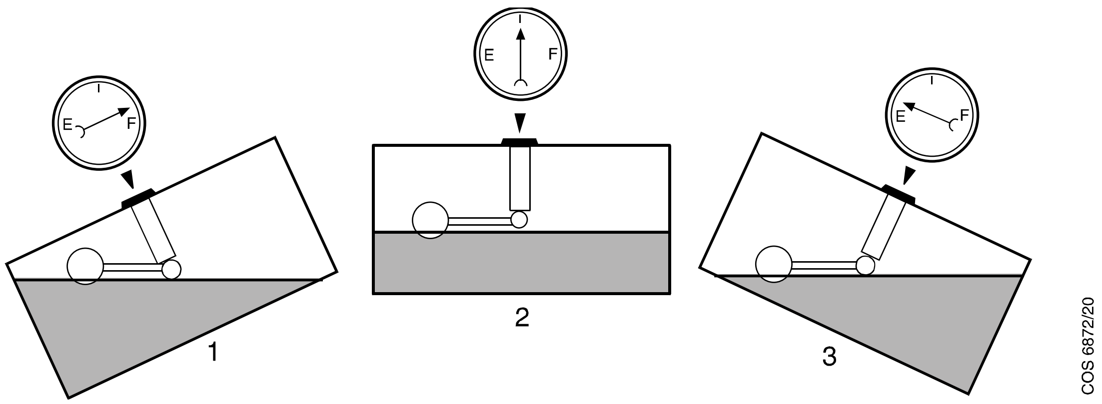
c. Find the capacitance of a single capacitor that would be equivalent to these two capacitances in series.

PRACTICAL APPLICATIONS (FOR INFORMATION ONLY)

38. This note explains briefly how the principles of capacitor storage ability are used in certain practical aircraft applications.

CAPACITOR FUEL CONTENTS GAUGES

39. A simple float operated system may be suitable for static or MT fuel contents indication, figure 21(2) but are subject to attitude errors if used in aircraft, see figure 21(1) and (3) below, eg:



Error can be over reading (1) or under reading (3)

Figure 21

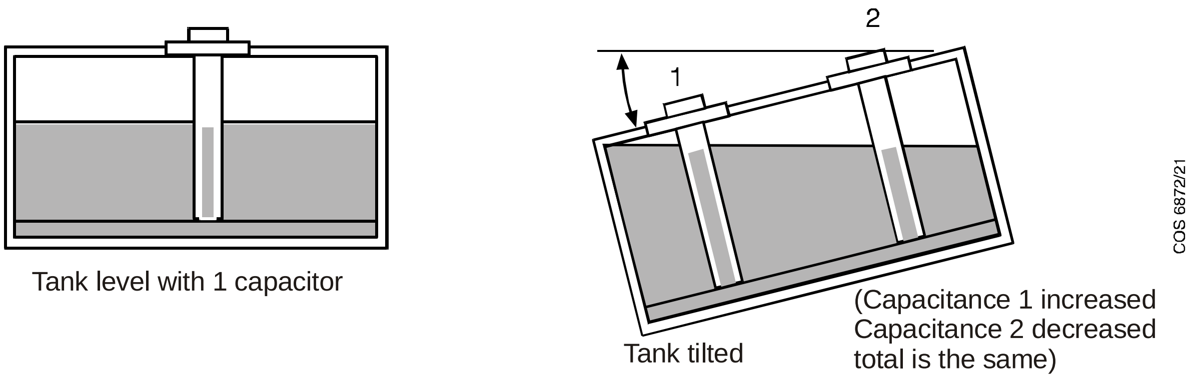
40. A capacitor level detector can overcome this problem by utilising the two basic capacitor principles of:

a. $C = \frac{kA}{d}$ (where k is the permittivity of the dielectric).

b. $C_T = C_1 + C_2 + C_2$ ... etc.

41. From paragraph 40a above, the capacitance value depends upon the permittivity of the dielectric (k) between the plates. If the capacitive tank units are fitted vertically in the fuel tanks, the capacitance will increase as the tank fills with fuel. As the permittivity of fuel is approximately twice that of air, the capacitance value will represent the fuel contents, figure 22(a) overleaf.

42. The effect of aircraft attitude is overcome by installing two or more tank units in each tank and connecting them in parallel, see figure 22(b). As the total capacitance is the sum of the individual capacitors in parallel (refer to sub-paragraph 40b above) the tilting of the tank will increase the capacitance of one unit and decrease the capacitance of the other, thus maintaining a constant total capacitance value.



(a) One Capacitor **(b) Two Capacitors**

Figure 22 – Capacitor Level Detectors

43. Also, several aircraft fuel tanks can be monitored to give a total fuel readout, by connecting all the capacitor units in parallel as in figure 23 below.

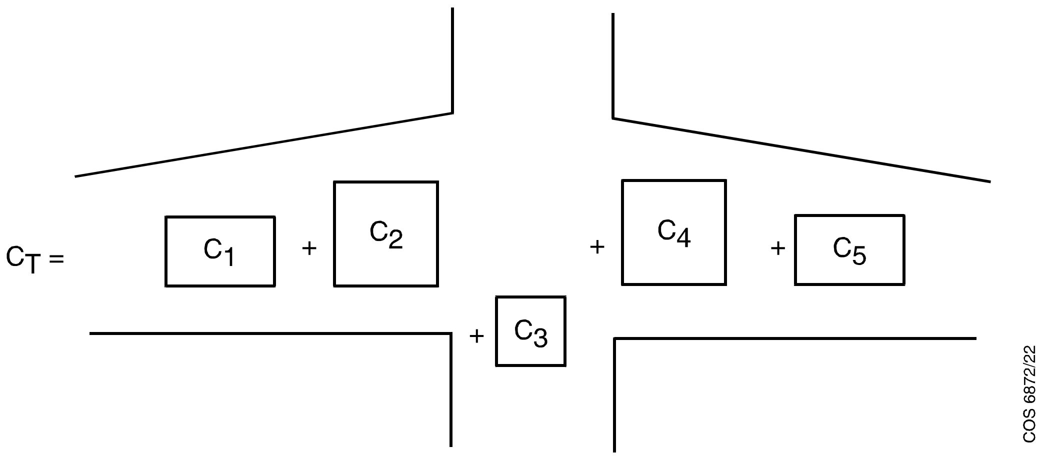


Figure 23

BRIDGE CONTENTS SYSTEM

44. The diagram below indicates how the capacitive tank units can be used in a Wheatstone Bridge system to indicate fuel contents.

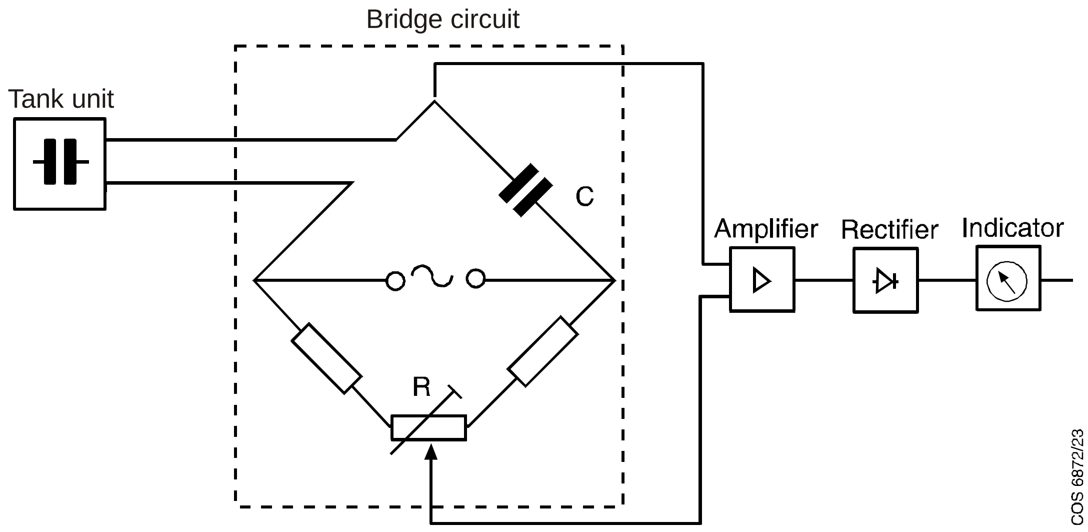


Figure 24

45. The tank unit is the variable arm of the bridge and when empty, the bridge is balanced (adjusted for zero output by R).

46. As tank contents increases, reactance of tank unit decreases, resulting in out of balance condition of bridge.

47. The bridge output is amplified, rectified and applied to the indicator (moving coil meter calibrated in fuel contents).

NAVIGATION LIGHTS

48. Some navigation lights are continuous, others flash with a controlled time sequence. Flashing lights are operated by electric motors or by electronic timers or by the simple time-delay circuit shown below:

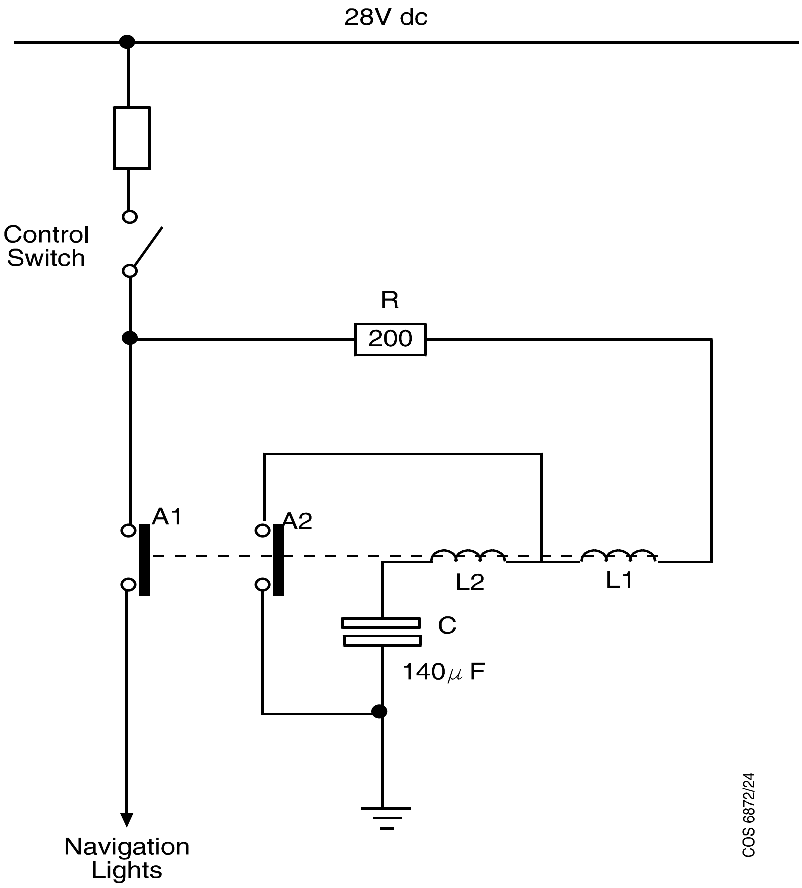


Figure 25 – Navigation Lights Flasher Circuit

49. **Operation.** The relay contacts A1 and A2 are normally closed but will be opened when the relay coils L1 and L2 are energized. When the contacts are closed, A2 short-circuits L2 and C. The operating sequence is as follows:

a. When the control switch is closed the navigation lamps are supplied with 28 V dc. Current also flows to earth through R and L1, a circuit with a short time-constant. After a short period the rise in current is sufficient to energize L1, and A1 and A2 are now opened and the navigation lights are extinguished.

b. Current now flows through R, L1, L2 to charge C. This charging current keeps the relay energized for a period determined mainly by the time-constant CR. When the current decays sufficiently, L1 and L2 release the contacts back to the closed position. The navigation lights are again temporarily lit and the cycle is repeated.

50. The flasher unit is ‘fail-safe’ since if the relay fails the navigation lights remain on when the control switch is closed.

SELF-ASSESSMENT QUESTIONS

1. Draw and label the symbols used for fixed, electrolytic, variable and pre-set capacitors.

2. What is the effect on capacitance of an increase in the area of overlap of a variable capacitor?

3. What factors must be taken into account when:

   a. Removing a capacitor from a circuit?

   b. Connecting an electrolytic capacitor into a dc circuit?

4. State the meaning of ‘time constant’.

5. What is meant by ‘steady state value’?

6. Describe, with the aid of a diagram, the charging of a 1 μF capacitor from a dc supply which rises from 0 to + 10 V instantaneously. The circuit has a total series resistance of 1 MΩ

7. Explain the meaning of the following statement: ‘A capacitor blocks dc but allows current flow in an ac circuit’.

8. State the three physical factors that affect the capacitance value of a capacitor.

9. Briefly explain the operation of a fuel contents system, with reference to the factors stated in question 8.

10. Explain how a capacitor can help to reduce the sparking across contacts that carry current in a highly inductive circuit.