CAE Oxford Aviation Academy

ELECTRICS AND ELECTRONICS

ATPL GROUND TRAINING SERIES

BOOK THREE

EASA FIRST EDITION

REVISED FOR NPA 29

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Introduction

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ATPL Book 3 Electrics and Electronics

DC Electrics

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I

Introduction

Chapter 1

DC Electrics - Basic Principles

Introduction

An electric current is created when electrons are caused to move through a conductor. Moving electrons can explain most electrical effects.

All materials consist of tiny particles called atoms. Atoms are made up of a nucleus and electrons. Atoms of different materials have different numbers of electrons. The electrons orbit the nucleus like the sun with planets spinning around it.

The electrons have a negative charge and the nucleus has an equal number of positive charges (protons) making the atom electrically neutral. The negative electron is held in its orbit by its attraction to the positive nucleus. Electrons in outer orbits are not so strongly attracted to the positive nucleus and may easily fly off and attach themselves to a neighbouring atom in the material. These are called free electrons.

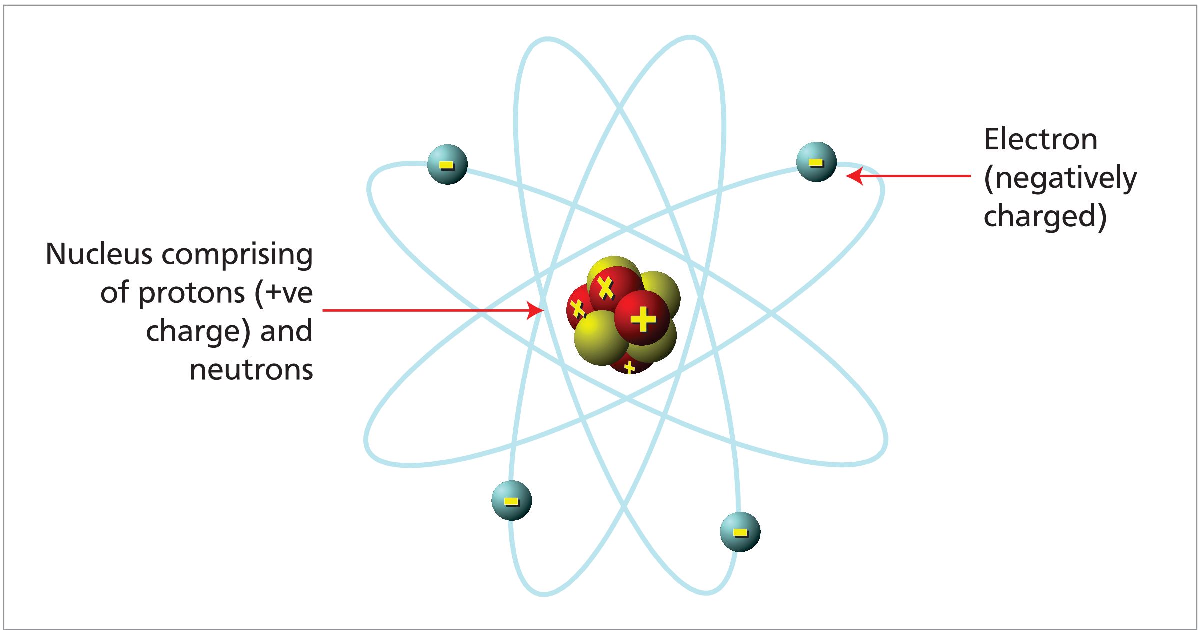


Figure 1.1

An atom that has lost an electron becomes more positive and is called a positive ion, an atom that has gained an electron becomes more negative and is called a negative ion. If the free electrons can be made to move in a particular direction through the material, an electric current has been created.

Materials which have free electrons are called conductors, e.g. copper, silver and aluminium. Materials which have very few free electrons are called insulators, e.g. wood, rubber, glass and plastics.

Electrons are caused to move along a piece of wire by applying a positive charge from some source at one end and a negative charge at the other. The positive charge attracts the free electrons and the negative charge repels them so there is a flow of electrons in one direction through the wire from the negative terminal to the positive terminal.

To maintain the current flow, the force which caused the electrons to flow in the first place must be maintained otherwise the electrons will all collect at the positive terminal and the current flow will cease. To keep the current flowing, the source of the force which caused the electrons to move must be capable of absorbing the electrons from the positive terminal and transferring them through itself back to the negative terminal.

In this way the current can be maintained as long as there is a complete circuit.

Electricity had been in use before electrons were discovered and it had been assumed that electricity was the flow of something from positive to negative and all the laws of electricity were based on this idea. This is known as conventional flow. Flow from negative to positive is known as electron flow.

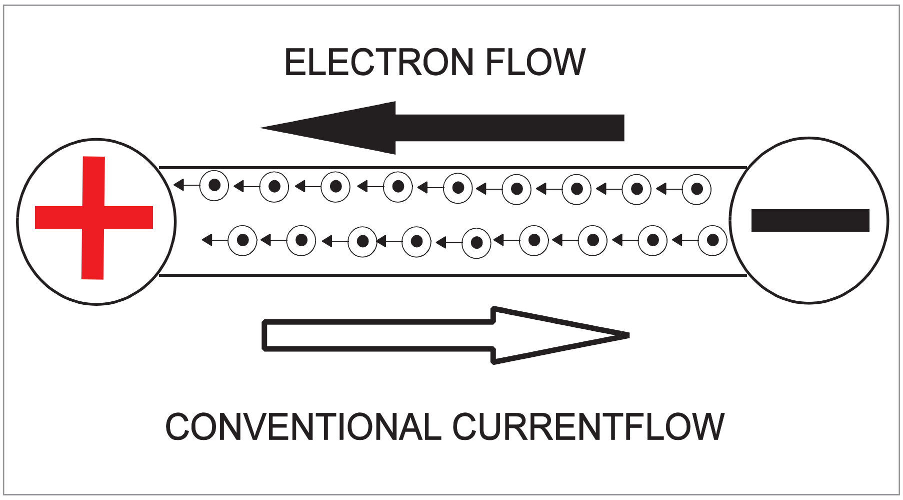


Figure 1.2

There are six basic means to provide the force which causes electrons to flow:

- Friction - static electricity
- Chemical Action - cells and batteries (primary and secondary cells)
- Magnetism - generators and alternators
- Heat - thermocouples (junction of two dissimilar metals)
- Light - photo electric cell
- Pressure - piezoelectric crystals

Of the six basic methods, only Chemical Action (batteries) and Magnetism (generators) produce electrical power in sufficient quantities for normal daily needs.

Electromotive Force (EMF)

For electric current to flow there must be a force behind it. In the same way that water needs a force (pressure) to make it flow, electricity needs pressure, Electromotive Force (EMF), to make it flow. In a water tank if pressure decreases, flow decreases. In electrics if the EMF decreases, the flow of electrons decreases.

EMF is measured in units of **Voltage**. The number of volts is a measure of the EMF or **Potential Difference** (pd) (the difference in electrical potential between the positive and negative terminal). Voltage is given the symbol **V** or **E.**

By increasing the voltage the flow of electrons increases past any point in a circuit, and decreasing the voltage decreases the flow. To maintain the correct flow it is normal to keep a constant voltage in a circuit.

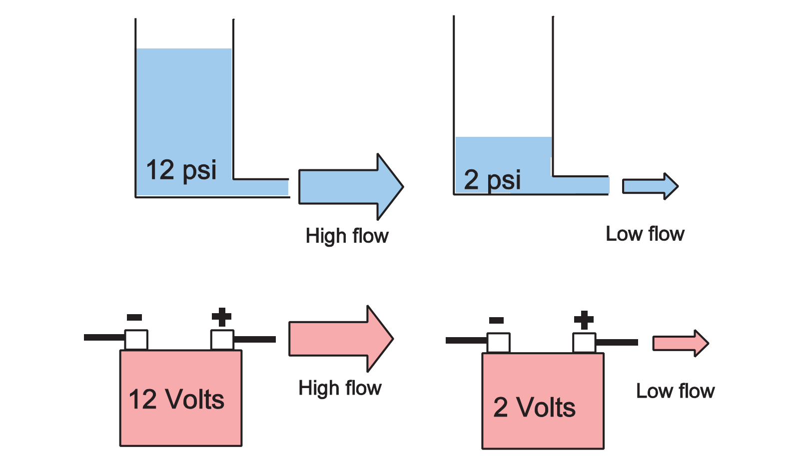


Figure 1.3 Comparison between voltage and water pressure

The source of the voltage can be a battery or a generator. Batteries become discharged as their voltage is used so are limited in their use. Generators are used to maintain a constant voltage.

For high and low voltages the following prefixes are used:

One Microvolt - one millionth of a volt (1 μV)

One Millivolt - one thousandth of a volt (1 mV)

One Kilovolt - one thousand volts (1 kV)

To measure voltage a **voltmeter** is used. It is connected across the two points between which the voltage is to be measured without disconnecting the circuit.

Current

The current (**symbol I**) in a conductor is the number of electrons passing any point in the conductor in one second and is measured in **amperes or amps** (symbol A).

Current can be measured by an instrument called an **ammeter** which is connected into the circuit so that the current in the circuit passes through the ammeter.

Small values of current are given the following prefixes:

One Microamp - one millionth of an ampere (1 μA)

One Milliamp - one thousandth of an ampere (1 mA)

Effects of an electric current:

- **Heating Effect**. When a current flows through a conductor it always causes the conductor to become hot - electric fires, irons, light bulbs and fuses.

- **Magnetic Effect**. A magnetic field is always produced around the conductor when a current flows through it - motors, generators and transformers.

- **Chemical Effect**. When a current flows through certain liquids (electrolytes) a chemical change occurs in the liquid and any metals immersed in it - battery charging and electroplating.

Resistance

For a current to flow there must be a complete path or circuit. The fewer obstructions in the circuit the greater will be the current flow. The higher the voltage the greater will be the current flow.

The obstruction in the circuit which opposes the current flow is called resistance. Different materials have different numbers of free electrons those with more free electrons will have a lower resistance than those with few free electrons, so those with more free electrons are better conductors of electricity.

For a fixed voltage the smaller the resistance the larger will be the current flow and the larger the resistance the smaller will be the current flow. The current in the circuit can therefore be adjusted by altering the resistance.

Factors Affecting the Resistance

- Type of material. e.g. silver is a better conductor than copper
- Length. The longer the wire the greater the resistance
- Cross sectional area. The thicker the wire the smaller the resistance
- Temperature. The symbol for temperature coefficient is α (alpha). If resistance increases with an increase of temperature, the resistor is said to have a Positive Temperature Coefficient (PTC). If resistance decreases with an increase of temperature, the resistor is said to have a Negative Temperature Coefficient (NTC). Resistors having these characteristics are used in aircraft systems for temperature measurement.

Units of Resistance

The unit of resistance is the **ohm** (symbol Ω). A material has a resistance of one ohm if an applied voltage of one volt produces a current flow of one ampere.

For larger and smaller values:

One millionth of an ohm	=	one microhm (1 μΩ)
One thousandth of an ohm	=	one milliohm (1 mΩ)
One thousand ohms	=	one kilohm (1 kΩ)
One million ohms	=	one megohm (1 MΩ)

Resistors

Sometimes resistance is used to adjust the current flow in a circuit by fitting resistors of known value. These can be either fixed or variable and can be drawn like this:

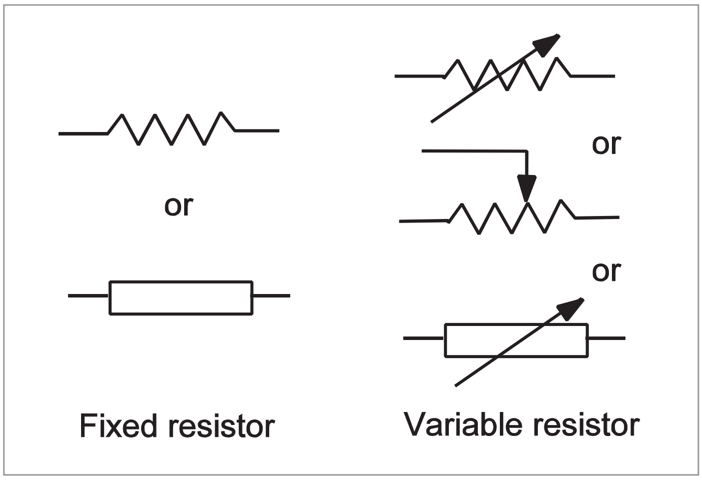


Figure 1.4

Ohm's Law

In a closed circuit there is a relationship between Voltage, Current and Resistance. If the voltage remains constant, any increase in resistance will cause a decrease in current and vice-versa (current inversely proportional to resistance).

If the resistance remains the same, any increase in voltage will cause an increase in current and vice- versa (current directly proportional to voltage).

This is expressed as Ohm's Law:

$$V = IR$$

And by transposition

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

Power

When a Force produces a movement then Work is said to have been done, and the rate at which work is done is called Power.

In an electric circuit work is done by the voltage causing the **current** to flow through a **resistance**, creating heat, magnetism or chemical action.

The rate at which work is done is called **Power** and is measured in **Watts**.

Watts (W) = Voltage (V) × Amperes (I)

Three formulae for calculating power can be derived from the two basic formulae V=IR and W=V×I

- Voltage unknown $W = I^2 R$
- Resistance unknown $W = V \times I$
- Current unknown $W = \frac{V^2}{R}$

When a current passes through a resistor it becomes hot and will eventually melt if the current becomes excessive.

The amount of heat developed by a current (I) in a resistor (R) is I^2R watts, therefore it can be seen that the heating effect is proportional to the square of the current. So a small increase in current can cause a significant increase in heating effect.

Each electrical component will be given a Power Rating (maximum wattage) which, if exceeded, will cause the component to overheat, e.g. 60 watt light bulb.

Each electrical circuit in an aircraft will be protected by a fuse or circuit breaker which will prevent the maximum power rating of a component to be exceeded by breaking the circuit if the current increases.

Series and Parallel Circuits

More than one resistance can be connected in any one circuit and they may be connected in Series - one after the other, or in Parallel - alongside each other.

- Series

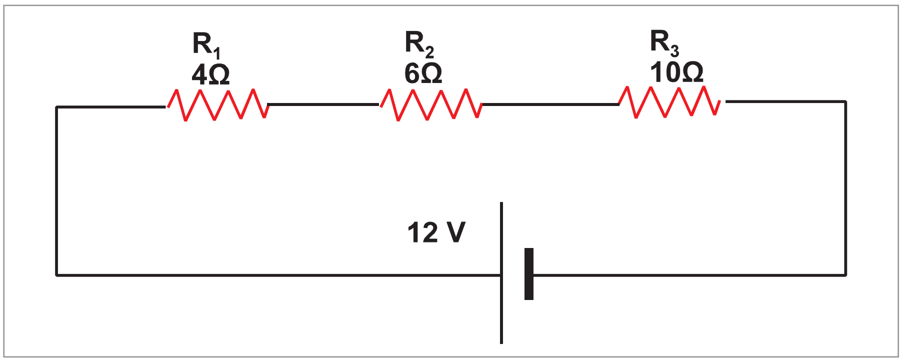


Figure 1.5

Series connection reduces current flow and therefore power consumption, but can be impractical because individual loads (resistances) cannot be individually controlled. Also the failure of one resistance would mean failure of the rest of the circuit.

The total circuit resistance can be calculated by summing the individual resistances.

$R_T = R_1 + R_2 + R_3$

i.e. $R_T = 4 + 6 + 10$

R_T = 20 ohms

V = IR so current $= \frac{12}{20} = 0.6$ amps

- Parallel

Parallel connection ensures each resistor is individually controllable and receives the same voltage. Failure of one resistor will not affect the others. Most aircraft loads are connected in parallel.

The total circuit resistance can be found by the following method.

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

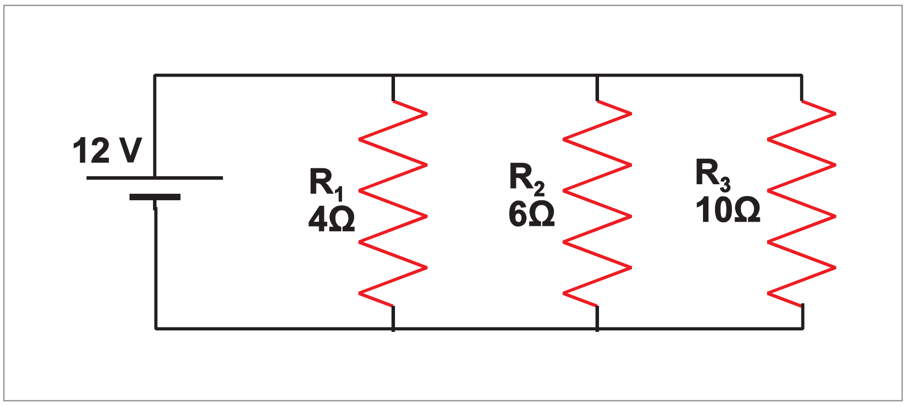


Figure 1.6

$$\frac{1}{R_T} = \frac{1}{4} + \frac{1}{6} + \frac{1}{10}$$

$$\frac{1}{R_T} = \frac{15 + 10 + 6}{60}$$

$$\frac{1}{R_T} = \frac{31}{60}$$

$$R_T = \frac{60}{31}$$

R_T = 1.94 ohms

V = IR so current = $\frac{12}{1.94}$ = 6 amps approx

- Combination of series and parallel resistors

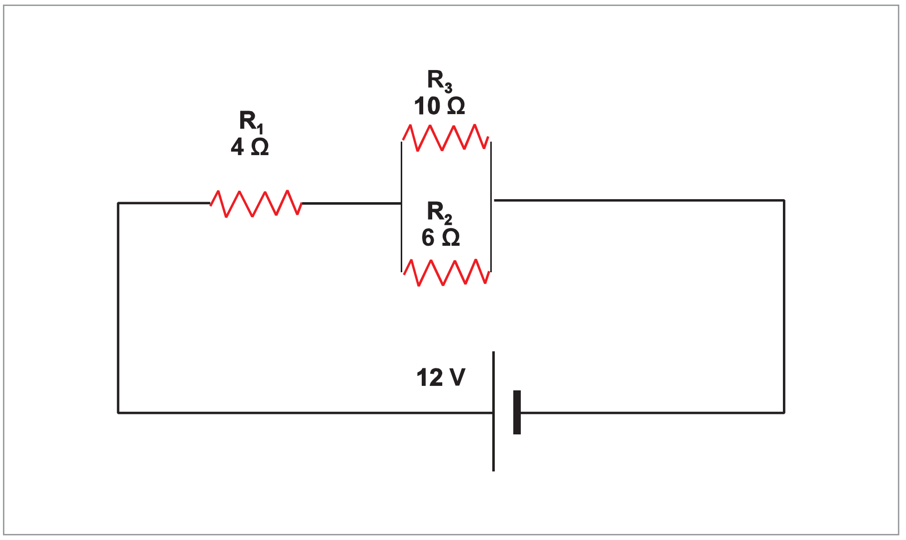


Figure 1.7

First evaluate the parallel resistors then add the result to the series resistor.

$$\frac{1}{R_T} = \frac{1}{10} + \frac{1}{6}$$ Find the lowest common denominator

$$\frac{1}{R_T} = \frac{3 + 5}{30}$$

$$\frac{1}{R_T} = \frac{8}{30}$$

$$R_T = \frac{30}{8}$$ Therefore the total resistance for the two parallel resistors is:

R_T = 3.75 ohms

An alternative method of calculating the resistance of 2 resistors in parallel is:

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

Using the above example

$$R_T = \frac{10 \times 6}{10 + 6}$$

$$R_T = \frac{60}{16}$$ R_T = 3.75 ohms

Note: The total resistance of resistors in parallel is always less than the value of the lowest resistor e.g. 3.75 ohms is less than 6 ohms.

Total circuit resistance is 3.75 ohms plus 4 ohms = **7. 75 ohms**

Kirchoff's Laws

- First law

  The total current flow into a point on a circuit is equal to the current flow out of that point e.g.

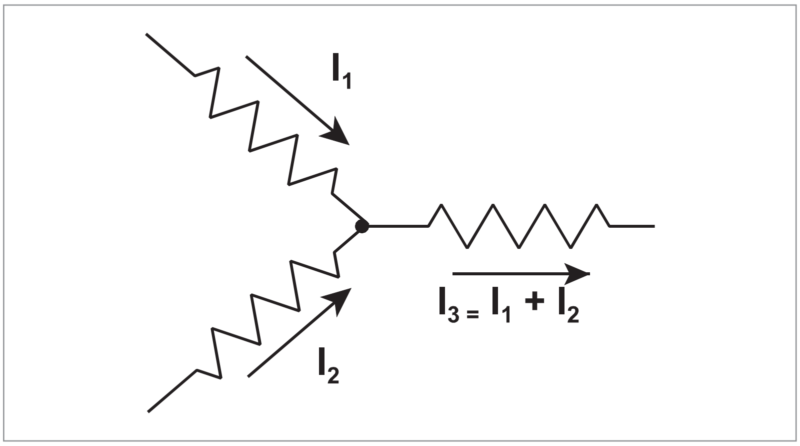


Figure 1.8

- Second law

  If all the voltage drops in a closed circuit are added together, their sum always equals the voltage applied to that closed circuit.

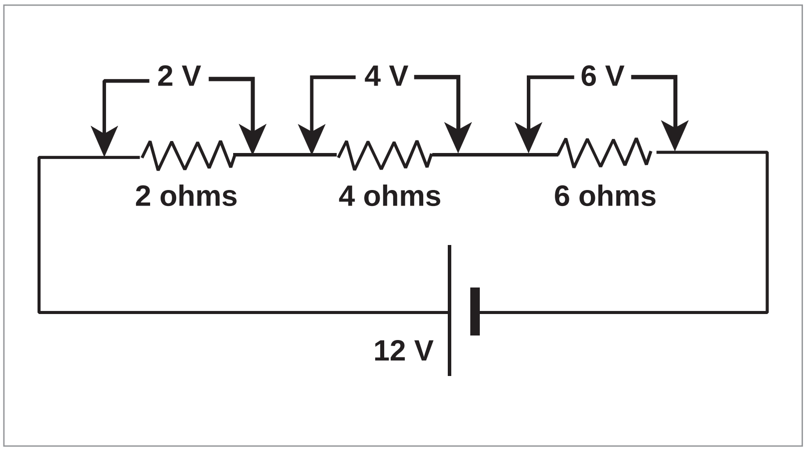


Figure 1.9

To prove Kirchoff's 2nd Law, first we must calculate the current and therefore the total resistance:

$R_T = R_1 + R_2 + R_3$
$R_T = 2 + 4 + 6$
$R_T = 12$ ohms

From Ohm's Law

$V = IR$ » $I = \frac{V}{R}$

$I = \frac{12}{12}$

I = 1 amp

We can now calculate the voltage drops throughout the circuit. At present all we know is there is 12 volts before the 2 ohm resistor and zero volts after the 6 ohm resistor.

Using Ohm's Law V= IR. To calculate the voltage drop across the 2 ohm resistor:

V = 1 amp × 2 ohms = 2 volts

Therefore, the voltage drop is 2 volts i.e. 12 volts enters the 2 ohm resistor and 10 volts exits. Using the same approach for the 4 ohm resistor:

V = 1 amp × 4 ohms = 4 volts i.e. 10 volts enters the 4 ohm resistor and 6 volts exits.

Finally, calculating the voltage drop across the 6 ohm resistor:

V = 1 amp × 6 ohms = 6 volts i.e. 6 volts enters the 6 ohm resistor and zero volts exit.

Therefore, the voltage drop in the closed circuit is 2 volts + 4 volts + 6 volts = 12 volts which equals the voltage applied.

Questions - Theory

1. **All effects of electricity take place because of the existence of a tiny particle called the:**

   a. electric
   b. proton
   c. neutron
   d. electron

2. **The nucleus of an atom is:**

   a. positively charged
   b. negatively charged
   c. statically charged
   d. of zero potential

3. **An atom is electrically balanced when:**

   a. its protons and electrons balance each other
   b. the protons outnumber the electrons
   c. the electrons outnumber the protons
   d. the electric and static charges are balanced

4. **The electrons of an atom are:**

   a. positively charged
   b. neutral
   c. negatively charged
   d. of zero potential

5. **A material with a deficiency of electrons becomes:**

   a. positively charged
   b. negatively charged
   c. isolated
   d. overheated

6. **A material with a surplus of electrons becomes:**

   a. positively charged
   b. negatively charged
   c. over charged
   d. saturated

7. **Heat produces an electric charge when:**

   a. like poles are joined
   b. a hard and soft glass is heated
   c. the junction of two unlike metals is heated
   d. hard and soft material are rubbed together

8. **Friction causes:**

   a. mobile electricity
   b. basic electricity
   c. static electricity
   d. wild electricity

9. **Chemical action produces electricity in:**

   a. a light meter
   b. a generator
   c. a primary cell
   d. starter generator

10. **A photo electric cell produces electricity when:**

   a. two metals are heated
   b. exposed to a light source
   c. a light source is removed
   d. exposed to the heat of the sun

Questions - Units 1

1. **The difference in electric potential is measured in:**

   a. kVARs
   b. watts
   c. amps
   d. volts

2. **Electrical power is measured in:**

   a. watts
   b. amperes
   c. ohms
   d. volts

3. **The unit measurement of electrical resistance is:**

   a. the volt
   b. the watt
   c. the ohm
   d. the ampere

4. **An ammeter measures:**

   a. current
   b. power dissipation
   c. differences of electrical potential
   d. heat energy

5. **Materials containing ‘free electrons’ are called:**

   a. insulators
   b. resistors
   c. collectors
   d. conductors

6. **The unit used for measuring the EMF of electricity is:**

   a. the ohm
   b. the ampere
   c. the volt
   d. the watt

7. **The unit used for measuring:**

   a. current - is the volt
   b. resistance - is the ohm
   c. electric power - is the capacitor
   d. EMF - is the amp

8. Three resistors of 60 ohms each in parallel give a total resistance of:

a. 180 ohms
b. 40 ohms
c. 30 ohms
d. 20 ohms

9. A voltmeter measures:

a. electromotive force
b. the heat loss in a series circuit
c. the current flow in a circuit
d. the resistance provided by the trimming devices

10. Watts =

a. resistance squared × amps
b. volts × ohms
c. ohms × amps
d. volts × amps

Questions - Units 2

1. The total resistance of a number of power consumer devices connected in series is:

a. the addition of the individual resistances
b. the addition of the reciprocals of the individual resistance
c. twice the reciprocal of the individual resistances
d. the reciprocal of the total

2. The total resistance of a number of resistances connected in parallel is:

a. $R = R_1 + R_2 + R_3 + R_4$

b. $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$

c. $\frac{1}{R_T} = R_1 + R_2 + R_3 + R_4$

d. $\frac{R}{T_1} = \frac{1}{R} + \frac{R_2}{1} + \frac{1}{R} + \frac{R_4}{1}$

3. Ohm's Law states:

a. $\text{Current in amps} = \frac{\text{Resistance in ohms}}{\text{Electromotive force in volts}}$

b. $\text{Resistance in ohms} = \frac{\text{Current in amps}}{\text{Electromotive force in volts}}$

c. $\text{Current in amps} = \frac{\text{Electromotive force in volts}}{\text{Resistance in ohms}}$

4. A device consuming 80 watts at 8 amps would have a voltage supply of:

a. 640 volts
b. 12 volts
c. 10 volts
d. 8 volts

5. In a simple electrical circuit, if the resistors are in parallel, the total current consumed is equal to:

a. the sum of the currents taken by the resistors divided by the number of resistors
b. the sum of the currents taken by the resistors
c. the average current taken by the resistors times the number of the resistors
d. the sum of the reciprocals of the currents taken by the resistors

6. The symbol for volts is:

a. E or W
b. V or E
c. I or V
d. R or W

7. **Electrical potential is measured in:**

   a. watts
   b. bars
   c. volts
   d. ohms

8. **If a number of electrical consuming devices were connected in parallel, the reciprocal of the total resistance would be:**

   a. the sum of the currents
   b. the sum of the reciprocals of the individual resistances
   c. the sum of their resistances
   d. volts divided by the sum of the resistances

9. **The current flowing in an electrical circuit is measured in:**

   a. volts
   b. ohms
   c. inductance
   d. amps

10. **Electromotive force is measured in:**

   a. amps × volts
   b. watts
   c. ohms
   d. volts

Questions - General

1. Ohm's Law is given by the formula:

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

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

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

d. $R = V \times I$

2. The current flowing in a circuit is:

a. directly proportional to resistance, indirectly proportional to voltage
b. directly proportional to temperature, inversely proportional to resistance
c. inversely proportional to resistance, directly proportional to voltage
d. inversely proportional to applied voltage, directly proportional to temperature

3. The unit of EMF is the:

a. ampere
b. vol
c. watt
d. ohm

4. Potential difference is measured in:

a. amps
b. volts
c. watts
d. ohms

5. The unit of current is the:

a. ampere
b. volt
c. watt
d. ohm

6. The unit of resistance is the:

a. ampere
b. volt
c. watt
d. ohm

7. Electrical power is measured in:

a. amperes
b. volts
c. watts
d. ohms

8. **1250 ohms may also be expressed as:**

a. 1250 k ohms
b. 1.25 k ohms
c. 1.25 M ohms
d. 0.125 k ohms

9. **1.5 M ohms may also be expressed as:**

a. 15 000 ohms
b. 1500 ohms
c. 150 000 ohms
d. 1500 k ohms

10. **550 k ohms may also be expressed as:**

a. 550 000 M ohms
b. 0.55 M ohms
c. 55000 ohms
d. 0.55 ohms

11. **If the voltage applied to a simple resistor increases:**

a. current will decrease but power consumed remains constant
b. resistance and power decrease
c. current flow will increase and power consumed will increase
d. current flow increases and power consumed decreases

12. **What is the total resistance in this circuit:**

a. 11.5 ohms
b. 11 500 k ohms
c. 11.5 k ohms
d. 11.5 M ohms

LOOK AT THE CIRCUIT AT ANNEX A AND ANSWER THE FOLLOWING QUESTIONS

13. **The total resistance of the circuit is:**

a. 14 ohms
b. 39.6 ohms
c. 25.6 ohms
d. varies with the applied voltage

14. **The current flow indication on ammeter 'A' would be:**

a. 2 amps
b. 2 volts
c. 2.5 amps
d. 2.5 volts

15. The total power consumed in the circuit will be:

a. 14 kilowatts
b. 56 kilowatts
c. 56 watts
d. 14 watts

16. The power consumed by R_5 alone is:

a. 14 watts
b. 28 watts
c. 112 watts
d. 28 kilowatts

17. The indication on voltmeter V1 will be:

a. 2.3 volts
b. 28 volts
c. 9.2 volts
d. 92 volts

18. The indication on voltmeter V3 will be:

a. 28 volts
b. 14 volts
c. 14 amps
d. 3.5 volts

19. The indication on voltmeter V2 will be:

a. 28 volts
b. 4.8 volts
c. 9.6 volts
d. 14 volts

20. The current flowing through R_2 is:

a. 0.04 amps
b. 0.4 amps
c. 4 amps
d. 40 milliamps

21. The current flowing through R_3 is:

a. 0.04 amps
b. 0.4 amps
c. 4 amps
d. 40 milliamps

22. The current flowing through R_4 is:

a. 120 milliamps
b. 1.2 amps
c. 19.2 amps
d. 1.92 milliamps

23. **The power consumed by R_2 alone is:**

a. 1.92 kilowatts watts
b. 1.92 watts
c. 65.3 watts
d. 65.3 kilowatts

24. **The power consumed by R_3 alone is:**

a. 1.92 kilowatts watts
b. 1.92 watts
c. 65.3 watts
d. 65.3 kilowatts

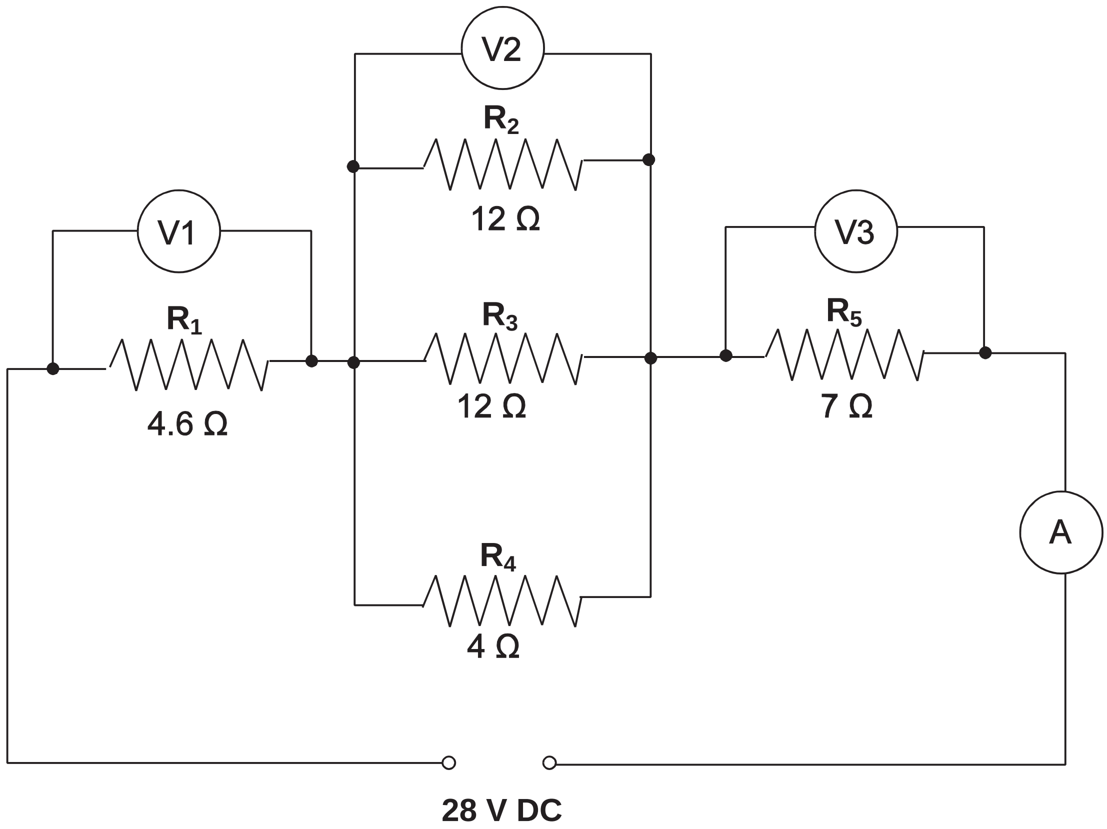
25. **The power consumed by R_4 alone is:**

a. 5.76 kilowatts
b. 5.76 volts
c. 5.76 watts
d. 3.33 watts

26. **The power consumed by R_1 alone is:**

a. 18.4 kilowatts
b. 42.32 watts
c. 18.4 watts
d. 4.232 kilowatts

Annex A



Answers - Theory

1	2	3	4	5	6	7	8	9	10
d	a	a	c	a	b	c	c	c	b

Answers - Units 1

1	2	3	4	5	6	7	8	9	10
d	a	c	a	d	c	b	d	a	d

Answers - Units 2

1	2	3	4	5	6	7	8	9	10
a	b	c	c	b	b	c	b	d	d

Answers - General

1	2	3	4	5	6	7	8	9	10	11	12
c	c	b	b	a	d	c	b	d	b	c	c

13
a

Total circuit resistance, evaluate the total resistance of the three resistors in parallel first

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

$$\frac{1}{R_T} = \frac{1}{12} + \frac{1}{12} + \frac{1}{4}$$

$$\frac{1}{R_T} = \frac{1 + 1 + 3}{12}$$

$$\frac{1}{R_T} = \frac{5}{12}$$

$$R_T = \frac{12}{5} = 2.4\,\Omega$$

Then add the resistances in series

$4.6 + 2.4 + 7 = 14\,\Omega$

14
a

$$I = \frac{V}{R} = 2 \text{ amps}$$

15	16	17	18	19	20	21	22	23	24	25	26
c	b	c	b	b	b	b	b	b	b	c	c

Chapter

2

DC Electrics - Switches

Switches

The initiation and control of aircraft circuits is achieved by switches and relays. Some typical switches are described here.

Toggle Switch

A general purpose switch common in older aircraft having a number of isolating contacts inside. It can be a two position switch (on or off) or a multi-position switch sprung biased to the centre or off position and then pressed and held to select in the desired direction.

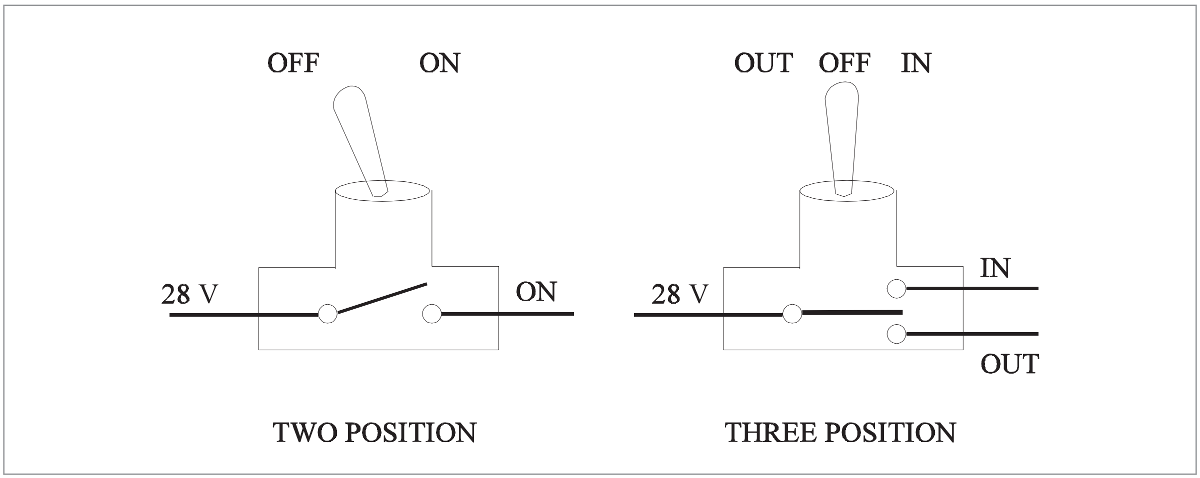


Figure 2.1

Switch Light

Switch lights have largely replaced toggle switches in modern aircraft and combine the functions of a switch with a push action and an indicator light for the associated function.

There are two basic types

- **Momentary action** press and hold to activate, release to deactivate.
- **Alternate action** press and release to activate, press and release a second time to deactivate.

The indicator in the lens confirms the selected position or provides a warning which requires the switch to be selected.

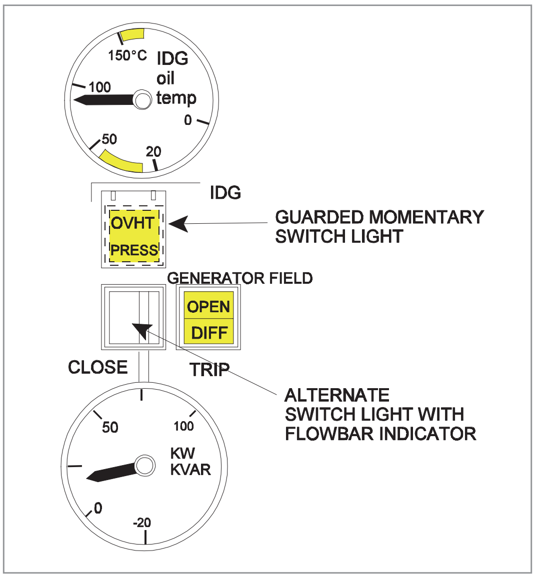


Figure 2.2

Guarded Switches
Toggle switches or switch lights can be guarded to prevent inadvertent operation, e.g. generator disconnects the fuel dump master. (See previous diagram)

Microswitch
Microswitches are still used in modern aircraft to detect the position of a particular device e.g. door opened or closed.

The name Microswitch describes the small movement between the 'make and break' position. Microswitches can activate indications on the flight deck or control relays for a sequenced operation. They are largely replaced by proximity detectors on modern aircraft.

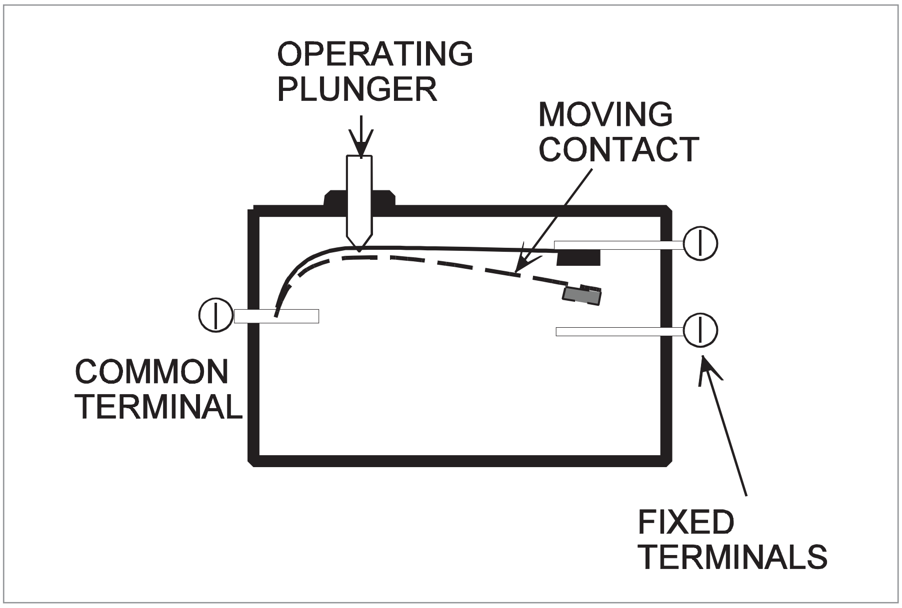


Figure 2.3 Microswitch

Bimetallic Switch (Thermal Switch)
Bimetallic switches are temperature sensitive switches and are activated when a certain value of temperature is reached to provide an indication to the pilot or to activate / deactivate a circuit, e.g. fire detection circuits, battery overheat switch, oil temperature warning light.

Proximity Detectors

Proximity detectors are electrical or electronic sensors that respond to the presence of a material. The electrical or electronic response is used to activate a switch, relay or transistor. There are many types of proximity detectors, the major types being inductive, capacitive and magnetic. The inductive and magnetic sensors need the monitored material to be metal, but the capacitive type can monitor either metal or non-metal materials.

Inductive Type
This type of sensor has an inductance coil whose inductance changes when a ferromagnetic material (target) is brought into close proximity with it.

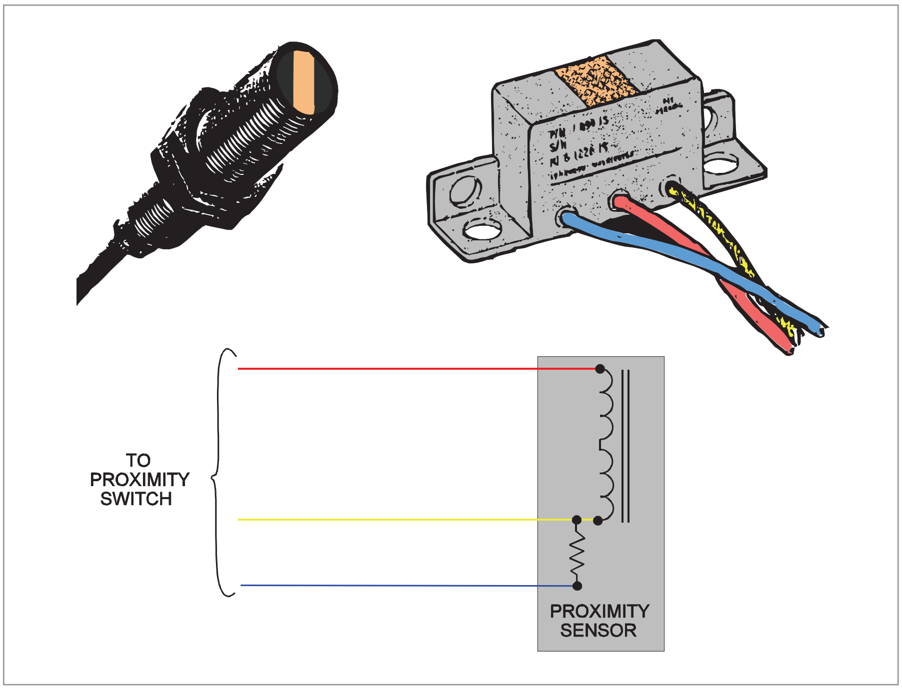


Figure 2.4

This type of sensor is used in undercarriage systems in place of microswitches. A typical undercarriage system is described below. Each proximity switch consists of three components:

- A printed circuit card located in what is called the landing gear accessory unit.
- A sensor located on appropriate landing gear structure.
- An actuator (or target) for each sensor, located adjacent to its sensor.

The proximity sensor is a hermetically sealed unit, and is actuated by the presence of the actuator or target, i.e. it is not touched by it. As a result, the proximity switch is unaffected by atmospheric conditions, and is highly reliable.

Capacitive Type

In this type of sensor detection is made by a capacitor undergoing a capacitance change owing to the proximity of material.

The capacitive proximity detector is an extremely versatile device in that it is capable of detecting all materials, liquid and solid. As well as detecting the presence of a ferrous or non-ferrous target, it can be used to detect high or low liquid levels in a hydraulic or fuel system.

Magnetic Type

A coil situated in a magnetic field will have an electromotive force (EMF) induced in it if the magnetic flux changes. The magnitude of the induced EMF will depend on the rate at which the flux is changed. These are the basic principles on which the magnetic proximity detectors operate.

In its simplest form, a coil is wound around a bar magnet and one pole of the magnet is then located close to a ferrous object. If the ferrous object moves, the flux in the magnet changes and an EMF is induced in the coil. If a number of ferrous objects move past the magnet, a train of pulses is induced in the coil.

Magnetic detectors are most commonly used in conjunction with mild steel gear wheels, each tooth in the wheel being, in effect, a ferrous object. The detector is located radially and close to the periphery of the wheel and provides an output having a frequency equal to the frequency of passage of the teeth past the detector.

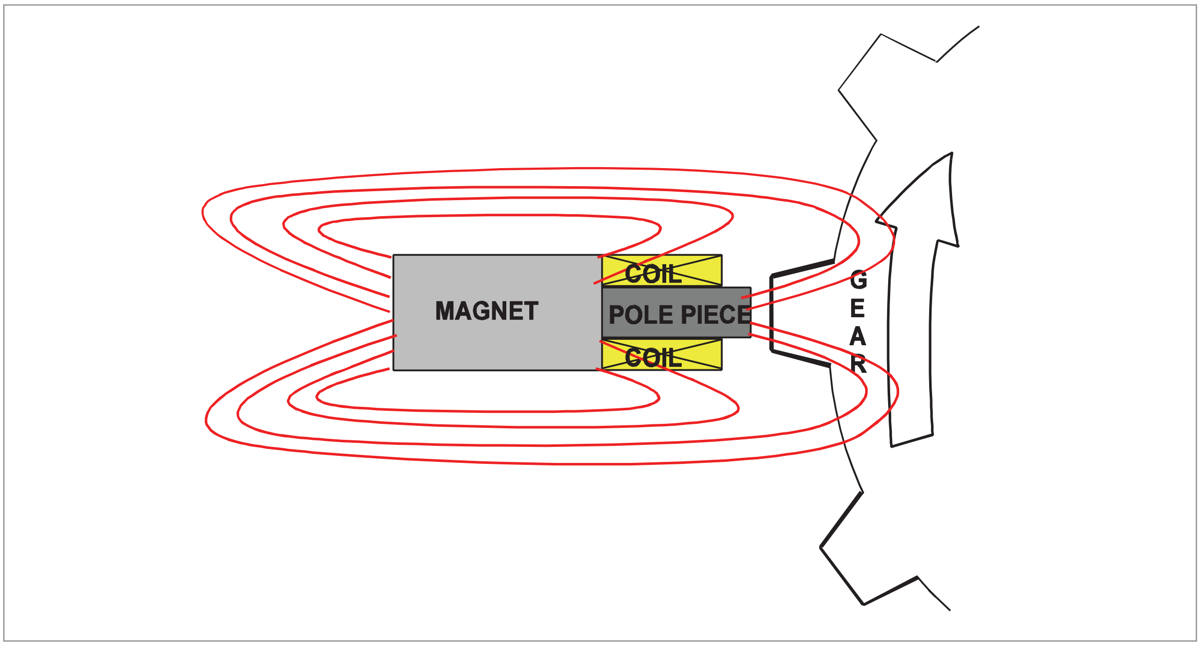


Figure 2.5

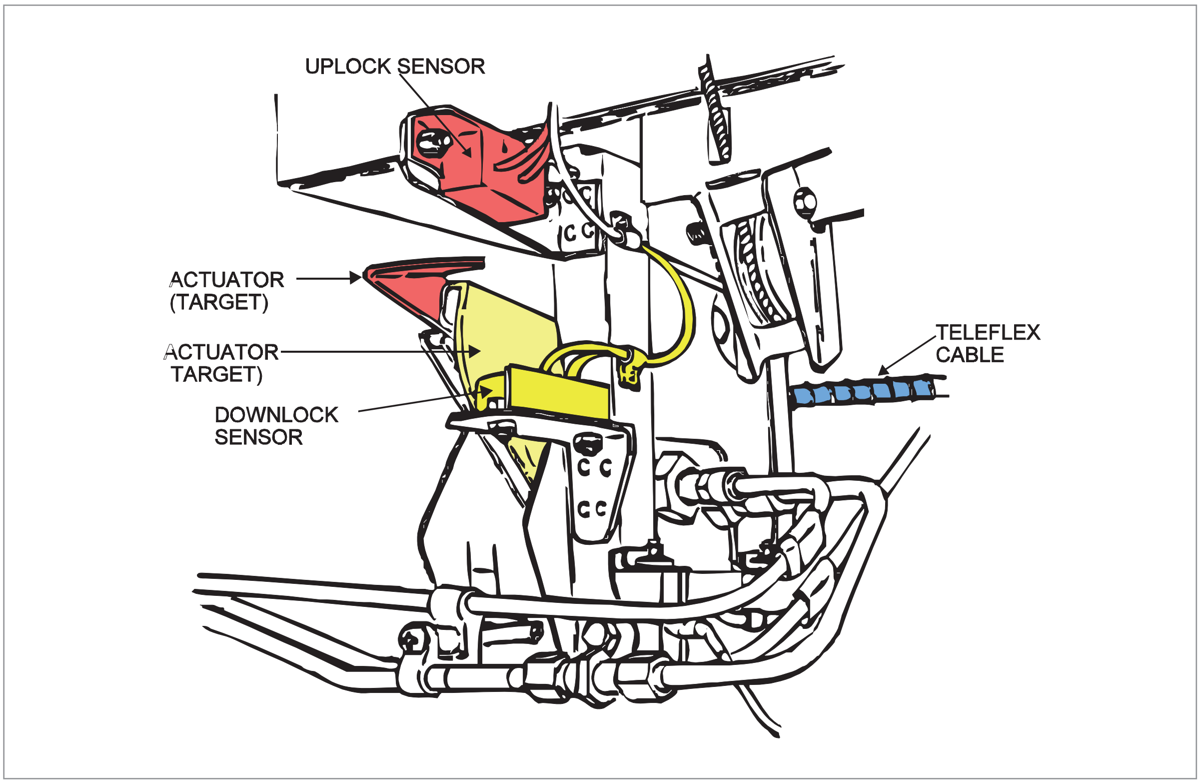


Figure 2.6

Time Switches

Time switches or relays can be initiated electrically or mechanically to activate a circuit after a specific time interval has occurred, e.g. auxiliary power unit air intake door closes 30 seconds after APU has shut down.

Centrifugal Switches

These can be set to activate or de-activate a circuit as the RPM of a device increases or decreases, e.g. starter motor cut-out switch.

Chapter

3

DC Electrics - Circuit Protection and Capacitors

Electrical Faults

In an electrical circuit, abnormal conditions may arise for a variety of reasons, which can cause overcurrent or overvoltage conditions.

If allowed to persist, these abnormal conditions or faults will lead to damage or destruction of equipment and in extreme cases, loss of life. Certainly the essential power supplies will fail, and it is therefore necessary to protect circuits against all such faults, by the use of fuses and circuit breakers.

Circuit Protection Devices

There are a number of protection devices used in aircraft electrical systems but only 2 basic types are discussed here:

- Fuses
- Circuit breakers

The fundamental difference in the type of protection provided by fuses and circuit breakers is in their time of operation relative to the attainment of maximum fault current.

A fuse normally opens the circuit before full fault current is reached, whereas the circuit breaker opens after the full fault current is reached.

This means that when circuit breakers are used as the protection device, both the circuit breaker and the component must be capable of withstanding the full fault current for a short time.

The circuit breaker has the capability, which the fuse has not, of opening and closing the circuit, and can perform many such operations before replacement is necessary. It may also be used as a circuit isolation switch.

Fuses

There are 3 basic types of fuse currently in use on aircraft:

- Cartridge fuse
- High rupture capacity (HRC) fuse
- Current limiter fuse

The Cartridge Fuse

The cartridge type fuse consists of a tubular glass or ceramic body, 2 brass end caps and a fuse element.

The element may be one of the following:

- Tinned copper wire
- Silver wire
- A strip of pure zinc - electro tinned

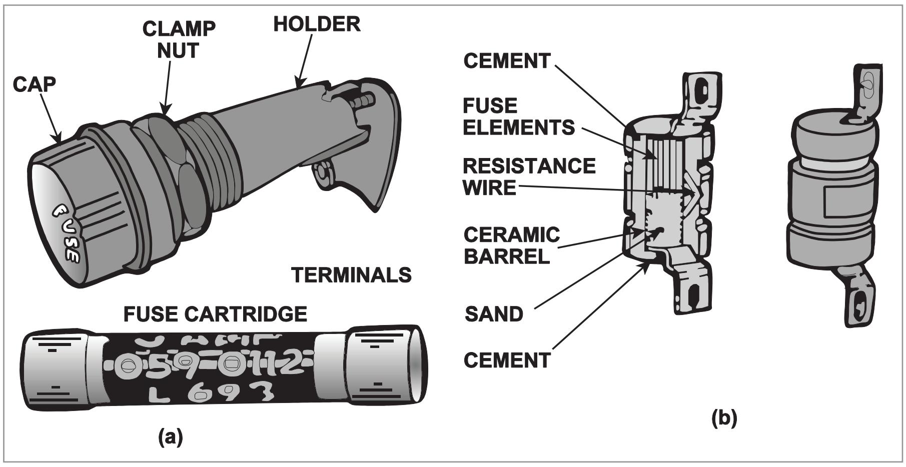


Figure 3.1 Typical fuses
a. A light duty circuit fuse *b. A high rupturing capacity fuse*

The latter type element is generally used in heavy duty circuits, the zinc strip being cut to a specified width.

A fuse operates when the current flowing through it is sufficient to melt the wire or strip element, the time taken varying inversely with the current.

All fuses are rated at a specific current value, i.e. the rating indicates the current they will carry continuously or intermittently without unduly heating up or deteriorating.

The rating of a fuse for a particular circuit is such that it is not less than the normal current flowing in the circuit, but that it operates (‘blows’) at a current level below the safety limit of the equipment or cable used.

For this reason only the specified fuse should be used in a particular circuit. The diagram shows typical aircraft fuses; the ratings can vary between 0 .5 and 500 amps, the higher ratings being limited to the HRC or current limiter types.

Fuses are made of a type of wire which has a low melting point, and when it is placed in series with the electrical load it will melt, blow or rupture when a current of higher value than its ampere rating is placed upon it.

Fuses are rated in ‘amps’.

A blown fuse may be replaced with another of the correct rating once only. If it blows again when switching on, there is a defect in the system and the fuse must not be changed again until the circuit has been investigated.

Spare Fuses

The carriage of spare fuses is mandatory, the quantity of spares being at least 10% of the number of each rating installed, with a minimum of 3 of each.

High Rupture Capacity (HRC) Fuses

The high rupture capacity (HRC) fuse is an improvement on the cartridge type fuse. It is used mainly for high current rated circuits.

The body is a ceramic material of robust construction and has one or more element holes. The element holes are filled with powdered marble or clean quartz sand. The end caps are of plated brass or copper.

The HRC has the following advantages over the normal glass cartridge type:

- more accurate operation
- operates without flame
- does not deteriorate with age
- is more robust
- operates rapidly
- is not affected by ambient temperature

Dummy Fuses

Aircraft electrical circuits which are not in use will have dummy fuses fitted. If it is necessary to isolate a particular circuit by the removal of the fuse in order that the system be made 'safe' or for work to be carried out, a dummy fuse or fuse holder should replace the fuse which has been removed.

To distinguish the dummy fuse, a red streamer is attached to it.

Dummy fuse links are manufactured to standard fuse dimensions from red plastic, the centre portion being square in section with corrugated sides to facilitate identification.

Services protected by circuit breakers are made safe in a similar manner, a warning flag or plate is clipped to the tripped circuit breaker, indicating that the service has been rendered safe for servicing.

Current Limiters

Current limiters, as the name suggests, are designed to limit the current to some predetermined amperage value.

They are also thermal devices, but unlike ordinary fuses they have a **high melting point**, so that their time/current characteristics permit them to carry a considerable overload current before rupturing.

For this reason their application is confined to the protection of heavy-duty power distribution circuits. The output of a Transformer Rectifier Unit would be a prime location for a current limiter to be used.

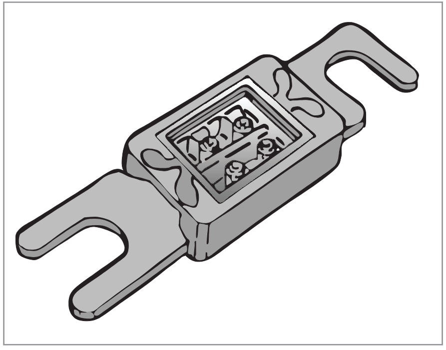


Figure 3.2 A typical current limiter (an airfuse)

A typical current limiter (manufactured under the name of 'Airfuse') is illustrated in *Figure 3.2*, it incorporates a fusible element which is, in effect, a single strip of tinned copper, drilled and shaped at each end to form lug type connections, with the central portion 'waisted' to the required width to form the fusing area.

The central portion is enclosed by a rectangular ceramic housing, one side of which is furnished with an inspection window which, depending on the type, may be glass or mica.

Circuit Breakers

Circuit breakers combine the function of fuse and switch and can be used for switching circuits on and off in certain circumstances.

They are fitted to protect equipment from damage resulting from overload, or fault conditions. The design and construction of CBs is wide and varied.

Generally, the CB incorporates an automatic thermo-sensitive tripping device and a manually or electrically operated switch.

Some electrically operated CBs may also include electromagnetic and reverse current tripping devices.

The smaller type single button CBs, shown in *Figure 3.3*, range from 5 amps to 45 amps, whereas the larger reverse current CBs can be rated up to 600 amps.

The diagram shows two typical CBs, the single push pull button type has a white marker band to assist in identifying a 'tripped' circuit breaker amongst a panel of many.

The CB at (b) is fitted with a "manual trip" button and is more usually associated with a heavy duty circuit.

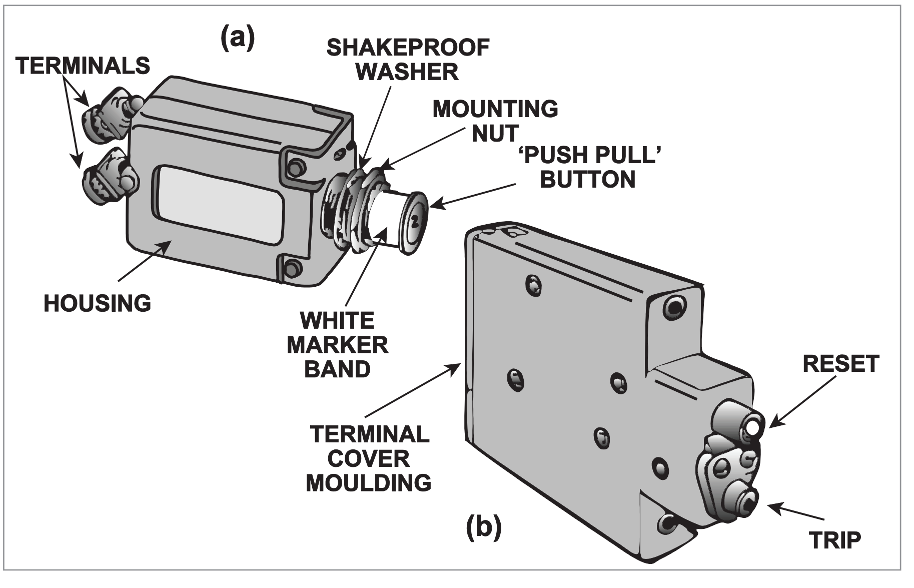


Figure 3.3 Circuit breakers

CBs are common on the flight deck of modern aircraft and can be categorized as either:

- a Non-trip Free Circuit Breaker, or
- a Trip Free Circuit Breaker.

The **non-trip free circuit breaker** may be held in under fault conditions and the circuit will be made, this is clearly dangerous.

The **trip free** circuit breaker if held in under the same circumstances, the circuit can **not** be made.

Pressing the re-set button will reset either CB if the fault has been cleared.

Reverse Current Circuit Breakers

These CBs are designed to protect power supply systems and associated circuits against fault currents reversing against the normal current direction of flow of a magnitude greater than those at which cut-outs normally operate.

They are furthermore designed to remain in a "locked-out" condition to ensure complete isolation of a circuit until a fault has been cleared.

Capacitors

Introduction:

A capacitor can perform three basic functions:

- Stores an electrical charge by creating an electrical field between the plates.
- Will act as if it passes Alternating Current
- Blocks Direct Current flow

Construction:

In its simplest form a capacitor consists of two metal plates separated by an insulator called a **dielectric**. Wires connected to the plates allow the capacitor to be connected into the circuit.

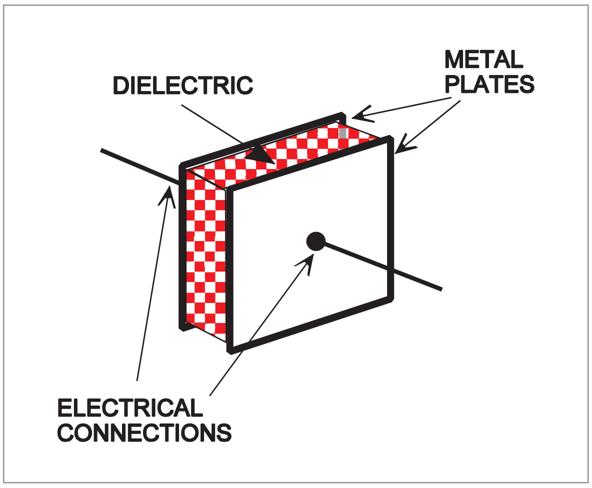


Figure 3.4 The construction of a simple capacitor

Symbols:

Figure 3.5 shows the electrical circuit symbols for various capacitors. With the polarized capacitor it is important to connect the positive terminal to the positive supply. Non-polarized types can be connected either way round.

Figure 3.5 Capacitor symbols

Capacitance

The capacitance (C) of a capacitor measures its ability to store an electrical charge. The unit of capacitance is the **FARAD** (F). The farad is subdivided into smaller, more convenient units.

1 microfarad (1 μF)	= 1 millionth of a farad	= 10^{-6} F
1 nanofarad (1 nF)	= 1 thousand millionth of a farad	= 10^{-9} F
1 picofarad (1 pF)	= 1 millionth millionth of a farad	= 10^{-12} F

Factors Affecting Capacitance:

- Area of the plates - a large area gives a large capacitance
- Distance between the plates - a small distance gives a large capacitance
- Material of the dielectric - different materials have different values of capacitance, for example paper, mica, air and fuel. The value of the dielectric is referred to as the **dielectric constant (k)**. For example, waxed paper has a k value of about 3, whereas air has a k of 1. So a capacitor having waxed paper as its dielectric would have 3 times the capacitance of the same capacitor having air as its dielectric.

Working Voltage:

This is the largest voltage DC or Peak AC which can be applied across the capacitor. It is often marked on the case of the capacitor and if it is exceeded, the dielectric may break down and permanent damage result.

Capacitor in a DC Circuit

Figure 3.6 shows a capacitor in series with a battery and a switch. If the switch is closed, electrons are pushed by the battery on to plate Y building up a negative charge. This charge exerts a repelling force across the dielectric which causes electrons to leave the plate X and be attracted to the positive plate of the battery. While this charging action is taking place electrons are passing through the connecting wires **but no current flows through the dielectric**.

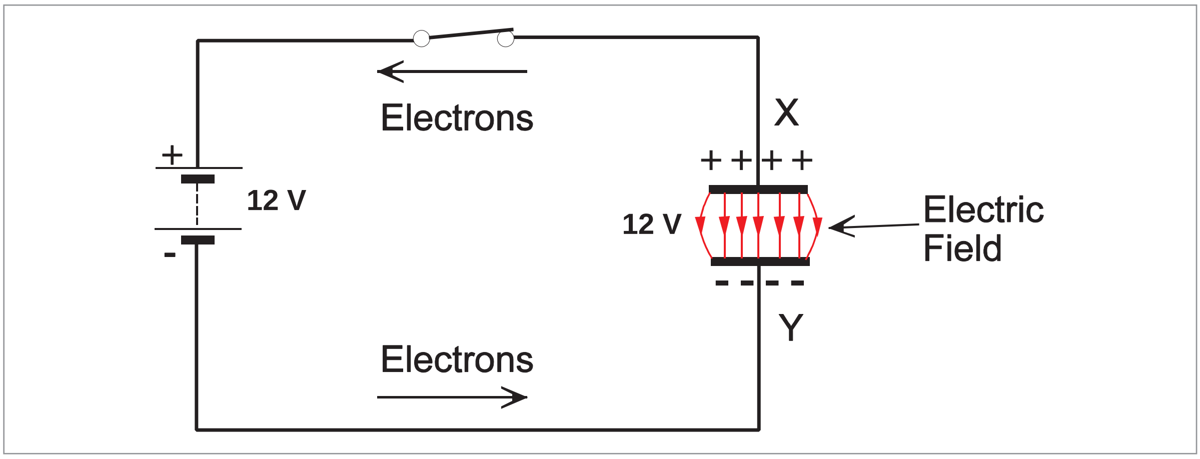


Figure 3.6

After a short time the difference in charge between the plates results in a potential difference existing between the plates. The flow of electrons will reduce and stop when the potential difference between the plates is equal to the supply voltage. The capacitor is now fully charged, current has stopped flowing, the plates are said to be charged and there exists an **electric field** between the plates. The **capacitor is now blocking DC flow**.

If the switch is opened and the capacitor is disconnected from the battery, it holds its charge: **a capacitor stores electrical energy by the formation of an electric field between the plates.** The capacitor will only discharge if it is now connected to an external circuit.

Capacitor in an AC Circuit

Figure 3.7 shows the battery replaced with an Alternating Current Supply. A light bulb is placed in series with the supply and the capacitor.

As the terminals X and Y are now changing from positive to negative at a rate depending on the frequency of the supply, current is first flowing in one direction, reversing and flowing in the opposite direction. The capacitor is charging in one direction, discharging and then charging in the opposite direction. This process continues until the supply is disconnected. The bulb will be continuously ON. **Current flows in the wires but no current flows through the dielectric.**

Therefore: **A capacitor appears to pass AC**

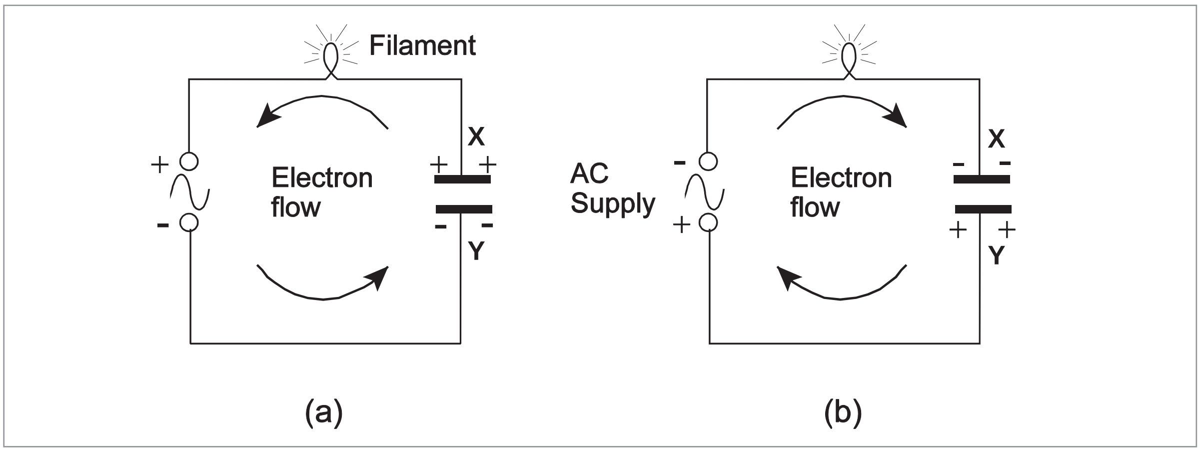


Figure 3.7

Capacitors in Parallel

Capacitors connected in parallel are effectively increasing the area of the plates. The total capacitance C_T can be found by adding the individual capacitances:

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

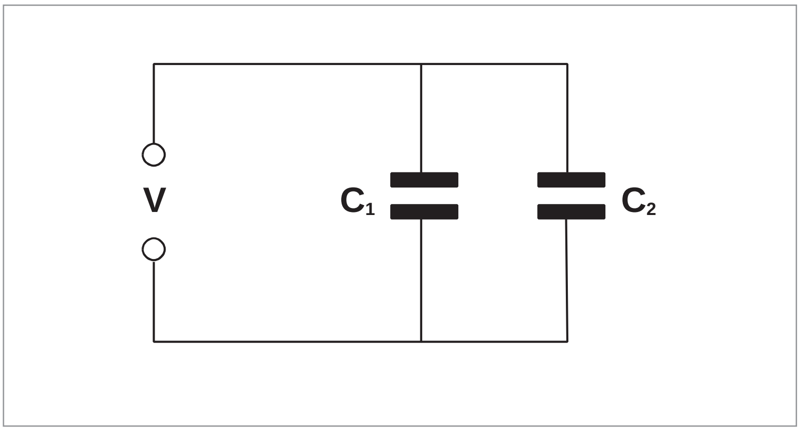


Figure 3.8

Capacitors in Series

Capacitors in series have effectively increased the distance between the plates and therefore the total capacitance has decreased. The total capacitance is found by using the formula for resistances in parallel:

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

Figure 3.9

Questions - Circuit Breakers

1. In a circuit fitted with a non-trip free circuit breaker if a fault occurs and persists:

a. if the reset button is depressed and held in, the circuit will be made
b. the trip button may be pressed to reset, but not permanently
c. a non-trip free circuit breaker can never be bypassed
d. the reset button may be pressed to make the circuit permanent

2. A trip free circuit breaker that has tripped due to overload:

a. can be reset and held in during rectification
b. can never be reset
c. can be reset after overhaul
d. may be reset manually after fault has been cleared

3. Circuit breakers and fuses:

a. are used in DC circuits only
b. are used in AC or DC circuits
c. are used in AC circuits only
d. are used in low current circuits only

4. A trip free circuit breaker is one which:

a. cannot be reset by holding the lever in while the fault persists
b. can be reset by holding the lever in while the fault persists
c. must be held in during checks to find faults
d. can be bypassed

5. If the reset button is pressed in the trip free circuit breaker, the contacts with the fault cleared will:

a. be made and kept made
b. only be made if there is a fuse in the circuit
c. reset itself only after a delay of 20 seconds
d. not be made and the reset will remain inoperative

6. A circuit breaker is a device for:

a. controlling rotor movement only
b. isolating the service on overload
c. isolating the battery when using the ground batteries
d. earthing the magnetos when switching off

7. A non-trip free circuit breaker is:

a. one which can make a circuit in flight by pushing a button
b. a wire placed in a conductor which melts under overload
c. another type of voltage regulator
d. an on-off type tumbler switch

8. **A non-trip free circuit breaker that has tripped due to overload:**

   a. can never be reset
   b. can only be reset on the ground by a maintenance engineer
   c. can be reset and held in if necessary
   d. cannot be reset while the fault is still there

9. **A thermal circuit breaker works on the principle of:**

   a. differential expansion of metals
   b. differential thickness of metals
   c. differential density of metals
   d. differential pressure of metals

10. **Circuit breakers are fitted in:**

   a. series with the load
   b. parallel with the load
   c. across the load
   d. shunt with the load

Questions - Fuses

1. **A fuse is said to have blown when:**

a. an excess current has burst the outer cover and disconnected the circuit from the supply
b. the circuit is reconnected
c. a current of a higher value than the fuse rating has melted the conductor and disconnected the circuit from the supply
d. the amperage has been sufficiently high to cause the fuse to trip out of its holder and has therefore, disconnected the circuit from the supply

2. **In a fused circuit the fuse is:**

a. in parallel with the load
b. in series with the load
c. in the conductor between generator and regulator
d. only fitted when loads are in series

3. **Overloading an electrical circuit causes the fuse to 'Blow'. This:**

a. increases the weight of the insulation
b. fractures the fuse case
c. disconnects the fuse from its holder
d. melts the fuse wire

4. **What must be checked before replacing a fuse?**

a. The ohms of the circuit
b. The amps being used in the circuit
c. The amps capacity of the consuming device in the circuit
d. The correct fuse volt or watts rating

5. **The size of fuse required for an electrical circuit whose power is 72 watts and whose voltage is 24 volts is:**

a. 24 amps
b. 10 amps
c. 5 amps
d. 15 amps

6. **When selecting a fuse for an aircraft circuit the governing factor is:**

a. the voltage of the circuit
b. cable cross-sectional area
c. resistance of the circuit
d. power requirements of the circuit

7. **A fuse in an electrical circuit is 'blown' by:**

a. cooler air
b. the breaking of the glass tube
c. excess voltage breaking the fuse wire
d. excess current rupturing the fuse wire

8. **A fuse is used to protect an electrical circuit, it is:**

a. of low melting point
b. of high capacity
c. of high melting point
d. of low resistance

9. **Fuses:**

a. protect the load
b. protect the cable
c. protect the generator
d. protect both the circuit cable and load

10. **A current limiter:**

a. is a fuse with a low melting point
b. is a circuit breaker
c. is a fuse with a high melting point
d. is a fuse enclosed in a quartz or sand

Answers - Circuit Breakers

1	2	3	4	5	6	7	8	9	10
a	d	b	a	a	b	a	d	a	a

Answers - Fuses

1	2	3	4	5	6	7	8	9	10
c	b	d	c	c	d	d	a	d	c

Chapter

4

DC Electrics - Batteries

Batteries

The purpose of a battery in an aircraft is to provide an emergency source of power when the generator is not running and to provide power to start the engine.

A battery is made up of a number of **cells** which convert **chemical energy** into **electrical energy** by a transfer of electrons from one material to another causing a potential difference between them. During the transfer of electrons the chemical composition of the two materials changes.

Primary Cell

A primary cell consists of two electrodes immersed in a chemical called an electrolyte. The electrolyte encourages electron transfer between the electrodes until there is a potential difference between them. When the electron transfer ceases the cell is fully charged and the potential difference is approximately 1.5 volts between the two electrodes.

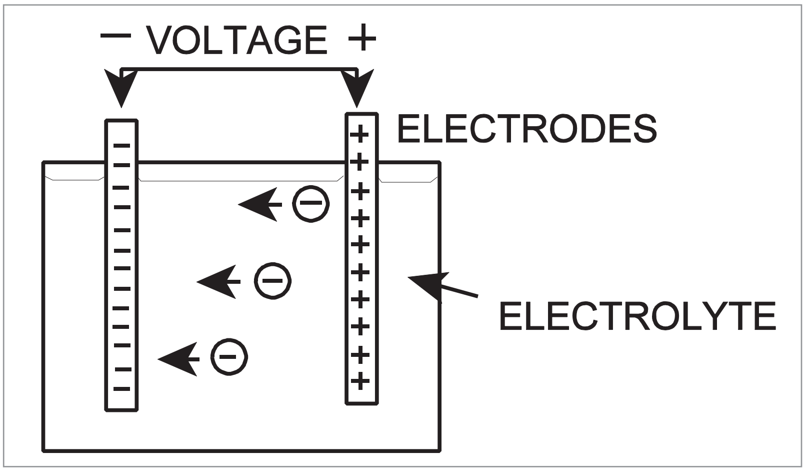


Figure 4.1 A primary cell

When the positive and negative terminals are connected to an external circuit electrons flow from the negative terminal to the positive terminal through the circuit. At the same time more electrons are allowed to transfer inside the cell from the positive electrode to the negative electrode. As this circulation of electrons continues, the negative electrode slowly dissolves in the electrolyte until it is eventually eaten away and the cell is then “dead” and is discarded. Primary cells cannot be recharged.

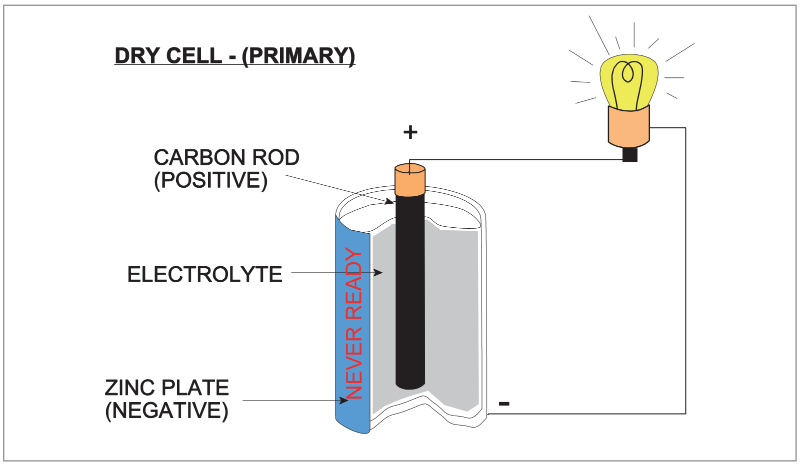


Figure 4.2 A dry cell (primary)

Secondary Cells

Secondary cells work on the same principle as primary cells but the chemical energy in the cell can be restored when the cell has been discharged by passing a “charging current” through the cell in the reverse direction to that of the discharge current. In this way the secondary cell can be discharged and recharged many times over a long period of time

During recharging electrical energy is converted into chemical energy which is retained until the cell is discharged again.

The **Capacity** of a cell is a measure of how much current a cell can provide in a certain time. Capacity is measured in **Ampere hours (Ah)** and is determined by the area of the plates; the bigger the cell the greater its capacity.

A cell with a capacity of 80 Ah should provide a current of 8 A for 10 hours, or 80 A for 1 hr. Theoretically that should be true but in practice the capacity will reduce as the rate of discharge is increased. Capacity is normally measured at the 1 hour rate.

A single cell battery may be used on its own or cells may be connected in series, or in parallel depending on the voltage and capacity required

For cells in series the positive terminal of one cell is connected to the negative terminal of the next and so on. The total voltage is the sum of the individual cell voltages. But the capacity is that of one cell.

For cells in parallel the positive terminals are joined together and the negative terminals are joined together. The total voltage is that of one cell but the capacity is the sum of the individual cell capacities.

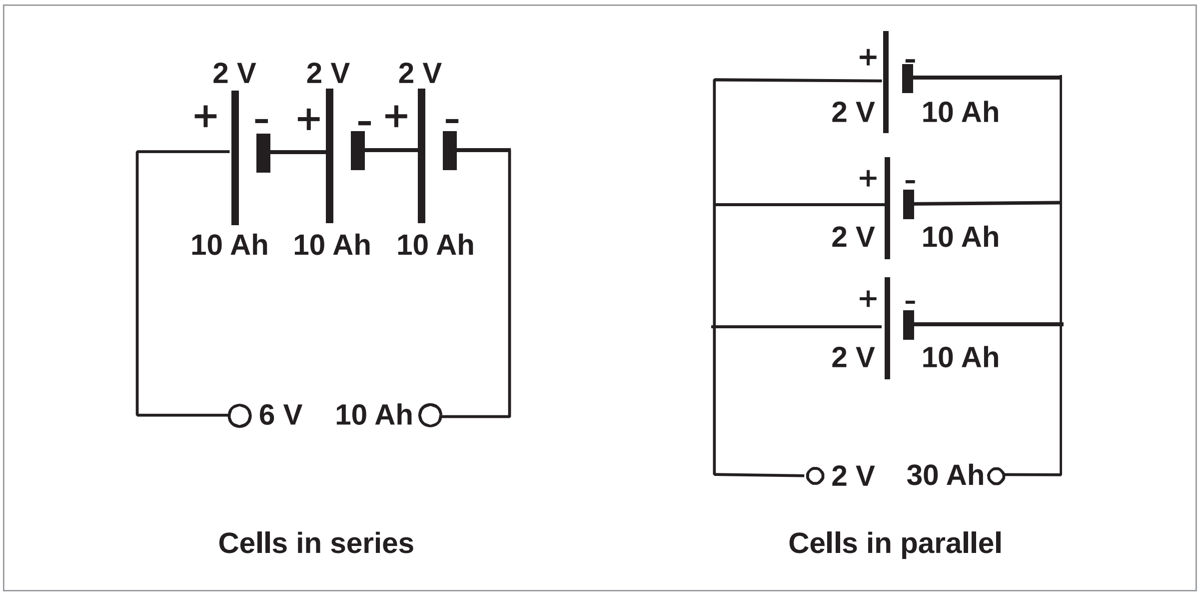


Figure 4.3

Lead Acid Battery

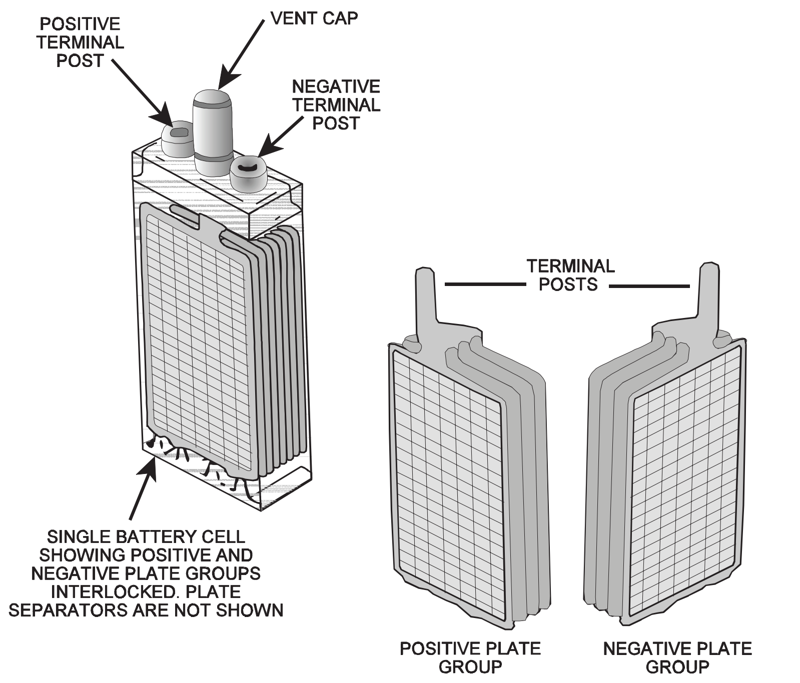


Figure 4.4

One of the most common types of secondary cell is the **Lead Acid** cell.

The active material of the positive plate is **lead peroxide** and the negative plate is **spongy lead**, both plates are immersed in an electrolyte solution of **water and sulphuric acid**. The container is glass or hard plastic with a filler cap to allow replenishment of distilled water, which is lost through evaporation during use. A vent hole in the cap allows the escape of hydrogen gas, which is produced when the cell is working

The state of charge of a lead acid cell can be determined by measuring the strength of the electrolyte solution. This is done with a hydrometer which measures the specific gravity (SG). A fully charged cell will have a SG of 1.27, a discharged cell will have a SG of 1.17.

When the cell is connected to an external circuit and current is flowing, lead sulphate is formed at both plates and the specific gravity will fall as the acid becomes weaker. When the SG has fallen to 1.17 and the voltage to 1.8 volts the cell should be recharged.

To charge a cell it is connected to a battery charger which applies a slightly higher voltage to the cell and causes current to flow in the reverse direction through the cell. While this is happening the lead sulphate which had been deposited on the plates is removed and the SG of the electrolyte rises to 1.27. The voltage 'on load' should have returned to just above 2 volts.

When charging a lead acid battery it is important that the rate of charge is controlled. Charging too quickly can cause 'gassing' and evaporation to occur which may lead to boiling the battery dry and causing damage to the plates.

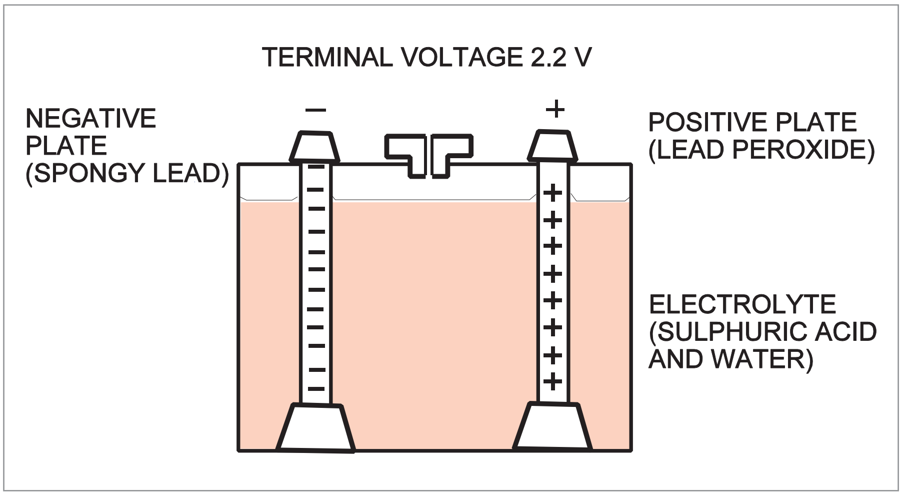


Figure 4.5 A lead acid secondary cell

The SG of the electrolyte is an indication of the battery's state of charge or serviceability. The value of the SG is checked using a **hydrometer**. The level of the electrolyte is maintained just above the top of the plates by topping up with distilled water. Loss of water is caused by gassing at the plates when fully charged.

The on load/nominal voltage of each cell of a lead acid battery is 2 volts.

The off load voltage of each cell of a lead acid battery is 2.2 volts.

Electrolytes are highly corrosive and if spilled in aircraft can cause extensive damage.

The neutralizing agent to be used for an acid electrolyte is a **sodium bicarbonate solution**. The performance of a battery is affected by temperature. In low temperatures the rate of discharge is decreased because of higher internal resistance. In warm temperatures the battery rate of discharge will increase. In general the battery performs better in warm temperatures (just like a car battery). As a lead acid battery discharges the SG of the electrolyte reduces. In freezing temperatures with a discharged battery there is a risk of the electrolyte freezing. It is therefore important to maintain the battery in a fully charged state during winter operations.

Figure 4.6 shows a free liquid type of lead acid battery where the electrolyte is in liquid form. *Figure 4.7* shows an absorbed liquid type of lead acid battery where the electrolyte is absorbed into the active materials in the plates making it less prone to spillage.

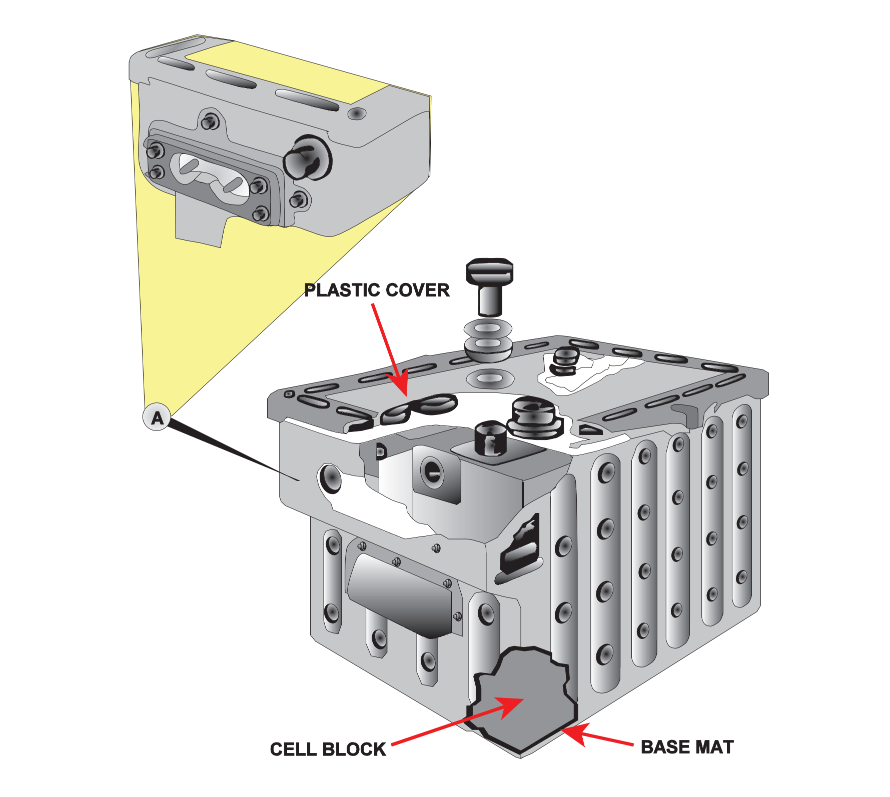


Figure 4.6 Lead acid battery (free liquid type)

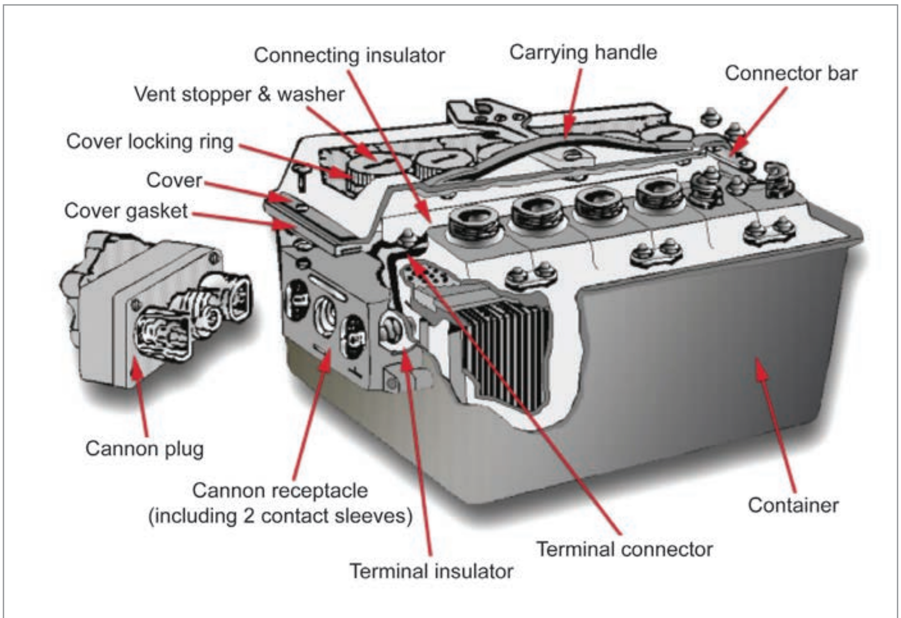


Figure 4.7 Lead acid battery (absorbed liquid type)

Alkaline Battery (Nickel Cadmium, NiCad)

Lead acid batteries are still used in some smaller aircraft but have been largely replaced by **Nickel Cadmium** (alkaline type) batteries. These use different materials for their plates and electrolyte. The plates are **nickel oxide** and **cadmium** and the electrolyte is **potassium hydroxide**. The SG of the electrolyte is 1.24 - 1.30.

The on-load voltage of one cell is about 1.2 volts.

Unlike the lead acid battery, the relative SG of the nickel-cadmium battery electrolyte does not change and the voltage variation from "fully charged" to "fully discharged," is very slight. The only way to determine the state of charge is to carry out a measured discharge test i.e. a capacity test.

The terminal voltage remains substantially constant at 1.2 volts throughout most of the discharge. Due to its low internal resistance it is also capable of supplying high current during its discharge cycle and low current during recharging without violent fluctuations of terminal voltage.

NiCad batteries have a low thermal capacity; the heat generated in certain conditions is faster than it can dissipate, so causing a rapid increase in temperature.

This has the effect of lowering the effective internal resistance thus allowing an ever increasing charging current, which, unless checked, leads to the total destruction of the battery.

This condition is known as a **thermal runaway**, and can cause so much heat that the battery may explode. For this reason the charging of the battery must be closely monitored and includes some safety features.

A built-in thermal switch monitors the temperature and operates on a preset value of temperature. This effectively isolates the battery from the charging source until a reduction in temperature reverts the switch back to its normal position. Associated with the temperature switch may be an indicator light on the flight deck to alert the pilot.

The nickel cadmium battery, however, is more robust and can hold a constant terminal voltage much better during the discharge cycle. It is therefore much preferred in large modern aircraft because in the event of a total failure of the aircraft generators the NiCad battery will provide a much more stable voltage.

Figure 4.8 is a graphical representation of a comparison of the discharge voltage of a lead acid against a NiCad during discharge.

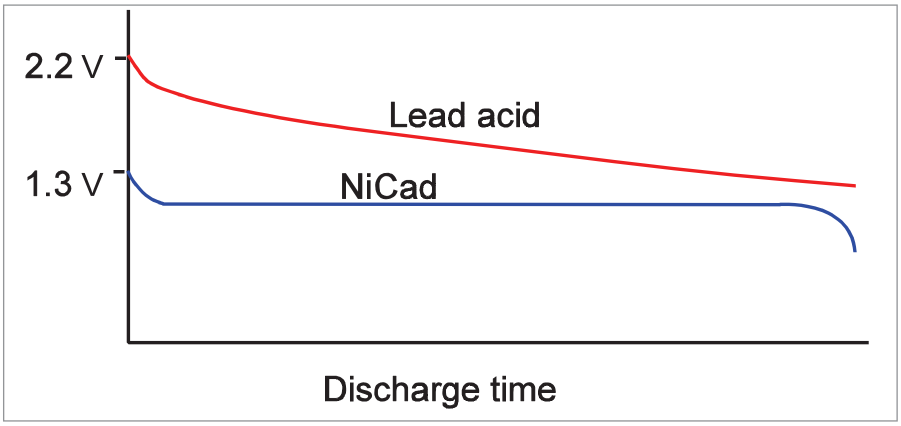


Figure 4.8

Battery Checks

The Capacity of a battery is the product of the load in amperes that the manufacturers state it will deliver, and the time in hours that the battery is capable of supplying that load.

The capacity is measured in ampere hours (Ah).

A 40 Ah battery when discharged at the 1 hour rate should supply 40 amps for the 1 hour. This is known as the **'rated load'**. Alternatively the battery could supply 4 amps for 10 hours at the 10 hour rate.

Actual Capacity is determined by the battery's deterioration in service. If a 60 Ah battery when discharged at the 1 hour rate lasts only for 0.7 hour, or 42 minutes, then the actual capacity is 70% of its rated capacity. In other words, the battery is only 70% efficient.

A **Capacity Test**, a test to determine the actual capacity of aircraft batteries, is carried out every **3 months** and the efficiency must be **80**% or more for the battery to remain in service.

This capacity will ensure that essential loads can be supplied for a period of 30 minutes following a generator failure.

Loads (electrical equipment) would include: attitude information, essential communication equipment, lighting, pitot heat, plus any other services necessary for continued safe flight, or loads which cannot easily be switched off (load shedding).

Spare batteries will be held ready for use in the electrical workshop. Lead acid batteries are stored in a charged state to prevent deterioration of the battery by sulphation. NiCad batteries can be stored in a discharged state with no detrimental effect to the battery and therefore have a longer storage life or 'shelf life'.

The **On-load Check** is carried out by applying the rated load to the battery circuit for a short period of time, during which time the battery voltmeter reading must remain constant and not fall below a stated value. Modern aircraft use times as low as 10-20 seconds with the rated load selected.

The pilot's preflight check of a battery may include comparing the '**on load**' voltage with the '**off load**' voltage to give an indication of the state of charge of the battery.

If the battery is not supplying any load then it is likely to show its nominal voltage (off load voltage). If the battery is then loaded up by switching on selective loads (e.g. pitot heater, landing lights, blower motors) and the voltage is maintained then the battery is in a good state of charge. If the voltage falls below a stated value within a time limit determined by the manual then the battery is in a low state of charge and should be replaced.

Battery Charging

A **Constant Voltage Charging** system is employed with most lead acid batteries to maintain the battery in a fully charged condition during flight. With this system the output voltage of the generator is maintained constant at 14 volts for a 12 volt battery and 28 volts for a 24 volt battery.

The generator voltage exceeds the battery voltage by 2 volts for every 12 volts of battery potential.

With alkaline batteries which are susceptible to thermal runaway it may be that a **constant current charging** system is employed by a dedicated battery charger which monitors battery temperature and voltage. Some charging systems use a method known as pulse charging and once the battery is up to 85% capacity, the battery charger delivers short pulses of charging current.

NOTE: *After starting an engine using the aircraft's battery, whether it is a lead acid battery or an alkaline battery, the generator, when it is on line, recharges that battery.*

This is indicated by the high initial reading on the generator's ammeter (load ammeter) or the battery ammeter (centre zero). This reading should quickly reduce as the battery is recharged, but if the charge rate increases, or remains high, it could be an indication of a faulty battery.

A high charge rate could result in a battery overheating and subsequent damage.

Secondary Batteries Summary

Secondary batteries: Summary.

CHARGED | DISCHARGED

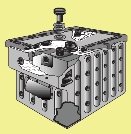
	POSITIVE	NEGATIVE	ELECTROLYTE	SPILLAGE	SG
LEAD ACID 	lead peroxide	spongy lead	sulphuric acid	Sodium bicarbonate + water	1.270
	lead sulphate	lead sulphate	weak sulphuric acid		1.170
ALKALINE 	nickel oxide	cadmium	potassium hydroxide / distilled water	Boric acid	1.240 - 1.300
	nickel hydroxide	cadmium hydroxide	potassium hydroxide / distilled water		

Figure 4.9

Questions - Batteries 1

1. **Battery voltage is tested with:**

   a. a megometer
   b. a voltmeter on rated load
   c. an ammeter with a rated voltage
   d. a hygrometer

2. **Two 12 V 40 Ah batteries connected in series will produce:**

   a. 12 V 80 Ah
   b. 12 V 20 Ah
   c. 24 V 80 Ah
   d. 24 V 40 Ah

3. **Two 12 V 40 Ah batteries connected in parallel will produce:**

   a. 12 V 80 Ah
   b. 24 V 80 Ah
   c. 12 V 20 Ah
   d. 24 V 40 Ah

4. **A battery capacity test is carried out:**

   a. 6 monthly
   b. 2 monthly
   c. 3 monthly
   d. every minor check

5. **An aircraft has three batteries each of 12 volts with 40 Ah capacity connected in series. The resultant unit has:**

   a. a voltage of 36 and a capacity of 120 Ah
   b. a capacity of 120 Ah and a voltage of 12
   c. a capacity of 36 Ah and 120 watts
   d. a voltage of 36 and a capacity of 40 Ah

6. **An aircraft has a battery with a capacity of 40 Ah. Assuming that it will provide its normal capacity and is discharged at the 10 hour rate:**

   a. it will pass 40 amps for 10 hrs
   b. it will pass 10 amps for 4 hrs
   c. it will pass 4 amps for 10 hrs
   d. it will pass 40 amps for 1 hr

7. **Battery capacity percentage efficiency must always be:**

   a. 10% above saturation level
   b. above 70%
   c. 80% or more
   d. above 90%

8. **The method of ascertaining the voltage of a standard aircraft lead acid battery is by checking:**

   a. the voltage on open circuit
   b. the current flow with a rated voltage charge
   c. the voltage off load
   d. the voltage with rated load switched ON

9. **A battery is checked for serviceability by:**

   a. using an ammeter
   b. measuring the specific gravity of the electrolyte
   c. a boric acid solution
   d. using an ohmmeter

10. **In an AC circuit:**

   a. the battery is connected in series
   b. a battery cannot be used because the wire is too thick
   c. a battery cannot be used because it is DC
   d. only NiCad batteries can be used

Questions - Batteries 2

1. **The specific gravity of a fully charged lead acid cell is:**

a. 1.270
b. 1.090
c. 1.120
d. 0.1270

2. **The nominal voltage of the lead acid cell is:**

a. 1.2 volts
b. 1.5 volts
c. 1.8 volts
d. 2.0 volts

3. **A lead acid battery voltage should be checked:**

a. on open circuit
b. using a trimmer circuit
c. with an ammeter
d. on load

4. **In an aircraft having a battery of 24 volts nominal off load and fully charged the voltmeter would read:**

a. 22 volts
b. 24 volts
c. 26 volts
d. 28 volts

5. **The system used to maintain aircraft batteries in a high state of charge is the:**

a. constant current system
b. constant load system
c. constant resistance system
d. constant voltage system

6. **If you connect two identical batteries in series it will:**

a. double the volts and halve the capacity
b. reduce the voltage by 50%
c. double the volts and leave the capacity the same
d. double the volts and double the amps flowing in a circuit with twice the resistance

7. **The nominal voltage of an alkaline cell is:**

a. 2.2 volts
b. 1.8 volts
c. 1.2 volts
d. 0.12 volts

8. **The specific gravity of a fully charged alkaline cell is:**

a. 0.120 - 0.130
b. 1.160
c. 1.240 - 1.30
d. 1.800

9. **The electrolyte used in the lead acid cell is diluted:**

a. hydrochloric acid
b. sulphuric acid
c. boric acid
d. potassium hydroxide

10. **The electrolyte used in an alkaline battery is diluted:**

a. saline solution
b. sulphuric acid
c. cadmium and distilled water
d. potassium hydroxide solution

Questions - Batteries 3

1. The number of lead acid cells required to make up a twelve volt battery is:

a. 8
b. 12
c. 6
d. 10

2. A voltmeter across the terminals of a battery with all services off will indicate:

a. electromotive force
b. resistance
c. a flat battery
d. residual voltage

3. The voltage of a secondary cell is:

a. determined by the number of plates
b. determined by the area of the plates
c. determined by the diameter of the main terminals
d. determined by the active materials on the plates

4. The level of the electrolyte must be maintained:

a. just below the top plate
b. above the plates level with the filler cap
c. one inch below the top of the plates
d. just above the top of the plates

5. To top up the electrolyte add:

a. sulphuric acid
b. distilled water
c. sulphuric acid diluted with distilled water
d. boric acid

6. Non-spill vents are used on aircraft batteries to:

a. prevent spillage of electrolyte during violent manoeuvres
b. stop spillage of the water only
c. prevent the escape of gases
d. prevent spillage during topping-up

7. The capacity of a lead acid battery is:

a. determined by the area of the plates
b. determined by the active materials on the plates
c. determined by the size of the series coupling bars
d. determined by the number of separators

8. Acid spillage in an aircraft can be neutralized by using:

a. caustic soda
b. soap and water
c. soda and water
d. bicarbonate of soda and water

9. When the battery master switch is switched off in flight:

a. the generators are disconnected from the bus bar
b. the ammeter reads maximum
c. the battery is isolated from the bus bar
d. the battery is discharged through the bonding circuit diodes

10. When the generator is on line the battery is:

a. in parallel with the other loads
b. in series with the generator
c. in series when the generator is on line and is relayed when the generator is off line
d. load sharing

Answers - Batteries 1

1	2	3	4	5	6	7	8	9	10
b	d	a	c	d	c	c	d	b	c

Answers - Batteries 2

1	2	3	4	5	6	7	8	9	10
a	d	d	c	d	c	c	c	b	d

Answers - Batteries 3

1	2	3	4	5	6	7	8	9	10
c	a	d	d	b	a	a	d	c	a

Chapter

5

DC Electrics - Magnetism

Magnetism

A magnet has the following properties:

- It will attract and pick up bits of iron and steel.
- If freely suspended, it will come to rest pointing in a N-S direction.
- A magnetic field (a region surrounding a magnet in which its magnetic effects can be detected).

If iron filings are sprinkled on to a sheet of paper which is placed over a magnet, the filings arrange themselves into a distinctive pattern. They trace out invisible lines of influence in the magnetic field. These lines are called **lines of flux or lines of force**.

We can give **direction** to the lines of flux by putting arrowheads on them in the direction a compass needle would point if placed in the magnetic field.

Lines of flux of a magnet emerge from the N pole and re-enter at the S pole.

Although, in diagrams, some lines of flux are shown incomplete they are in fact **always continuous**.

Lines of flux **never cross**

When two magnets are brought close together their **resultant field** is modified by the fact that lines of flux cannot cross. Where lines of flux from the two magnets are in the same direction they reinforce one another and the flux density is increased.

When lines of flux from the two magnets oppose one another they tend to cancel each other out. Magnetic effects are most powerful at two points, usually near the ends of the magnet, called the **poles** of the magnet.

When a magnet is freely suspended and comes to rest, the end nearest to the earth's magnetic north pole is called the 'north seeking' or North (N) pole of the magnet. The other is the South (S) pole. If the N pole of a magnet is brought near the N pole of another magnet, the two poles repel each other. Similarly two S poles repel each other.

Attraction occurs between a N and a S pole.

LIKE POLES REPEL

UNLIKE POLES ATTRACT

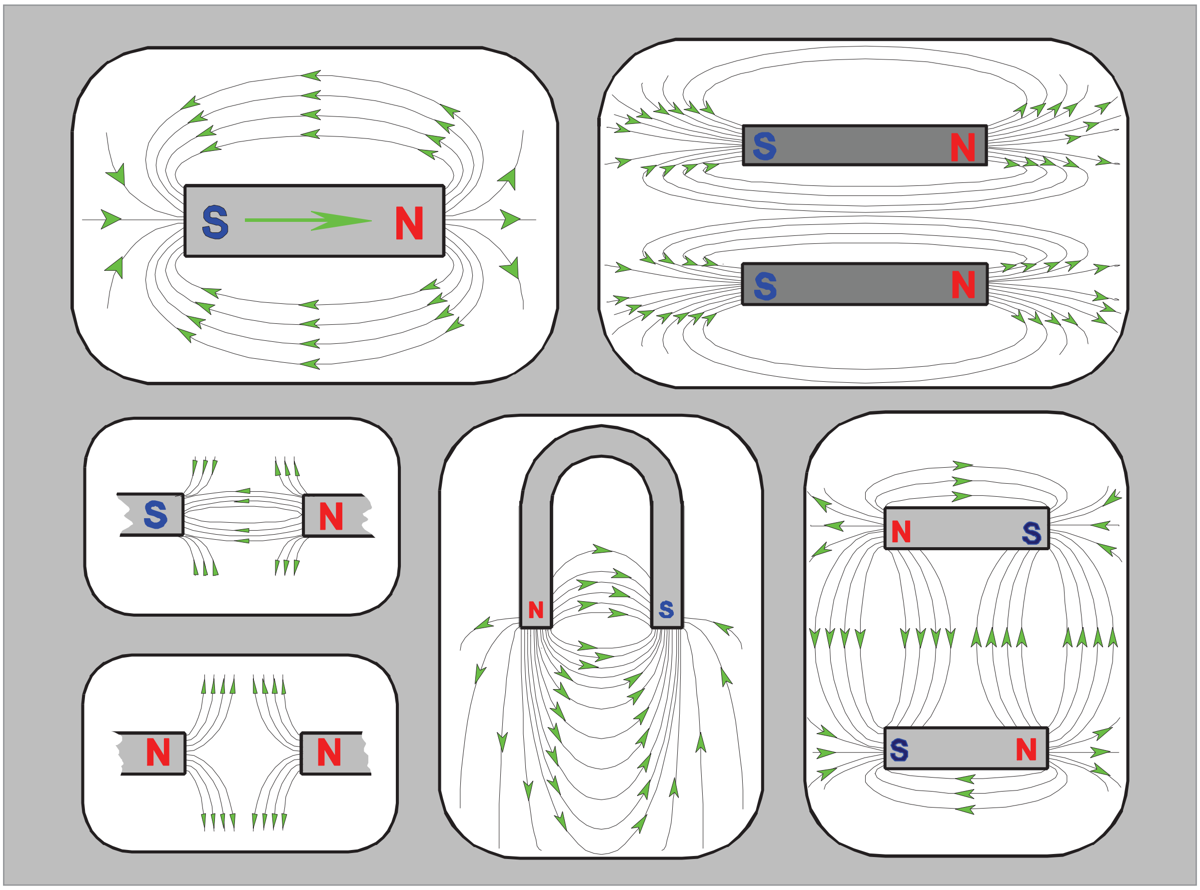


Figure 5.1 Flux distribution

Temporary Magnets

Temporary magnets are made from **soft iron** which is easily magnetized but readily loses its magnetic properties.

Permanent Magnets

Permanent magnets are made from hard alloy steels which are difficult to magnetize but retain their magnetism well.

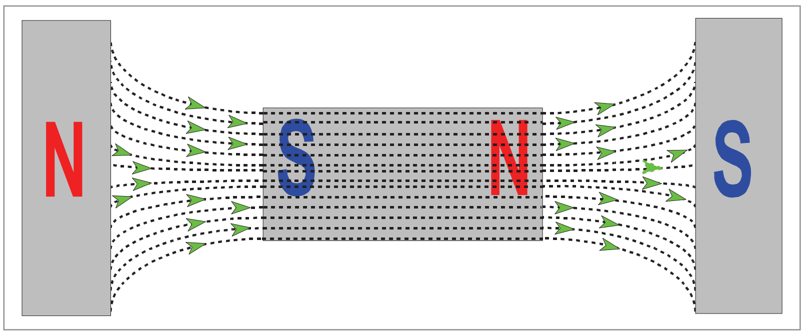


Figure 5.2 Temporary magnet

Permeability

If an unmagnetized piece of soft iron is placed in a magnetic field, the lines of flux concentrate to flow through the iron. The iron itself becomes magnetized and produces additional lines of flux.

This property of increasing the flux density is called **permeability**.

If it is removed from the magnetic field, the soft iron loses most of its magnetism. Soft iron is said to have low magnetic **retentivity**. The little magnetism which remains is called its **residual magnetism.**

Magnetism

Magnetism may be destroyed by:

- Heating the material.
- Hammering the material.
- Placing the material inside a solenoid which is supplied with an alternating current.

The Molecular Structure of Magnets

In an unmagnetized piece of soft iron, the molecules tend to form closed chains. When the iron is magnetized, the magnetized molecules tend to line up with invisible lines of influence in the magnetic field which are called the **lines of flux**. When all the molecules line up, the magnet is said to be **saturated** and it cannot be magnetized further.

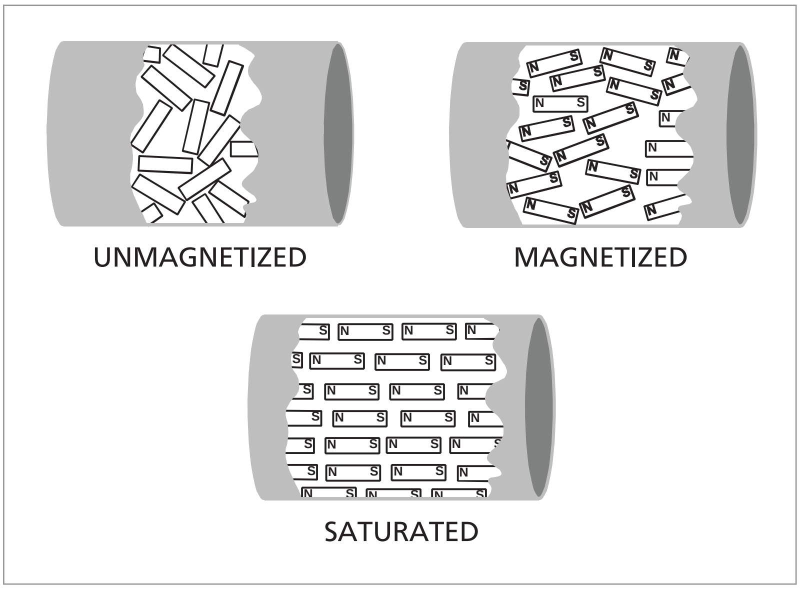


Figure 5.3 Molecular distribution

The Magnetic Effect of a Current

When a conductor carries a current, a magnetic field is set up about the conductor in the form of concentric lines of flux.

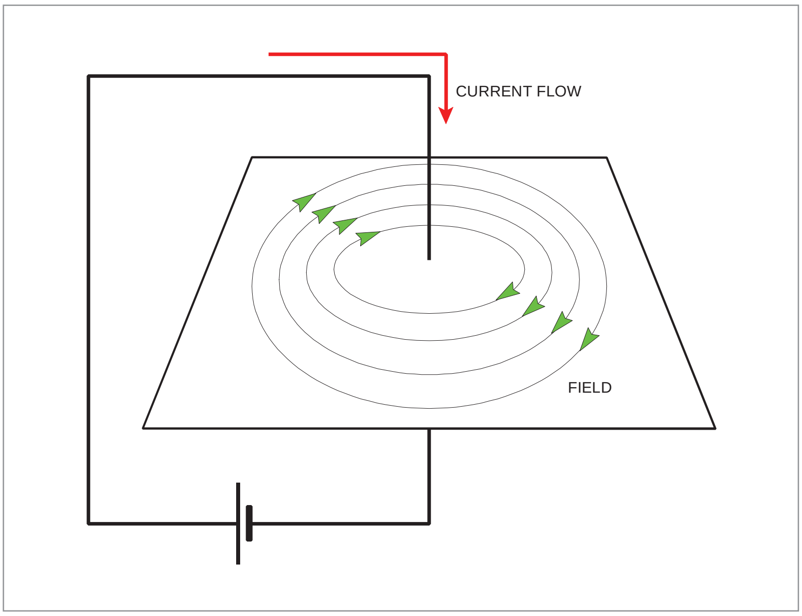


Figure 5.4 Magnetic effect of a current

The Corkscrew Rule

If a right-handed corkscrew is turned so as to move in the direction of the conventional current in the conductor, the direction of rotation of the corkscrew is the direction of the lines of flux.

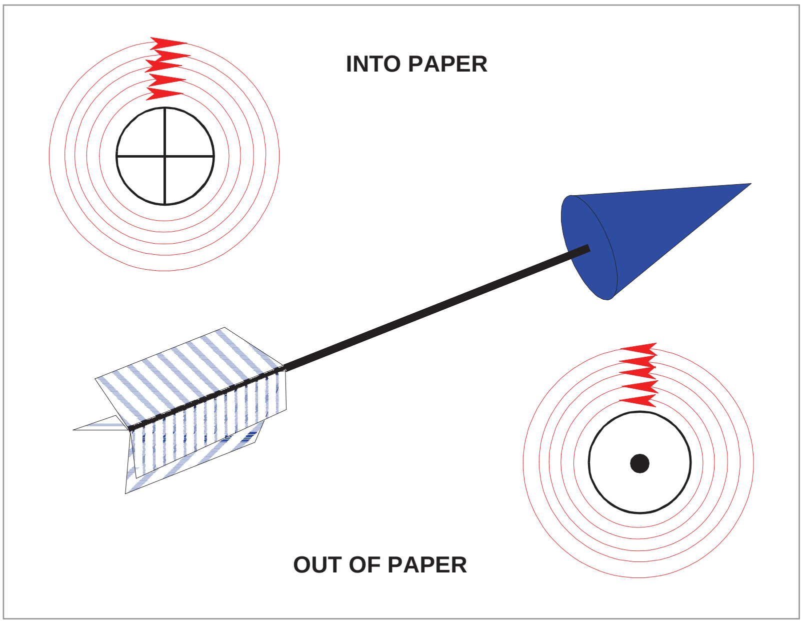


Figure 5.5 Direction of current flow

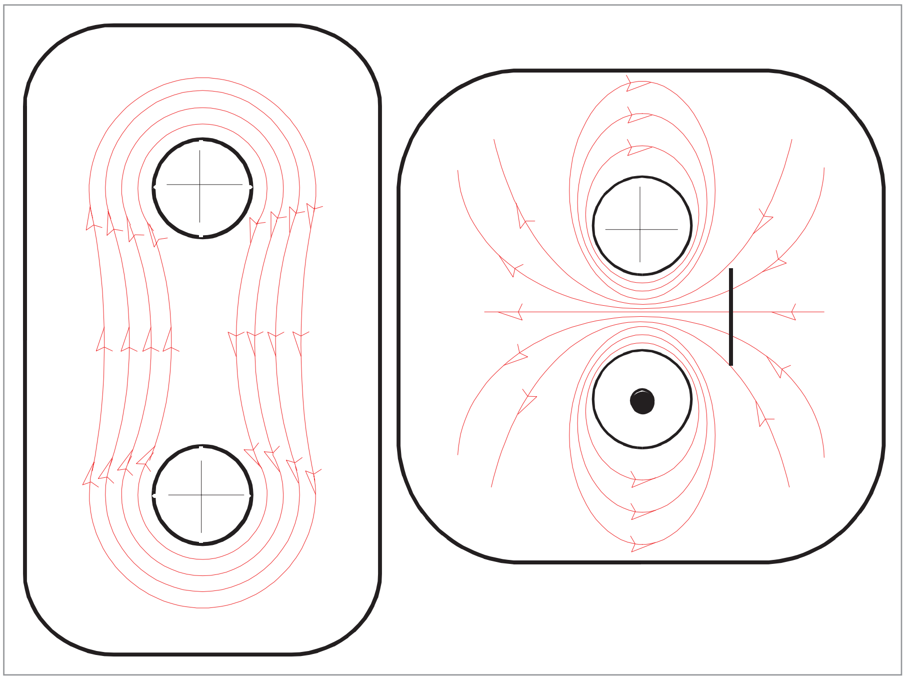


Figure 5.6 Combined magnetic fields

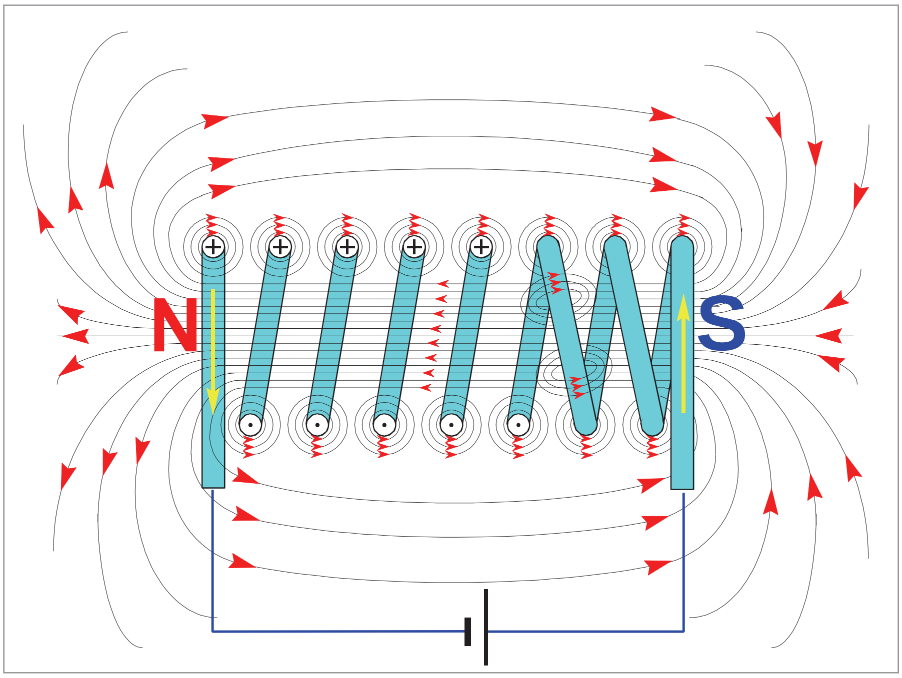


Figure 5.7 Magnetic field in a coil

The Magnetic Field of a Solenoid

A **solenoid** (electromagnet) is a coil of a large number of turns of **insulated** wire. Between the coils the flux cancels out. The field pattern is similar to that of a bar magnet. The polarity of a solenoid may be found by the **Right Hand Grasp Rule**. Electromagnets and the principle of electromagnetism play a vital part in the operation and control of many aircraft electrical circuits.

The Right Hand Grasp Rule

If a solenoid is held in the right hand so that the fingers are curled round it pointing in the direction of the conventional current, the outstretched thumb points to the North pole of the solenoid.

The Strength of the Field of a Solenoid

The strength of the field of a solenoid can be increased by:

- increasing the number of turns on the coil.
- increasing the current.
- using a soft iron core.

When the current is switched off the magnetic field collapses leaving a little residual magnetism in the soft iron core.

Solenoid and Relay

Solenoids and relays are nothing more than remotely controlled switches. By switching a small current from the flight deck a large current can be switched at the solenoid or relay, e.g. the starter solenoid in the starting circuit for a piston engine.

The solenoid has a moving core whereas the relay has a stationary core and an attracted armature.

The wires that form the coil of the solenoid or relay are insulated and have no physical or electrical contact with the circuit which is controlled by the contacts.

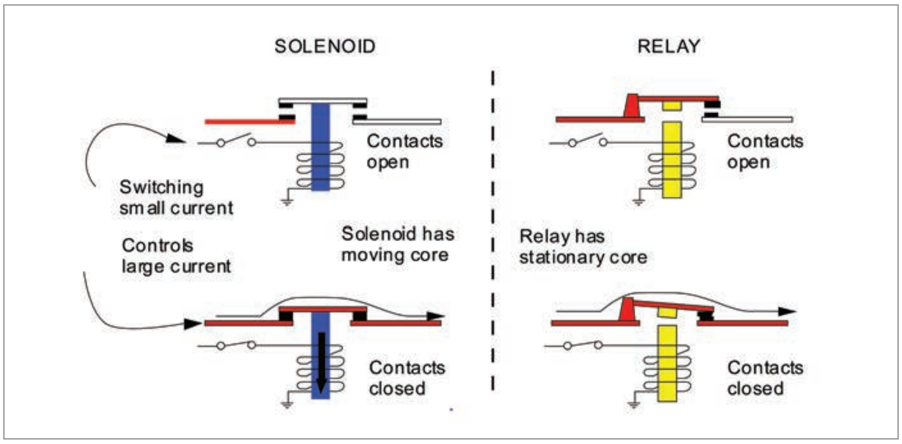


Figure 5.8 Solenoid and relay

The Forces on a Conductor Which is Carrying a Current

If a current carrying conductor is placed between two magnets, the interaction of the two magnetic fields will produce a strong magnetic field on one side of the conductor and a weak magnetic field on the other. The resultant stronger force will cause the conductor to move.

This is the basic motor principle and the direction of movement can be deduced by using **Fleming's Left Hand Rule**. This will be explained in the section dealing with motors.

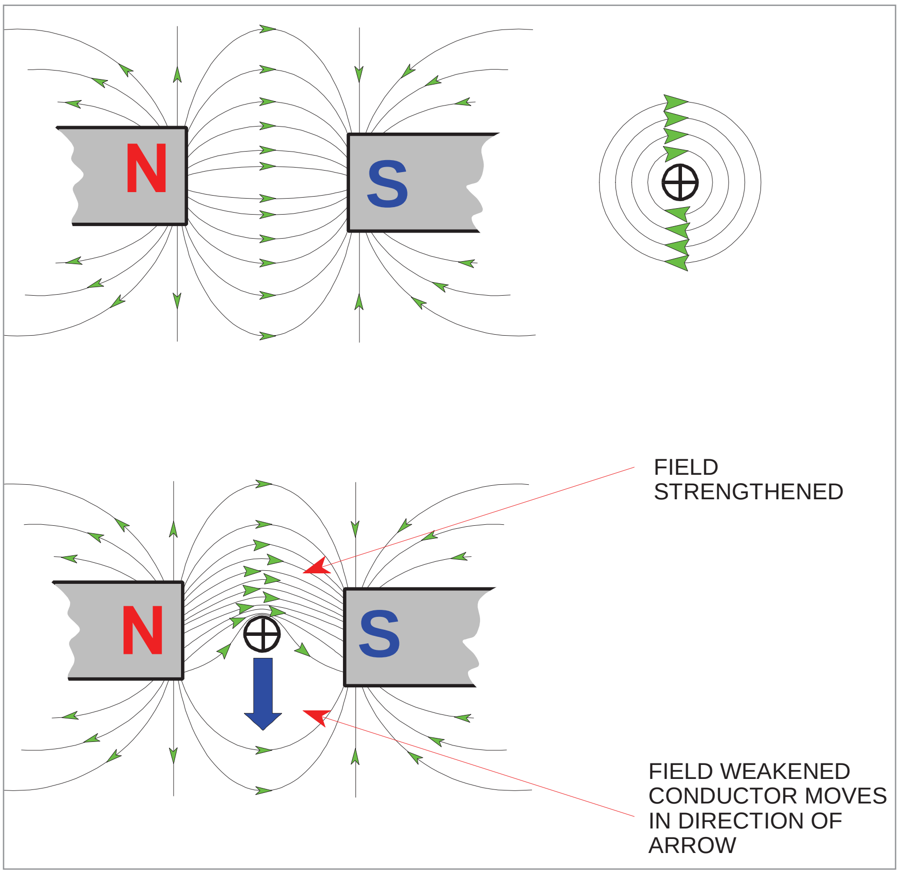


Figure 5.9 Interaction between two magnetic fields

The motion caused by the effects of current through a conductor suspended in a magnetic field is known as Lorentz force.

Questions

1. The area of force around a magnet is termed:

a. conductance
b. stable
c. magnetic resistance
d. magnetic field

2. When a magnet is unable to accept any further magnetism it is termed:

a. reluctance
b. saturation
c. active
d. reactance

3. Permanent magnets are manufactured from:

a. steel
b. plastic
c. liquid
d. glass

4. Magnetic lines of force flow externally from:

a. one main line station to another
b. the master station
c. the north to the south pole
d. in a random direction

5. Which of the two poles has the greatest strength?

a. North seeking pole
b. South seeking pole
c. Both poles have the same strength
d. The saturated pole

6. Electromagnetism is a product of:

a. voltage
b. current
c. resistance
d. engine resistance

7. To increase electromagnetic force one would:

a. increase coil resistance
b. reduce current flow
c. lower EMF
d. increase current flow

8. If you bring two magnets together:

a. like poles will attract
b. unlike poles will attract
c. over heating will occur
d. their magnetic fields will adjust to avoid overcrowding

9. **A soft iron core in an electromagnet:**

a. increases flux density
b. decreases flux density
c. reduces arcing
d. increases the lines of strength

Answers

1	2	3	4	5	6	7	8	9
d	b	a	c	c	b	d	b	a

Chapter

6

DC Electrics - Generators and Alternators

Electromagnetic Induction

Batteries are a good source of DC electricity by conversion of chemical energy, but they are not inexhaustible and will go flat after a period of time and need recharging. The primary source of electricity in an aircraft is always the generator or alternator.

Magnetism can be used to generate electricity by converting mechanical energy to electrical energy by **Electromagnetic Induction**.

If a conductor is moved in a magnetic field, the conductor will 'cut through' the invisible lines of flux. When this happens an Electromotive Force EMF (voltage) is induced into the conductor as long as the conductor keeps moving. If the conductor stops, the induced EMF ceases. It does not matter if the conductor or the magnetic field is moved as long as there is relative movement between the two.

If the conductor is connected to a complete circuit then a current will flow in the circuit in proportion to the induced EMF.

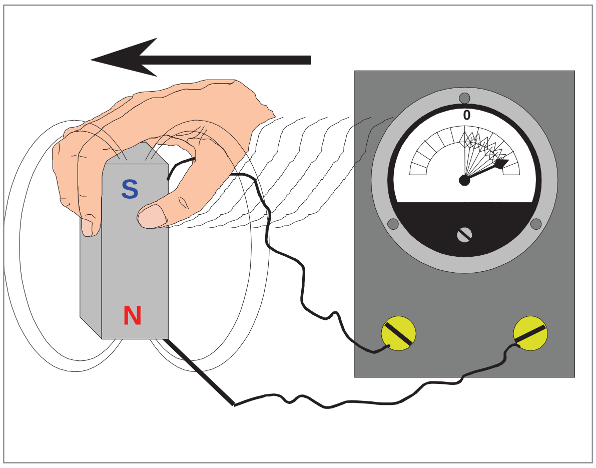


Figure 6.1 The situation with relative motion between the magnet and the coil

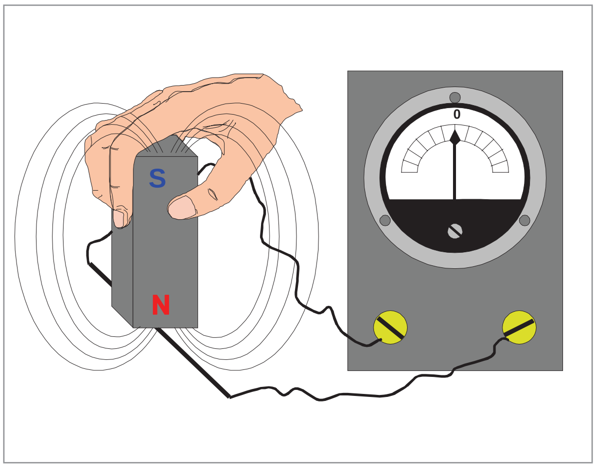


Figure 6.2 The situation with the magnet at rest

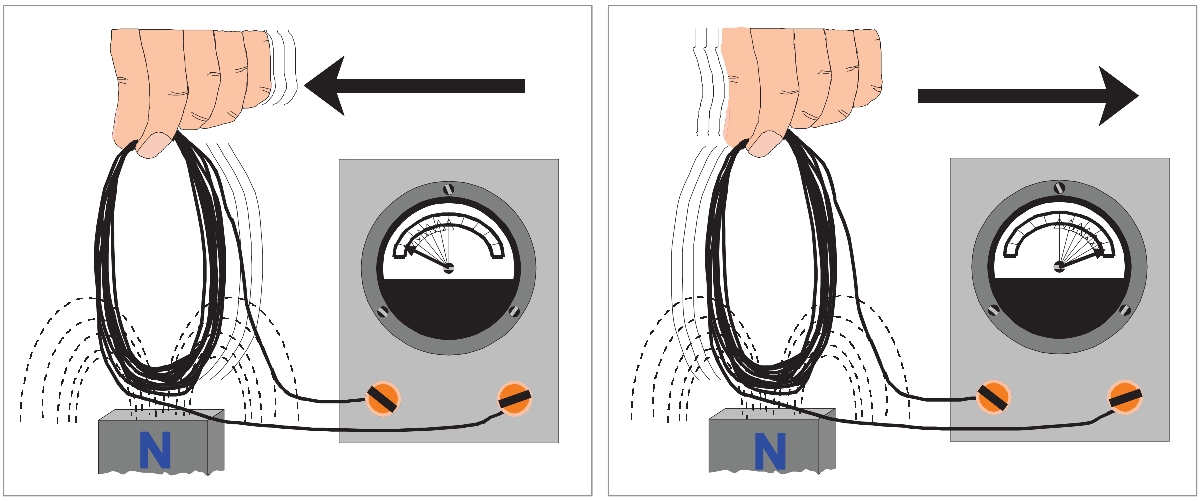


Figure 6.3 The direction of the relative motion determining the direction of current flow

Fleming's Right Hand Rule

The direction of the current can be determined by Fleming's Right Hand Rule (*Figure 6.4*). To do so, align the first finger with the field from the North Pole to the South Pole. Point the thumb in the direction of rotation and the second finger will show the current direction.

For example, in *Figure 6.4* the first finger is aligned with the field and the thumb is pointing upward in the direction of rotation of the red half of the armature. The second finger shows the current coming out of the red (negative) half of the armature. The blue half of the armature is moving downward therefore, with the first finger still aligned with the field, if the hand is rotated through 180 degrees, the second finger will show the current going into the armature.

If the direction of rotation or the field polarity is reversed, then so will be the direction of the current. However, if both are reversed the direction of current remains unchanged.

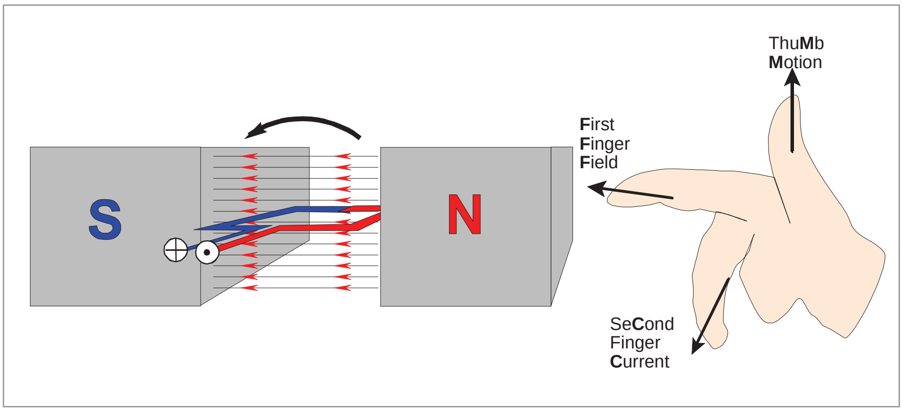


Figure 6.4 Fleming's right hand rule

The magnitude of the induced voltage can be affected in three ways:

- The rate of cutting of lines of force. (Speed)
- The strength of the magnetic field. (Flux density)
- The number of turns of wire. (Larger coil)

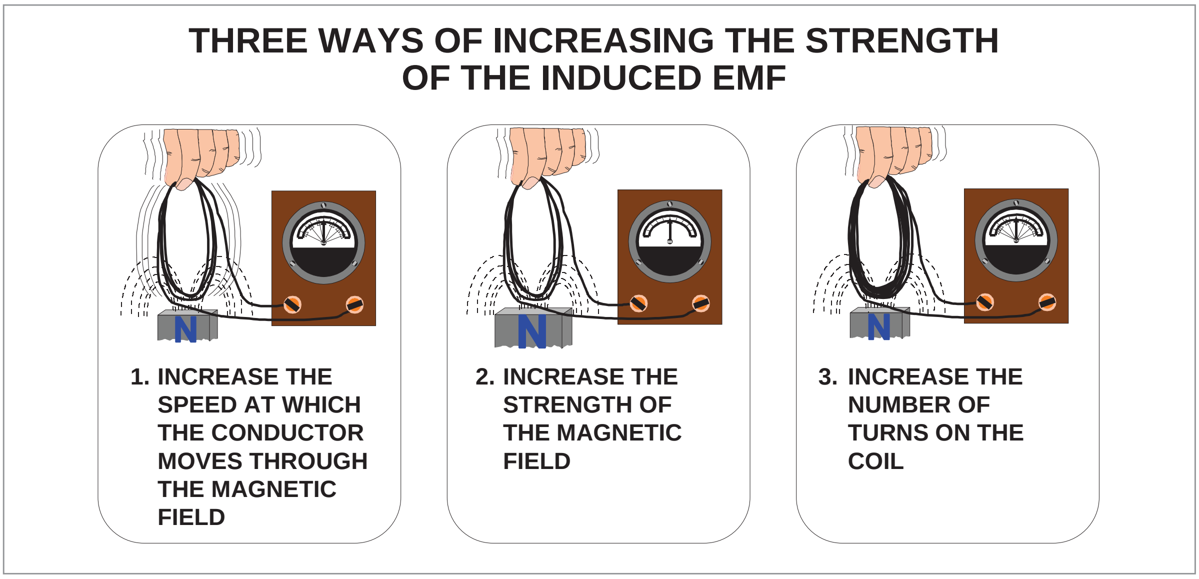


Figure 6.5 Factors which determine the strength of the induced EMF

Faraday's Law

Faraday's law states:

When the magnetic flux through a coil is made to vary, a voltage is set up. The magnitude of this induced voltage is proportional to the rate of change of flux.

Lenz's Law

Lenz's law states:

A change of flux through a closed circuit induces a voltage and sets up a current. The direction of this current is such that its magnetic field tends to oppose the change in flux.

This action produces a **back EMF**. (See next chapter on Motors).

Simple Generator

The simplest form of a generator is a single loop of wire turning in a fixed magnetic field produced by a permanent magnet (*Figure 6.6*). The closed circuit is made by attaching rotating slip rings to both ends of the loop which are in contact with stationary carbon brushes. Continuous contact between the slip rings and the brushes is maintained by spring pressure. The brushes are attached to cables which form a closed circuit.

- The rotating loop is known as the **armature**.
- The magnetic field is termed the **field**.
- In a simple generator the **armature rotates in the field**.
- An **EMF is induced in the armature by electromagnetic induction**.
- The slip rings, brushes and cables complete the closed circuit and current will flow.

This type of generator produces an AC voltage in the armature and therefore an Alternating Current in the external circuit (first flowing one way, then changing direction and flowing the opposite way).

Figure 6.6 and *Figure 6.7* show the layout of a simple AC generator and the voltage output rising then falling then changing direction as the armature sides reverse their direction through the magnetic field. The graphical view shows how a sine wave output of AC is generated. The maximum voltage is induced when there is maximum cutting of lines of flux. The position where no voltage is induced (position 1, 3 and 5 *Figure 6.7*), when the armature is moving parallel to the lines of flux, is known as the **neutral plane**.

A coil of wire can be wrapped around the two poles of the magnet. Passing a current through this coil will allow the magnetic field strength to be increased and so increase the voltage output of the generator. This is termed the **field coil** and is used to control the voltage to a fixed value irrespective of the generator speed.

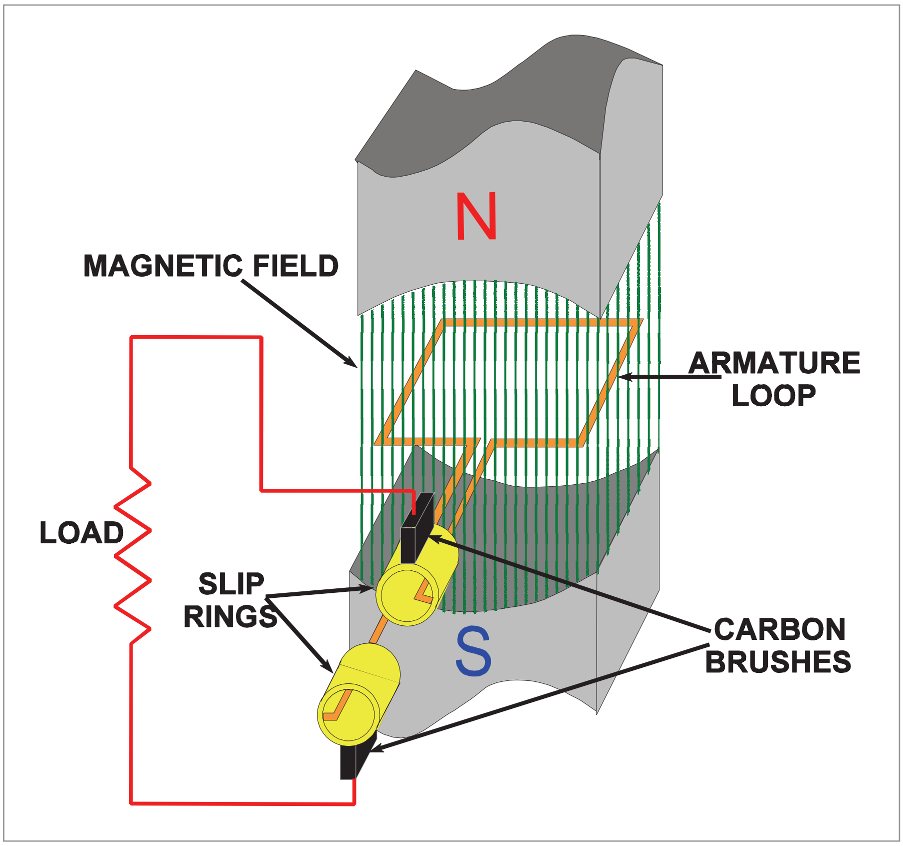


Figure 6.6 A simple AC generator

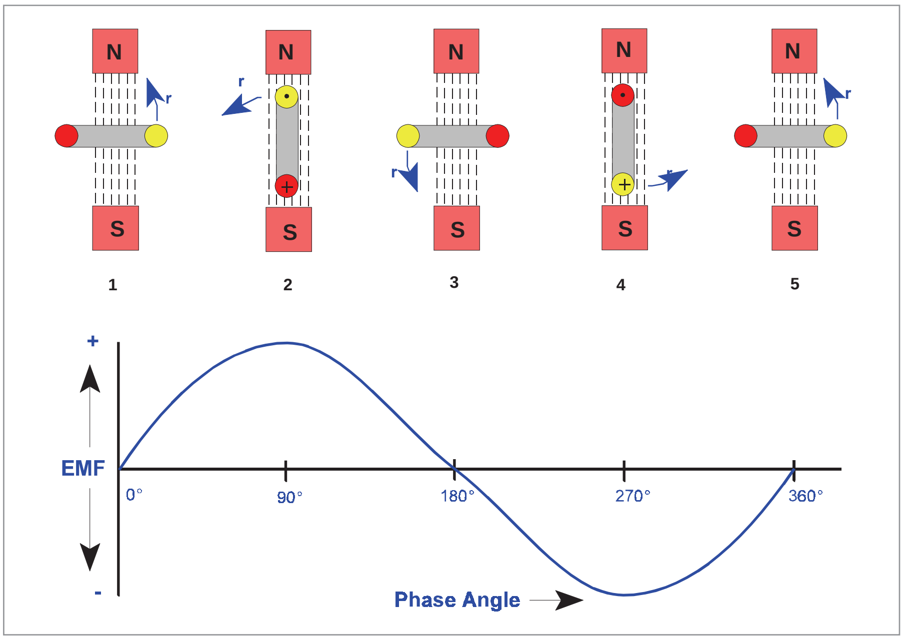


Figure 6.7 AC generator voltage output

Simple DC Generator

To produce a DC output from the simple generator it is required to change the **AC EMF** induced into the armature to a **DC** output at the generator terminals. This is done by replacing the slip rings with a **Split Ring Commutator**.

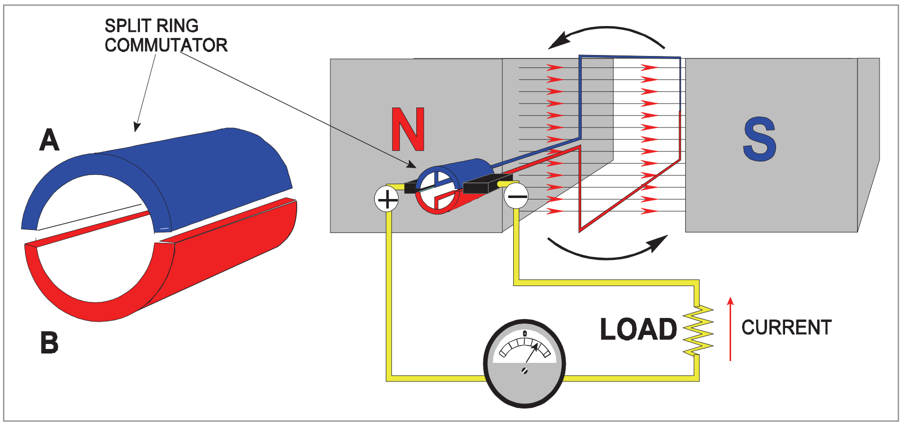


Figure 6.8 The simple DC generator

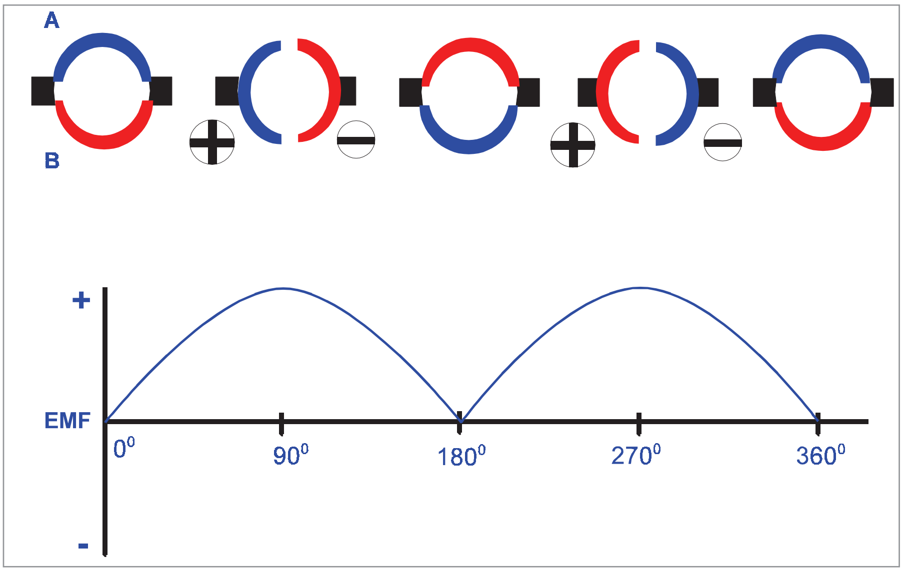


Figure 6.9 DC generator voltage output

A split ring commutator is constructed of a single ring of conductive material with an insulator electrically separating each half of the ring. The armature is constructed with one end of the loop connected to one conductor of the split ring and the other end to the other one. The commutator rotates with the armature.

Electrical continuity from one side of the armature, through the armature circuit and to the other side of the armature is achieved by the use of carbon brushes.

As the armature rotates from 0° to 180° (*Figure 6.9*) the positive brush is in contact with commutator segment A, and the negative brush is in contact with commutator segment B. As it rotates from 180° to 360° the positive brush is in contact with commutator segment B and the negative brush is in contact with commutator segment A. The result is that every 180° the armature terminals are reversed. This causes the current and voltage in the armature circuit to become DC after commutation.

Characteristics of the Series Wound DC Generator

In a series wound DC generator, the **armature** (the rotating coil), **the field coils** (wire wrapped around the pole pieces to add strength to the magnetic field) **and the external circuit are all in series.**

This means that the same current which flows through the armature and external circuit also flows through the field coils.

Since the field current, which is also the load current, is large, the required strength of magnetic flux is obtained with a relatively small number of turns in the field windings. As the load draws more current from the generator this additional current increases the field strength and generates more voltage in the armature winding. A point is soon reached, A, where further increase in load current does not result in greater voltage, because the magnetic field has reached saturation point (this is the point where no more magnetic lines of force can be absorbed by the pole pieces). Because a constant voltage is required for aircraft systems the series generator cannot be used.

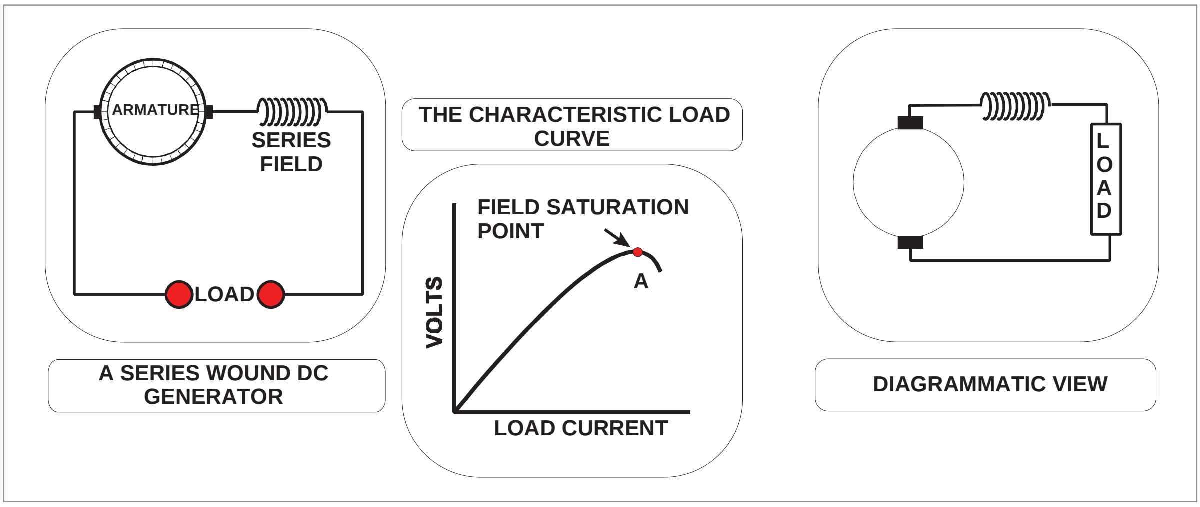


Figure 6.10 Series wound generator

Commutator Ripple

Commutator ripple is the term given to the fluctuation of the voltage output of a DC generator as the voltage rises and falls during the rotation of the armature loop, particularly at low RPM. By increasing the number of coils in the armature or the number of field coils, or indeed both then the pulsating or ripple effect of the DC produced by a generator can be reduced. The following diagram compares a single coil armature with a multiple coil.

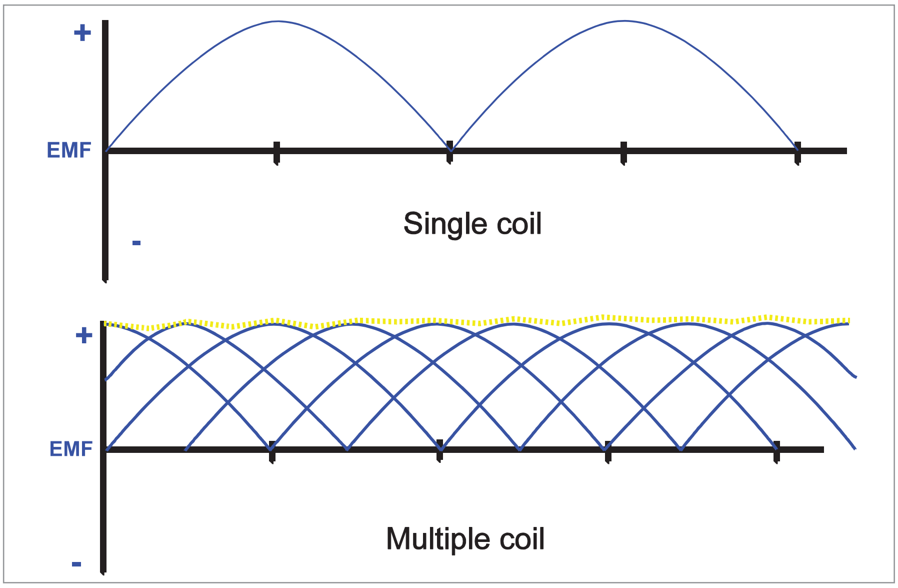


Figure 6.11 Single coil and multiple coil armature outputs

Characteristics of the Shunt Wound DC Generator

A shunt wound DC generator has its field winding connected in **parallel (or shunt)** with the armature. Therefore the current through the field coils is determined by the terminal voltage and the resistance of the field.

The shunt field windings have a large number of turns, and therefore require a relatively small current to produce the necessary field flux.

When a shunt generator is started, the build-up time for rated terminal voltage (the maximum voltage at which the generator can continuously supply its rated load current) at the brushes is very rapid since field current flows even though the external circuit is open.

Figure 6.12 shows a schematic diagram and characteristic curve for the shunt generator. It should be noted that over the normal operating range of ‘no load’ to ‘full load’, the drop in terminal voltage as the load current increases is relatively small The shunt generator is therefore used where a virtually constant voltage is desired, regardless of load changes.

The terminal voltage of a shunt generator can be controlled by a variable resistance connected in series with the shunt field coils.

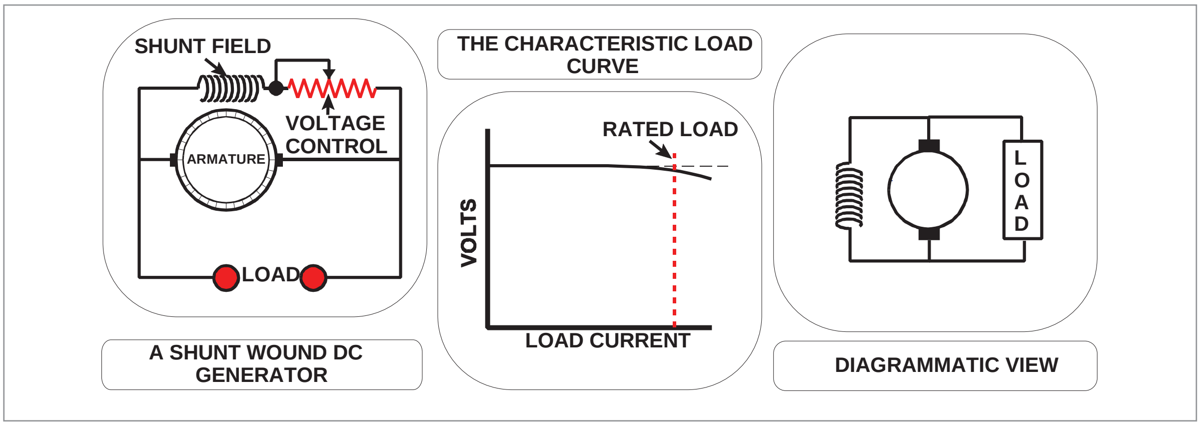


Figure 6.12 Shunt wound generator