NUCLEAR AND ATOMIC PHYSICS

Atomic model

An atom has a central nucleus, which contains protons that are positively charged and neutrons that are neutral. The nucleus is surrounded by negatively charged electrons which move in orbits.

Mass number (A) is the number of protons and neutrons.

Atomic number (Z) is the number of protons or electrons in a neutral atom.

In a neutral atom the protons and electrons are equal and the resultant charge is zero. If electrons are removed, the resultant charge is positive while if added the resultant charge is negative.

An atom is written as ${}^{A}_{z}X$ e.g. ${}^{35}_{17}Cl$ means that A = 35, Z = 17, P = 17 and N = 18

Qn: Find the number of protons, electrons and neutrons in the elements below

a) ${}^{40}_{20}Ca$ c) ${}^{12}_{6}C$ e) ${}^{16}_{8}O$

b) ${}^{28}_{11}Na$ d) ${}^{37}_{17}Cl$ f) ${}^{14}_{7}N$

Isotopes

Isotopes are atoms of the same element with the same atomic number but different mass number e.g. chlorine ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$, oxygen ${}^{16}_{8}O$, ${}^{17}_{8}O$ and ${}^{18}_{8}O$, uranium ${}^{324}_{92}U$ and ${}^{238}_{92}U$

Isotropy

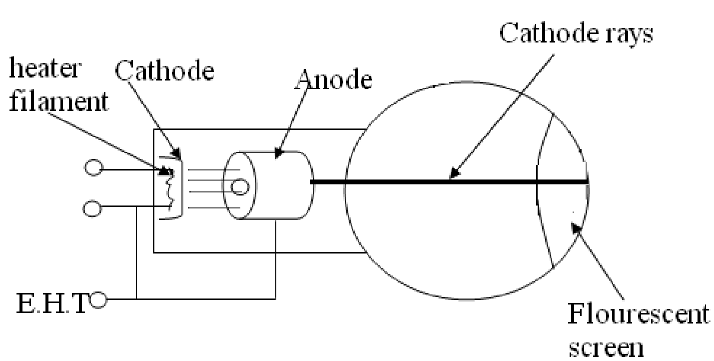
Isotropy is the existence of atoms of the same element with the same atomic number, but different mass number.

Atoms of the same element having the same atomic number but different mass number are called isotopes of the element. The element is said to be isotopic. Isotopes which are radioactive in nature are called radio isotopes.

CATHODE RAYS

Cathode rays are fast moving electrons produced from a hot cathode.

Production of cathode rays

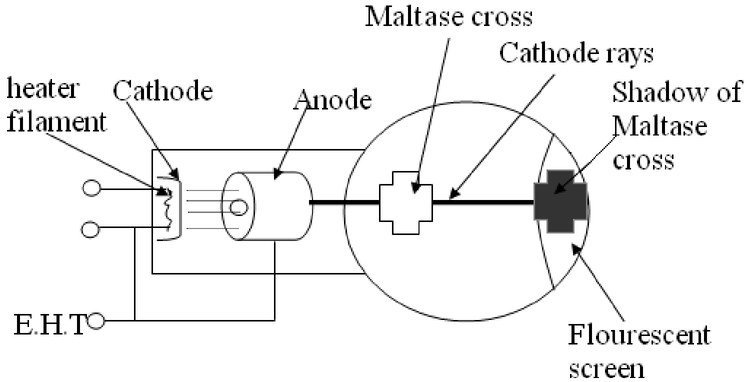


When a cathode is heated, electrons are emitted by thermionic emission process. The emitted electrons are accelerated by the high potential difference (E.H.T) between the cathode and anode. The anode focuses the electrons into a fine beam onto the screen which then fluoresces.

The process by which electrons are emitted from a hot metal is referred to as **thermionic emission.**

Properties of cathode rays

1. They cause fluorescence in several substances.
2. They travel in straight line. This is illustrated by placing an object in the path of the cathode rays. A sharp shadow is then seen on the fluorescent screen.

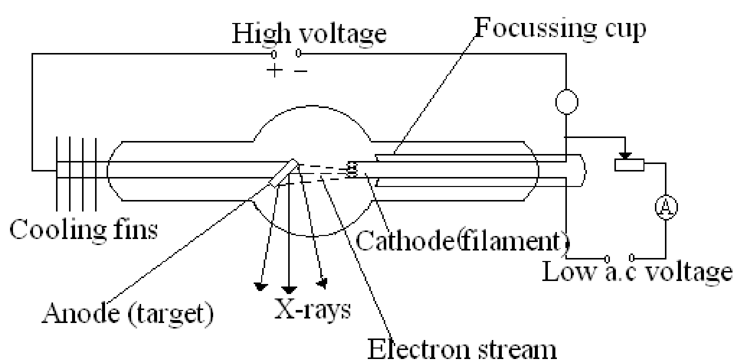


3. They are negatively charged. When cathode rays are directed to the cap of a negatively charged electroscope, there is an increase in the divergence of the leaf.
4. They are detected by a magnetic field. Since they are negatively charged, they are attracted by the North Pole of a magnet and repelled by the South Pole.
5. They are deflected by an electric field to the positive plate.
6. They posses kinetic energy. This is shown when the rays rotate a small light paddle wheel pivoted between the anode and cathode.
7. They produce x-rays when they strike matter.

X-RAYS

X-rays are electromagnetic radiations produced when fast moving electrons strike matter.

Production



Electrons from a hot filament are produced by thermionic emission. The electrons are accelerated by the high potential difference across the cathode and anode. On striking the tungsten target, part of its kinetic energy is converted to x-rays and the rest to heat.

The heat produced is removed by means of cooling fins.

Quality of x-rays

Quality of x-rays is a measure of the penetrating power of the x-rays. This depends on the kinetic energy of the electrons from the cathode which depends on E.H.T.

Soft x-rays are produced when the potential difference between the cathode and the anode is low. They have low energy, long wave length and less penetrating power.

Hard x-rays are produced when the potential difference the potential difference between the cathode and the anode is high. They have high energy, short wave length and high penetrating power.

The number of electrons striking the target per second determines the intensity of the x-rays. Increasing the filament current can raise this.

The absorption of x-rays by matter is greatest by materials of high density and of high atomic number.

Properties of x-rays

1. They readily penetrate matter.
2. They are not detected by electric or magnetic fields.
3. Cause ionization of gas molecules.
4. They are electromagnetic in nature.
5. X-rays affect a photographic film.
6. They cause fluorescence.
7. They travel in a straight line.
8. They give interference and diffraction effects.

Uses of x-rays

1. In medicine
   a) To investigate bone fractures.
   b) To detect lung cancer.
   c) To treat cancer by radiotherapy.
2. In industry
   a) To study imperfections e.g. flows in metal castings and welded joints.
   b) To study the changes in the work of art especially pigments variation and type.
   c) In x-ray crystallography. In studying crystal structure of various substances.

Hazards of x-rays

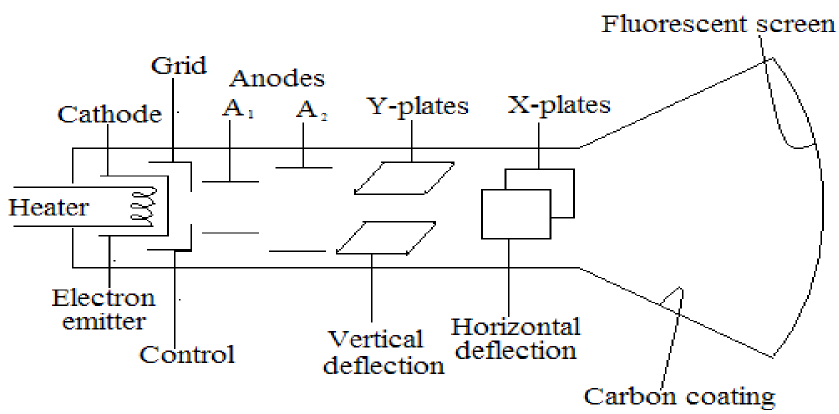
1. Destroy cells especially hard x-rays.
2. Cause gene mutation.
3. Damage eye sight.
4. Produce deep-sealed skin burns.

Precautions for safety

1. Avoid unnecessary exposure to x-rays
2. Keep the exposure time short.
3. X-rays should be restricted to only parts under investigation.
4. A worker dealing with x-rays should wear a lead jacket.
5. The number of x-rays exposure should be limited for any patient.
6. Exposure should be avoided for unborn babies and very young children.

CATHODE RAY OSCILLOSCOPE (C.R.O)

A C.R.O is an instrument used for studying the current and voltage wave forms in various electric circuits.



The chief feature of an oscilloscope is the cathode ray tube, which is a vacuum tube containing three major components:

1. **The electron gun**

This consists of:

Heater: It's for heating the cathode.

Hot cathode: this emits electrons by thermionic emission.

Grid control: it's at negative potential and controls the number of electrons reaching the screen and the brightness of the spot on the screen.

The anode: it's at high positive potential and it accelerates and focuses electrons into a fine beam.

2. **The deflecting system**

This consists of metal plates which can deflect the electron beam either vertically or horizontally.

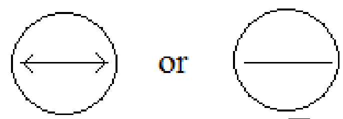
Y-plates (horizontal plates) deflect the electron beam vertically.

X-plates (vertical plates) deflect the electron beam horizontally.

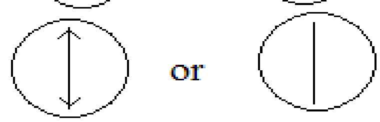
The x-plates are connected with the C.R.O to a special type of circuit called the time base circuit.

Appearance of the beam

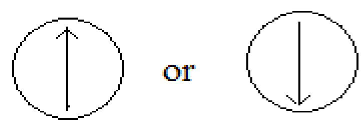
a) Time base on x-plate only



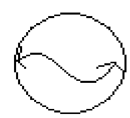
b) A.C on Y-plate only



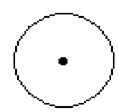
c) D.C on Y-plate only



d) A.C on Y-plate and time base on X-plate



e) Both time base and Y-plate off



3. **The fluorescent screen**

It is at the end of the tube. It receives the focused bright spot of electrons and displays it.

The graphite coating on the inner wall of the cathode ray tube traps stray electrons emitted from the screen and makes the potential in that region uniform.

The tube is evacuated to avoid energy loss by electrons dues to collision with air molecules.

Uses of C.R.O

1. Used to measure potential drop.
2. Used to measure frequency of an alternating current (a.c)
3. Used to study waves.
4. Measurement of time interval.
5. Measurement of phase difference between two voltages.

Applications of C.R.O

1. Television sets.
2. Computer monitors.
3. Ultrasound scanning devices.

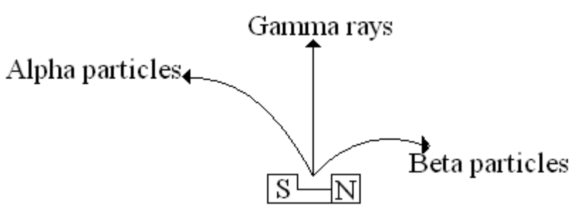
RADIOACTIVITY

Radioactivity is the spontaneous disintegration of unstable nuclei with emission of radiations e.g. alpha particles (α), beta particle (β) or gamma (γ) radiations. Elements that emit radiations spontaneously are said to be radioactive.

Summary of nature of radiations

radiation	nature	charge	mass	ionisation	penetration
Alpha (α)	Helium nucleus (He)	+2	4	100 (most)	1 (least)
Beta (β)	An electron (e)	-1	0	10	10
Gamma (γ)	electromagnetic	none	none	1 (least)	100 (most)

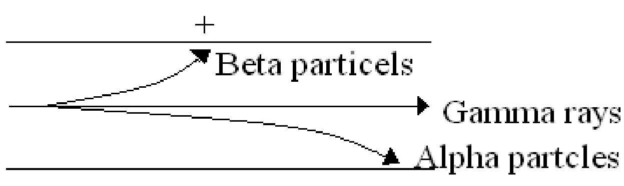
When radiations from a radioactive source are subjected to a magnetic field, the field affects their path as shown below.



Alpha particles are deflected in a direction opposite to that of beta particles and are deflected less than beta particles implying that alpha articles are heavier than beta particles.

The gamma rays are not deflected implying that they have no charge.

Similarly if the radiations are subjected to an electric field, the path below is seen.

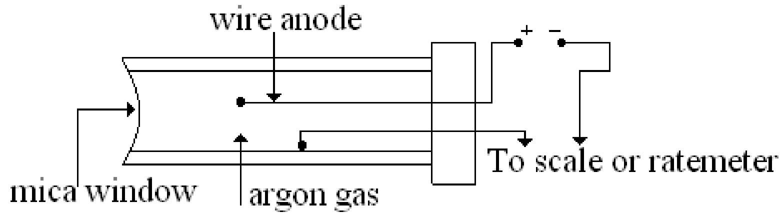


Alpha particles are deflected to the negative plate and beta particles to the positive plate. This shows that alpha particles are positively charged while beta particles are negatively charged.

Ionizing effect of radiation

A charge electroscope discharges when a radioactive source (e.g radium) is brought near the cap. Radiation knocks electrons out of surrounding molecules leaving them positively charged air ions. The positive ions are attracted to the cap if it is negatively charged; if it is positively charged the electrons are attracted thus discharging the electroscope.

Geiger miller (GM) tube



The ionizing effect is used to detect radiation. When radiation enters a GM tube through mica window, it ionizes the argon gas. The ions are accelerated towards the electrons and produce a current pulse which is amplified and fed to a rate meter or a scaler which shows count rate or counts received in a certain time.

The penetrating power can be investigated by observing the effect on count rate when the following is placed in turn between the GM tube and the lead sheet.

i) A sheet of thick paper.
ii) A sheet of aluminum 2mm thick.
iii) A sheet of lead 2cm thick.

Alpha particles (rays)

Are stopped by a thick sheet of paper and have a range in air of only a few centimeters since they cause intense ionization in a gas due to frequent collisions with gas molecules. From a particular substance, they are all emitted with the same speed.

Beta particles (rays)

Are stopped by a few millimeters of aluminum and some have a range in air of several meters. They are emitted with a range of speeds up to that of light. Their ionizing power is much less than that of α-particles.

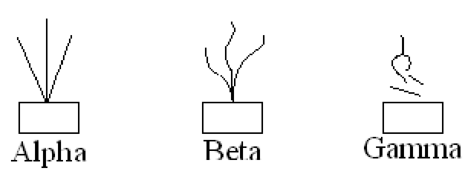
Gamma rays

Are most penetrating and are stopped only by many centimeters of lead. It has least ionizing power. They give interference and diffraction effects and are electromagnetic radiation traveling at the speed of light. A GM tube detects α-particles, β-particles and γ radiations but a charged electroscope detects α-particles only.

All three types of rays cause fluorescence.

Particle tracks

The paths of particles of radiation were shown by the ionization they produced in cloud chambers.



α-particles gave straight, thick tracks because they are massive and therefore cannot be easily detected.

fast β-particles produced thin straight tracks while slower ones gave short, twisted thicker tracks because beta particles are very light therefore suffer frequent repulsion from the electron of atoms near which they pass.

γ-rays did not produced cloud tracks a long their own paths. Instead γ– rays eject electrons from air molecules; the ejected electrons behave like β-particles in the cloud chamber and produced their own tracks.

RADIOACTIVE DECAY

Radioactive atoms have unstable nuclei and decay (disintegrate) into atoms of different elements with more stable nuclei when they emit α or β-particles.

The rate of decay is unaffected by the temperature.

Half-life

Is the time taken for a given mass of a radioactive substance to decay to half of the initial mass.

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^{\frac{T}{t_{\frac{1}{2}}}}$$, where N = mass of the substance remaining after time, T

N_0 = initial mass of the substance

$\frac{N}{N_0}$ = fraction remaining after time, T

It is independent of the original quality and varies with different radioactive elements

For each radioactive nuclide, there exists a decay constant (λ), from which the rate of decay can be calculated.

Questions

1. The half-life of a radioactive element is 10 minutes. Calculate how long it takes for 90% of a given mass of the element to decay.
2. A radioactive source has a half – life of 20 minutes. What fraction is left after 1 hour
3. The half-life of a radioactive substance is 24 days. Calculate the mass of the substance which has decayed after 72 days if the original mass is 0.64g.
4. The mass of radioactive substance decays to $1/16^{th}$ of its original mass after 16 days. What
   i) Is its half-life?
   ii) Fraction of the original mass will have decayed after 20 days?
5. A radioactive sample has a half – life of 3×10^3 years.

i) What does the statement half-life of 3 x 10^3 years mean?

ii) How long does it take for three – quarters of the sample to decay?

6. i) Define half – life.

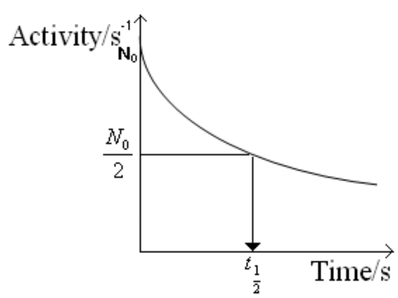
ii) X grams of a radioactive material, of half life of 3 weeks, decays and 5.12g remains after 15 weeks, decays and 5.12g remains after 15 Weeks. Determine the value of x.

iii) A certain mass of radioactive materials contains 2.7 x 10^{24} radioactive atoms. How many atoms will have decayed after 3200y if the half life of the material is 1600y?

7. The half-life of a radioactive source is 4hrs. find the mass of the element that decays after 24hrs if the initial mass is 9.6g
8. A radioactive material of mass 8g has a half-life of 20 days. Find how much of it will decay after 60 days.
9. The count rate of a radioactive isotope falls from 600 counts per second to 75 counts per second in 75 minutes. Calculate the half life
10. The half life of uranium is 24 days. Calculate the mass of Uranium which remains after 120 days if the initial mass is 64g
11. The half life of a radioactive material is 20 days. Find the initial mass of the material if 2g of it remain after 80 days,

Decay curve

Is a graph of count –rate against time.



Question

When a suitable counter was placed near a radioactive source of β-particles, the following rates of emission were obtained at the times shown.

Time (min)	0	5	10	15	20
Count rate	295	158	86	47	25

Plot a suitable graph and use it to find half-life of the source.

Laws of Radioactive Decay

1. When an element undergoes disintegration by emission of an alpha particle, it turns into another element similar to that two places earlier in the periodic.
2. When an element undergoes disintegration by emission of a beta particle, it turns into another element similar to that one place later in the periodic table.

i) Alpha decay $^{280}_{96}X \rightarrow ^{276}_{94}Y + ^{4}_{2}He$

ii) Beta decay $^{289}_{90}Y \rightarrow ^{289}_{91}Z + ^{0}_{-1}e$

iii) Gamma emission usually occurs at the same moment as either alpha or beta particle the nucleus is left in an excited state, so it release the excess energy in form of gamma radiation. Such emission has no effect on the mass number nor atomic number.

Qn.1

a) Describe the composition of the $^{23}_{11}Na$ atom

b) A radioactive nuclide $^{226}_{88}X$ emits an alpha particle and turns into another nuclide Y.

i) Write a balanced equation to represent this reaction.

ii) How would the nuclide X be affected if a beta particle was emitted instead of an alpha particle?

iii) Compare the nature and properties of an alpha particle with those of a beta particle.

c) A radioactive nuclide $^{230}_{90}X$ emits 4 α – particles, 2-β-particles and gamma radiations and turns into another nuclide Y. Find the mass number and atomic number of Y.

Qn. 2

a) A radioactive nuclide $^{226}_{88}Ra$ decays by emission of two alpha particles and two beta particles to a nuclide Y

i) What is meant by radioactive nuclide

ii) Give three differences between alpha and beta particles

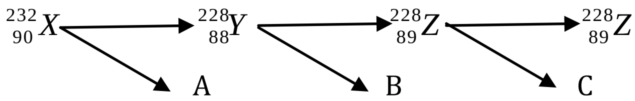
iii) State the atomic number and mass number of Y

b) What precautions would have been taken when handling radioactive materials.

c) List in order the energy changes that occur in an x-ray tube

d) The activity of the radioactive source decreases from 4000 counts per minute to 250 counts per minute in 40 minutes. What is the half life of the source?

Qn. 3



a) Identify the particles or radiations A, B and C emitted in the decay process shown above

b) State two differences between radiation A and B

Nuclear splitting

The nuclei of light atoms can be split by alpha particles, neutrons and protons.

To split the nuclei by alpha particles and protons; They (alpha – particles and protons) have to be accelerated at extremely high speed so as to over come the mutual repulsion between the nuclei and the particles themselves.

However splitting by a neutron is easily achieved because neutron has no charge so there is no repulsion between it and the nucleus to be split.

i) Disintegration by an alpha – particle $^{14}_{7}N+^{4}_{2}He\rightarrow^{17}_{8}O+^{1}_{1}H$

ii) Disintegration by a proton $^{7}_{3}Li+^{1}_{1}H\rightarrow^{4}_{2}He+^{4}_{2}He$

iii) Disintegration by a neutron $^{10}_{5}B+^{2}_{0}n\rightarrow^{7}_{3}Li+^{4}_{2}He$

Nuclear Fission

Is the splitting of heavy nucleus into lighter nuclei with a release of vast amounts of energy E.g.?

$^{235}_{92}U+^{1}_{0}n\rightarrow^{144}_{56}Ba+^{90}_{36}Vr+2^{1}_{0}n+Energy$

The energy produced is ten times greater than the energy produced in ordinary nuclear splitting. This energy released is used in nuclear plants and fro manufacture of nuclear weapons (atomic bombs). This is achieved when neutrons are accelerated to a high speed.

Nuclear Fusion

Is a nuclear reaction where by two smaller nuclei unite to form a single heavier nucleus with liberation of nuclear energy. E.g.: $^{2}_{1}H+^{1}_{0}n\rightarrow^{4}_{2}He+Energy$

This reaction takes place at extremely high temperature e.g. in hydrogen bombs and in the sun.

Uses of radioactivity

1. **Gauge control and fault finding**

If a radioisotope is placed on one side of a moving sheet of material and a GM tube on the other, the count rate decreases if the thickness increases. Flows in a material can be detected in a similar way; the count-rate will increase where a flaw is present.

2. **Radioactive tracers**

A small amount of a weak radioisotope is injected into the system and traced by a GM tube or other detector.

- In medicine is used to detect brain tumors and internal bleeding.
- In agriculture to study the uptake of fertilizers by plants.
- In industry to measure fluid flow in pipes.

3. **Radiotherapy**

Gamma rays are used in the treatment of cancer and detecting breakages in bones.

4. **Sterilization**

Gamma rays are used to sterilize medical instruments and foods.

5. **Archaeology**

Living plants and trees take in radioactive carbon. When a tree dies, no fresh carbon is taken and the carbon starts to decay. By measuring the residual activity of carbon containing material such as wood, charcoal the age of archaeological remains can be estimated.

Hazards of radioactive radiations

Gamma rays are most harmful since they penetrate deeply into the body.

- Damage the body cells and tissues
- Cause radiation skin burns
- Cause cancer leukemia
- Affect eyesight.

Safety precautions

- Personnel working in radioactive plants should wear lead jackets
- Exposure time should be short
- Radioisotopes should be handled by tongs with remote control.
- Radiation should be directed away from the people around.

NB: We are all exposed to background radiation due to cosmic rays, radiations from radioactive minerals (radon in the atmosphere, potassium – 40 in the body) and X-rays from television screens.

Revision questions

a) Name two health hazards of radioactivity.

b) What is the difference between nuclear fusion and nuclear fission? Give example where each occurs

c) Describe what happens when a beam of radiations consisting of α, β and γ- rays are incident on a thin sheet of lead.

d) A radioactive source which emits all the three radiations is placed in front of cardboard, aluminum and lead sheets as above. Name the radiations likely to be between the:

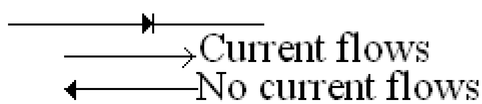
i) Cardboard and the aluminum sheet

ii) Aluminum and lead sheet.

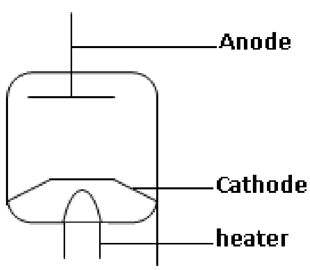
RECTIFICATION

Is the conversion of alternating current (a.c) to direct current (d.c) by use of diodes. There are two types of diodes: Vacuum (thermionic) diode and semi conductor diode. The diode conducts current only when the anode is positive in potential relative to the cathode.

The symbol:



Thermionic diode valve



The valve is made up of two electrodes; the anode, the cathode which is heated up by a heater connected to a low voltage supply.

When the cathode is heated, the electrons are emitted thermionically.

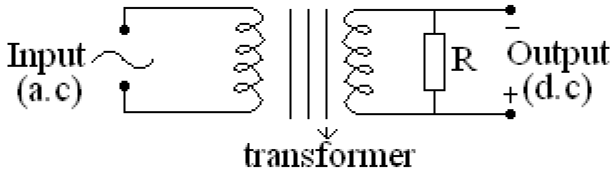
When the anode is positive with respect to the cathode, these electrons are attracted to the anode and flow past the anode as anode current.

If the anode is made negative with respect to the cathode, electrons are repelled by the anode and no current flows.

So the diode behaves as a valve, allowing current in one direction only.

Thermionic diode as a rectifier

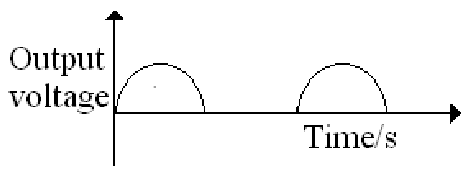
A rectifier is a device, which changes alternating current to direct current.



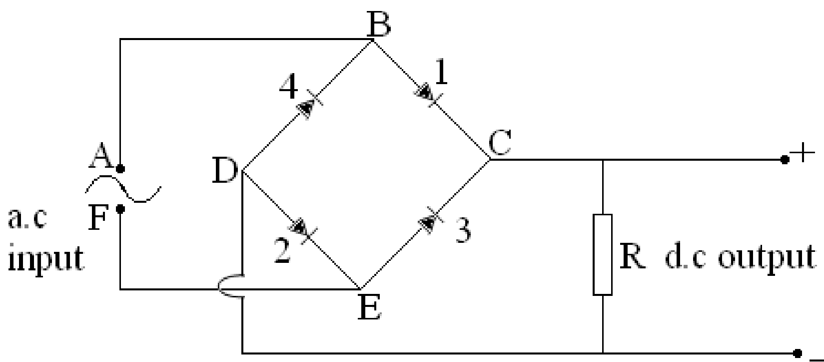
During the half of the cycle when the anode is positive, it attracts electrons and current flows through R.

During the other half when the anode is negative, it repels electrons, so no current flows.

The output is a sense of pulses of current, which is called half wave rectification



However, full wave rectification can be achieved by using four diodes or a bridge, rectifier.

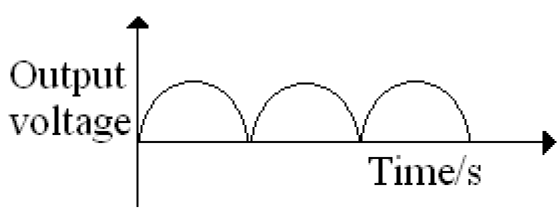


If A is positive during the first half-cycle, diodes 1 and 2 conduct current along ABC through R and back through DEF.

On the next half-cycle, F is positive and diodes 3 and 4 conduct current along FEC through R and back through DBA.

During both cycles, current flows through R in the same direction hence full rectification.

The output is the graph below.



Photoelectric emission

This is a phenomenon whereby electrons are emitted from a metal surface when ultra-violet light falls on it.

This emission of electrons is called photoelectric effect.

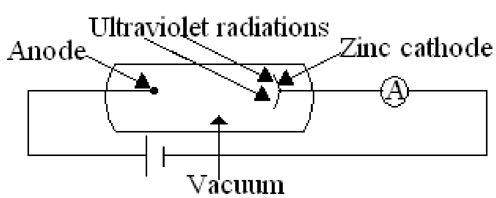
NB:

i) electrons are emitted only if the frequency of light exceeds a certain critical value called the threshold frequency
ii) The maximum kinetic energy of the ejected electrons depends on the frequency of the incident light and not on its intensity.
iii) Increasing intensity of the incident light causes more electrons to be emitted, but does not increase their energy.

Photoelectric effect is used to make photocells. Photocells contain light sensitive metals and are used in:

i. Automatic devices for switching on at dusk and off at dawn.
ii. Burglar alarms.
iii. Automatic doors where a beam of light crossing the doorway is broken when some one approaches.

Qn: A zinc cathode was enclosed in an evacuated glass tube as below.



When the cathode was irradiated with ultra violet (UV) radiations, the ammeter gave a reading. Explain why the ammeter gave a reading.

Ans: Electrons are emitted from zinc cathode by photoelectric emission and move to the anode and thus completing the circuit for current flow.

Qn: A gas was gradually introduced into a glass tube. Explain what happened.

Ans: Ammeter reading gradually dropped to zero. The electrons collided more frequently with the gas and thereby losing their kinetic energy hence not reaching the anode.

END