Static Electricity

Electric Charge

- Types of charges:
    - Neutrons
    - Protons
    - Electrons

- If electrons are removed , the atom becomes positively charged . - If electrons are added , the atom becomes negatively charged . - If the number of negative and positive charges are equal , the object is electrically neutral - An atom that is charged is called an ion

- The law of conservation of charge is one of the fundamental laws of Physics
    - The net charge of a closed system remains unchanged.
    - The net charge of a system is the algebraic sum of the charges while taking into consideration the positive and negative signs of the charges.

Interaction Between Charges

- Like charges repel
- Unlike charges attract

Measuring Electric Charges

- The SI unit of electric charge is the coulomb (C).
- The amount of charge carried by an electron is $1.6 \times 10^{-19} C$

Electrical Insulators and Conductors

- Objects around us can be classified into two broad categories:

1. electrical insulators
2. electrical conductors

	electrical insulators	**electrical conductors**
motion of charged particles	charged particles (electrons) are not free to move about	charged particles (electrons) are free to move about
ability to conduct electricity	low	high
method of charging	by friction (e.g. rubbing)	by induction

	electrical insulators	electrical conductors
examples	glass, perspex, silk wool	copper, steel, fluids with mobile charged particles

Electrostatic by Friction

- Some materials like silk and glass, gain static charges when they are rubbed together

Example:

- When the glass rod and silk cloth are rubbed together, electrons move from the glass rod to the silk cloth.
- The glass rod loses electrons and becomes positively charged.
- The silk cloth gains electrons and becomes negatively charged.
- The electrons transferred are not able to move freely in the silk cloth.
- They remain at the surface where the silk cloth was rubbed.
- Materials in which the electrons do not move freely are called insulators.
- Insulators are charged by friction (e.g. rubbing)
- Different materials have different affinities to electrons. Some attract electrons weakly, while others attract electrons strongly.

Electrostatic Charging by Induction

- Conductors cannot be charged by friction because mobile electrons can be easily transferred to and away from conductors.
- Metallic conductors can be charged by induction in which a conductor is charged without contact with the charging body.

Method 1: Charging two metal

1. Two metal spheres (conductors) on insulating stands are placed side by side.

- They are touching each other.

2. A negatively-charged rod is brought near, but not touching, sphere A. Like charges repel.

- Electrons in both spheres A and B are repelled to the far end of sphere B.
- sphere A has excess positive charges,
- while sphere B has excess negative charges.

3. While holding the negatively charged rod in place (near sphere A), move sphere B away from sphere A.

4. The charged rod is removed.

- Sphere A is now positively charged and sphere B negatively charged.
- Spheres A and B have an equal number of opposite charges.
- Both spheres have been charged by induction.

5. When the charged rod is removed *before* the two spheres are moved apart,

- The electrons will be redistributed in sphere A and B and both will become neutral again.

Method 2: Charging a single conductor by induction

1. A positively charged rod is brought near, but not touching, a metal conductor on insulating stand.

- The electrons in the conductor are drawn (attracted) towards the end near the positively-charged rod.

2. Without removing the positively-charged rod, the positively charged end of the conductor is earthed by touching it with a person's hand.

- Free electrons move from earth to the conductor through the person.
- This neutralises the positive charges on the end of the conductor.

> Earthing is a process which a conducting path is connected from a conductor to earth. This allows electrons to either flow into or out of the conductor. Earth refers to a large body of charge that remains electrically neutral regardless of the amount of charge that is added or removed from it.

5. When the charged rod is removed before the earthing process is stopped,

- The excess electrons in the conductor will flow to the earth and discharging occurs. The conductor will then become electrically neutral.

Neutralising/Discharging a Charged Insulator

- A charged object is neutralised by discharging the excess charges on it.

Discharging through heating

- The heat from the flame ionises the surrounding air particles.
- For a positively-charged glass rod, the ions neutralise the excess charges on the glass rod.

Discharging due to humid conditions

- Water molecules in air are electrical conductors
- For a negatively charged insulator, excess charges are transferred to the water molecule.

Neutralising / Discharging a Charged Conductor

- A charged conductor can be discharged through earthing
- When we earth a charged conductor, we provide a path (usually lower resistance and connected to the earth) for

- excess electrons to flow away from the charged conductor, or
- electrons to flow to the charged conductor if it has excess positive charges

Hazards and Applications of Electrostatics

Hazards of Electrostatics

1. **Lightning**

- The clouds are **charged by friction** between water molecules in the clouds and air molecules in the atmosphere.
- **Negative charges** accumulate at the **bottom** of the clouds.
- These **repel** the **electrons** near the surface of the earth, causing the **surface** of the Earth to be **positively charged**.
- When the accumulation of charges is large, the **air particles** are **ionised**.
- The **ionised air particles** provide a **conducting path** for the electrons in the clouds to reach the Earth.
- When the **electrons travel down** the conducting path to the Earth, **lightning** forms.

2. **Electrostatic discharge**

- Excessive charges may build up on objects due to **friction**
- Electronic equipment, such as computer boards and hard drives, can be easily damaged by electrostatic discharge.
- Such equipment is usually packed in **antistatic packaging**.

3. **Electrostatic discharge of vehicles**

- Electric charges can accumulate on trucks due to **friction** between
  - the road and the rotating tyres of the truck
  - the moving air molecules and the body of the truck
- When a **sudden discharge** occurs, this may cause **sparks** and **ignite** any flammable items that the truck might be carrying.
- Gas tankers are equipped with a **metal chain** at the rear end hanging/touching near to the **ground** to provide an **earthing path** for excess charges.
- During refueling, the gas tankers are also connected to an earth source to prevent static charges from accumulating on the body of the gas or fuel tanker.

Applications of Electrostatics

Photocopiers

- Photocopiers make use of static electricity to produce copies of documents.

1. The metal drum inside the photocopier is coated with **selenium**.

- Selenium is a **photoconductor** (light-sensitive semiconductor). It only conducts electricity in the presence of light. When no light shines on the selenium, it is a good insulator.

- The selenium coating on the drum is initially in the dark. Behaving as an insulator, it can be electrically charged. When the selenium is illuminated, it becomes conducting wherever light falls on it.
- The drum's surface is charged **positively** by a charged wire.

2. The original image to be photocopied is placed on a sheet of clear glass above the drum.

- An intense light beam is shone onto the image.
- The **darker** areas of the image reflect less light and therefore, the corresponding regions on the drum remain **positively** charged.
- The regions on the drum corresponding to the **lighter** areas conductive. Electrons from the surroundings, which are attracted to these regions, discharge them.

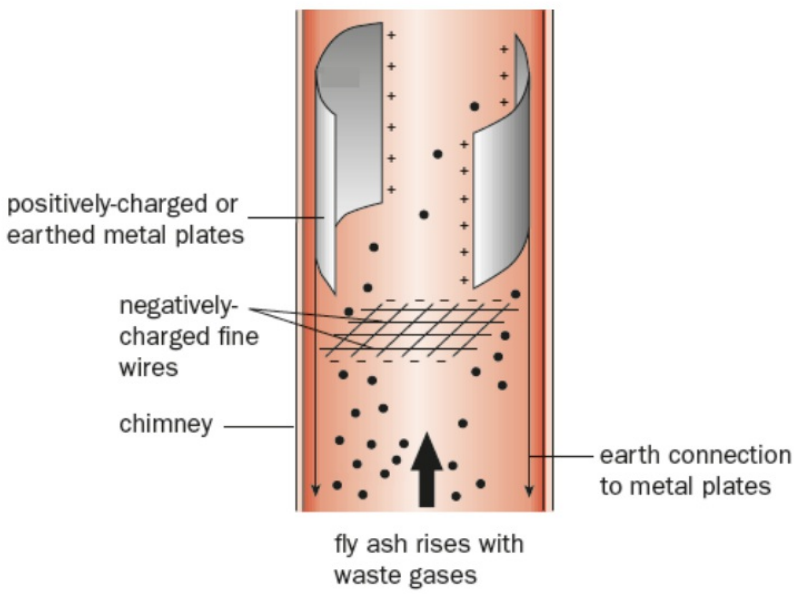
3. The drum continues turning, and the positively-charged image on the drum attracts the **negatively-charged** toner powder.

4. A **positively-charged** sheet of paper is passed over the drum's surface.

- The paper attracts the **negatively-charged** toner and the image is formed on the paper.
- The paper is heated and pressed to fuse the toner powder to the paper permanently.

Electrostatic Precipitator

- The electrostatic precipitator is used to remove fly ash from the exhaust of a chimney.



Removing fly ash from the exhaust gas

The fly ash (smoke and dust particles) is passed through a negatively charged wire grid making the particles to become negatively charged. The negatively charged particles are passed through positively charged or earthed plates which attract the negatively charged particles. Hence, air emitted into the atmosphere is cleaner. The fly ash are collected and used in making cement.

Spray Painting

- The electrostatic spray painter is used to provide an even coat on the part to be painted.

Even Coating

As the paint leaves the nozzle, the droplets are charged by friction. These made all the paint droplets to have the same charge and repel each other. Hence, they spread out evenly. Less paint is needed because the charged droplets are all attracted to the object (neutral or positively charged).

Electromagnetic Induction

Electricity and Magnetism

Laws of Electromagnetic Induction

Faraday's law of electromagnetic induction

The magnitude of the electromotive force (e.m.f) induced in a closed circuit is directly proportional to the rate of change of the magnetic flux linkage through the area bounded by the circuit.

- Thus, the magnitude of the electromotive force (e.m.f) induced in a conductor is directly proportional to the rate at which magnetic field lines and the conductor cut each other.
- If the conductor is part of a closed circuit, the induced e.m.f produces an induced current through the conductor.

Lenz's Law

The direction of the induced electromotive force (and hence the direction of the induced current in a closed circuit) is such that its magnetic effect opposes the motion or change producing it.

- If the conductor is part of a closed circuit, the induced current produces induced magnetic poles that oppose the cause of the induced emf.

Electromagnetic induction when magnetic field strength changes

Faraday's experiments demonstrate electromagnetic induction by moving a pole of a magnet moves nearer or further away from a solenoid, such that magnetic field lines cut through the solenoid.

Case 1: S moves towards solenoid

1. The South pole of the magnet moves towards the solenoid
2. (By Faraday's law of induction,) the changing magnetic flux linkage through the solenoid (or the magnetic field lines cutting the solenoid) induces an e.m.f in the solenoid.
3. Since the circuit is closed, the induced e.m.f produces an induced current.
4. By Lenz's law, the magnet is repelled by the south pole induced on the right of the solenoid produced by the clockwise induced current when viewed from the right (using the right hand grip rule) that flows from B to A.

Radioactivity

Composition of an Atom

- An atom is very tiny and typically has a size of **$1 \times 10^{-10} \pu{m}$**.
- It is made up of **subatomic particles** such as protons, neutrons and electrons.
- An atom consists of a positively charged nucleus and negatively charged electrons moving around the nucleus.
- The nucleus of an atom consists of two types of particles - protons and neutrons.
- Strong attractive electrostatic forces between the positively charged nucleus and negatively charged electrons hold the electrons to the atom.

Proton (atomic) Number Z.

- The **proton number *Z*** is the number of protons in an atom.
- The proton number is also known as the **atomic number**.
- In a neutral atom, the number of protons is the same as the number of electrons.
- Each element has a unique proton number.

Nucleon (Mass) Number A

- Proton and neutrons are called **nucleons**.
- The **nucleon number** is the total number of neutrons and protons in the nucleus of an atom.
- The symbol *A* is used to represent the nucleon number of an element.
- The nucleon number is also known as the **mass number.**
- The mass of an atom depends on the mass of nucleons in the nucleus of the atom as the mass of an electron is very small and thus negligible.
- To find the number of neutrons in an atom,

$$Number \space of \space neutrons = A - Z$$

- Note that in nuclear physics and nuclear chemistry, the various species of atoms whose nuclei contain a particular number of protons and neutrons are called **nuclides.**
- The nucleus of an atom can be represented by the **nuclide notation:**

$$\ce{^{A}_{Z}X}$$

Isotopes

- **Isotopes** are atoms of the same element that have the same number of protons but different numbers of neutrons.
- Isotopes of the same elements have *identical* chemical properties.
- Example: carbon isotopes

Nuclear Decay

- **Nuclear decay** is also known as radioactive decay or radioactivity.

- Nuclear decay is a random process by which an unstable atomic nucleus loses its energy by emission of electromagnetic radiation or particle(s).
- The radiation emitted by a radioactive nucleus is *spontaneous* and *random* in direction.
- Spontaneous decay means that the decay is not affected by environmental changes (e.g. temperature and pressure.)
- Random decay means that the decay cannot be predicted which particular nucleus will decay next.
- A material containing unstable nuclei is considered radioactive.
- The instability of the atomic nuclei is because the nuclear forces within the nuclei are not enough to bind the nucleons together.
- Since the direction of the emissions and the time between emissions cannot be predicted, hence it is:
    - not possible to make the radioactive nucleus emit radiation by heating, cooling, chemical means or any other method;
    - not possible to predict when a radioactive nucleus will emit radiation; and
    - not possible to know the direction in which the emitted radiation will leave a nucleus.

Types of Nuclear Emission

There are three types of nuclear emission: **alpha (*α*) particles, beta (*β*) particles and gamma (*γ*) rays.** Different nuclear emissions have different compositions, ionising effects and penetrating abilities.

Ionisation refers to the ability to eject electrons from atoms to form positively charged cations. Since the atoms lose electrons, the number of protons is greater than the number of electrons. Thus, ions carry a charge. The nuclei of the same isotope will emit the same type of nuclear radiation. During alpha decay or beta decay, the nucleus changes to that of a different element.

Alpha Decay

- When a radioactive nucleus undergoes alpha decay:
    - it emits an alpha particle (identical to helium nucleus $\ce{^4_2He}$)
    - the nucleon number A decreases by 4
    - the proton number Z decreases by 2
- A **nuclide equation** involving nuclide notation can be used to represent the changes in the composition of the nucleus. The arrow in the equation means "reacts to form".

Example: Radium-226 (Ra) nucleus emits an alpha particle and decays to radon-222 (Rn).

$$\ce{^{226}_{88}Ra -> ^{222}_{86}Rn + ^4_2He}$$

Note that in a nuclear reaction, the **mass and charge are conserved.** Hence, before and after the reaction,

- The total number of neutrons and protons remain constant, and
- The total relative charge should also be the same (i.e. sum of proton number before and after decay should be the same.)

Beta Decay

- When a radioactive nucleus undergoes ß-decay:
  - it emits a ß-particle (an electron); and
  - the nucleon number A remains the same
  - the proton number Z increases by 1

Example

$$\ce{^{238}_{92} U -> ^{234}_90 Th + ^4_2He + 2 ^0_0\gamma}$$

Gamma Radiation

- Usually, when radioactive nuclei undergo alpha-decay or beta-decay, gamma radiation is also emitted.
- Example: When uranium-238 (U) emits an alpha particle, it decays to thorium-234 (Th) and two gamma rays of different energies are emitted.

$$\ce{^{238}_{92}U -> ^{234}_90 Th + ^4_2 He + 2 ^0_0 \gamma}$$

Measuring Ionising Nuclear Radiation

A **Geiger-Muller (GM) counter** is an instrument used to measure ionising nuclear radiation.

The SI unit for the amount of radioactivity is the **Becquerel (Bq)**. One becquerel (1 Bq) is equal to 1 disintegration per second. It refers to the amount of ionising radiation released when a radioactive atom (e.g. uranium) spontaneously emits electromagnetic radiation as a result of the radioactive decay.

Alternative unit: count rate: counts per second or minute

Why is ionising radiation still detected even if radioactive sources aren't brought into the environment?

Background radiation from natural or man-made sources is always present. These sources include cosmic radiation from outer space, nautrally occurring radioactive isotopes, man-made radioactive isotopes, radioactive waste from nuclear power stations, and so on.

How would this affect our results when measuring radioactivity from a radioactive substance?

In general, the results collected will not present an accurate account of the radioactivity of the substance being measured, since the radiation detected comes form the radioactive substance being investigated, as well as background radiation.

Suggest what could be done to get a more accurate account of the radioactivity of the substance being investigated.

The background count should be measured and subtracted from the total count.

Background Radiation

Background radiation refers to nuclear radiation in an environment where no radioactive source has been deliberate introduced.

Radiation is all around us. For example, we have learned in Unit 11 Electromagnetic Spectrum that the visible light and infraerd radiation are electromagnetic radiation from the sun. The microwaves and the radio waves are radiation used in communication systems. These are non-ionising radiation, thus they have little biological effect.

Ionising radiation is radiation with high energies that can knock off electrons from atoms to form ions. For example:

- Ionising electromagnetic radiation: Very high frequency ultraviolet rays, X-rays and gamma rays.
- Ionising nuclear radiation: Highly energetic particles from cosmic rays (from outer space) and from naturally occurring radioactive materials

Sources of background radiation that can be artificial (man-made) or natural:

Artificial Sources

- Medical X-rays
- Building materials
- Waste products from nuclear power stations

Natural sources

- Rocks
- Radon gas in the air
- Food and drink (e.g. food high in potassium such as bananas, carrots and salt may contain radioactive potassium-40).

Natural background radiation accounts for about 80% of the radiation that we are exposed to. The amount of background radiation we encounter is usually well below the recommended limit of radiation exposure.

Half-Life

- Since nuclear decay is spontaneous, we will not know exactly when a particular nucleus will decay.
- Every nuclide has a fixed rate of decay. The **half-life** of a radioactive nuclide is the time taken for half the nuclei of that nuclide in any sample to decay.
- Predictions about the decay of a large number of nuclei of a particular nuclide can be made because it has a fixed half-life.

Nuclear Fission and Nuclear Fusion

Nuclear Fission

- **Nuclear fissoin** is a process in which a **parent nucleus** splits (usually into two **daughter nuclei**) and releases a huge amount of energy.

- The original parent nucleus becomes nucleus of two different elements.
- The daughter nuclei may be stable or may decay further
- There may be several possible fission products and it is important to check that the total number of nucleons and the total relative charge (proton number Z) before and after the reaction are the same.

Nuclear Fusion

- **Nuclear fusion** is a process in which two light atomic nuclei combine to form one heavier atomic nucleus and releases a huge amoutn of energy.
- Two atoms join to become another bigger atom of a different element.

Energy Changes During Nuclear Processes

- Nuclear fuel is a material used in nuclear power stations.
- Some examples of nuclear fuel are uranium and plutonium. Isotopes such as uranium-233, uranium-235 and plutonium-239 are commonly involved in nuclear fission.
- The nuclear fuels undergo nuclear reactions to release energy
- During **nuclear fission**, energy is transferred form the **nuclear store** of the unstable nucleus to:
  - the **kinetic** and **nuclear stores** of the daughter nuclei and neutrons
  - the **internal store** of the surroundings
- The internal store of the surroundings is used to heat the water so that it changes into steam.
- The neutrons produced in the nuclear fission will go on to split more nuclei.
- This creates a self-sustaining chain reaction taht is controlled in a nuclear reactor.
- The processes involved in mining, refining, purifying, using and disposing of nuclear fuel are collectively known as the nuclear fuel cycle.
- Energy can also be released from **nuclear fusion.**
- During nuclear fusion, energy is transferred from the **nuclear stores of the two nuclei to**:
  - The **kinetic** and **nuclear store** of the bigger nucleus.
  - The **internal store** of the surroundings.
- The internal store of the surroundings can be used in the electical power generation process.
- A lot of work is done to overcome the repusive forces between the positively charged nuclei during nuclear fusion
- Nuclear fusion cannot happen at low temperature and pressure as the two nuclei cannot come into close range of each other due to the repulsive forces.
- Hence, nuclear fusion requires **very high temperatures and pressures** and is currently not used in nuclear power plants.
- Example: Nuclear fusion can take place in the sun where temperature and pressure are high.
- Scientists and engineers are working on reactors where nuclear fusion can take place in a safe and controlled manner.

Uses Related to the Damage of Cells

Medical

Detection of Tumors - Gamma Rays

- Isotope, technetium-99, is used in the detection of tumours
- Small amount of isotope is taken into the body and travels to the internal organs
- A gamma camera is used to detect the gamma-rays emitted from the internal organs due to the technetium-99.
- The images formed will help in the diagnosis of tumours
- The isotope has a short half-life (6 hours) so it does not remain in the body for too long.

Gamma Knife Radiosurgery - Gamma Rays

- Gamma rays from a radioactive source (cobalt-60) are directed at the brain to destroy brain tumours.
- The isotope has a long half-life (5.3 years) so it remains in the body for a long time. Hence, only a small quantity over a long treatment time.

Cancer Treatment - Beta Particles

- Isotope, iodine-131, is used in the treatment of thyroid disorder.
- When small amount is taken into the body, it can destroy the thyroid cells including cancer cells.
- The isotope has a short half-life (8-days) so it does not remain in the body for too long.

Safety

Food Safety - Gamma Rays

- Fodo decays due to the actions of microbes
- Gamma rays can be used to kill the microbes so that the food is safe for consumption and can last longer.
- The isotope has a long half-life (a few years).
- Only a small quantity is needed over a long time.

Sterilisation of Medical Equipment - Gamma Rays

- Medical equipment such as syringes and scapels are kept in sealed packaging and exposed to gamma rays.
- The microbes present on the equipment will be killed and the equipment is sterile.
- Gamma rays can be used to kill the microbes so that the medical equipment is sterile
- The isotope has a long half-life (a few years)

Uses Related to Radioactive Decay and Half-life

Geology

Determine how old an object/material is - Alpha Particles

- The isotopes, uranium-238, is found in most rocks and has a half-life of 4.5 billion years
- The isotope decays to a stable isotope, lead-206.
- y determining the relative amounts of uranium-238 and lead-206 in a sample, the age of the rock can be known.
- The greater amount of lead-206 present, the older the rock.

Uses Related to the Penetrating Abilities and Ionising Effects

Safety

Smoke Detectors - Alpha Particles

- The isotope, Americium-241, is used in smoke detectors.
- When the alpha particles emitted fall on the detector, a current flows in the detector as alpha particles have high ionising ability.
- WHen smoke enters the detector, the smoke absorbs the radiation and disrupts the flow of current in the detector.
- The disruption triggers the detector's alarm.

Industrial

Measure the Thickness of Materials - Beta-particles / Gamma-rays

- Manufacturer needs to ensure that the materials are of uniform thickness.
- Beta particles or gamma rays from a radioactive source are directed at the material.
- A detector measures the amount of radiation passing through.
- If the material is too thick, the amount of radiation is low and vice-versa.
- Beta-particles are more suitable for thinner materials such as papers.
- Gamma rays are more suitable for slightly thicker materials such as metal plates.

Question: Why are alpha-particles not suitable?

Alpha particles have low penetrating power and will be absorbed by the materials most easily.

Hazards of Radioactivity

Protecting Ourselves from Radioactive Materials

Limit Contamination

If we are present at a site where there may have been a radioactive incident, we can take the following precautions.

1. Leave the immediate area quickly to avoid being contaminated with radioactive materials. Follow the directions of officials to the nearest safe building or area.

2. Remove the outer layer of the clothing as the radioactive materials may be on the clothing. Removing the clothing will reduce the risk of contamination.
3. Wash all exposed parts of the body with soap and lukewarm water. This removes radioactive materials that may be present on the body and reduces the risk of contamination.

Reduce Exposure

1. Reduce exposure time
    - Experiments involving radioactive materials should only be carried out in designated locations.
2. Increase distance between radioactive source and living tissue.
    - The intensity of all ionising radiation decreases with distance.
    - Use long tongs or remote-controlled device to increase the distance between radioactive materials and body.
3. Shielding
    - Wear materials that absorb the ionising radiation (e.g. lead-lined gloves)
    - Use thick concrete walls and lead-lined doors for rooms in which ionising radiation is used.
4. Storage
    - Store radioactive mateirals in a selaed container that will absorb hte radiation from the source (e.g. lead box)
    - This prevents the nuclear radiation from penetrating through the container and escaping into the air
    - Label the container with radioactive sign and keep in a secure place that is not accessible by anyone.