TJC IP4 PHYSICS

TOPIC 11 – STATIC ELECTRICITY

Content:

- Laws of electrostatics
- Principles of electrostatics
- Electric field
- Applications of electrostatics

Learning Outcomes:

Candidates should be able to:

(a) state that there are positive and negative charges and that charge is measured in coulombs

(b) state that unlike charges attract and like charges repel

(c) describe an electric field as a region in which an electric charge experiences a force

(d) draw the electric field of an isolated point charge and recall that the direction of the field lines gives the direction of the force acting on a positive test charge

(e) draw the electric field pattern between two isolated point charges

(f) show understanding that electrostatic charging by rubbing involves a transfer of electrons

(g) describe experiments to show electrostatic charging by induction

(h) describe examples where electrostatic charging may be a potential hazard

(i) describe the use of electrostatic charging in a photocopier, and apply the use of electrostatic charging to new situations

Essential Questions:

By the end of the lesson, students should be able to answer the questions:

1. What are the different types of charges existing?
2. What are the interactions between charges?
3. How can you charge an object?
4. How can you distinguish between the types of charges?
5. What are the possible hazards of charges?

TJC IP4 PHYSICS

TRIGGER:

http://www.express.co.uk/news/uk/265646/The-girl-13-who-could-die-if-she-combs-her-hair

Megan Stewart, 13, has a rare condition, Hair Brushing Syndrome, which means she must avoid wearing polyester or touching balloons. Any contact with electrical charges could confuse her brain into switching itself off or sending signals to her heart and lungs to make them do so.
Megan has to dampen her hair to reduce static and lie down before combing it and is banned from taking part in school science experiments.

The teenager, from Wishaw, Lanarkshire, was diagnosed three years ago, after she collapsed as her mother ¬Sharon brushed her hair. Mrs Stewart, 41, said: "I was brushing her hair when she flopped over and her lips turned blue. I thought she was having a fit, so we called the paramedics. It was really scary." Megan was taken to Wishaw General Hospital where medics revived her. Neurologists made the diagnosis two months later. Doctors at the Royal Hospital for Sick Children at Yorkhill in Glasgow, believe birth complications may be responsible for the condition.

Megan was born three months prematurely, weighing just 2lb 5oz with a diaphragmatic hernia, a hole in her stomach leading right up into her chest, which only allowed space for only one lung to grow. She spent the first 18 months of her life in hospital.

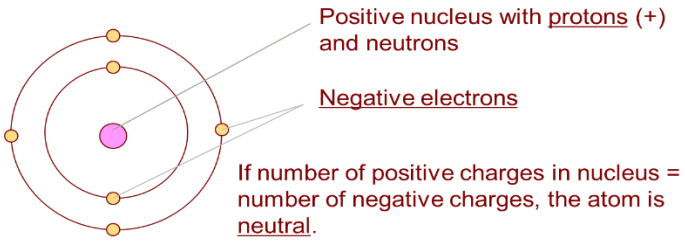
She also suffers from asthma and dorsal stream dysfunction, a problem with the connection between her eye and brain which means she can't see fast-moving objects.

But the Uddingston Grammar School pupil is determined to get on with her life. She said: "I know not to brush my hair too fast and if I feel unwell to stop doing it. I think I know what my limits are. I don't let it affect me and I can still live a normal life."

How much do you know about static charges? What is an advice you could give a person diagnosed with such a condition?

1 Electrostatic Charge: The study of electric charges which are not moving. *LO (a)*

1.1 Atomic Structure:



1.2 Two types of electrostatic charges:

(a) Positive charges. Consist of:
- Protons
- Positive ions: formed by atoms losing electrons

(b) Negative charges. Consist of:
- Electrons
- Negative ions: formed by atoms gaining electrons

S.I. Unit: coulomb (C)

A proton has a positive charge of 1.6×10^{-19} C.

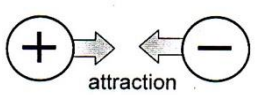
An electron has a negative charge of 1.6×10^{-19} C.

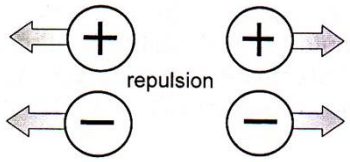
What is the charge carried by 1 electron? Charge carried by 1 electron = - 1.6 x 10-19 C.

How many electrons in 1 C of charge? No. of electrons = $1/ 1.6 \times 10^{-19}$ C = 6.25×10^{18}

2 Attraction and Repulsion *LO (b)*

The **law of electrostatics** states that like charges repel and unlike charges attract.

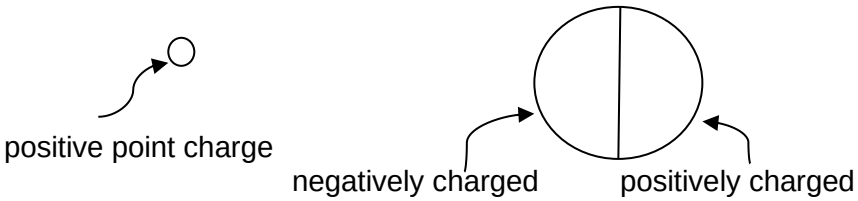




The ***force* of attraction** and **repulsion *increases*** as the ***distance*** between charges ***decreases***.

Only repulsion between a specimen and a charged object **is a sure test** that allows us to conclude that the specimen is charged (not neutral). The specimen should have a similar charge as the charged object.

Example 1: A small ball with zero net charge is positively charged on one side, and equally negatively charged on the other side. The ball is placed near a positive point charge (charge with a very small volume) as shown.



a. State and explain whether the ball would be attracted toward, repelled from, or unaffected by the positive point charge.
The ball will be attracted towards the point charge as the attractive force between point charge and negative hemisphere is larger than the repulsive force between point charge and positive hemisphere. This is due to the negative hemisphere being closer to the point charge.

b. State the factors that affect the strength of the forces between the two objects.
The amount of charge in both objects;
The distance between the centres of the two objects.

Electrical Conductors allow electric charges to flow through them easily. Eg: metals, acids, graphite, water, salt solutions and ionized air. Metals are good electric conductors due to the presence of free electrons which can move freely when there is an electric force.

Electrical Insulators do not allow electric charges to flow through them easily.
The electrons are tightly bound to their own atoms and not free to move between atoms.
Eg: rubber, glass and plastic.

Main difference between conductors and insulators
Conductors have 'free electrons' (found in metals and graphite) or free moving ions (water, weak acids and salt solutions) that are able to move freely. Insulators do not have such 'free electrons' or free moving ions.

Question 1: *Can positive charges move in a metallic conductor?*

** Note:* *Always refer to the movement of negative charges (which are electrons) and not positive charges.*

3 Electric Field *LO (c), (d) & (e)*

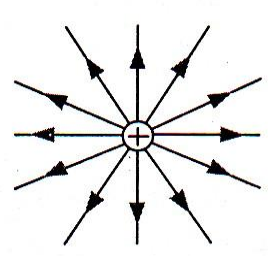
3.1 Definition:

An electric field is a region where an electric charge experiences an electric force.

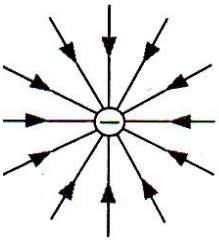
- This electric field can be illustrated by drawing electric lines of force. An electric line of force is the path a positive charge would take if it was free to move
- That is, **the direction of electric field is the direction of how a positive test charge would move**.
- A ***stronger*** electric field is denoted by having ***more electric lines of force*** which are ***drawn closer*** to each other.

3.2 Drawing Electric Lines of Force (Non-uniform electric fields):

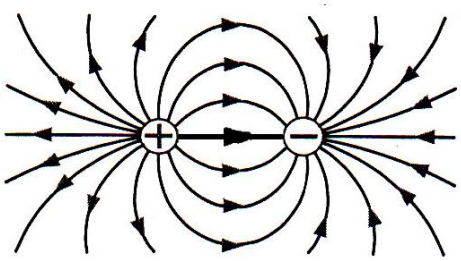
- draw arrows to indicate correct direction of electric field *[Check how a positive test charge would move to identify the direction of electric field lines (lines must begin from positive charges and end on negative charges)]*
- No field lines can cross or touch each other
- Appropriate spacings/gaps between electric field lines [small spacings → strong field]
- Field pattern is symmetrical (for O-level or IP questions)



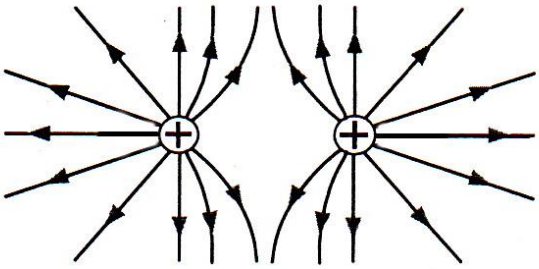
Electric field around a positively charged sphere.



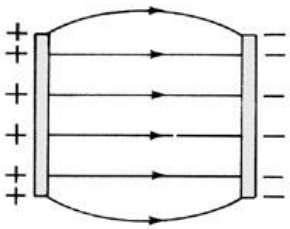
Electric field around a negatively charged sphere.



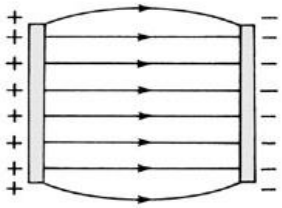
Combined electric field between two opposite charges



Combined electric field between two similar positive charges



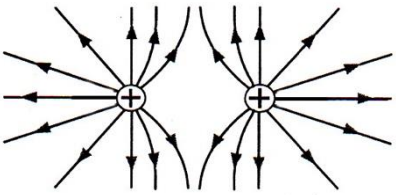
Electric field between two oppositely charged plates
Almost uniform electric field



Stronger electric field between two oppositely charged plates (increased density of electric field lines)
Almost uniform electric field

*Indicate the position of the neutral point by marking it with an "**X**" in the diagram below.*

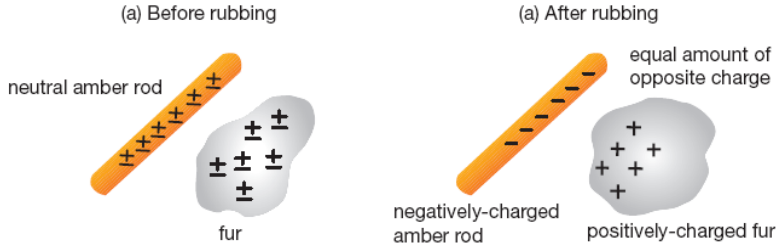
What is the significance of the neutral point?



4 Electrostatic Charging by Friction [For Insulators of Electricity] *LO (f)*

Electrostatic charging by friction

- When two different materials (especially insulating materials) are rubbed together, negative charges (electrons) are transferred from one object to another
- Electrons from fur is deposited onto amber when fur rubs amber rod
- The material that loses electrons will become positively charged while the material that gains electrons will become negatively charged.
- Amber becomes negatively charged while fur is positively charged



4.1 Electron Affinity

- If atoms of a material have a high electron affinity, then that material will have a relatively higher tendency to acquire more electrons.
- Different materials have different affinities for electrons. By rubbing a variety of materials against each other and testing their resulting interaction with objects of known charge, the tested materials can be ordered according to their affinity for electrons. Such an ordering of substances is known as a triboelectric series.
- If the affinity of a material is negative, that material will most probably be a receiver of electrons. If the affinity of a material is positive, that material will most probably be a donor of electrons.

Triboelectric Series

+ Acquires more positive charge	Human Hands
	Rabbit Fur
	Glass
	Mica
	Human Hair
	Nylon
	Wool
	Fur
	Lead
	Silk
	Aluminum
	Paper
	Cotton
	Steel
	Wood
	Amber
	Sealing Wax
	Hard Rubber
	Noble Metals and Nickel
	Sulfur
	Acetate Rayon
Acquires more negative charge –	Polyester
	Celluloid
	Polyurethane
	Polyethylene
	PVC (vinyl)
	Silicon
	Teflon

Common materials that can be electrostatically charged by friction

Negatively-charged	Positively-charged
Polythene (rubbed with wool)	Perspex (rubbed with wool)
Ebonite/Amber/Rubber (rubbed with fur)	Glass (rubbed with silk)

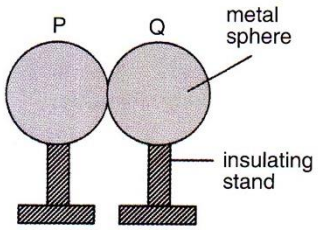
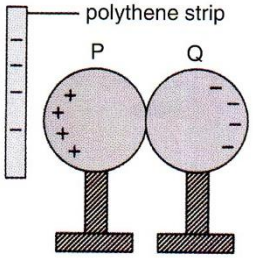
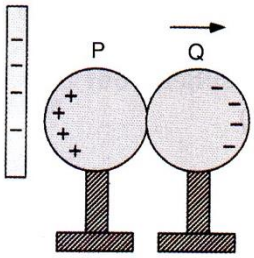
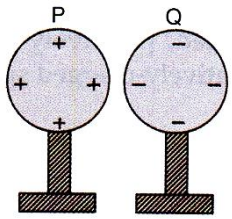
4.2 Neutralising Electrostatic Charges

Two methods

- **for insulators:** pass the apparatus quickly through a bunsen flame
- **for conductors:** touch the apparatus to allow the excess charges (electrons) to flow through our body to the ground (earthed)

5 Charging by Induction [For Conductors of Electricity] *LO (g)*

5.1 Charging <u>two</u> neutral insulated metal spheres

	Step 1: Two neutral metal spheres mounted on insulating stands, P and Q are placed touching each other.
	Step 2: A negative polythene strip is brought near to P. Electrons on P are repelled away from the strip and move into Q, leaving behind excess positive charges on the end of P nearer to the negatively-charged strip.
	Step 3: Sphere Q is then separated from P while the negatively-charged polythene strip is kept in position.
	Step 4: Polythene strip is removed. Sphere P becomes positively-charged while sphere Q become negatively-charged. Since spheres P and Q are conductors, they have equal amounts of opposite charges which are redistributed throughout spheres P and Q.

***Note: Only electrons are able to move. Positive charges are ions (atoms with fewer electrons than usual) and thus are unable to move.**

Question 3: *Why are the metal spheres placed on insulating stand?*

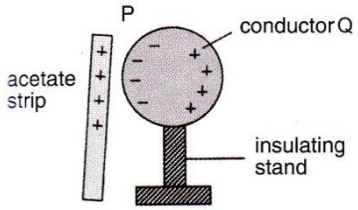
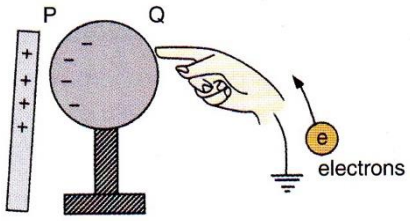
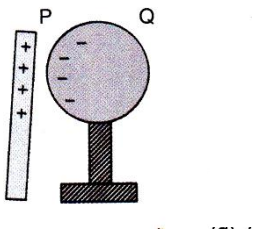
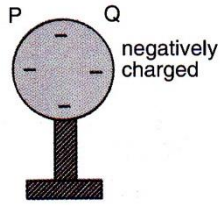
Question 4: *What is the advantage of charging by induction?*

Question 5: *Can we charge a conductor by rubbing? Can we charge two conductors by rubbing?*

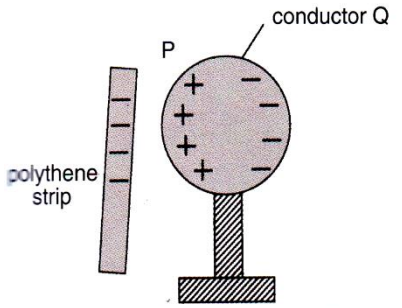
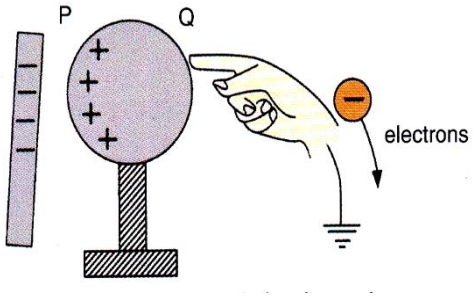
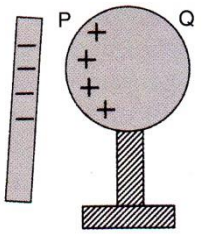
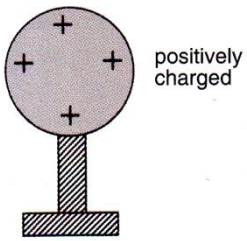
Question 6: *Can we charge an insulator by induction?*

5.2 Charging a <u>single</u> insulated metal sphere

5.2.1 Steps –To obtain negative charges by induction

	Step 1: Positively-charged acetate strip is brought near to a neutral conductor (metal sphere) mounted on an insulating stand.. *Electrons of the conducting sphere are attracted to the positively-charged strip at end P, leaving behind positively charges at the other side, Q of the conductor.*
	Step 2: The conductor is then earthed by touching it with a finger. *As the negative charges at P are attracted to the positive charges of the strip, this allows electrons to flow up from the Earth to neutralize the positive charges at Q.*
	Step 3: Finger is then removed from the conductor.
	Step 4: Acetate strip is removed and there is a *re-distribution of the excess negative charges on the sphere due to law of electrostatics and the sphere is left negatively-charged as shown.*

5.2.2 Steps - To obtain positive charges by induction (Homework)

	Step 1:
	Step 2:
	Step 3: Finger is then removed from the conductor.
	Step 4:

6 Electrostatic Hazards *LO (h)*

Electrostatic discharge, apart from causing slight discomfort when it occurs to us, is also a hazard in certain situations.

Some hazards of electrostatics and ways to overcome

Electrostatic hazard	*Ways to overcome*
1. Lightning	Thunderclouds are charged by friction between the water molecules in the thunderclouds and air molecules. It then ionises the air and the ionised air provides a conducting path for electric charge to be discharged to the nearest or sharpest object on the ground. Lightning conductors on buildings which provide a conducting path for electrons in the air to discharge safely to the ground
2. Fires due to sparks caused by sudden electrostatic discharge.	- Excess charges on a petrol tanker flow safely through a metal chain to the ground - Synthetic rubber tyres (which contains graphite) to aid in electric discharge to the ground
3. Damage to electronic equipment	Electrical components are stored in antistatic packaging (metallised film)

7 Application of Electrostatics *LO (i)*

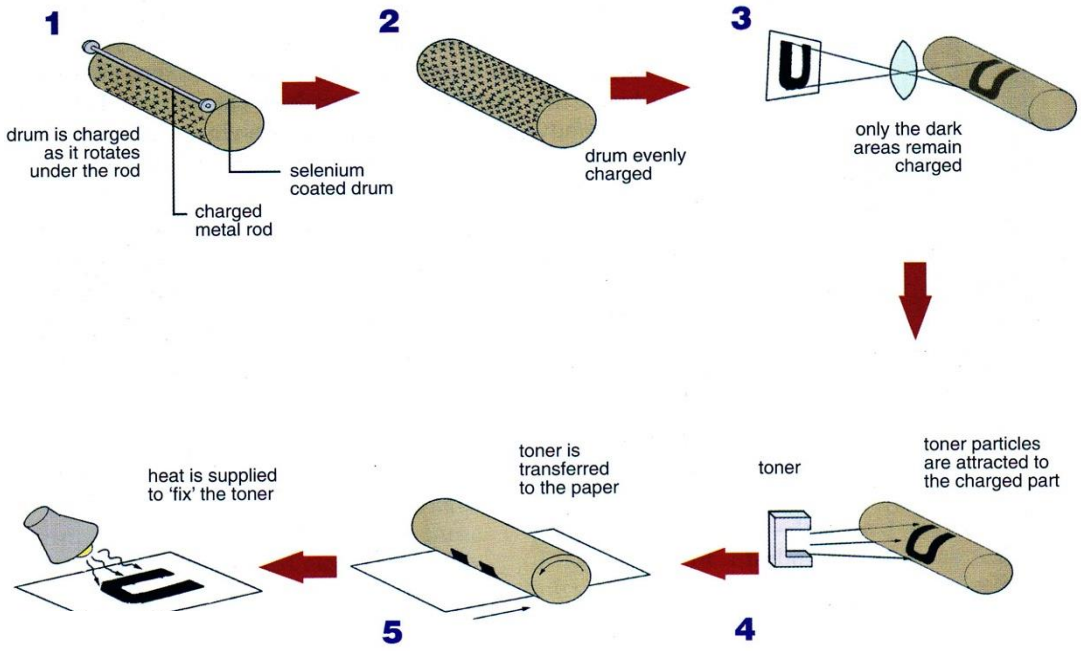
7.1 Electrostatic Paint Spraying

Electrostatic spray painting is used to ensure an even coat of paint.
Steps:

- Paint droplets from an aerosol become charged from rubbing against the nozzle of the spray.
- Droplets attracted to the metal body of the car which is earthed.
- Since droplets have the same charge, they repel each other in the spray and spread out evenly, resulting in an even coat of paint.

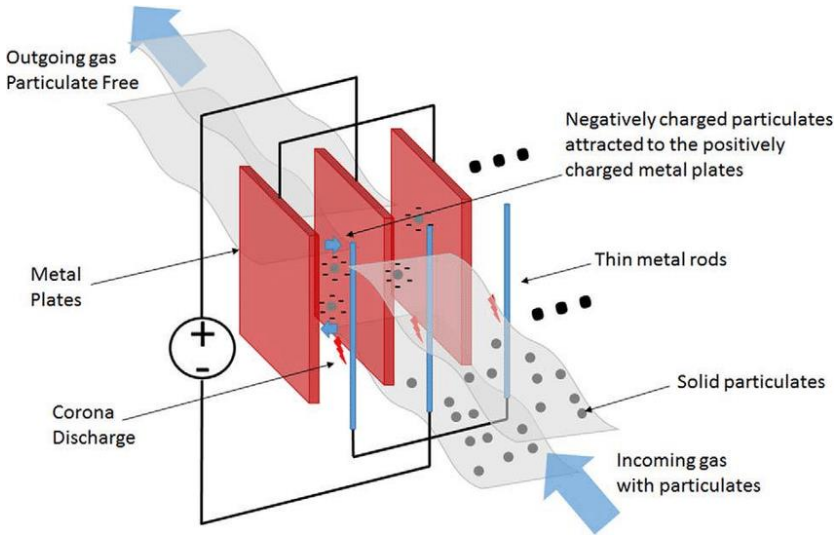
7.2 Photocopier

- makes uses of a metal selenium (a **photoconductor**) which conducts when it is in the light and is an insulator when it is in the dark
- Whole surface of drum is charged positively by rotating it near a highly charged metal wire.
- When a printed page is photocopied, light is reflected off the page and projected onto the drum
- White parts of the page reflect light to some parts of the drum, these areas become conducting & lose their charges.
- Other parts of the drum correspond to the black parts of the page: these areas on the drum receive no light & remain insulating and charges remain
- Fine particles of the carbon powder (toner) are attracted to the charged areas of drum & presses against the copy paper.
- Toner is transferred onto the photocopy as the drum rotates and presses against the copy paper. Heat is then supplied to melt the toner powder and fix it onto the paper surface



7.3 Electrostatic Precipitator

An electrostatic precipitator is used to remove fine ash and dust from chimneys.



- It consists of metal plates that are positively charged and a number of metal rods running through them which are negatively charged.
- Air molecules around rods are ionized. Positive ions attracted back to rods. Negative ions picked up by tiny particles of ash and dust.
- Negatively charged particulates are attracted to the metal plates where they are collected.