Chapter 16 – Static Electricity

Subject content

Content

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

Learning outcomes

(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

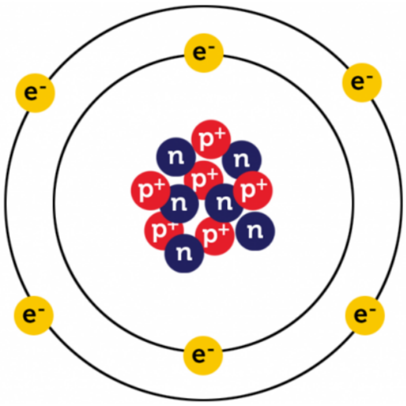
Definitions

Term	Definition
Electric charge	Physical property of matter that causes it to experience a force when placed in an electromagnetic field
Electrostatics	Study of static electric charges
Induction	Charging a conductor without contact b/w conductor & charging body
Electric force	Attractive / repulsive force that electric charges exert on one another
Electric field	Region in which an electric charge experiences electric force

16.1 Electrostatics

Electric charges

Atomic model:



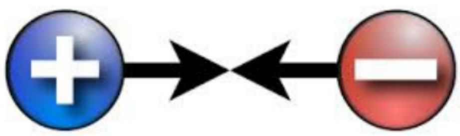
*ONLY **electrons** can move

2 types of electric charges

1. **Positive charges**
2. **Negative charges**

Aspect	**Positive charge** (of an object)	**Negative charge** (of an object)
Subatomic particles with this charge	proton	electron
Positively charged body	**e < p** (lose e)	
Negatively charged body	**e > p** (gain e)	
Neutral body (no excess charges)	**p = e**	
Force acting on charge	Like charges repel Unlike charges attract	

Positive and negative charges interact

Like charges repel	**Unlike charges attract**
	

Measuring electric charge

- Amount of charges carried by 1 electron / proton = **1.6×10^{-19} C**
- Make charge of 1 C = **6.25×10^{18}** electrons
- Electric charge measured using coulombmeter

Electrical insulators and conductors

Aspect	**Electrical insulators**	**Electrical conductors**
Motion of charged particles	Not free to move about	Free to move about
Ability to conduct electricity	Low	High
Method of charging	By friction (rubbing)	By induction
Examples	• Glass • Perspex • Silk • Wood	• Metals (copper, iron, steel) • Graphite • Fluids (contain charged particles)

Electrostatic charging by friction – gain / loss of e
Transfer of electrons (negative charges)

Stage	Explanation	Figure
Before rubbing	• Both electrically neutral (p = e)	
During rubbing	• Glass rod: smaller electron affinity → attract e weakly • Silk: larger electron affinity → attract e strongly • e transfer: glass rod → silk	
After rubbing	• Glass rod: + charge (lose e, e < p) • Silk: – charge (gain e, e > p)	

Note:
- Insulator: electrons transferred X move freely in silk
- Only surface electrons are transferred → remain on surface (where rubbed)
- Rubbing → force electrons off

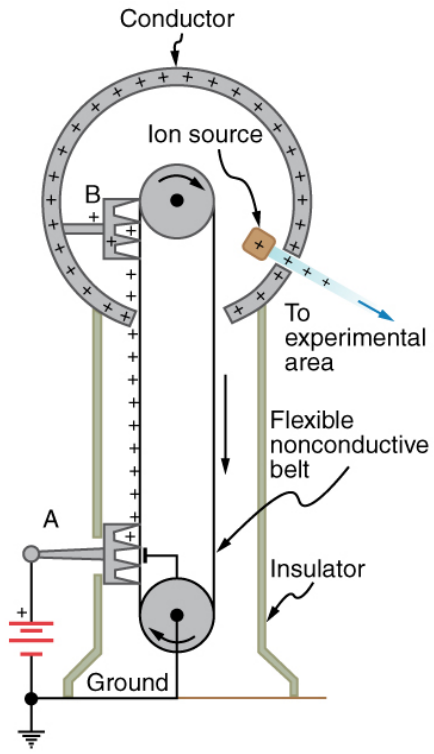
Examples of materials:

Electron transfer	
+	**–**
glass rod	**silk**
fur	ebonite rod
perspex rod	wool
wool	polyethene
hair	rubber balloon

Van de Graaff generator

Van de Graaff generator: produce large p.d.

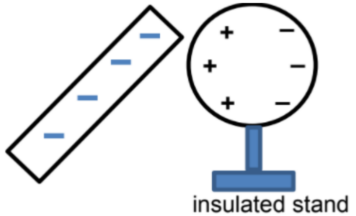
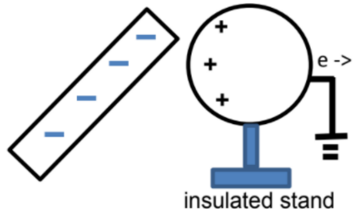
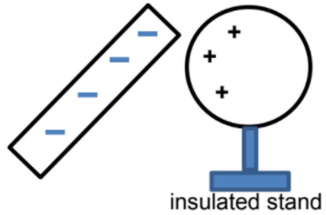
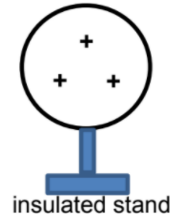
1. Silk belt pass repeatedly over 2 rollers → charged
2. +ve charged comb: draw e– away from silk belt → +ve charge on belt
3. +ve charge carried up to metal sphere
   - comb at top transfer e–: metal sphere → +ve charged belt
   - belt discharged → return to pulley
4. Metal sphere : +ve charged
   Spherical device : –ve charged



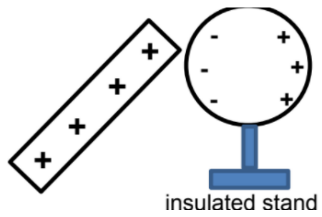
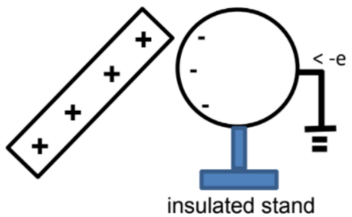
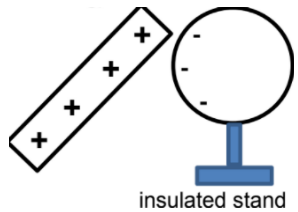
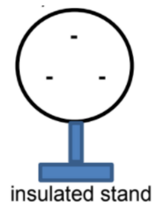
16.2 Principles of Electrostatics

<u>Charging conductors by induction</u>

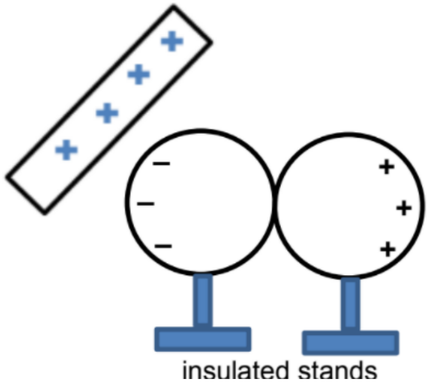
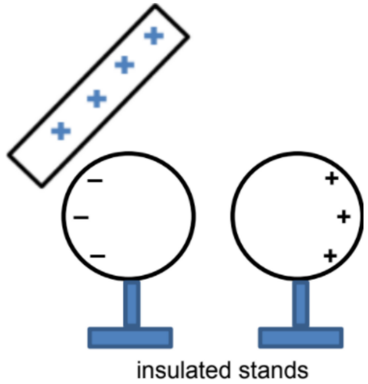
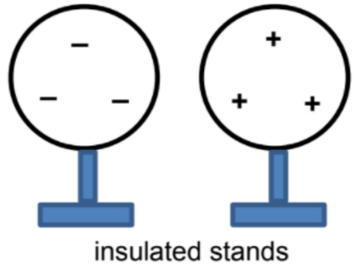
1 metal conductor (+ve)

1. **Bring negatively charged rod near sphere**	2. **Earth the sphere**	3. **Remove earthing**	4. **Remove negatively charged rod**
			
e^- repelled by rod → RHS ● RHS: –ve charge induced ● LHS: +ve charge induced	RHS: Excess e^- move into earth ● +ve & –ve charge balanced	LHS: p > e^- ● +ve charge remains induced	e^- redistribute ● Whole sphere +ve charged

1 metal conductor (–ve)

1. **Bring positively charged rod near sphere**	2. **Earth the sphere**	3. **Remove earthing**	4. **Remove positively charged rod**
			
e^- attracted by rod → LHS ● RHS: +ve charge induced ● LHS: –ve charge induced	RHS: e– move up to neutralise excess +ve charge ● +ve & –ve charge balanced	LHS: e^- > p ● –ve charge remains induced	e^- redistribute ● Whole sphere –ve charged

2 metal conductors

1. **Bring positively charged rod near spheres**	2. **Bring two spheres apart**	3. **Remove positively charged rod**
		
e^- attracted by rod → move to left ● LHS: –ve charge induced ● RHS: +ve charged induced	● LHS: e^- > p ● RHS: p > e^-	e^- redistribute ● LHS: +ve charged ● RHS: –ve charged

<u>Neutralising charged insulators & conductors</u>

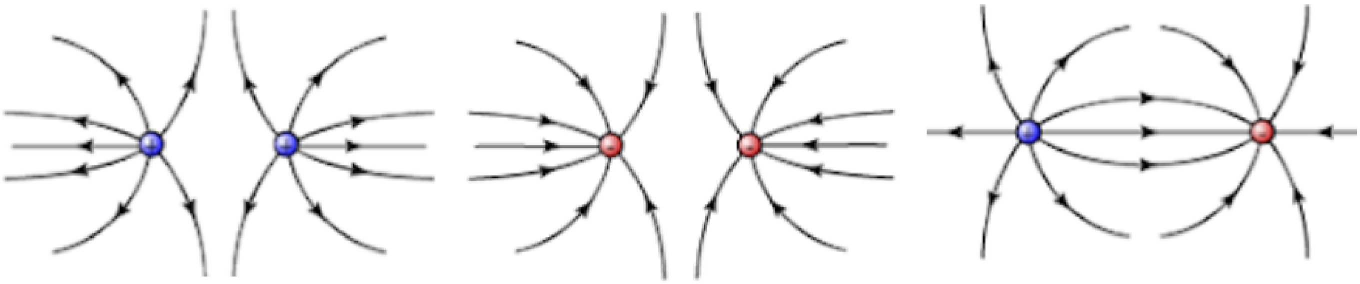
Discharging excess charges

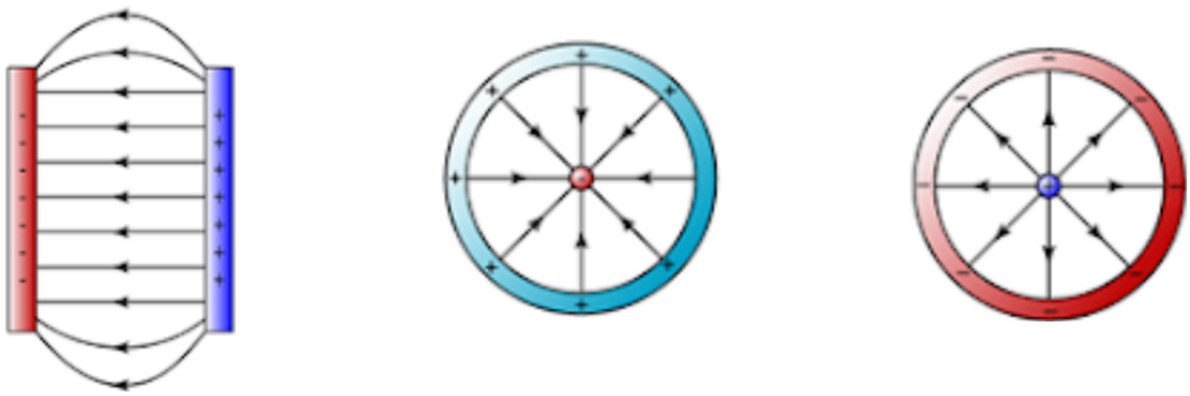
Insulators	Conductors
1. **Heating** ● +ve charged glass rod near flame ● intense heat → ionise nearby air particles ● ions neutralise excess charges 2. Provide **humid** conditions ● –ve charged balloon in humid air ● water mol in air: electrical conductor ● excess charges → water mol	1. **Earthing** ● human body: good conductor ● provide path for 1) –ve charged: excess e– flow away 2) +ve charged: e– flow to

16.3 Electric Field

Representing electric fields

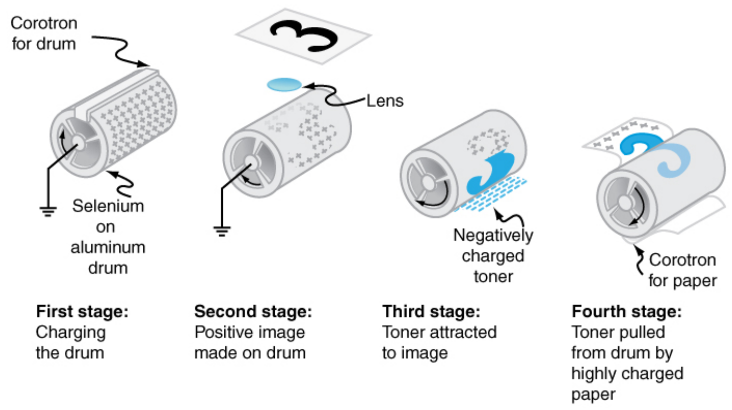
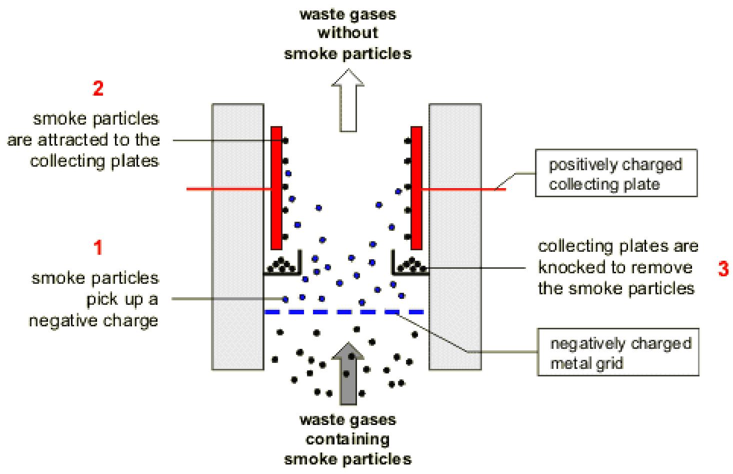
1. **Direction**: direction of force that would act on small positive charge
2. **Strength**: how close field lines are to one another

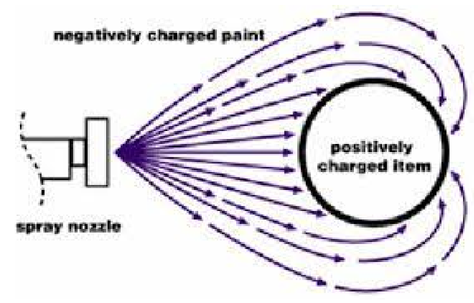




16.4 Hazards and Applications of Electrostatics

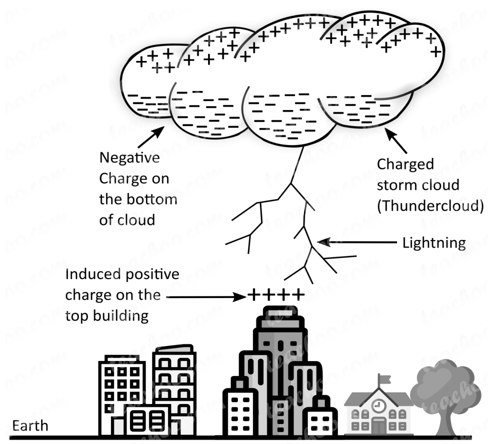
Applications

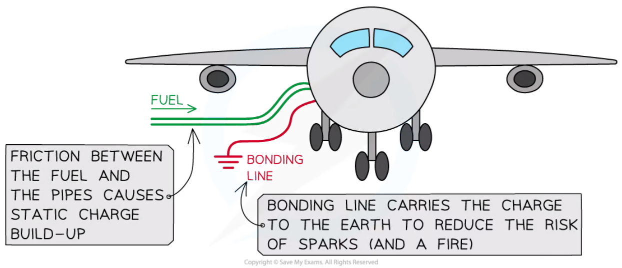
Application	Description	Figure
1. **Photocopier**	1) Metal drum coated with selenium (photoconductor: only conducts electricity in presence of light) → +ve charged (rotate drum near charged wire) 2) Original image: placed on glass above drum Intense beam of light shone on image ● Dark area reflect less light → insulating → +ve charge ● Light area reflect more light → conducting → discharged 3) Drum roll: +ve charged image on drum → attract –ve charged toner powder 4) +ve charged paper passed on drum surface → –ve charged toner attracted onto paper 5) Paper heated + pressed → fuse toner permanently	
2. **Electrostatic precipitator**	● Waste gas + fly ash pass through –ve charged wire grid → –ve charge ● Fly ash routed past +ve charged metal plates ● Metal plated attract –ve charged fly ash → gas free of fly ash	

3. **Spray painting** 4. **Crop sprayer**	• Paint leave nozzle of spray paint gun → charged by friction • Paint particles contain like charge → repel one another → spread out • Charged paint particles attracted to metallic car body → **<u>UNIFORM COAT</u>** of paint	

<u>Hazards</u>

Hazard	Description	Figure

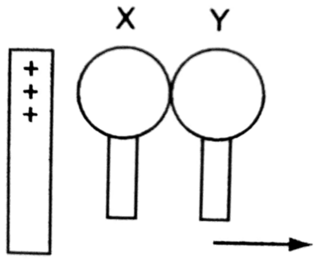
1. **Lightning**	• Friction b/w <u>water molecules in thundercloud</u> & <u>air particles in atm</u> → thundercloud electrically charged → –ve charges gather at bottom of cloud
	• –ve charged bottom of cloud → induce +ve charge on earth surface
	• Accumulation of charges large enough → ionise air particles nearby → conducting path for e^- in cloud to reach earth surface (e^- follow discharge path to surface → lightning)
	• **<u>Lightning conductors</u>** protect buildings
	  ○ conducting path for e^- in air: top of building → surface
	  ○ prevent lightning from damaging buildings
		

2. **Sudden discharge**	• Refuelling: charging due to friction → fuel lose e^- → +ve charged • +ve charged fuel → plane +ve charged • Sudden discharge → spark → ignite fuel vapour • **<u>Earthing</u>**: excess charges discharged via earthing path → ground (prevent sudden discharge)	

Typical questions

Multiple choice questions

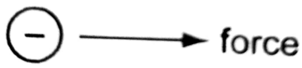
1 Two insulated, uncharged metal spheres X and Y are initially in contact.
While a positively-charged rod is near X, the spheres are moved apart.
After this action, X has a negative charge.



The charge on Y is (2012 P1 Q28)

A negative and smaller than the charge on X.
B negative and the same size as the charge on X.
C positive and smaller than the charge on X.
D positive and the same size as the charge on X.

2 A stationary negative charge in an electric field experiences an electric force in the direction shown.



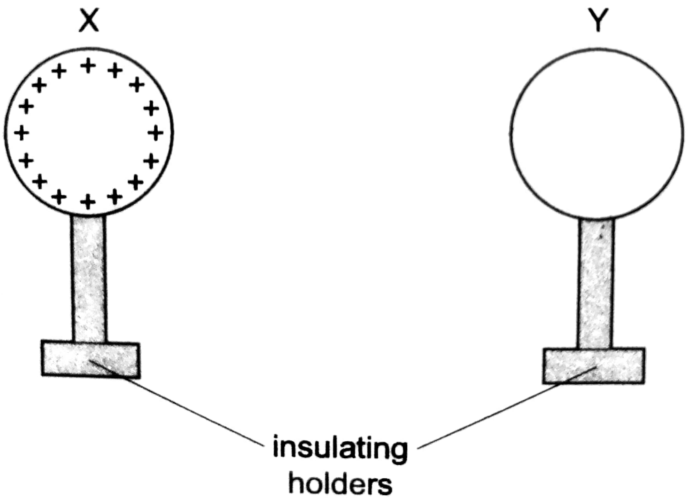
What is the direction of the electric field? (2013 P1 Q30)

A horizontally to the left
B horizontally to the right
C vertically downwards
D vertically upwards

3 A student holds a rod in one hand and rubs the rod with a thin sheet of material held in his other hand.
Both the rod and the thin sheet become charged and remain charged.
From what could the rod and the thin sheet be made? (2014 P1 Q28)

	rod	thin sheet
A	copper	silk cloth
B	glass	aluminium foil
C	iron	paper handkerchief
D	nylon	woollen duster

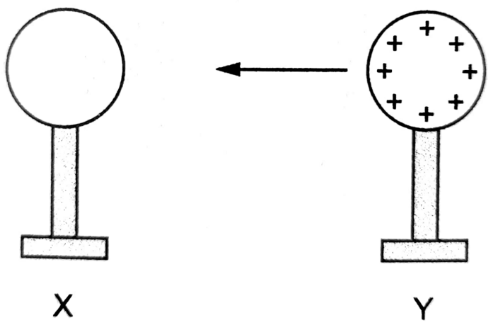
4 Sphere X has a positive charge and metal sphere Y is uncharged.



X is moved close to Y but the spheres do not touch. Y is then earthed by touching it with a wire which is then removed. X is then moved far away from Y.
What is the final charge distribution on Y? (2015 P1 Q30)

A negative all over the surface
B negative on the left and positive on the right
C positive all over the surface
D positive on the left and negative on the right

5 An isolated metal conductor X is uncharged.
Another isolated metal conductor Y, which is positively charged, is moved towards X as shown.



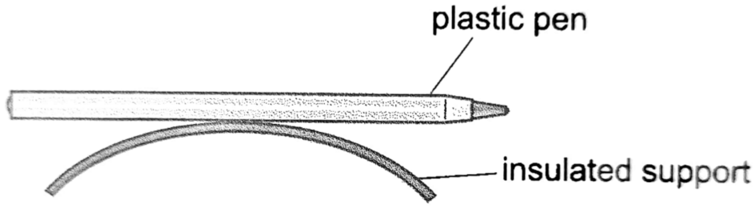
What happens as Y is brought close to X? (2016 P1 Q29)

A Positive charges move from Y to X.
B Some positive charges on X move to the left and some negative charges on X move to the right.
C Some negative charges on X move to the right, but the positive charges on Y do not move.
D Some positive charges on X move to the left, but the negative charges on X do not move.

6 What **always** experiences a force when placed in an electric field? (2017 P1 Q31)

A a current-carrying wire
B a magnet
C a piece of aluminium
D an electric charge

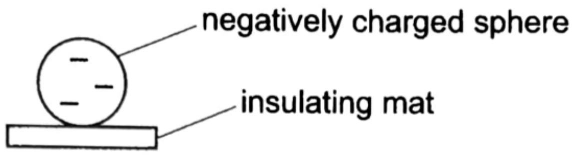
7 A teacher has two identical plastic pens. They are both rubbed with identical cloths. The first pen is balanced on an insulated support, as shown.



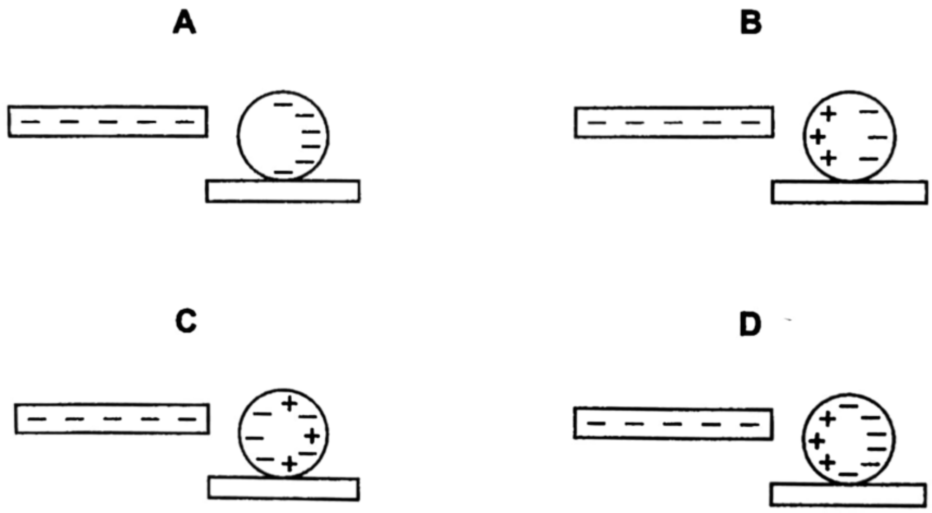
The balanced pen rotates when the cloth or the second pen are held near it.
Which statement is correct? (2019 P1 Q29)

A Both the cloth and the second pen attract the balanced pen.
B Both the cloth and the second pen repel the balanced pen.
C The cloth attracts the balanced pen and the second pen attracts the balanced pen.
D The cloth repels the balanced pen and the second pen attracts the balanced pen.

8 A negatively charged copper sphere rests on an insulating mat.



A negatively charged polythene rod is brought near to the copper sphere.
Which diagram shows the charge distribution on the sphere? (2019 P1 Q30)



Structured questions

1 A polythene strip may be charged by rubbing with a soft cloth. Before rubbing the polythene strip with a soft cloth, both the strip and the cloth are neutral. After rubbing, the polythene strip is negatively charged.

(a) Does a neutral body possess any charges? Explain.

Yes. The total number of protons (positive charges) is equal to the total number of electrons (negative charges).

(b) Is the soft cloth charged after rubbing?

Yes. It is positively charged.

(c) Explain how the polythene strip becomes negatively charged after being rubbed with the soft cloth.

The polyethene is charged by friction.

The strip gains electrons from the cloth and becomes negatively charged.

2 A student conducts an experiment to show charging by induction using two metal spheres, P and Q, each mounted on an insulated stand. The spheres are initially uncharged and in contact, as shown in Figure (a).

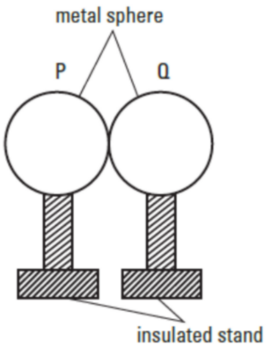


Figure (a)

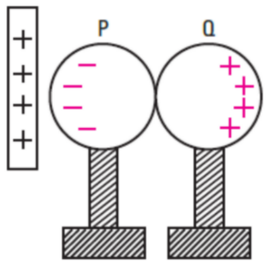


Figure (b)

(a) A positively charged rod is brought near the spheres, as shown in Figure (b).
State and explain the movement of electrons in spheres P and Q.

Electrons move from right side of sphere Q to left side of sphere P, as they are attracted towards the positively charged rod since unlike charges attract.

(b) On Figure (b) above, draw the charges on spheres P and Q.

(c) Spheres P and Q are separated while the positively charged rod is held in position, as shown in Figure (c). Draw the charges on spheres P and Q in Figure (c).

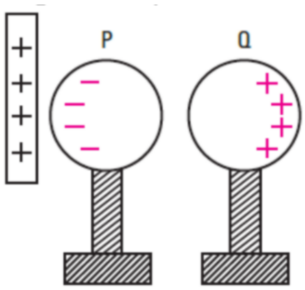


Figure (c)

(d) The positively charged rod is removed, as shown in Figure (d). Draw the charges on spheres P and Q in Figure (d).

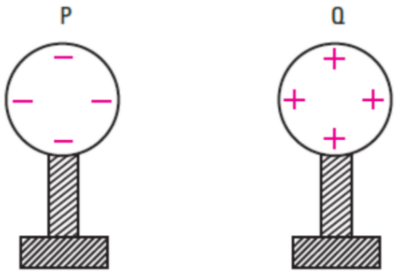


Figure (d)

(e) Another student conducted a similar experiment.
He placed the two spheres as shown in Figure (a) and brought a positively charged rod near the spheres as shown in Figure (b). The positively charged rod was removed. The spheres P and Q were then separated.
What charge, if any, would P and Q have? Explain why.

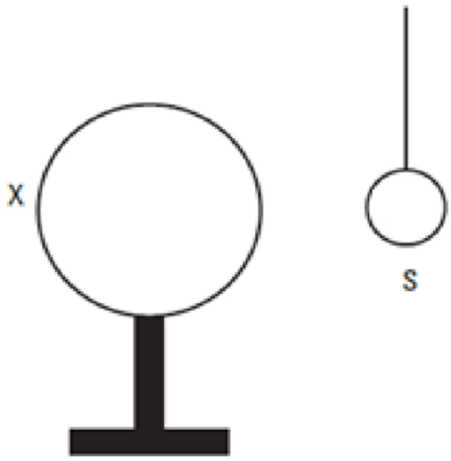
<u>Spheres P and Q would be neutral.</u>

<u>When the positively charged rod was removed, the electrons would no longer be attracted to the left side. As the spheres are still in contact, the excess electrons in sphere P would move back to sphere Q.</u>

(f) What is the role of the insulated stand in the experiments?

<u>Prevents electron transfer between the earth and metal sphere.</u>

3 The diagram shows a large conducting sphere X mounted on an insulating pillar. X is given a positive charge. A small, uncharged metal sphere S, suspended on an insulating thread, is brought near X.



(a) Show on the diagram the charges induced on S.

(b) What will happen to S? Explain your answer.

S will move towards X.

Electrons in S move towards the left because they are attracted to the positively charged X as unlike charges attract. Negative charge is induced on the side of S nearer to X.

Positive charge is induced on the side of S further away from X.

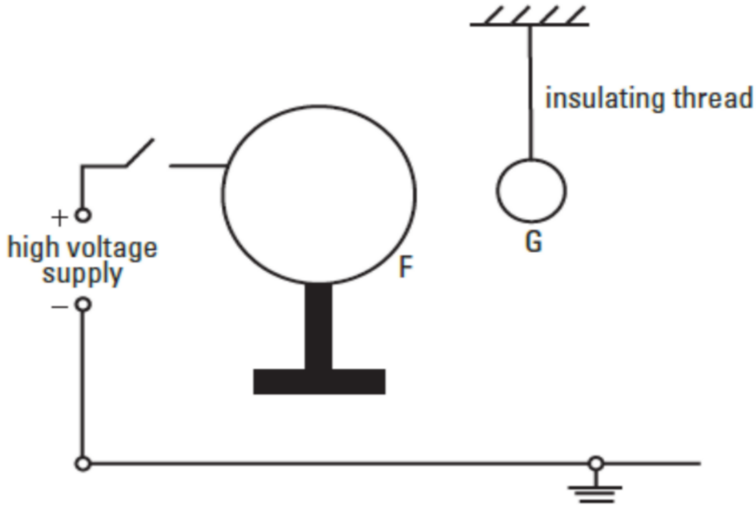
Therefore, there is a resultant attractive force between X and S.

(c) If S is moved horizontally so that it touches X. Explain what happens to S.

Some electrons flow from S to X when they touch each other. S also becomes positively charged and thus it repelled by X which is positively charged.

Therefore, S moves away from X as there is a resultant repulsive force.

4 The figure below shows a large conducting sphere F connected through a switch to the positive terminal of a supply of high voltage. A light conducting sphere G hangs from an insulating thread as shown. Both spheres are uncharged initially.



(a) Describe the movement of charges which takes place. State what happens to F when the switch is closed.

Electrons will move towards the positive terminal of the high voltage supply.

F becomes positively charged.

(b) Describe and explain the effect the charge on F has on sphere G.

Electrons in G move towards the left hand side because they are attracted to the positively charged F as unlike charges attract.

Negative charge is induced on side of G nearer to F, positive charge is induced on side of G further from F. A resultant attractive force between F and G causes G to tilt towards the left.

(c) G is now connected to earth. Describe the effect of this on (i) the charge on G, (ii) the position of G.

G will be negatively charged.

Electrons from the earth will flow to G and neutralise the excess positive charges on the right hand side of G.

G will be tilted more towards the left because the resultant attractive force is now stronger.

5 An aeroplane becomes positively charged as it flies through the air, because it loses particles from its metal surface.

(a) State the name of the particles lost from the metal surface.

Electrons

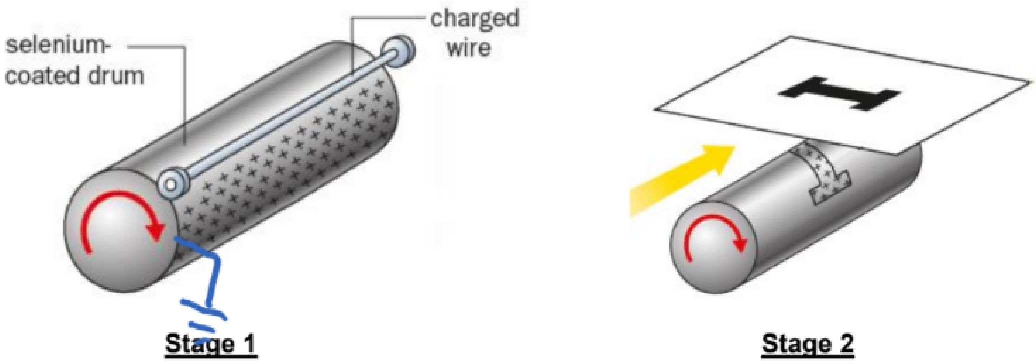
(b) The tyres of an aeroplane are made from an electrical conductor. Explain what happens to the charge on the aeroplane when it lands.

The excess positive charges will be neutralised because electrons flow from earth to the aeroplane through the conducting tyres as unlike charges attract.

6 Suggest why it is necessary to keep an aeroplane connected electrically to earth during refuelling.

During refuelling, excess electric charges can accumulate on the fuel due to charging by friction. Earthing the aeroplane will allow excess charges to be discharged via the earthing path thus preventing a sudden discharge of accumulated charges that may cause sparks and ignite the fuel.

7 Two stages in the production of a photocopy are shown below.



In Stage 1, the surface of the drum is insulating and is charged positively by a highly positively charged wire. The drum is in the dark. The inside of the drum is made of metal and is connected to earth.
In Stage 2, the image is placed above the drum and an intense light beam is shone onto the image. Reflected light from white parts of the image hits the positively charged drum at some sections, leaving the charge as shown in Stage 2.

(a) Based on the information provided, state the effect of light on the drum.

Light causes the section of drum that it strikes to be conducting.
Hence, the positive charge there will be neutralised.

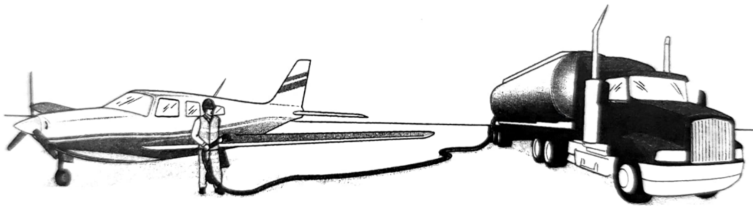
(b) Explain what happens to the charge on the drum in the regions that the light strikes.

Electrons from earth flows into drum to neutralise the positive charge.

(c) Explain why negatively-charged toner particles are attracted to and stick to the drum.

The regions on the drum which are still positively charged will attract the negatively charged toner particles as unlike charges attract.

8 The figure shows a worker refuelling an aircraft.



Both the fuel and the hose through which it passes are insulators. The fuel passing into the aircraft becomes positively charged and this causes the aircraft to be positively charged. There is then a danger that the fuel may ignite.

(2015 P2A Q7)

(a) Explain how the fuel becomes charged. [1]

As the fuel passes through the fuel hose, it rubs against the sides of the hose. This causes the fuel to be charged by friction. It loses electrons and becomes positively charged.

(b) Suggest how the charge may cause the fuel to ignite. [1]

When there is a sudden discharge of the excess charges, such as when a conductor is placed near the fuel / aircraft, a spark could be produced, igniting the fuel.

(c) The danger is reduced by connecting a wire from the aircraft to the ground. Explain how this prevents the build-up of positive charge on the aircraft. [1]

The wire from the ground allows electrons from the ground to move upwards to the aircraft, neutralising the excess positive charges on the aircraft.

(d) Apart from refuelling, state one other example where electrostatic charging is a nuisance or a potential hazard. [1]

Lightning. Due to the movement of air and clouds, excess charges could be built up in the clouds during a storm. The sudden discharge to the ground, i.e. lightning, could strike a person or a building, causing damage.

9 The figure shows a small, negatively charged sphere.

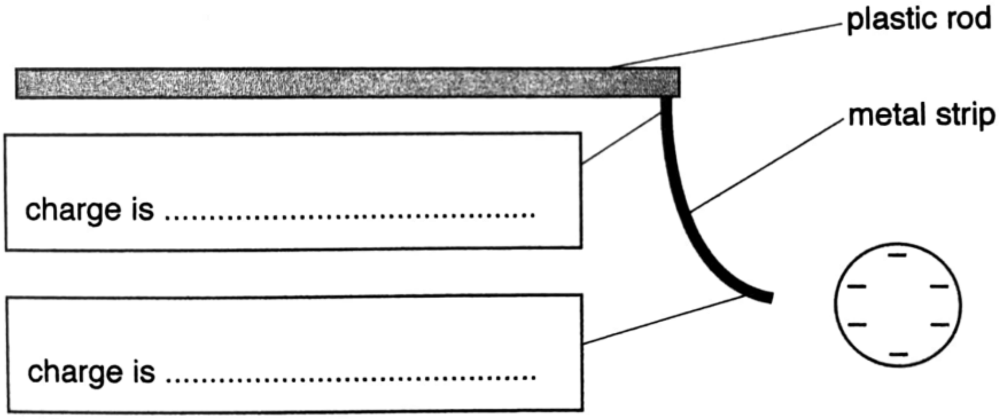
(2016 P2A Q6)

(a) On the figure above, draw the electric field pattern outside the sphere. [2]

(b) State what is shown by the direction of the electric field. [1]

The direction of the electric field shows the direction of movement of a positive charge placed at that point.

(c) A thin strip of metal is fixed to an uncharged plastic rod. The metal rod is initially uncharged and hangs vertically downwards. When placed close to the sphere, the strip bends, as shown in the figure below.

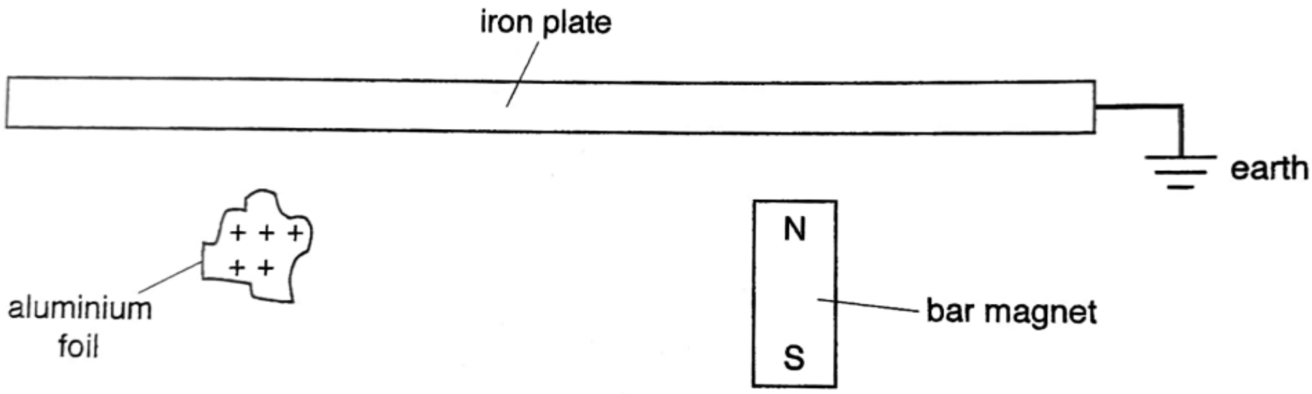


(i) On the figure above, write in the boxes the net charge found at each end of the metal strip. [1]

(ii) The force exerted by the sphere on the charges on the bottom of the metal strip is larger than the force it exerts on the charges on the top of the strip. Suggest why. [1]

The magnitude of the force is dependent on the distance. As the bottom of the metal strip is nearer to the sphere, the force is larger.

10 The figure above shows a very small piece of aluminium foil and a small bar magnet placed just beneath an earthed iron plate.



The aluminium foil has a positive electrical charge.
Both the foil and the magnet are attracted to the iron plate and move upwards.

(2018 P2A Q5b,c)

(a) Explain why the foil is attracted to the earthed iron plate. You may draw on the figure above, if you wish. [2]

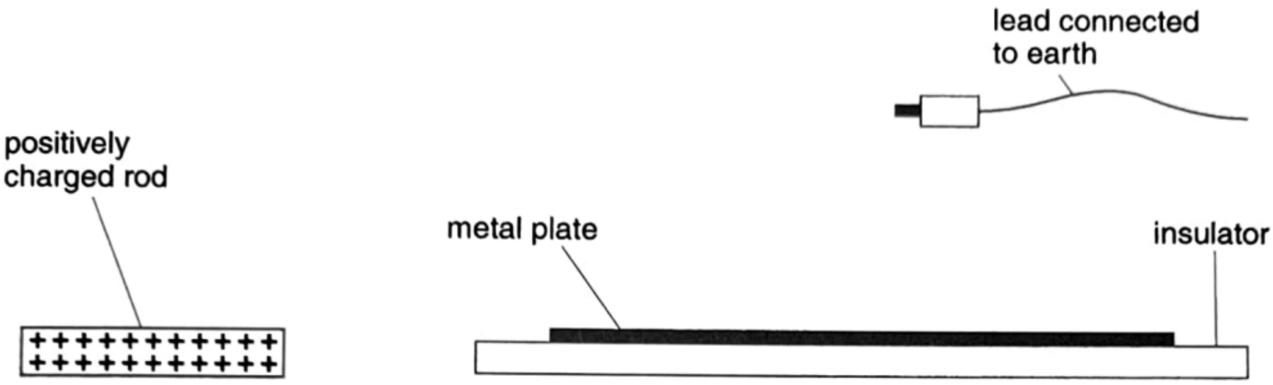
Free electrons from earth are attracted to the part of the iron plate nearest to the aluminium foil. As unlike charges attract, the foil moves upwards to the iron plate.
(Note: There is no positive region in the iron plate due to the earth connection.)

(b) When the foil touches the iron plate, it stops being attracted to the plate. Explain why. [2]

There is a transfer of electrons from the iron plate to the foil when they touch.
As such, the charges on the foil is neutralised, as is the iron plate. Since both objects are now neutral, the foil is no longer attracted to the plate.

11 (2012 P2B Q11 OR)

(a) The figure below shows a positively charged, insulated rod, an uncharged metal plate resting on an insulator and a lead connected to earth.



The apparatus is used to charge the metal plate by the process of induction and to leave the metal plate with a charge spread over all its surface.

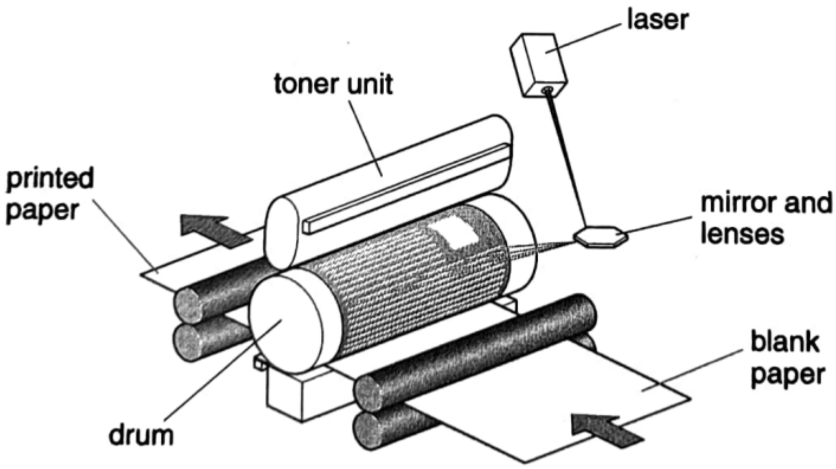
(i) State the steps taken to charge the metal plate. [4]

1. Bring the positively charged rod close to, but not touching, the metal plate.
2. With the positively charged rod still close to the metal plate, connect the lead to the opposite end of the metal plate.
3. Disconnect the lead to the metal plate.
4. Remove the positively charged rod. The metal plate is now negatively charged.

(ii) State and explain what happens to the charge on the metal plate during the charging process. [3]

1. When the positively charged rod is brought close to the metal plate, the electrons in the metal plate are attracted to the positively charged rod, as unlike charges attract. This leaves behind positive charges on the opposite end of the metal plate.
2. When the lead is connected to the metal plate, electrons from earth are attracted to positive charges, as unlike charges attract. When the lead is removed, there is now an excess of negative charges in the metal plate.
3. When the positively charged rod is removed, the electrons rearrange themselves evenly on the surface of the metal plate.

(b) The working parts of one type of laser printer are shown in the figure above.



Initially, the surface of the drum is insulating and is positively charged. It is in the dark. The inside of the drum is made of metal and is connected to earth.
The regions where light strikes the drum become conducting.

(i) Explain what happens to the charge on the drum in the regions that the light strikes. [1]

The positive charge on the drum is neutralised when the light strikes.

(ii) The toner, a fine black powder, is charged and sprayed onto the drum. The toner does not stick where the drum is positively charged. In such places, the final print appears white. Where light strikes the drum, the final print is black.

1. Suggest why the toner does not stick to the positively charged regions of the drum. [1]

The toner is positively charged. Thus, it is repelled by the positively charged regions, as like charges repel.

2. Suggest why the toner does stick to the conducting regions of the drum. [1]

The conducting regions are neutral. Thus, the positively charged toner powder attracts the electrons in the conducting regions, causing a separation of charges in the conducting region, as unlike charges attract.
This causes the surface of the conducting region to become negatively charged, causing the toner to stick to the conducting regions.