

Static electricity: notes and practice questions

These notes and questions cover electric charge for Cambridge O Level Physics (5054) and Cambridge IGCSE Physics (0625). For 0625 the syllabus content is in 4.2.1 Electric charge, and in 4.2.2 Electric current for the coulomb and $Q = It$. The topics are charging by friction, positive and negative charge, attraction and repulsion, conductors and insulators, electric fields and field-line patterns, and the coulomb. Induction, earthing, the gold-leaf electroscope and the uses and dangers of static electricity were in older versions of these syllabuses. They are included here as background and extension, and may not be examined on the current syllabus. Check with your teacher. Sections and questions marked **Extension** cover this material. Those marked **Supplement** are for Extended (Supplement) candidates on IGCSE 0625. Read the notes first. Then try Sections A to C (60 marks) before you check the answers at the end.

Notes

Key ideas

- There are two kinds of charge, **positive** and **negative**. Like charges repel and unlike charges attract.
- When two insulators are rubbed together, only **electrons** move. The object that gains electrons becomes negative. The object that loses electrons becomes positive. Charge is never created or destroyed.
- **Conductors** have free electrons that move easily. In **insulators** the electrons are held in place.
- An **electric field** is a region in which an electric charge experiences a force. Its direction is the direction of the force on a **positive** charge.
- Charge is measured in **coulombs (C)**, and $Q = It$.

1. Charging by friction

All matter is made of atoms. Each atom has a positive nucleus with negative electrons around it. A neutral object has equal amounts of positive and negative charge. The protons stay locked inside the nuclei. When two **solids** are rubbed together, only the outer electrons of some atoms can move.

- Rub a polythene rod with a woollen cloth. Electrons move from the cloth onto the rod. The rod becomes **negative** and the cloth becomes equally **positive**.
- Rub a cellulose acetate rod with a cloth. Electrons move from the rod onto the cloth. The rod becomes **positive** and the cloth becomes equally **negative**.

A positive object has a **shortage** of electrons. It has not "gained protons". This is a common exam error.

Simple test for charge. Hang one charged rod in a paper stirrup from a nylon thread. Bring a second charged rod near it. If the hanging rod turns away, the charges are alike. If it turns towards the second rod, they are opposite. Repulsion is the only sure sign that an object is charged,

because a charged object also attracts *uncharged* objects (see section 3).

2. Conductors and insulators

	Conductors	Insulators
Electron model	Many free (delocalised) electrons that can move through the material	Electrons tightly held by their atoms, so almost no free electrons
Examples	copper, aluminium, steel, graphite, the human body (a fair conductor)	polythene, PVC, nylon, glass, rubber, dry wood, dry air
Charge after rubbing	Spreads over the whole object. If the object is held in the hand, it escapes through the body to earth.	Stays where the rubbing happened

Testing a material. Connect a cell, a lamp (or an ammeter) and two crocodile clips in series. Clip the sample between the clips. If the lamp lights, or the ammeter shows a current, the sample is a conductor. If not, it is an insulator.

A metal rod *can* be charged by rubbing if it is held by an insulating handle. The handle stops the charge leaking away.

3. Induction and earthing (Extension)

When a charged rod is brought near a conductor, the free electrons in the conductor move. They are attracted towards a positive rod or repelled away from a negative rod. The near side gets the charge opposite to the rod's and the far side gets the same charge as the rod. This separation is called **induced charge**. The conductor as a whole is still neutral.

Charging an insulated metal sphere by induction (using a negative rod):

1. Bring the negative rod near the sphere, without touching. Electrons are repelled to the far side. The near side is left positive.
2. Keep the rod in place and touch the sphere with a finger, or connect it to earth. The repelled electrons flow away to earth.
3. Remove the finger (the earth connection) **first**.
4. Then remove the rod. The sphere is left **positive**, the opposite sign to the rod, and the charge spreads evenly over its surface.

Why neutral objects are attracted. A charged comb picks up small bits of paper. The comb induces opposite charge on the near side of each bit and like charge on the far side. The opposite charge is closer, so the attraction is stronger than the repulsion. The overall force is attractive. In an insulator such as paper the electrons cannot flow, but within each atom or molecule they shift slightly away from (or towards) the rod, so the near surface still gets an opposite charge.

Earthing means connecting an object to the ground with a conductor. The Earth is so large that it can give or take any number of electrons without its own charge changing noticeably. An earthed object therefore loses its charge, unless a nearby charged object holds some charge in place, as in step 2 of charging by induction.

4. The gold-leaf electroscope (Extension)

Part	Material and job
Cap, rod, plate and leaf	All metal, so charge spreads over them. The leaf (gold or thin aluminium foil) is fixed at its top to the plate and is very light, so it is easily pushed away from the plate.
Plug where the rod enters the case	An insulator, such as plastic. It stops charge leaking from the rod to the case and to earth.
Case with glass windows	Protects the leaf from draughts and lets you see it.

- **Detecting charge:** when a charged object touches the cap, charge spreads over the cap, rod, plate and leaf. The plate and leaf now carry the same charge and repel, so the leaf rises (diverges). More charge gives a bigger divergence.
- **Finding the sign of a charge:** first give the electroscope a known charge. Then bring the test object near the cap. If the divergence **increases**, the object has the **same** sign. If the divergence **decreases**, the object is either oppositely charged or uncharged, so this result is not conclusive. Only an increase proves the sign.
- **Discharging:** touch the cap with a finger. The electroscope is earthed and the leaf falls.

5. Electric fields (Supplement / Extended only for IGCSE 0625)

There is an electric field around every charged object. An electric field is a **region in which an electric charge experiences a force**. We show a field with field lines:

- Arrows show the direction of the force on a small **positive** charge. They point **away from positive** charges and **towards negative** charges.
- Field lines never cross. Where lines are closer together, the field is stronger.

Arrangement	Pattern (described in words)
Isolated positive point charge (or charged conducting sphere)	Straight lines going out in all directions, like spokes of a wheel, arrows pointing outwards. The lines spread apart further out, so the field is weaker there. For a charged conducting sphere the lines start at the surface, at right angles to it, and point radially outwards as if from the centre. There are no field lines inside the sphere.
Isolated negative point charge	The same radial pattern, but arrows point inwards towards the charge
Two parallel plates, one positive and one negative	Straight, parallel, equally spaced lines between the plates. They meet both plates at right angles and point from the + plate to the – plate. The field is uniform, which means it is the same strength everywhere between the plates (ignoring the curved lines near the edges).

A **negative** charge (such as an electron) in a field feels a force in the direction **opposite** to the field lines.

6. The coulomb: worked examples

The unit of charge is the coulomb, C. Current is the rate of flow of charge: $Q = It$, where Q is in C, I in A and t in s. One electron carries a charge of about -1.6×10^{-19} C.

For IGCSE 0625, the coulomb and $Q = It$ are Supplement (Extended) content.

Worked example 1. A polythene rod gains a charge of -4.8×10^{-8} C by rubbing. How many electrons did it gain?

Step 1: number of electrons = total charge $\div$ charge on one electron

Step 2: $= (4.8 \times 10^{-8} \text{ C}) \div (1.6 \times 10^{-19} \text{ C})$ (use the sizes of the charges and ignore the signs)

Step 3: $= 3.0 \times 10^{11}$ electrons

Worked example 2. An earthing strap discharges a machine. A charge of 6.0×10^{-6} C flows to earth in 0.020 s. Calculate the average current in the strap.

Step 1: $Q = It$, so $I = Q \div t$

Step 2: $I = (6.0 \times 10^{-6} \text{ C}) \div (0.020 \text{ s})$

Step 3: $I = 3.0 \times 10^{-4} \text{ A}$ (that is, 0.30 mA)

The charge on the electron is not something you must memorise for the exam. If a question needs it, the value will be given.

7. Dangers and uses of static electricity (Extension)

Situation	What happens and why
Refuelling aircraft and road tankers (danger)	Fuel rubbing on the hose transfers charge, and a large charge can spark and ignite the fuel vapour. Safety: the vehicle and fuel supply are connected to each other and to earth before pumping, so charge flows away steadily.
Lightning and electronics (danger)	Lightning conductors give lightning a safe path to earth. A small spark from a charged person can damage microchips, so workers wear earthed wrist straps.
Photocopier (use)	A charged drum is lit by an image of the page. Lit areas lose their charge and dark (printed) areas stay charged, so oppositely charged toner sticks there before being transferred to paper and melted on. (In a laser printer, a laser beam controlled by the computer draws the image on the drum instead.)
Electrostatic spray painting (use)	Droplets all get the same charge, so they repel and spread into a fine, even spray. The earthed (or oppositely charged) object attracts them, even to its back and hidden surfaces, so less paint is wasted.
Electrostatic precipitator in a chimney (use)	Ash and dust particles are charged by high-voltage wires or grids, then attracted to oppositely charged or earthed collecting plates. The plates are knocked from time to time so the dust falls into a hopper.

Section A: multiple choice

Choose one answer for each question. Each question is worth 1 mark.

A1 A polythene rod is rubbed with a woollen cloth and becomes negatively charged. Which statement explains this? [1]

- A Protons moved from the cloth to the rod.
B Electrons moved from the cloth to the rod.
C Electrons moved from the rod to the cloth.
D Negative charge was created on the rod by the rubbing.

A2 Which material is an electrical conductor? [1]

- A glass
B dry nylon
C graphite
D rubber

A3 Two charged table-tennis balls, P and Q, hang on nylon threads and push each other apart. P is positive. Q is then brought near another charged table-tennis ball, R, and Q and R pull towards each other. What are the charges on Q and R? [1]

	charge on Q	charge on R
A	negative	positive
B	positive	positive
C	positive	negative
D	negative	negative

A4 (Supplement) Which quantity is equal to one coulomb? [1]

- A one ampere divided by one second
B one ampere multiplied by one second
C one joule divided by one second
D one volt multiplied by one ampere

A5 (Supplement) Two parallel metal plates are placed one above the other. The top plate is positive and the bottom plate is negative. Which describes the electric field between the plates, away from the edges? [1]

- A curved lines pointing from the bottom plate to the top plate
B straight, equally spaced lines pointing from the top plate to the bottom plate
C straight, equally spaced lines pointing from the bottom plate to the top plate
D straight lines spreading out from the centre of the top plate

A6 (Extension) A gold-leaf electroscope is negatively charged and its leaf is diverged. A rod is brought near the cap, without touching it, and the leaf diverges *further*. What must the rod be? [1]

- A positively charged
B negatively charged
C an uncharged conductor
D an uncharged insulator

A7 (Supplement) What does the direction of an electric field at a point show? [1]

- A the direction of the force on a positive charge placed at that point
B the direction of the force on an electron placed at that point
C the direction in which electrons drift in a metal wire

D the direction from a negative charge towards a positive charge

A8 (Extension) Before fuel is pumped into an aircraft, the aircraft and the fuel tanker are connected to earth with a cable. Why? [1]

- A to stop the fuel from evaporating
- B to let charge flow away so that a spark does not form
- C to make the fuel flow faster through the hose
- D to charge the fuel so that it sticks to the inside of the tank

Section B: short answer

B1 A cellulose acetate ruler is rubbed with a dry cloth. The ruler becomes positively charged.

- (a) State the type of charge on the cloth. [1]
- (b) Explain, in terms of electrons, how the ruler became positively charged. [2]

B2 A student holds a copper rod in her hand and rubs it with a cloth. She finds that the rod does not become charged. Explain why, and suggest how she could charge the rod by rubbing. [2]

B3 A balloon is rubbed on a jumper and becomes negatively charged. It then sticks to an uncharged wall. Explain why the balloon is attracted to the wall. [3]

B4 (Supplement) State what is meant by an electric field, and state how the direction of an electric field is defined. [2]

B5 You are given a cell, a lamp, connecting wires and a strip of an unknown material. Describe how you would find out whether the material is an electrical conductor or an insulator. [2]

B6 (Supplement) A small plastic bead has a charge of -2.4×10^{-9} C. The charge on one electron is -1.6×10^{-19} C. Calculate how many extra electrons the bead carries. [2]

B7 (Extension) In electrostatic spray painting, the paint droplets are charged as they leave the nozzle. Explain two advantages of charging the droplets. [2]

B8 (Supplement) Describe in words the electric field pattern around an isolated negative point charge. [2]

Section C: structured questions

C1 (Extension) A metal sphere stands on an insulating base. It is uncharged. A positively charged acetate rod is held close to the left side of the sphere, but does not touch it.

- (a) Describe and explain how charge is arranged on the sphere while the rod is held near it. [2]
- (b) With the rod still in place, a student touches the right side of the sphere with a finger. State which particles move, and in which direction. [2]
- (c) The student removes her finger and then takes the rod away. State the final charge on the sphere and describe how this charge is spread over the sphere. [2]
- (d) Explain why the finger must be removed *before* the rod is taken away. [2]

C2 (Extension) A gold-leaf electroscope has a metal cap joined to a metal rod and plate, with a thin gold leaf fixed to the plate. The rod passes into a glass-fronted case through a plug.

- (a) State a suitable material for the plug and explain why this material is needed. [2]

(b) The electroscope starts uncharged. A negatively charged polythene strip is touched on the cap. Explain why the leaf rises. [3]

(c) The electroscope is discharged and then given a positive charge. A negatively charged comb is slowly brought towards the cap without touching it. State and explain what happens to the leaf. [2]

(d) Another object makes the leaf of the positively charged electroscope fall slightly. Explain why this does not prove that the object is negatively charged. [1]

C3 A road tanker pumps petrol through a long rubber hose into an underground tank at a filling station.

(a) (Extension) Explain how the tanker can become charged while the petrol is flowing. [2]

(b) (Extension) Explain why this charge could be dangerous. [2]

(c) (Extension) Describe one way the danger is reduced, and explain how it works. [3]

(d) (Supplement) During a safety test, an earthing cable carries an average current of 4.0×10^{-5} A for 30 s. Calculate the charge that flows through the cable. [2]

C4 Two large parallel metal plates are held a few centimetres apart. The left plate is connected to the positive terminal of a high-voltage supply and the right plate to the negative terminal.

(a) (Supplement) Describe the electric field between the plates, away from their edges. [3]

(b) (Supplement) A tiny negatively charged dust particle is between the plates. State the direction of the electric force on it, and explain your answer. [2]

(c) (Extension) A power station uses an electrostatic precipitator to remove ash from its waste gases. Explain how the precipitator removes the ash particles. [3]

(d) (Extension) Suggest why the collecting plates of the precipitator are knocked from time to time. [1]

Total: Section A 8 marks, Section B 18 marks, Section C 34 marks = 60 marks.

Answers

Section A

A1 B. Electrons (not protons) move. The rod gains them.

A2 C. Graphite has free (delocalised) electrons.

A3 C. Q repels positive P, so Q is positive. R attracts Q, so R is negative (R is stated to be charged).

A4 B. $Q = It$, so $1 \text{ C} = 1 \text{ A} \times 1 \text{ s}$.

A5 B. The field is uniform and points from + to –.

A6 B. Only a charge of the same sign as the electroscope increases the divergence.

A7 A. By definition, the field direction is the direction of the force on a positive charge. An electron

feels a force the opposite way (B).

A8 B. Earthing lets charge flow away as it is produced, so no large charge builds up to cause a spark that could ignite the fuel vapour.

Section B

B1 (a) negative [1]

(b) Electrons moved from the ruler to the cloth [1]. The ruler now has fewer electrons than protons / a shortage of electrons [1].

Do not award the mark for "gained positive charge" or "gained protons".

B2 Copper is a conductor, so the charge flows through the rod and her body to earth [1]. Hold the rod by an insulating handle, such as plastic, or wear an insulating glove [1].

B3 The negative balloon repels electrons in the surface of the wall away from it (or: it induces charge in the wall) [1]. The surface nearest the balloon becomes positive [1]. Opposite charges attract, and the positive charge is closer than the negative charge, so the attraction is greater than the repulsion [1].

Also accept "the wall's surface becomes positively charged by induction / polarisation" for the first two marks.

B4 A region in which an electric charge experiences a force [1]. Its direction is the direction of the force on a positive charge placed in the field [1].

B5 Connect the cell, the lamp and the strip in series to make a complete circuit [1]. If the lamp lights, the material is a conductor. If it does not light, it is an insulator [1].

B6 number = $2.4 \times 10^{-9} \div 1.6 \times 10^{-19}$ [1]
= 1.5×10^{10} electrons [1]

B7 Any two, 1 mark each:

- The droplets have the same charge and repel each other, so they spread out into a fine, even spray / even coat.
- The droplets are attracted to the earthed or oppositely charged object, so less paint is wasted.
- The droplets are pulled round to coat the back and hidden surfaces of the object.

B8 Straight (radial) lines coming from all directions to the charge, evenly spread around it [1]. The arrows point inwards, towards the charge [1].

Section C

C1

(a) Free electrons in the sphere are attracted towards the positive rod [1]. So the left side becomes negative and the right side becomes positive (and the sphere is still neutral overall) [1].

(b) Electrons [1] flow from earth, through the finger, into the sphere [1].

- (c) Negative [1]. Spread evenly over the whole surface of the sphere [1].
(d) If the rod were removed first, the extra electrons would no longer be held by the rod [1]. They would flow back to earth through the finger, and the sphere would be left uncharged [1].

C2

- (a) An insulator, such as plastic, rubber or polythene [1]. It stops charge leaking from the rod to the case and to earth [1].
(b) Electrons pass from the charged polythene strip onto the cap [1]. They spread over the cap, rod, plate and leaf, because metal is a conductor [1]. The leaf and plate now have the same (negative) charge, so they repel and the leaf moves away from the plate [1].
(c) The leaf falls / the divergence decreases [1]. The negative comb repels free electrons down from the cap to the plate and leaf; these electrons cancel (neutralise) some of the positive charge on the plate and leaf, so they repel less [1].
Also accept the equivalent answer that positive charge is drawn up to the cap, leaving less positive charge on the leaf and plate. Extension: if the comb is brought very close, the leaf may collapse completely and then rise again, because the leaf and plate now carry a net negative charge.
(d) An uncharged object brought near the cap would also make the leaf fall slightly, so the object could be uncharged instead of negative [1].

C3

- (a) Friction between the petrol and the hose (or pipes) [1] transfers electrons, so charge builds up on the tanker because the rubber tyres/hose insulate it from earth [1].
(b) A large charge can cause a spark to jump to earth or to a nearby object [1]. The spark can ignite the petrol vapour, causing a fire or explosion [1].
(c) Connect the tanker to earth, or bond it to the tank, with a metal cable before pumping [1]. Charge flows away through the cable as it forms [1], so it never builds up enough to make a spark [1].

Also accept: using a conducting (not insulating) hose, with the same explanation.

(d) $Q = It = 4.0 \times 10^{-5} \times 30$ [1]

$Q = 1.2 \times 10^{-3} \text{ C}$ [1]

Correct answer with unit and no working scores 2. A missing or wrong unit loses the final mark.

C4

- (a) Any three, 1 mark each:
- straight, parallel lines
 - equally spaced (the field is uniform)
 - at right angles to the plates
 - pointing from the positive (left) plate to the negative (right) plate
- (b) Towards the positive (left) plate [1]. The particle is negative, so the force on it is opposite to the field direction / unlike charges attract [1].
(c) The ash particles pass charged wires or grids and pick up (for example, negative) charge [1]. The charged particles are attracted to collecting plates that are oppositely charged or earthed [1]. The particles stick to the plates, so they are removed from the gas before it leaves the chimney [1].
(d) This makes the collected ash fall off into a hopper, so the plates stay clean and keep working / the ash does not build up [1].