**Chapter 19: Static Electricity**

***Please remember to photocopy 4 pages onto one sheet by going A3→A4 and using back to back on the photocopier***

**Questions to make you think**

1. Why do you sometimes get goose-pimples in cold weather?
2. Why does your hair stand up when you get a fright?
3. What do you think is the evolutionary purpose behind this (hint: it also happens when you get an electrical shock)?
4. Electrons are negatively charged, protons are positively charged and opposite charges attract. So why don’t the electrons ‘fall’ into the nucleus? Why do lots of similarly-charged protons co-exist peacefully in the nucleus?
5. Why is it that socks which are dried in a tumble-dryer come out lovely and soft while those which are dried on a clothesline outside are often hard/abrasive?
6. Why is (uncharged) paper attracted to a charged balloon?
7. Why is a car antenna always on the outside of the car?

**Student notes**

**Charge**

If an object has more electrons than protons it is negatively charged, if the object has more protons that electrons then it is positively charged)\*.

Opposite charges attract; similar charges repel each other.

You can demonstrate this by hanging two oppositely charged rods as shown and note that they both move towards each other.

**The symbol for charge is Q.**

**The unit of charge is the Coulomb – symbol is C.**

So for example an electron has a charge of 1.6 × 10-19 coulombs (this value is in the log tables so you don’t need to learn it.
*{A proton happens to have the same charge as an electron (we have no idea why – we suspect it’s not coincidence)}*



**The Gold Leaf Electroscope**

You must know the structure of an Electroscope and list some of its functions.

If the GLE is uncharged, the leaves will fall together.

If the leaves become charged – either positively or negatively – the leaves will stand apart (why?).



**Functions**:

1. To detect charge
2. To distinguish between positive and negative charge
3. To indicate approximate size of a charge
4. To test if an object is a conductor or an insulator

How would you use an electroscope to demonstrate each of these?

Can you figure out why the case needs to be metal (some designs have a timber case but have a metal strip all along the inside)?

**Earthing**

If an object becomes charged (due to a build-up of electrons say), and the object is then ‘earthed’ (connected to earth), the electrons will separate as much as possible, resulting in most of them quite literally ‘going to earth’.

The object then becomes neutral.

**Charging a conducting object by induction**

To charge an insulated conductor positively



1. Bring a negatively charge rod near the conductor *{the positive and negative charges become separated on it}*
2. Keeping the charged object in place, earth the conductor by touching it with your finger {s*ome of the negative charge on the metal flows through you to earth}.*
3. Remove your finger, then *and only then* remove the rod *{the conductor is now positively charged}*

You should now be able to draw the relevant diagrams to show how to charge an object negatively by induction.

***{Exam tip****: The charged rod is brought near to* ***but does not touch*** *the electroscope; to state or imply that it does meant only getting 4 marks out of 10 when it was asked in 2008}*

**Coulomb’s Law\***

**Coulomb’s Law** states that the force between two point charges is proportional to the product of the charges and inversely proportional to the square of the distance between them.

Mathematically: F ∝ (Q1 Q2),

And F ∝ 1 / d2

**F =  **

 Putting this together where the proportional constant is 

ε (epsilon) is known as “the permittivity” of the medium {*it represents the extent to which one charge will be affected by another, e.g. glass has a different permittivity value than air}*

Note that εair (the permittivity of air) is taken to have the same value as ε0 (the permittivity of a vacuum or free space).

(ε0 = 8.9 × 10-12 F m-1)

**Electric fields and electric field strength**

*{All charged objects create an electric field that extends outward into the space that surrounds it. This charge will have an effect on any other charged object that enters the field. The strength of the electric field is dependent upon how charged the object creating the field is and upon the distance of separation between the two charges****}***

**An electric field** is a region of space where *electrostatic* forces can be felt.

**Electric field strength (E) at a point is the force *per unit charge* at that point**\*

*{This is one of the most asked definitions on the syllabus}*

$$E=\frac{F}{Q}$$

The unit of electric field strength is the newton per coulomb (N C-1).

E =

Also note that because F =   ⇒

**Direction of electric field lines**

The convention is that lines come out of positive charges and go into negative charges.

**Question:**

The diagram shows a negative charge at a point X.

Copy the diagram and show on it the direction of the electric field strength at Y.

**Solution:**

*{“The electric field strength at Y” means “the force that would be exerted on a* ***unit******positive*** *charge if it was at position Y”.
To determine the direction of the electric field strength at Y imagine that* ***you are that positive charge*** *at Y; what direction would you be pushed or pulled in?}*

Answer: In this case you would put an arrow going from Y towards the left.

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**To demonstrate electric field patterns\***



1. Place two electrodes in a petri-dish.
2. Pour some oil into the petri-dish and sprinkle on some semolina powder.
3. Connect a high voltage source (about 2,000 volts) to the metal electrodes.

Result: The semolina lines up in the direction of the field, showing the electric field.

***{Exam tips:***

1. *You will lose marks in an exam if you do not stress the high voltage.*
2. *You will need to draw the circuit diagram to show how the apparatus is connected together.*
3. *You must specify semolina or a similar power; metal filings are not acceptable.}*

**Distribution of charge on an insulated conductor\***

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**All static charge resides on the *outside* of a conductor.**

**Demonstration**

1. Charge the conductor (a metal can will do fine).
2. Using ***a*** ***proof plane***, touch the inside of the can and bring it up to the GLE.

Notice that there is no deflection.

1. Touch the proof plane off the outside of the can and bring it up to the GLE.

Notice that there is a deflection.

1. Conclusion: charge resides on outside only

**Application**:

* A Van de Graff Generator is used to generate a large build-up of charge which resides on the outside surface of the dome.
* A full-body metal-foil suit protects an operator when working on high voltage power lines (strictly speaking it doesn’t even have to be solid – a wire mesh would also work).

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{**Exam Tip:** ‘A faraday cage’ is not precise enough to be acceptable if given as an application}

**Static charge on a conductor tends to accumulate where the conductor is *most pointed*\*.**

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**Demonstration**

1. Charge a pear-shaped conductor .
2. Use a proof plane to bring charge from the curved end to the GLE, and note that there is a minimal deflection.
3. Use a proof plane to bring charge from the pointed end to the GLE, and note that the deflection is much greater.
4. Conclusion: Most of the charge is at the pointed end.

**Point discharge (also known as ‘The point effect’)**

* We have seen that on a pear-shaped conductor, most charge accumulates on the pointed end (or at least it should!).
* Now let’s assume the object is charged negatively.
* If the build-up of charge at the pointed end is sufficiently large, it can attract nearby positive ions from the air and cause them to accelerate towards the pointed end.
* En route, these ions are likely to crash off other molecules, causing them to become ionised (by knocking electrons off the atoms).
* Ions with opposite charge to that on the point move towards this end and neutralise the charge on it.
* Ions with the same charge move away from this end creating an ‘electric wind’.

**Demonstrating point discharge**

Attach a nail to the surface of a Van der Graff generator.

Bring up a candle and notice that the flame moves away from the Van der Graff. This is because of the ‘wind’ generated by point discharge.

**Applications of electric fields**

1. Precipitators (Used to extract smoke particles from the air.
2. Photocopier machines

**Industrial hazards**

1. Explosion in flour-mills or when fuelling aircraft
2. Damage to integrated circuits.
3. Electric shock

You are also expected to know a little about lightning and lightning conductors.\*

**Leaving Cert Physics Syllabus**

|  |  |  |  |
| --- | --- | --- | --- |
| **Content** | **Depth of Treatment** | **Activities** | **STS** |
|  |  |  |  |
| **CHARGES** |  |  |  |
| 1. Electrification bycontact | Charging by rubbing together dissimilar materials.Types of charge: positive, negative.Conductors and insulators.Unit of charge: coulomb. | Demonstration of forces between charges. | Domestic applications:• dust on television screen• static on clothes.Industrial hazards:• in flour mills• fuelling aircraft. |
|  |  |  |  |
| 2. Electrification byinduction |  | Demonstration using an insulated conductor and a nearby charged object. |  |
|  |  |  |  |
| 3. Distribution ofcharge onconductors | Total charge resides on outside of a metal object.Charges tend to accumulate at points.Point discharge. | Van de Graaff generator can be used to demonstrate these phenomena. | Lightning.Lightning conductors. |
|  |  |  |  |
| 4. Electroscope | Structure. |  | Uses. |
| **ELECTRIC FIELD** |  |  |  |
| 1. Force betweencharges | Coulomb’s lawF =  – an example of an inverse square law.**Forces between collinear charges.** | **Appropriate calculations.** |  |
|  |  |  | . |
| 2. Electric fields | Idea of lines of force.Vector nature of electric field to be stressed.**Definition of electric field strength.** | Demonstration of field patterns using oil and semolina *or* other method.**Appropriate calculations – collinear charges only.** | Precipitators.Xerography.Hazards: effect of electric fields on integrated circuits. |



**Extra Credit**

**\*If an object has more electrons than protons . . .**

Just to complicate things, when scientists were first getting to grips with this stuff, they envisioned that there were two types of charge – positive and negative – and that they could both move.

It was actually American scientist/politician Benjamin Franklin who proposed the *positive and negative charges* theory. We now know of course that in actual fact it is only the negative charges (electrons) which can move along a material – the positive charges (protons) are stuck in the nuclei of the atoms and most definitely do not move.

As it so happens, all the phenomena we study in this chapter can be explained in terms of both types of charge moving, *or* just in terms of only electrons moving.

For some reason I still can’t fathom, we explain static electricity phenomena in terms of both charges moving.

As an exercise for yourself you could try to explain each concept in terms of only electrons moving.

Remember that if an object is neutral or uncharged, it does not mean that the object has no charge; merely that it has an equal amount of positive and negative charge, and they cancel each other out.

**\*Coulomb’s Law**

The direction of the force is an attractive force if they are opposite charges, and a repulsive force if they are similar charges.

‘Permittivity’ is actually an unfortunate term – it should be called ‘*unpermittivity’* or something more helpful, because the higher the value of ε, the less will be the force between the two charges.

**\*An Electric Field** is a region is space where an electric charge *at rest* experiences a force other than the force of gravity.

Not strictly true; a proton at rest could experience a ‘strong’ nuclear force, but we will conveniently ignore that for now.

**An Electric Field Line** is a line drawn in an electric field showing the direction of the force *on a positive charge* if placed in the field.

It’s easy to forget, but don’t leave out the part in italics

*A simpler way of saying this is to say that the lines come out of positive charges and go into negative charges.*

Note that where the electric field is strong, the field lines are close together; where the field is weak the lines are far apart.

**\* Electric Field Strength’**

Why have a concept called ‘Electric Field Strength’?

Because we may need to know what effect a given charge would have on another charge, if that second charge was placed a certain distance from it.

But you can’t say that the first charge would produce a force of say 10 Newtons. Why not?

Because the size of the force depends on the magnitude of the *two* charges.

So to get around this we need a nominal second charge, and it makes sense to nominate this second charge to be unit charge, i.e. one Coulomb.

This means that if we know the effect the first charge will have on a charge of one Coulomb, we can get a feel for how strong it is.

This is important when designing circuit boards for example.

So there.

**\*To Demonstrate Electric Field Patterns**

I must admit I’m not too sure what’s going on here.

I’m guessing that the oil is made up of polar molecules, which means that one side of the molecule is positive and the other side negative.

The negative side then turns towards the positive electrode (metal plate), and will even try to move towards it if it can overcome the inertia of the fluid.

The semolina is just there for the ride, but acts to illustrate the motion of the oil underneath.

Alternatively it may be that the semolina moves and the oil remains still.

Don’t tell anyone, but after looking at the youtube video, it actually seems to be a little of both!

**\*Distribution of Charge on an Insulated Conductor**

Just so you know in advance, I rarely get these demonstrations to work properly!

Weather plays a part, but then a more experienced colleague mentioned to me casually one day: “*You’ll never move enough charge with one transfer; you will have to repeat 10 – 20 times to get any deflection on the electroscope!”*

Like I’m supposed to be clever enough to work this out for myself!

**\*Static Charge on a conductor tends to accumulate where the conductor is *most pointed*.**We are not given a full explanation of *why* charge resides on the outside, or *why* charge accumulates at the pointy end; we are just told that this is the way charge arranges itself in order for each individual charge to be as far away as possible from all other charges.

I think a full explanation would involve a whole lot of rather difficult maths (some of which was on the old syllabus, in use up to a few years ago) so I suppose we should consider ourselves lucky that we don’t need to know it.

Still, it would be nice if the text-books were to at least acknowledge this.

Here is how I usually explain it, but I reckon it may be highly simplified:

The two electrons that are circled (see diagram above) don’t feel the effect of each other because the body of the conductor gets in the way and shields them. This is why the charges congregate around the highly curved areas.

The fact that charge resides on the outside of a conductor – be it solid or hollow – has very serious implications for the electronics industry.

For instance ESB workers dealing with high voltage lines wear a suit of conducting material, which means that they can’t get a shock.

In fact the surface doesn’t even have to be solid; a wire mesh or a cage would also work. Michael Faraday himself used to stand inside a cage which had a potential of a few thousand volts connected up to it, and he was quite safe.

He used to do this in public lectures, and this arrangement is now referred to as a ‘Faraday Cage’.

Along with no charge residing inside a conductor, neither is there any Electric Field. There is therefore no electrical interference to any electrical signal passing along a cable which is inside this wire mesh.

This is the principle behind a ‘co-ax’ (co-axial) cable, used to cover the television line which comes into the back of your TV set.

See the ‘Lineman’ video on youtube. Awesome.

**\*Lightning and lightning conductors**

The temperature of the ionised gas in a lightning strike is typically 30,000 deg C, or five times hotter than the surface of the sun.

The current is typically 250,000A, but it only lasts for a few millionths of a second. Thus the average bolt of lightning could only provide the daily energy demand for perhaps 3 UK homes.

Worldwide though there are about 4 million flashes each day.

It was the American scientist/politician Benjamin Franklin who first established that lightning seemed to obey the same laws as electricity which was so intriguing to the scientists at the time.

He did this by attracting lighting from the sky by flying a kite during a thunderstorm. He was lucky not to have killed himself.

He also realised the significance of pointed conductors, and as a result invented the lighting conductor.

Because of the animosity which existed between America and Britain at this time, the British King (King George III) insisted that the lightning conductors at his palace should have round knobs on top.

The then president of the Royal Society resigned in protest at such idiocy.

These lightning conductors also attracted controversy when they were attached to the steeples of churches.

Many people believed that (i) they actually attracted lightning, and (ii) that the conductors were attempting to obstruct the will of God.

“*Benjamin Franklin’s lightning conductor is a sacrilege that tries to avert the wrath of God. The destruction of Lisbon by the earthquake and tidal wave is God’s punishment of Man for the sacrilege*”.

From a sermon by a Boston Minister (1753).

**Ions can also affect how we feel.**

Positive ions tend to induce a feeling of lethargy and irritability in the 30 per cent of the population who find themselves susceptible, and may induce nausea and headaches.

Air laden with positive ions occur during a thunderstorm, and also in the vicinity of fire.

Negative ions, on the other hand, have quite the opposite effect and induce a sense of physical and mental well-being. There is normally a high concentration of negative ions near the seashore, and in the rarefied air at the summits of very high mountains.

Negative ions are also created in the domestic shower and this is said to be why a shower produces a feeling of freshness and invigoration superior to the traditional bath.

Taken from an article by the late Brendan McWilliams in *The Irish Times*.

**Did you know?**

On a normal day, a cubic centimetre of air contains 1,200 positive ions and 1,000 negative ions.

These negative ions are generally oxygen with an extra electron, and the positive ones are carbon dioxide minus an electron.

Do you care?

**What do lightning conductors and Global Warming have in common?**

Recently when covering Static Electricity we looked at how lightning conductors work, but we also discussed why they took so long to catch on.

Try answering the following questions without looking at the answers (I know you’re not actually going to do this, but it gives you a sense how the conversation went in class).

Me: Give me some examples of what you can NOT insure your house against.

Students: Floods, hurricanes, earthquakes

Me: What are these collectively known as?

Students: Acts of God

Me: Why are they referred to as Acts of God?

Students: Because you can’t predict when or if they’re going to happen.

Me: But why would you call those events ‘Acts of God’?

Students: Because you can’t predict when or if they’re going to happen.

Repeat three times.

Finally

Me: But why would you call those things ‘Acts of God’?

Student: Because God must have wanted those things to happen – or at least that’s what the people believed back then.

Me: Exactly. And before you all laugh at how ridiculous that sounds remember that it’s not that they were any less intelligent than we are now, it’s just that life in the 16th and 17th century was incomparably different to today. We live in a so-called age of reason. We know you can’t say ‘well that’s obviously what God wanted’ every time something bad happens. And I’m pretty sure that if our civilisation survives another century or two the people who are around then will look back at some of the rather bizarre belief systems that we subscribe to.

Even Newton himself fell into this way of thinking. When he found out that the orbits of the planets didn’t quite match his mathematical equations his response was to say that God obviously needs to step in and give them a nudge every so often. It took Einstein to explain that the problem was that Newton’s equations weren’t exact enough and it needed his (Einstein’s) Theory of Relativity to sort out the anomaly.

The point is that, as with so much of the Church’s teachings, its beliefs can be traced back to either St. Augustine or St. Thomas Aquinas. In this case both believed that the air was filled with seriously questionable characters. Aquinas wrote that “Rain and winds, and whatsoever occurs by local impulse alone, can be caused by demons. It is a dogma of faith that the demons can produce winds, storms, and rain of fire from heaven.”

And so, presumably, can God.

So when Franklin suggested that his lightning rod could save church buildings he naturally thought that this would be well received (in fact he considered it to be one of his greatest accomplishments, which is no mean feat when one considers that he was also one of the founding fathers of the United States.) It turns out that his suggestion went down like the proverbial lead balloon.

If a building struck by lightning was an Act of God, then interfering with this process was akin to thwarting God’s plan. And that, in the eyes of the Church authorities at least, couldn’t be a good thing. So they simply refused to put them in.

But there was one small problem. The church building was invariably the tallest structure in every village and town. So it was also the most likely to get hit. Now as you can imagine this confused people greatly. Not only that but the bell-ringers whose job it was to alert the townsfolk about the impending storm also tended to become the first victims of any lightning strike. In Germany alone approximately 300 bell-ringers lost their lives in the last 30 years of the 19th century.

So slowly but surely Church authorities began to relent and accept that maybe it was time to accept that there was something to be said for these so-called ‘blasphemous devices’ after all. Lucky for them it wasn’t too late.

**So what’s all this got to do with Global Warming?**

According to one 2006 study, 76 percent of Republican citizens profess a belief in the Second Coming (the so-called ‘Apocalypse’). They also represent one of the largest groups who oppose scientific teaching on Global Warming. They simply refuse to accept that Global Warming has the potential to change the world irrevocably. Why? Because the end of the world will come at a time of God’s choosing, not ours, so whatever mankind is doing right now, it’s certainly not going to bring about the destruction of civilisation.

These religious conservatives have become a very powerful force in American politics in recent decades (how that came to be is an equally fascinating story, but not for today).

Add to this the lobby group for oil and other fossil fuels and you have a voice that is both loud and very difficult to dislodge.

Now for fun throw in optimism bias which is evolutionary hardwired into all of us. Optimism Bias is the belief that the future will be better than the past. So for example 10% of Americans expect to live to be 100 when in fact only 0.02% are likely to live that long.We all experience optimism bias. It’s why none of us mention Global Warming when political canvassers call to our door. We all just assume that it will get sorted somehow. It may even explain why we are all so reluctant to engage with the concept of our own mortality; deep down we all think we’re going to live forever.

So you can see why Global Warming remains low on everybody’s radar.

And it will most likely remain that way – until it’s too late.

Unlike lightning conductors.

This is a link to resources I use when teaching about Global Warming and The Apocalypse in Transition Year.**Exam questions**

(permittivity of free space = 8.9 × 10-12 Fm-1; charge on the electron = 1.6 × 10-19 C)

1. [2010 OL]

How would you detect the presence of an electric field?



1. [2009 OL]

Name the instrument shown in the diagram.

1. [2005 OL]

The diagram shows a gold leaf electroscope.

Name the parts labelled A and B.

1. [2005 OL]
2. Explain why the gold leaf on the electroscope diverges when a positively charged rod is brought close to the metal cap.
3. The positively charged rod is held close to the electroscope and the metal cap is then earthed.

Explain why the gold leaf collapses.

1. [2007 OL]
2. The diagram shows a positively charged gold leaf electroscope.

Describe how an electroscope is given a positive charge.

1. What is observed when the cap of an electroscope is earthed?
2. Why does this happen?
3. How is the cap of the electroscope earthed?
4. [2008]

Describe how an electroscope can be charged by induction

1. [2003 OL]

Describe, with the aid of a labelled diagram, how you would charge a conductor by induction.

1. [2005 OL]

Give one use of an electroscope.

1. [2010 OL][2003 OL]

What is the unit of electric charge?

1. [2005][2003][2007 OL][2010 OL]

State Coulomb’s law of force between electric charges.

1. [2006][2005]

Why is Coulomb’s law an example of an inverse square law?

1. Complete the table

|  |  |  |  |
| --- | --- | --- | --- |
| Charge 1 | Charge 2 | distance | Force of attraction |
| 1 C | 1 C | 1 m |  |
| 6.0 × 10-6 C | 7 × 10-9 C | 3 × 10-8 m |  |

1. [2005]

Give two differences between the gravitational force and the electrostatic force between two electrons.

1. [2010][2009][2007][2005][2003][2002]

Define electric field strength*.*

1. [2007][2003][2010]

Give the unit of electric field strength

1. [2003]

The diagram shows a negative charge – *Q* at a point X.

Copy the diagram and show on it the direction of the electric field strength at Y.

1. [2007][2005][2003]

Describe an experiment to show an electric field pattern.

1. [2008]

What is the force exerted on an electron when it is in an electric field of strength 5 N C–1?

1. [2005]
2. Calculate the electric field strength at the point B, which is 10 mm from an electron.
3. What is the direction of the electric field strength at B?
4. A charge of 5 μC is placed at B. Calculate the electrostatic force exerted on this charge.

***Note ‘μ’ is the symbol for ‘micro’ which in turn represents the prefix 10-6***

1. [2010]
2. ****Copy the diagram into your answer-book and show on it the direction of the electric field at point P.
3. Calculate the electric field strength at P.
4. [2007]
5. The dome of a Van de Graff generator is charged. The dome has a diameter of 30 cm and its charge is 4 C.

A 5 μC point charge is placed 7 cm from the surface of the dome.

Calculate the electric field strength at a point 7 cm from the dome.

1. Calculate the electrostatic force exerted on the 5 μC point charge.

2. [2005][2002 OL]

A pear-shaped conductor is placed on an insulated stand as shown. Copy the diagram and show how the charge is distributed over the conductor when it is positively charged.

1. [2007]

All the charge resides on the surface of a Van de Graff generator’s dome. Explain why.

1. [2007]

Describe an experiment to demonstrate that total charge resides on the outside of a conductor.

1. [2007]Give an application of the fact that all charge resides on the outside of a conductor.
2. [2010]

Under what circumstances will point discharge occur?

1. [2010 OL]
2. How does the lightning conductor prevent damage to the building?

Provides (safe) path for flow of current if struck // it earths the building //allows easy path for discharge etc.

1. Suggest a suitable material for a lightning conductor.

Metal e.g. copper.

1. [2008 OL]

Give one effect of static electricity?

1. [2004]

Identify two hazards caused by static electricity.

1. [2003 OL]

The build-up of electric charge can lead to explosions. Give two examples where this could happen.

1. [2003 OL]
How can the build-up of electric charge on an object be reduced?
2. [2002]

Read the following passage and answer the accompanying questions.

Benjamin Franklin designed the lightning conductor. This is a thick copper strip running up the outside of a tall building. The upper end of the strip terminates in one or more sharp spikes above the highest point of the building. The lower end is connected to a metal plate buried in moist earth. The lightning conductor protects a building from being damaged by lightning in a number of ways.

During a thunderstorm, the value of the electric field strength in the air can be very high near a pointed lightning conductor. If the value is high enough, ions, which are drawn towards the conductor, will receive such large accelerations that, by collision with air molecules, they will produce vast additional numbers of ions. Therefore the air is made much more conducting and this facilitates a flow of current between the air and the ground. Thus, charged clouds become neutralised and lightning strikes are prevented. Alternatively, in the event of the cloud suddenly discharging, the lightning strike will be conducted through the copper strip, thus protecting the building from possible catastrophic consequences.

Raised umbrellas and golf clubs are not to be recommended during thunderstorms for obvious reasons.

On high voltage electrical equipment, pointed or roughly-cut surfaces should be avoided.

(Adapted from “Physics – a teacher’s handbook”, Dept. of Education and Science.)

* 1. Why is a lightning conductor made of copper?
	2. Why do the ions near the lightning conductor accelerate?
	3. How does the presence of ions in the air cause the air to be more conducting?
	4. How do the charged clouds become neutralised?
	5. What are the two ways in which a lightning conductor prevents a building from being damaged by lightning?
	6. Why are raised umbrellas and golf clubs not recommended during thunderstorms?
	7. Explain why pointed surfaces should be avoided when using high voltage electrical equipment.

**Exam solutions**

1. Using an electroscope // electric field sensor // electric field meter
2. A gold leaf electroscope
3. A = insulation, B = metal case (sometimes the case is wooden but if so then there must be a metal strip inside it).
4. Some of the electrons at the bottom of the electroscope are attracted to the top due to the positive charge on the rod and as a result there is an excess of positive charge on the bottom, including on the gold leaf. Because similar charges repel the gold leaf moves away from the main section.
5. Some of the positive charges are repelled by the rod and so flow to the ground.
6. Bring a negatively charged rod close to the cap.

Earth the electroscope by touching it with your finger while still holding the rod close by.

Remove your finger, then remove the rod.

1. The leaves drop.
2. The positive charges move from the cap to the earth (or the negative charges move from the earth to the cap).
3. By touching it with your finger.
4. See previous question.
5. Apparatus e.g. conductor (hanging from insulated thread or mounted on an insulating stand) and a charged rod.

Bring a charged rod close to the conductor.

Earth the conductor by touching it with your finger while still holding the rod close by.

Remove your finger, then remove the rod.

1. To detect charge
2. The coulomb
3. The force between two charges is proportional to the product of the charges and inversely proportional to the square of the distance between them.
4. Force is inversely proportional to distance squared.
5. Don’t be such a baby - fill it in yourself!
6. Gravitational force is much smaller than the electrostatic force.

Gravitational force is attractive, electrostatic force (between two electrons) is repulsive.

1. Electric field strength is defined as force per unit charge at that point.
2. The unit of electric field strength is the newton per coulomb (N C-1).
3. Arrow towards X
4. High voltage and two metal plates /electrodes

Semolina and oil in container

Connect a (high) voltage to the plates in container

Semolina lines up in the field

1. F = Eq  F = 5(1.6 × 10–19)  F = 8.0 × 10–19 N
2. E = Q/4πεd2

= (1.6 × 10-19)/4π(8.9 × 10-12)(0.01)2

E = 1.4 × 10-5 N C-1

1. Towards the electron / to the right.
2. *F = Eq* or *F =* (1.4 × 10-5)(5 × 10-6)

= 7.2 × 10-11 N

Towards the electron

1. See diagram
2. (For electric fields the convention is to assume the point to be a unit positive charge, so the point would be repelled from the positive and attracted towards the negative).
3. The electric field strength at P is the sum of the electric fields acting on P from the other two charges. The electric field strength is towards the left in both cases (attracted to the negative charge and repelled from the positive charge). Because they are both in the same direction the individual field strengths can simply be added together.

Etotal = 3.77 × 106 N C-1

1. 



Answer: *E* = 7.39 x 1011 N C-1

1. ****F = E q

F = (7.39 × 1011)(5 × 10-6) or F = 3.69 × 106 N

1. See diagram. Charges are more concentrated at the pointed end.
2. Like charges repel and the charges are a maximum distance apart on the outside surface of dome.
3. Apparatus: metal can, gold leaf electroscope, proof plane.

Procedure: charge metal can and use proof plane to test inside and outside.

Observation: leaves on g.l.e. deflect for outside sample only.

Conclusion: charge resides on outside only .

1. Electrostatic shielding / co-axial cable / TV (signal) cable / to protect persons or equipment, enclose them in hollow conductors /Faraday cages (there is no electric field inside a closed conductor), etc.
2. It there is a very large electric field strength / If the potential at the point is very high / If there is a very high charge density at the point.
3. Provides (safe) path for flow of current if struck // it earths the building //allows easy path for discharge etc.
4. Metal e.g. copper.
5. Lightning, static discharge, receive shock after walking across carpets, attracts objects, can damage electronics.
6. Electric shock / explosion in flour mills /explosion when fuelling aircraft/ damage to electronic devices / electrical storm / static cling, etc.
7. Dust e.g. flour mill explosions, inflammable vapours e.g. fuelling aircraft, lightning
8. By earthing the object (i.e. using a conductor to connect the object to the earth which allows the charge to flow to earth).
9. It is a good conductor.
10. They experience a large electrostatic force of either attraction or repulsion.
11. The ions act as charge carriers.
12. Electrons flow to or from the ground through the air.
13. Neutralises charged clouds

It conducts charges to earth.

1. Because they act as lightning conductors.
2. Sparking is more likely to occur from these points due to point discharge.

**Demonstrating that charged objects can attract or repel each other**

The single greatest reason for non-results is the assumption that this experiment will be similar to investigating the forces between magnets.

In principle this is correct, but because the forces involved with static electricity are very much weaker, we must be much more diligent in our effort to control other variables.

For example when bringing one plastic rod close to another, don’t just bring one end close to the other – use as much overlap area as possible without actually going beyond half-way (why?)

Remember that whenever that whenever and wherever you hold one plastic rod you discharge the area of contact (the charges in this area can travel through you to earth). This is because, while you may think that your body is an insulator, the surface of your skin actually contains moisture and therefore can conduct electricity.

In fact many objects which you may not think of as being conductors actually are – e.g a carrot!

Watch out that you don’t confuse the plastic’s display of repulsion or attraction with its natural swinging motion due to having been touched or not having had adequate time to come to rest after having been hung.

This confusion is most likely to occur when the rod is changing direction.

You may find that one rod attracts another rod even though they are of different material, and therefore should have opposite charge (and should attract).

The most likely reason is that the first object was either not charged properly or lost its charge while being hung from the thread – much easier to simply balance this rod on a clock glass instead.

Which brings us to another – possibly unexpected – phenomena; a charged object will attract an uncharged object.

Most textbooks will show a photograph of a biro being used to pick up small pieces of paper (tissue-paper works best), but don’t explain *why* this is happening. Use the links in the website to see what’s happening.