GRADE 12

Physical Sciences

SELF STUDY GUIDE

ELECTROSTATICS

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

Second Chance
Matric Support Programme

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NATIONAL EDUCATION COLLABORATION TRUST

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1. Introduction

The declaration of COVID-19 as a global pandemic by the World Health Organisation led to the disruption of effective teaching and learning in many schools in South Africa. The majority of learners in various grades spent less time in class due to the phased-in approach and rotational/ alternate attendance system that was implemented by various provinces. Consequently, the majority of schools were not able to complete all the relevant content designed for specific grades in accordance with the Curriculum and Assessment Policy Statements in most subjects.

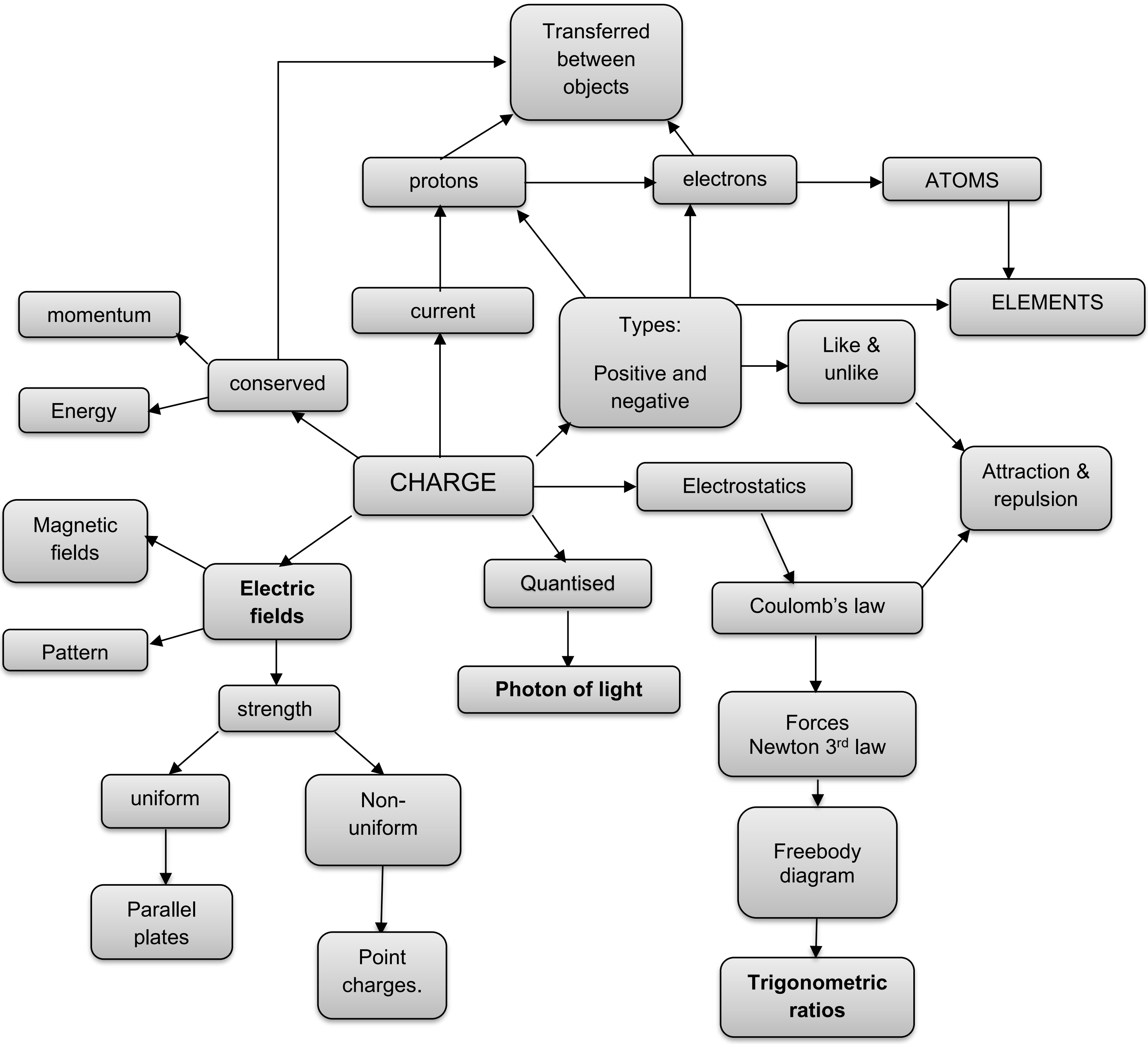
As part of mitigating against the impact of COVID-19 on the current Grade 12, the Department of Basic Education (DBE) worked in collaboration with subject specialists from various Provincial Education Departments (PEDs) developed this Self-Study Guide. The Study Guide covers those topics, skills and concepts that are located in Grade 12, that are critical to lay the foundation for Grade 12. The main aim is to close the pre-existing content gaps in order to strengthen the mastery of subject knowledge in Grade 12. More importantly, the Study Guide will engender the attitudes in the learners to learning independently while mastering the core cross-cutting concepts.

2. How to use this Self Study Guide?

This booklet is aimed at summarising important aspects in the study of Electrostatics. It is not aimed at replacing the prescribed textbook and it must be used in conjunction with the textbook and other relevant study materials. The booklet combines the definitions that have been provided since Grade 10, to show how the topic progresses up to Grade 12. It includes the examination guidelines, to provide guidance on how far the learner should go in terms of mastering the content. Additionally, misconceptions are clarified for ease of understanding. The exercises provided in this booklet will not ensure sufficient practise; therefore, the learner should supplement them with additional practise. Also read the side notes as they assist in clarifying the content.

3. ELECTROSTATICS (Charges at rest)

3.1 Mind map



DEFINITIONS	
Charge	It is a physical property of matter that causes it to experience a force when kept in electromagnetic field.
Principle of conservation of charge	The net charge of an isolated system remains constant during any physical process e.g. two charges making contact and then separating. The total (net) electric charge of an isolated system remains constant in any physical process.
Principle of charge quantization	All charges in the universe consist of an integer multiple of the charge on one electron, i.e. $1,6 \times 10^{-19}$ C
Polarization	The partial or complete polar separation of positive and negative electric charge in a system. A dipole.
Electric field lines	A way of representing an electric field. Arrows on the field lines indicate the direction of the field
Electric field	Is the region of space in which an electric charge experiences a force.
The direction of the electric field at a point	The direction that a positive test charge (+1C) would move if placed at that point
Electric field at a point (E)	The electrostatic force experienced per unit positive test charge placed at a point.
Coulomb's law	The magnitude of the electrostatic force exerted by one point charge Q_1 on another point charge Q_2 is directly proportional to the product of the two charges and inversely proportional to the square of the distance r between them.

3.2 Definitions and Objectives

Objectives
Coulomb's law
• State Coulomb's law: The magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance (r) between them:
• Solve problems using the equation $F = \frac{kQ_1Q_2}{r^2}$ for charges in one dimension (1D) (restrict to three charges).
• Solve problems using the equation $F = \frac{kQ_1Q_2}{r^2}$ for charges in two dimensions (2D) – for three charges in a right-angled formation (limit to charges at the 'vertices of a right-angled triangle').
Electric field
• Describe an *electric field* as a region of space in which an electric charge experiences a force. The direction of the electric field at a point is the direction that a positive test charge would move if placed at that point.
• Draw electric field patterns for the following configurations: ○ A single point charge ○ Two point charges (one negative, one positive OR both positive OR both negative) ○ A charged sphere **NOTE:** Restrict to situations in which the charges are identical in magnitude.
• Define the *electric field at a point*: The electric field at a point is the electrostatic force experienced per unit positive charge placed at that point. In symbols: $E = \frac{F}{q}$.
• Solve problems using the equation $E = \frac{F}{q}$.
• Calculate the electric field at a point due to a number of point charges, using the equation $E = \frac{kQ}{r^2}$ to determine the contribution to the field due to each charge. Restrict to three charges in a straight line.

3.3 Content

3.3.1 Study tips

Electrostatics requires a thorough revision of Vectors. You must be able to identify the forces that are acting on the charges and draw free body diagrams. Newton's third law applies in all force interactions. It is important to master Mathematical calculation of Trigonometric ratio of sin, cos and tan as Electrostatics involves triangles. You will be required to use Pythagoras theorem. Understand fields from grade 10 Magnetism.

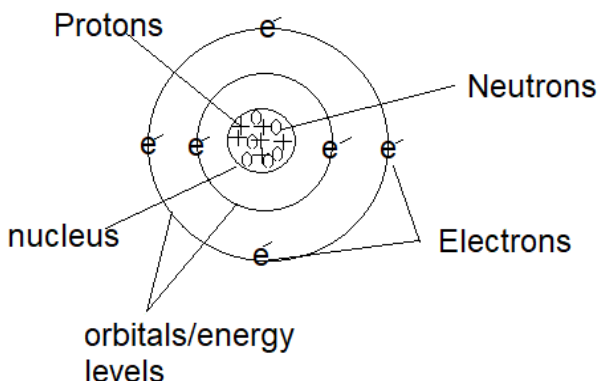
3.3.2 Charge

An atom is the basic unit of matter, it contains charges (protons and electrons).

Protons are positively charged, and electrons are negatively charged.

Bohrs' atomic model of carbon

Neutral atom



Electrons are the ones which are removed and transferred to the other object.

Charge is the fundamental quantities of electricity. It is fundamental to electricity as mass is to mechanics. It is associated with the atom and subatomic particles of material substances.

All matter contains charges.

The symbol of charge is (Q).

The SI unit of charge is coulomb (C).

Charge is conserved - the net charge in an isolated system remains constant during any physical interactions.

Example:

6 μC means 6 X 10^{-6}C

Conversion scale:

1 micro coulomb (μC)= 1x10^{-6}C

1nano Coulomb (nC)= 1x10^{-9}C

1pico coulomb (ρC) = 1x10^{-12}C

1 milli coulomb (mC) = 1x10^{-3}C

3.3.3 Principle/law of conservation of charge- the total (net) charge of an isolated system remains constant in any physical process.

Use the formula to apply the law of conservation of charge: $Q_{net} = \frac{Q_1 + Q_2}{2}$,

Note: if there are three charges touching simultaneously, add them and divide by three (3) and not two (2) as in the given equation.

$$\boxed{Q_{net} = \frac{Q_1 + Q_2 + Q_3}{3}}$$

Example:

Three metal spheres of equal size carry charges of -2 x 10^{-11} C, 5 x 10^{-11} C and -8 x 10^{-11} C respectively. They are brought into contact and then separated. What is the charge on each sphere after separation?

Solution:

charge on each sphere

$$Q_{net} = \frac{Q_1 + Q_2 + Q_3}{3}$$

$$Q_{net} = \frac{-2 \times 10^{-11} + 5 \times 10^{-11} + (-8 \times 10^{-11})}{3}$$

$$Q_{net} = -1.67 \times 10^{-11} C$$

Charge is **quantised** same as light. Quantised means charge is found in packets as eggs are sold in dozens, cold drinks in crates, etc. all charges are the multiples of the smallest charge, i.e., the charge of one electron is -1,6 X 10^{-19} C.

Getting the number of electrons transferred or added, we use the formula:

$$Q = n_{e^-} q_{e^-} \qquad\qquad n_{e^-} = \frac{Q}{-1.6 \times 10^{-19}}$$

Using the previous example: Calculate the number of electrons transferred or removed from the charge.

$$\Delta Q = Q_{final} - Q_{initial}$$

$$= -1.67 \times 10^{-11} - (-2 \times 10^{-11})$$

$$== 3.30 \times 10^{-12} C$$

$$Q = n_{e^-} q_{e^-}$$

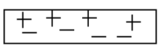
$$3.30 \times 10^{-12} = n_{e^-} 1.6 \times 10^{-19}$$

$$n_{e^-} = 2.63 \times 10^{7} \, electrons$$

Neutral charge- is an/a atom/material with equal number of protons and electrons.

Example:

In the diagram below the object contains four (4) protons and four (4) electrons

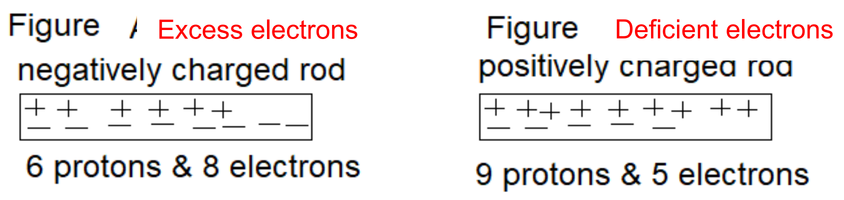


3.3.4 Types of charges

- Positive charge-proton
- Negative charge- electron

A positively charged object has more protons than electrons and a negatively charged object has more electrons than protons.

Example:



Note: In figure **A** electrons have been transferred to the object, and in figure **B** electrons have been removed.

Charging involves the transference/movement of **electrons** from one object to another.

3.3.5 How to charge

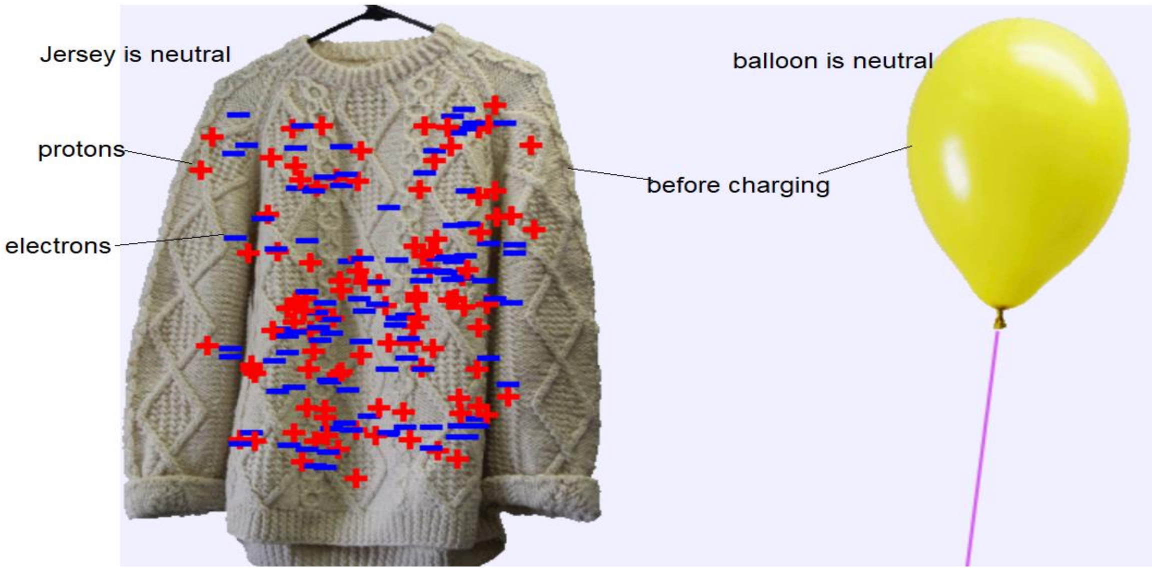
- By contact (friction) and
- Polarization or Induction.

Van de Graaf generator

Use to generate charges.

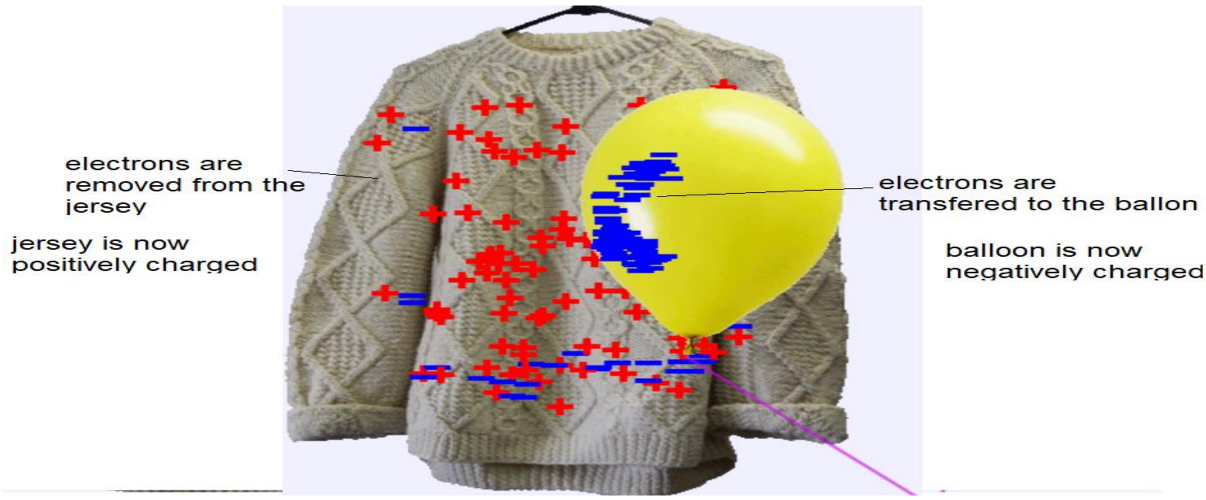
Charging by contact

Before



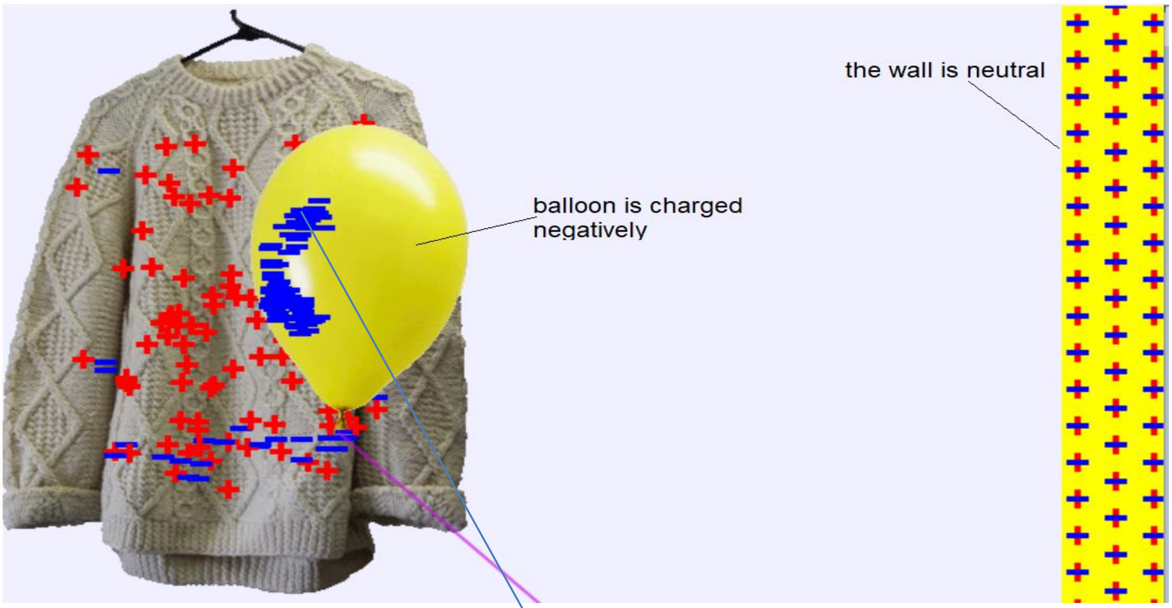
Picture courtesy of pHet simulations

After charging by contact

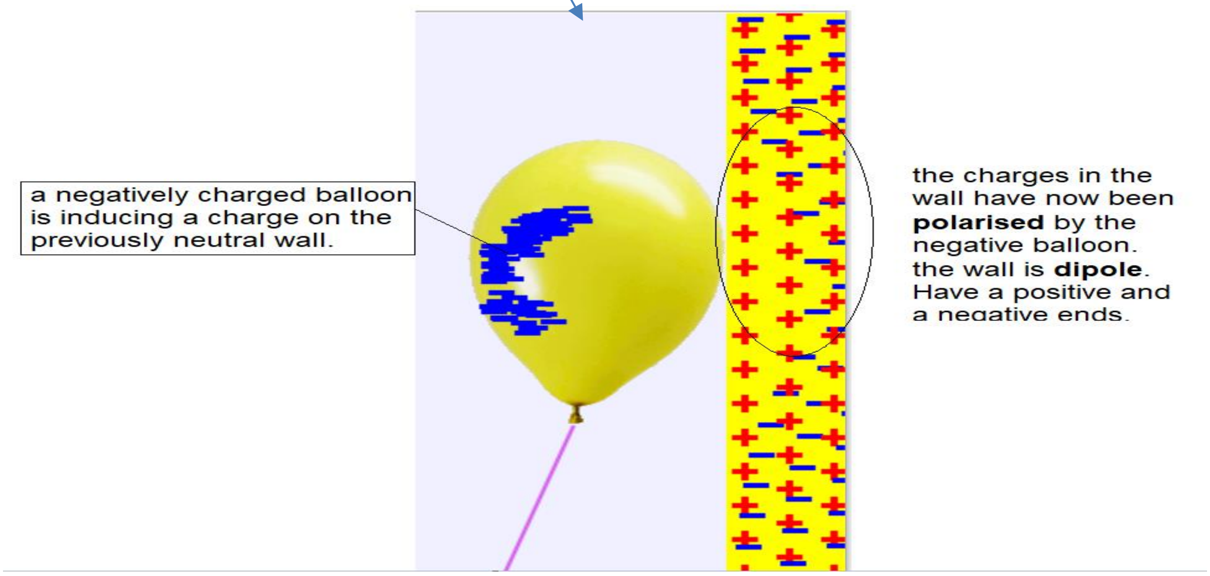


Picture courtesy of pHet simulations

Polarization of charge
Charging by induction



Using the charged balloon to charge the neutral wall.



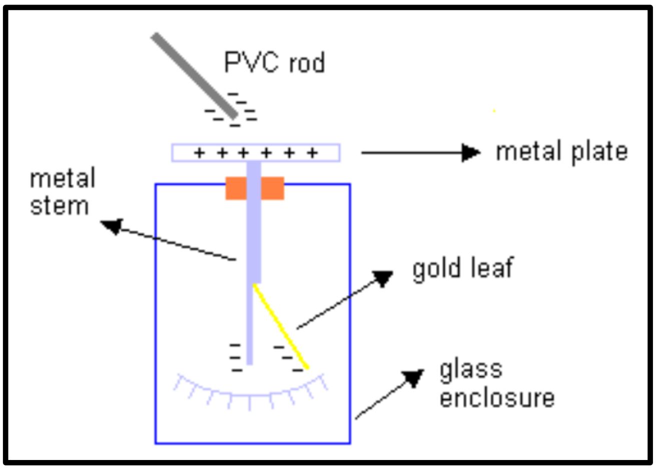
https://phet.colorado.edu/sims/html/balloons-and-static-electricity/latest/balloons-and-static-electricity_en.html use the link to download offline free simulations.

We use an **Electroscope:**

To detect whether an object is charged or not.

And determine the sign of the charge on charged object.

A **negatively charged rod** placed next to a metal causes the negative charges to be polarised to the gold leaf. Then the **gold leaf deflects** because of like charges.



3.3.6 Coulomb's law-Attraction and repulsion forces

Like charges repel each other, i.e., positive and positive; or negative and negative.

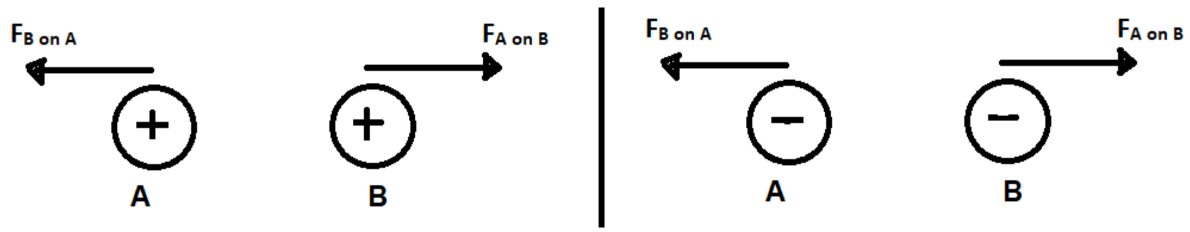


Diagram A

Unlike charges attract each other, i.e., negative and positive.

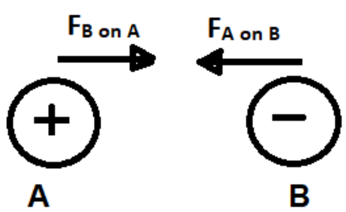


Diagram B

Coulomb's law

Coulomb's forces/electric/electrostatic force is one of the **four fundamental forces in nature**. Others include: Electromagnetic forces, weak and strong nuclear forces and gravitational force.

Electromagnetic forces are combination of electric and magnetic forces. They act from a distance.

NB: In both diagrams A and B, the objects exert equal but opposite forces on each other. **Newton's third law.**

All the four forces are examples of **conservative forces**.

Difference: gravitational force is only an attractive force, but electrostatic force is both attractive and repulsive forces.

Definition in words: Coulomb's law states that, the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the two charges and inversely proportional to the square of the distance (r) between them.

Mathematically

$$F = \frac{kQ_1Q_2}{r^2}$$

F – magnitude of force

r – distance between charges

Q_1 and Q_2 – magnitude of charges

$F \alpha Q_1Q_2$

$F \alpha \frac{1}{r^2}$

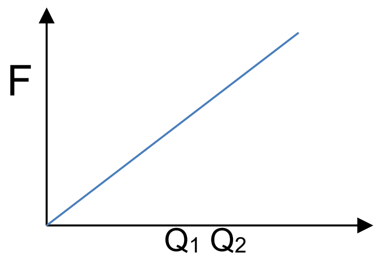
Directly proportional: when magnitude of charges increases, the force increases, vice versa.

Inversely proportional: when the distance between charges increases, the force decreases, vice versa

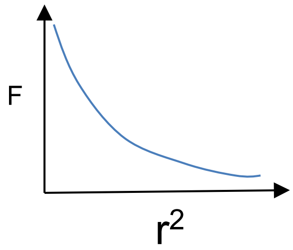
F

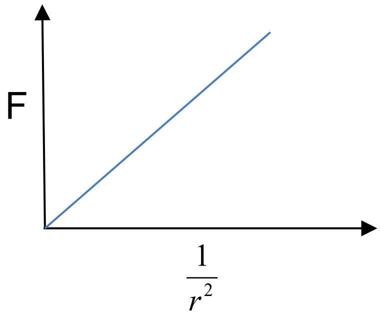
Formular will help you to remember the definition.

$F \alpha Q_1Q_2$ Definition Graphically



$F \alpha \frac{1}{r^2}$





Coulomb's law

$$F = \frac{kQ_1Q_2}{r^2}$$

Do not confuse this laws.
Similarities: both product of the quantities, inversely proportional to the square of the distance
Differences:
Different constant-
Coulomb is k and Newton is G
Coulomb: **attraction** and **repulsion**.
Newton is **attraction** only.
Newton- masses
Coulomb- charges

Newton – attraction only

Newton law of universal gravitation

$$F = \frac{Gm_1m_2}{r^2}$$

Example 1: What will be the magnitude of the electrostatic force between two charges Q_1 and Q_2 when the magnitude of both charges is doubled?

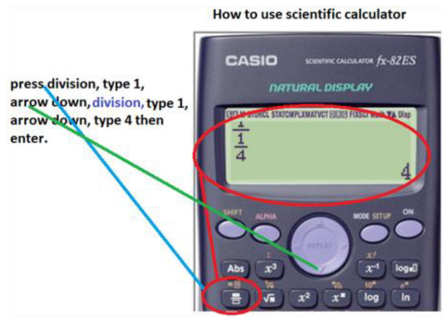
$$\begin{aligned} &F\,\alpha\, Q_1Q_2 \\ &F_{new}\,\alpha\, 2Q_1 2Q_2 \\ &F_{new}\,\alpha\, 4Q_1Q_2 \\ &F_{new}\,\alpha\, 4F \end{aligned}$$

Example 2: If charge Q_1 is halved and charge Q_2 is four times. What will be the magnitude of the electrostatic force?

$$\begin{aligned} &F\,\alpha\, Q_1Q_2 \\ &F_{new}\,\alpha\, \tfrac{1}{2}Q_1 4Q_2 \\ &F_{new}\,\alpha\, 2Q_1Q_2 \\ &F_{new}\,\alpha\, 2F \end{aligned}$$

Example 3: If the distance between two charges Q_1 and Q_2 is halved. What will be the force on each charge?

$$\begin{aligned} &F\,\alpha\, \frac{1}{r^2} \\ &F_{new}\,\alpha\, \frac{1}{(\frac{1}{2}r)^2} \\ &F_{new}\,\alpha\, \frac{1}{\frac{1}{4}} \times \frac{1}{r^2} \\ &F_{new}\,\alpha\, 4F \end{aligned}$$



Example 4: one of the charges is doubled and the distance is made a third. What will be the force?

$$F_{new}\,\alpha\, \frac{2Q_1Q_2}{(\frac{1}{3}r)^2}\,\alpha\, \frac{2}{\frac{1}{9}} \times \frac{Q_1Q_2}{r^2}\,\alpha\, 18F$$

Example 5: Two charges of magnitude +6nC and -3nC are placed 30mm apart. What is the magnitude and direction of the force acting on 6nC charge?

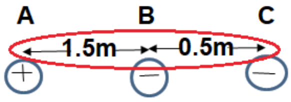
$$F = \frac{kQ_1Q_2}{r^2} = \frac{9\times10^{9}\times6\times10^{-9}\times3\times10^{-9}}{(\frac{30}{1000})^2} = 1.8\times10^{-4}\,N$$ Attraction to right

Convert 30 mm to metres by dividing by 1000.

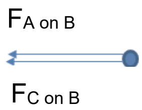
When substituting the charges in the equation do not include the negative sign of the charge

NB: Identify attraction and repulsion. Draw free body diagrams.

Charges in 1 dimension (1D): Identifying forces and free body diagram



net force acting at B freebody diagram



force of A on B is attractive to the left

force of C on B is also repulsive to the left

$$F_{net} = F_{A.on.B} + F_{C.on.B}$$

$$F_{net} = \frac{kQ_AQ_B}{r^2} + \frac{kQ_CQ_B}{r^2}$$

$$F_{net} = \frac{kQ_AQ_B}{1{,}5^2} + \frac{kQ_CQ_B}{0{,}5^2}$$

net force acting at C freebody diagram

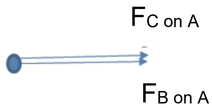
force of A on C is attractive to left
force of B on C is repulsive to the right

$$F_{net} = -F_{A.on.C} + F_{B.on.C}$$

$$F_{net} = -\frac{kQ_AQ_C}{r^2} + \frac{kQ_CQ_B}{r^2}$$

$$F_{net} = -\frac{kQ_AQ_C}{(1{,}5+0{,}5)^2} + \frac{kQ_CQ_B}{0{,}5^2}$$

net force acting at A freebody diagram



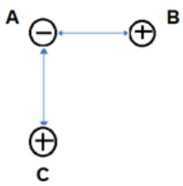
all forces acting on A attractive

$$F_{net} = F_{B.on.A} + F_{C.on.A}$$

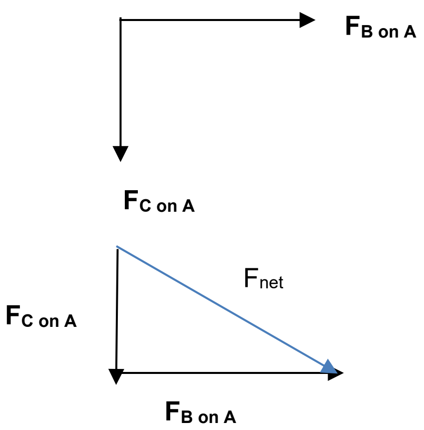
$$F_{net} = \frac{kQ_AQ_B}{r^2} + \frac{kQ_AQ_C}{r^2}$$

$$F_{net} = \frac{kQ_AQ_B}{(1{,}5)^2} + \frac{kQ_AQ_C}{(1{,}5+0{,}5)^2}$$

Charges in 2 dimension (2D): **Identifying forces and free body diagram**

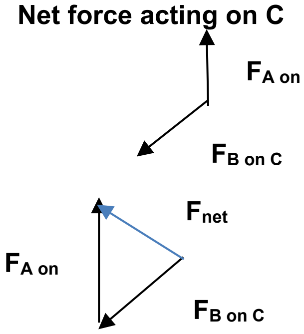


Net force acting on A



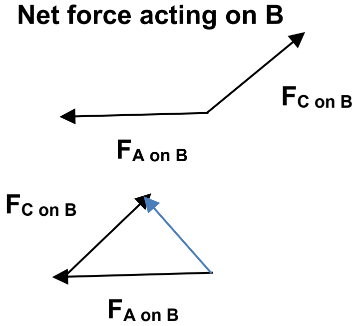
Use Pythagoras or trigonometric ratios to calculate.

Net force acting on C



Use sine rule.

Net force acting on B



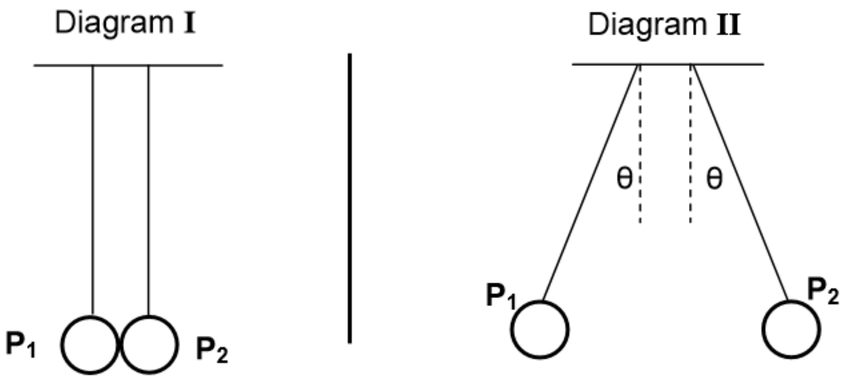
Use sine rule to calculate the values.

Use Pythagoras to resolve the forces.

$F^2_{net.A} = F^2_{c.on.A} + F^2_{B.on.A}$	or $F^2_{net} - F^2_{C.on.B} = F^2_B$	or $F^2_{net} - F^2_B = F^2_c$
$F^2_{net} = (\frac{kQ_cQ_A}{r^2})^2 + (\frac{kQ_BQ_A}{r^2})^2$	or $F^2_{net} - (\frac{kQ_BQ_C}{r^2})^2 = F^2_B$	or $F^2_{net} - (\frac{kQ_AQ_B}{r^2})^2 = F^2_c$

Example 6.1- Multiple Choice question

Two identical light graphite-coated spheres, **P_1** and **P_2**, are suspended using identical thin insulated threads. **P_1** is charged, but **P_2** is neutral. The spheres are then brought into contact with each other, as shown in diagram **I**. Thereafter the spheres assume the positions, as shown in diagram **II**.



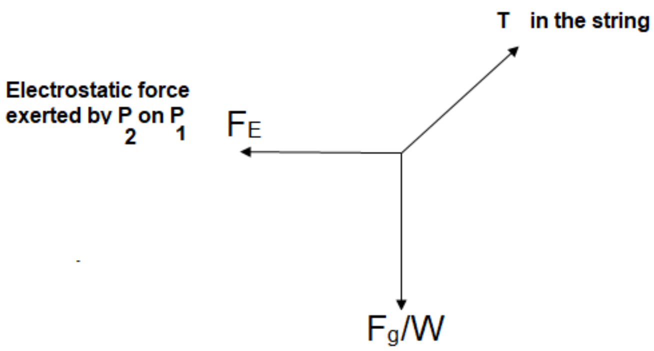
Which ONE of the following statements concerning the charges on the spheres possibly explains why the spheres move apart after touching, as shown in diagram **II**?

	SIGN OF CHARGE ON P_1	SIGN OF CHARGE ON P_2	MAGNITUDE OF CHARGES ON P_1 AND P_2
A	+	+	Unequal
B	-	-	Unequal
C	+	-	Equal
D	+	+	Equal

Answer: P_1 is charged, therefore when in contact with P_2 the electrons are going to be transferred. Charging by contact is taking place. After charging, distribution of charges is going to take place according to this equation, $Q = \frac{Q_1 + Q_2}{2}$ meaning both will acquire same (positive or negative) and equal charge. Force of repulsion will take place. So option C, D and B are close, but option C has a different sign, therefore option D is the correct One. Option A the problem is the unequal magnitude. Option B, is also repulsion but the problem is the unequal part.

Example 6.2:

Draw a free body diagram for all the forces acting on sphere P_1 in diagram 2 above.



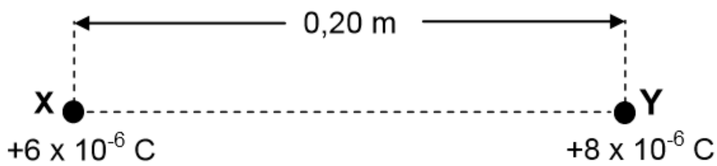
Exercise 6.3: do yourself:

Draw a free body diagram for all the forces acting on sphere P_2 in diagram 2 above.

Answer: For you to do.

Example 8:

Two small spheres, **X** and **Y**, carrying charges of +6 x 10^{-6} C and +8 x 10^{-6} C respectively, are placed 0,20 m apart in air.



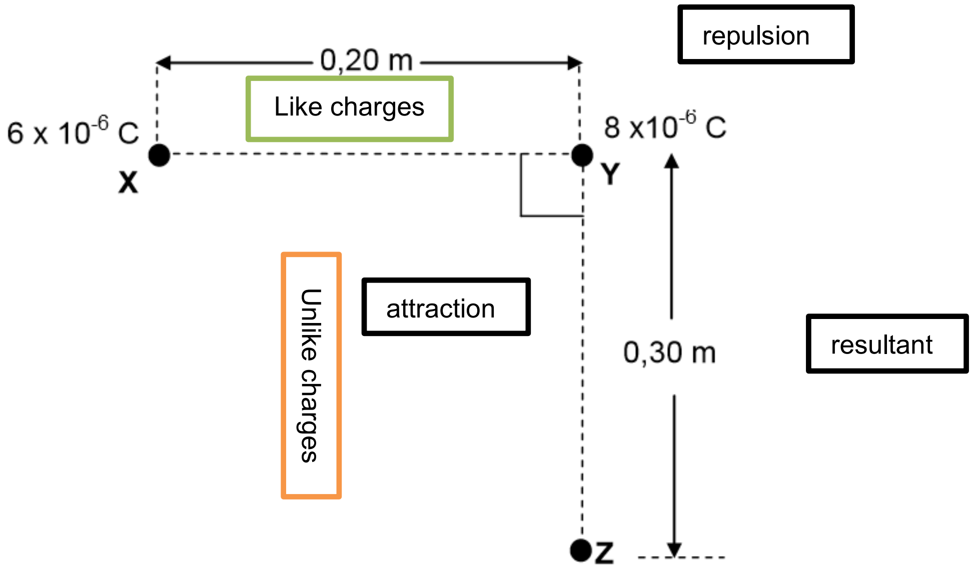
8.1 Calculate the magnitude of the electrostatic force experienced by charged sphere **X**.

$$F = \frac{kQ_1Q_2}{r^2}$$

$$F = \frac{9\times10^9 \times 6\times10^{-6} \times 8\times10^{-6}}{(0.2)^2}$$

$$F = 10.8N$$

A third sphere, **Z**, of unknown **negative** charge, is now placed at a distance of 0,30 m below sphere **Y**, in such a way that the line joining the charged spheres **X** and **Y** is perpendicular to the line joining the charged spheres **Y** and **Z**, as shown in the diagram below.



8.2 Draw a vector diagram showing the directions of the electrostatic forces **and** the net force experienced by charged sphere **Y** due to the presence of charged spheres **X** and **Z** respectively.

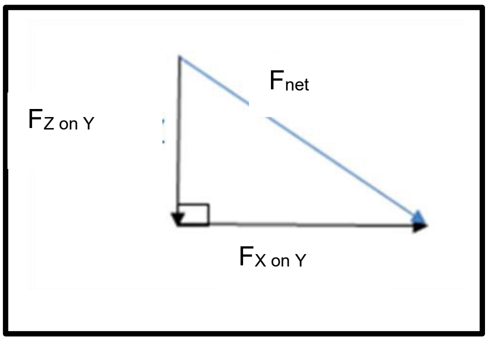
Answer:

Draw the vectors first. Show the correct direction.

Sphere Y has a positive charge and sphere Z is negative, therefore sphere Y will be attracted towards Z, **downwards**.

Sphere X is positive; therefore, sphere Y will be repelled away from sphere X to the **right**.

Vector diagram will be:

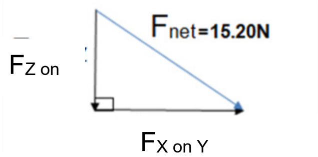


8.3 The magnitude of the net electrostatic force experienced by charged sphere **Y** is 15,20 N. Calculate the charge on sphere **Z**.

We use the **Theorem of Pythagoras** to calculate the force exerted by charge Z on sphere Y.

$$F_{net}{}^2 = F_{Z.on.Y}{}^2 + F_{X.on.Y}{}^2$$
$$15.20^2 = F_{Z.on.Y}{}^2 + 10.8^2$$
$$F_{Z.on.Y} = 10.70N$$

Complete a triangle of forces.



$$F = \frac{kQ_YQ_Z}{r^2}$$
$$10.70 = \frac{9\times10^9\times8\times10^{-6}\times Q_z}{0.30^2}$$
$$Q_z = 0.00001336875$$
$$Q_z = 1.34\times10^{-5}C$$

$F_{ZonY} = 0.70N$ is the force which sphere Y exert on sphere Z.

When using Coulomb's law, we must use the charge of Y with Z to get charge of Z.

3.3.7 Electric fields

We know magnets have **magnetic fields.** We define magnetic fields as a region in which a magnetic object will experience a force.

Gravitational field is a region in which a mass will experience a force.

The force of attraction and repulsion charges exert on each other is because of the electric field interaction.

Electric field is defined as the region in space in which an electric charge will experience a force.

Electric fields like magnetic field are represented by a pattern of **imaginary field lines**.

Properties of electric field lines

Field lines start on positive charge and ends on negative charge.

Fields lines never cross or touch each other.

Field lines are closer together in regions where the field is stronger and further apart in regions where the field is weak (non-uniform fields). Field lines are parallel where the field is uniform.

Electric fields are continuous.

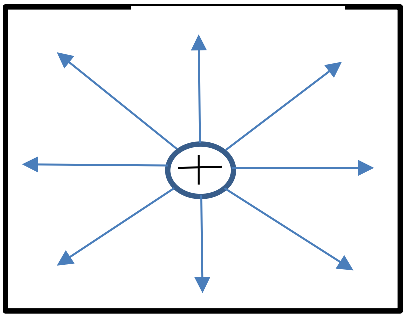
Field lines begin and end perpendicularly to the charged surface.

drawing electric field lines

Point charge

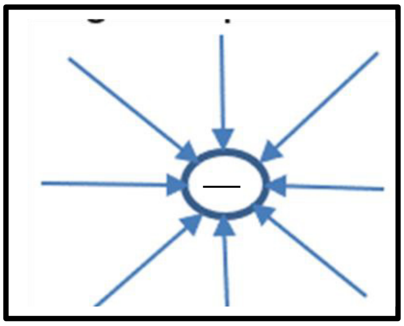
Electric fields point AWAY from a point charge

Positive point charge



Do not forget to draw the arrows.

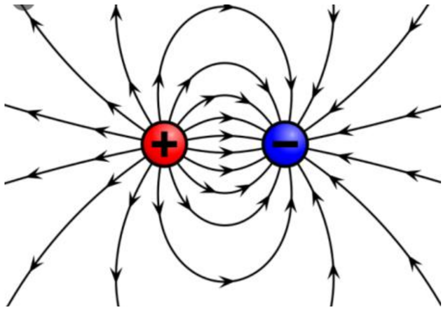
negative point charge



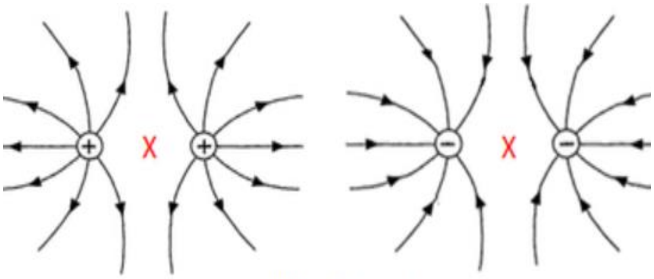
Electric fields point TOWARDS a point charge

Interaction of point charges due to their Electric fields

Attraction-unlike charges



Repulsion



Like Charges

3.3.8 Electric field at a point

Electric field at a point is the electrostatic force experienced per unit positive test charge placed at that point.

Symbol **E**

Unit is **N.C^{-1}**

E is a vector **quantity**

Mathematically:

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

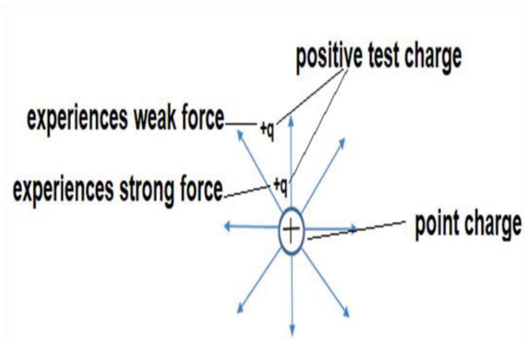
F- the force experienced by q.

q- the positive test charge.

$$E \alpha F$$

$$E \alpha \frac{1}{q}$$

When electric field at a point Increases, the force increases. Increasing the magnitude of a test charge, the electric field at a point decreases



Electric fields are non-uniform.

The Electric field decreases as the test charge moves away from the point charge.

Test charge experiences different forces at different distances.

Example 9:

Calculate the magnitude of the force exerted on a charge of 8μ placed in an electric field at a point of 4 X 10^4N.C^{-1}.

$$E = \frac{F}{q}$$
$$4\times10^4 = \frac{F}{8\times10^{-6}}$$
$$F = 0.32N$$

Convert 8μ into Coulomb

Coulomb's law and Electric field at a point both have forces, another formula to calculate Electric field at a point.

$$F = \frac{kQq}{r^2} \quad E = \frac{F}{q}$$

All experiences the same **Force (Newton's 3rd law)**, therefore, equating the two equations:

$$\frac{kQq}{r^2} = Eq$$

test charge **q** is cancelling out.

$$\therefore E = \frac{kQ}{r^2}$$

Q is the point charge.

Example 9:

Calculate the electric field at a point at 5mm from a point of charge of $-5\mu C$.

$$E = \frac{kQ}{r^2}$$
$$E = \frac{9\times10^9\times5\times10^{-6}}{(5\times10^{-3})^2}$$
$$E = 1.8\times10^9\,N.C^{-1}$$

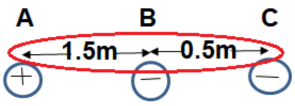
Convert 5mm to m.

$5/1000$

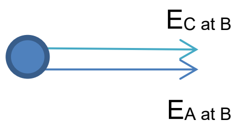
Convert microcoulomb to Coulomb

Charges in 1 Dimension: for Electric field at a point

Since $E = \frac{F}{q}$ what happens in the Force also happens in the Electric field at a point.



E acting at B freebody diagram



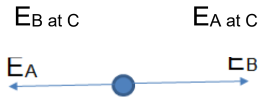
E of A and B are all to the right.

$$E_{net} = E_{A.at.B} + E_{C.at.B}$$

$$E_{net} = \frac{kQ_{AatB}}{r^2} + \frac{kQ_{CatB}}{r^2}$$

$$E_{net} = \frac{kQ_{AatB}}{1{,}5^2} + \frac{kQ_{CatB}}{0{,}5^2}$$

E acting at C freebody diagram



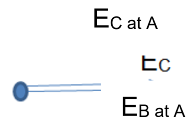
E of A is to the right and E of B is left Choose right as positive

$$E_{net} = E_{A.at.C} + E_{B.at.C}$$

$$E_{net} = -\frac{kQ_{AatC}}{r^2} + \left(-\frac{kQ_{BatC}}{r^2}\right)$$

$$E_{net} = \frac{kQ_{AatC}}{(1{,}5+0{,}5)^2} - \frac{kQ_{CatB}}{0{,}5^2}$$

E acting at A freebody diagram



all E acting on A attractive

$$E_{net} = E_{B.at.A} + E_{C.at.A}$$

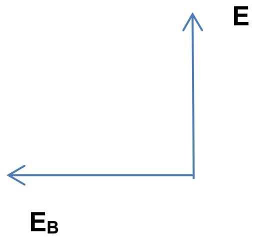
$$E_{net} = -\frac{kQ_{BatA}}{r^2} + \frac{kQ_{CatA}}{r^2}$$

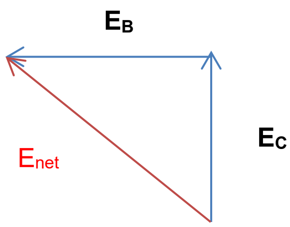
$$E_{net} = -\frac{kQ_{AatB}}{1{,}5^2} + \frac{kQ_{CatB}}{(1{,}5+0{,}5)^2}$$

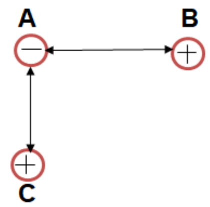
Distance between A and C, add AB and BC

Not Examinable for enrichment purposes. Charges in 2 Dimension: for Electric field at a point:

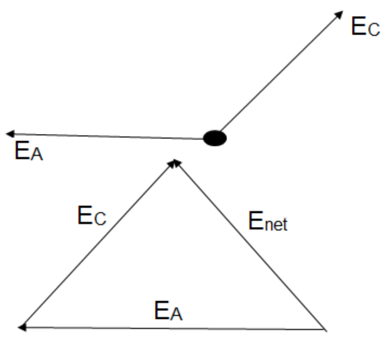
E_{net} acting at point A due to E_C and E_B freebody diagram



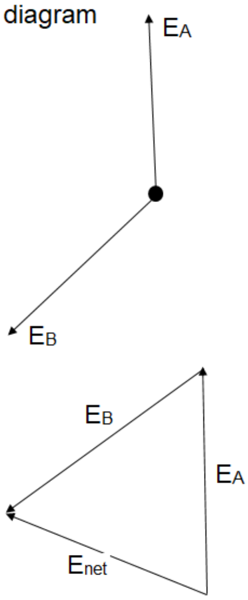




E_{net} acting at point B due to E_A and E_C freebody diagram



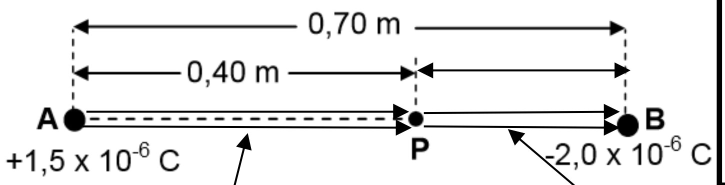
E_{net} acting at point C due to E_A and E_B freebody diagram



Use cosine and sine rule

Example 10

A and **B** are two small spheres separated by a distance of 0,70 m. Sphere **A** carries a charge of +1,5 x 10^{-6} C and sphere **B** carries a charge of -2,0 x 10^{-6} C.



Direction of Fields of both A and B at point P are to the right. Choose Right as positive.

P is a point between spheres **A** and **B** and is 0,40 m from sphere **A**, as shown in the diagram above.

10.1 Calculate the magnitude of the net electric field at point **P**.

Distance between sphere B and point P is 0.7 – 0.40= 0.3m

Check: Sphere A **field lines** will be directed to the right and sphere B **field lines** are to the right. Therefore, we choose **right as positive**

Remember not to substitute the negative sign in the formula.

$$\therefore E_{net} = E_A + E_B$$

$$E_{net} = \frac{kQ_A}{r^2} + \frac{kQ_B}{r^2}$$

$$E_{net} = \frac{9\times10^9 \times 1.5\times10^{-6}}{0.4^2} + \frac{9\times10^9 \times 2\times10^{-6}}{0.3^2}$$

$$E_{net} = 284375 N.C^{-1} right$$

10.2 A point charge of magnitude 3,0 x 10^{-9} C is now placed at point **P**.

Calculate the magnitude of the electrostatic force experienced by this charge.

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

$$284375 = \frac{F}{3.0\times10^{-9}}$$

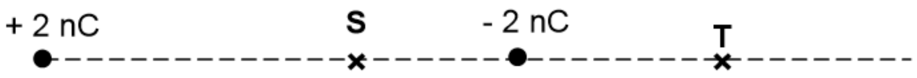
$$F = 8.53\times10^{-4} N$$

3.4 Questions

3.4.1 Multiple Choice

Question 1

1.1 Two charges of + 2 nC and - 2 nC are located on a straight line. **S** and **T** are two points that lie on the same straight line as shown in the diagram below.



Which ONE of the following correctly represents the directions of the RESULTANT electric fields at **S** and at **T**?

	DIRECTION OF THE RESULTANT ELECTRIC FIELD AT POINT S	**DIRECTION OF THE RESULTANT ELECTRIC FIELD AT POINT T**
A	Right	Left
B	Left	Left
C	Right	Right
D	Left	Right

1.2 The magnitude of an electric field, a distance r from a point charge is $\boldsymbol{E}$. The magnitude of an electric field, a distance $2r$ from the same point charge will be …

A $\frac{1}{4}\boldsymbol{E}$

B $\frac{1}{2}\boldsymbol{E}$

C $2\boldsymbol{E}$

D $4\boldsymbol{E}$

1.3 Two charged spheres of magnitudes 2Q and Q respectively are placed a distance r apart on insulating stands.

If the sphere of charge Q experiences a force **F** to the east, then the sphere of charge 2Q will experience a force …

A **F** to the west.

B **F** to the east.

C 2**F** to the west.

D 2**F** to the east.

1.4 P, Q and R are three charged spheres. When P and Q are brought near each other, they experience an attractive force. When Q and R are brought near each other, they experience a repulsive force.

Which ONE of the following is TRUE?

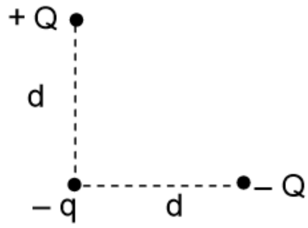
A P and R have charges with the same sign.

B P and R have charges with opposite signs.

C P, Q and R have charges with the same sign.

D P, Q and R have equal charges.

1.5 Two charges, + Q and – Q, are placed a distance d from a negative charge – q. The charges, + Q and – Q, are located along lines that are perpendicular to each other as shown in the diagram below.



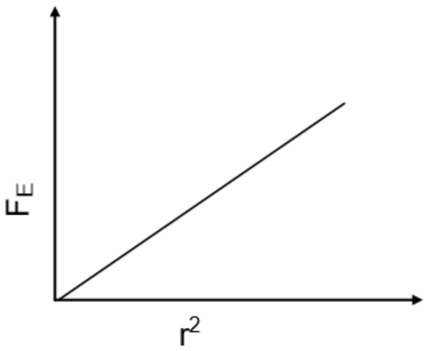
Which ONE of the following arrows CORRECTLY shows the direction of the net force acting on charge – q due to the presence of charges + Q and – Q?

A	→
B	↗
C	↖
D	←

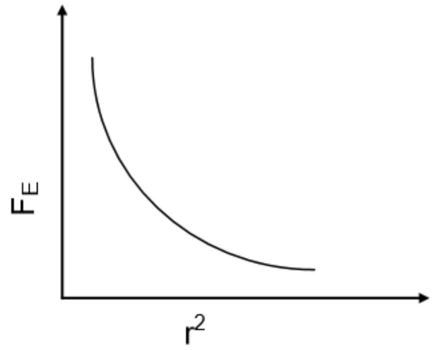
1.6 Two charged particles are placed a distance, r, apart. The electrostatic force exerted by one charged particle on the other is F_E

Which ONE of the graphs below CORRECTLY represents the relationship between the electrostatic force, F_E, and the square of the distance, r^2, between the two charges?

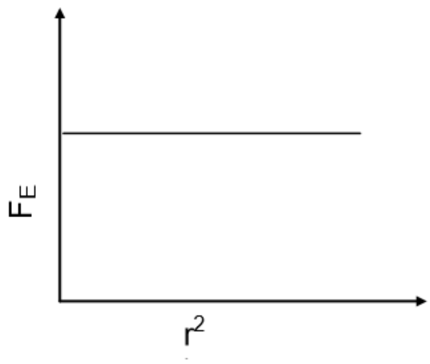
A



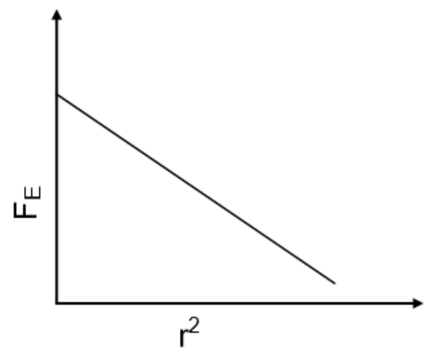
B



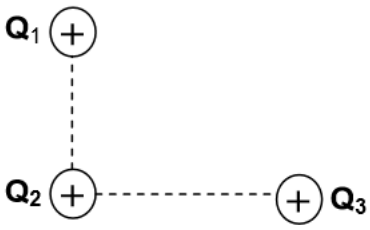
C



D



1.7 Three identical positive point charges, $\mathbf{Q_1}$, $\mathbf{Q_2}$ and $\mathbf{Q_3}$, are initially situated on a smooth flat table at the corners of a right-angled triangle. The diagram below shows the charges as viewed from above.

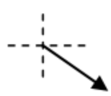


Which ONE of the following diagrams shows the direction in which $\mathbf{Q_2}$ will move as a result of the electrostatic forces exerted by $\mathbf{Q_1}$ and $\mathbf{Q_3}$ on it?

A 

B 

C 

D 

1.8 The magnitude of the electrostatic force on a charge $\mathbf{Q_1}$ due to another charge $\mathbf{Q_2}$ is **F**. Both charges are now doubled without changing the distance between them.

The magnitude of the new electrostatic force on $\mathbf{Q_1}$ will be:

A $\frac{\mathbf{F}}{2}$

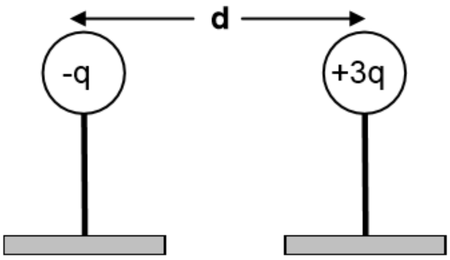
B 2**F**

C 4**F**

D 6**F**

1.9 Two small identical metal spheres, on insulated stands, carry charges -q and +3q respectively.

When the centres of the spheres are a distance **d** apart, the spheres exert an electrostatic force of magnitude ***F*** on each other.



The spheres are now made to touch and are brought back to the **same positions** as before.

The magnitude of the electrostatic force which the spheres now exert on each other, in terms of ***F***, is:

A $\frac{4}{3}\boldsymbol{F}$

B $\frac{1}{3}\boldsymbol{F}$

C $\frac{1}{2}\boldsymbol{F}$

D 3***F***

1.10 Particle P has charge Q and particle R has charge 2Q. They are separated by a small distance, *r*.

Which ONE of the statements below about the electrostatic forces, F_{PR}, which P exerts on R and F_{RP}, which R exert on P, is CORRECT?

A $F_{PR} = ½F_{RP}$

B $F_{PR} = F_{RP}$

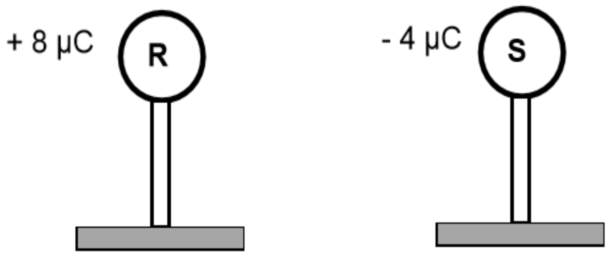
C $F_{PR} = 2F_{RP}$

D $F_{PR} = -F_{RP}$

3.4.2 Structured Questions

Question 2

The diagram below shows two small identical metal spheres, **R** and **S**, each placed on a wooden stand. Spheres **R** and **S** carry charges of + 8 μC and - 4 μC respectively. Ignore the effects of air.



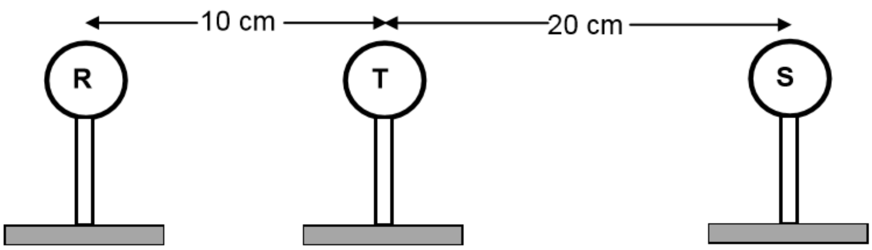
2.1 Explain why the spheres were placed on wooden stands. (1)

Spheres **R** and **S** are brought into contact for a while and then separated by a small distance.

2.2 Calculate the net charge on each of the spheres. (2)

2.3 Draw the electric field pattern due to the two spheres **R** and **S**. (3)

After **R** and **S** have been in contact and separated, a third sphere, **T**, of charge + 1 μC is now placed between them as shown in the diagram below.



2.4 Draw a free-body diagram showing the electrostatic forces experienced by sphere **T** due to spheres **R** and **S**. (2)

2.5 Calculate the net electrostatic force experienced by **T** due to **R** and **S**. (6)

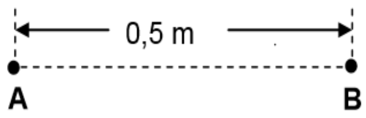
2.6 Define the *electric field at a point*. (2)

2.7 Calculate the magnitude of the net electric field at the location of **T** due to **R** and **S**. (Treat the spheres as if they were point charges.) (3)

[19]

Question 3

Two identical negatively charged spheres, **A** and **B**, having charges of the **same magnitude**, are placed 0,5 m apart in vacuum. The magnitude of the electrostatic force that one sphere exerts on the other is 1,44 x 10^{-1} N.



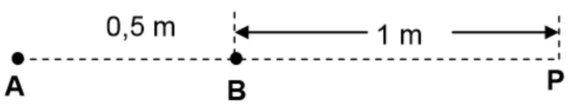
3.1 State Coulomb's law in words. (2)

3.2 Calculate the:

3.2.1 Magnitude of the charge on each sphere (4)

3.2.2 Excess number of electrons on sphere **B** (3)

3.3 **P** is a point at a distance of 1 m from sphere **B**.



3.3.1 What is the direction of the net electric field at point **P**? (1)

3.3.2 Calculate the number of electrons that should be removed from sphere **B** so that the net electric field at point **P** is 3 x 10^4 N·C^{-1} to the right. (8)

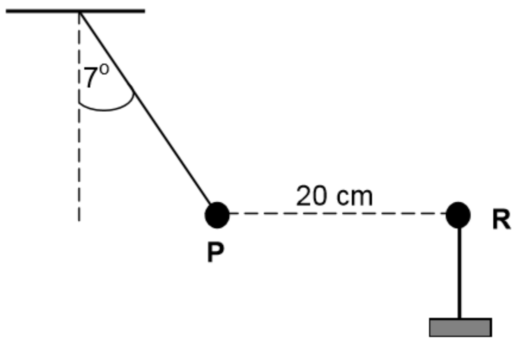
[18]

Question 4

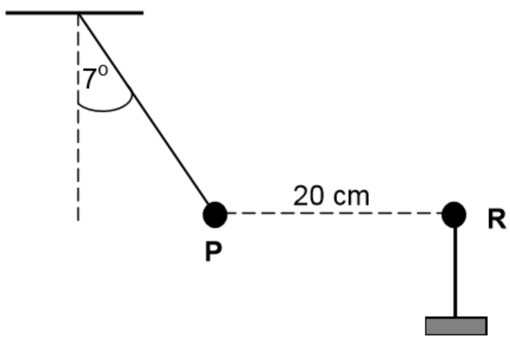
A very small graphite-coated sphere **P** is rubbed with a cloth. It is found that the sphere acquires a charge of + 0,5 μC.

4.1 Calculate the number of electrons removed from sphere **P** during the charging process. (3)

Now the charged sphere **P** is suspended from a light, inextensible string. Another sphere, **R**, with a charge of – 0,9 μC, on an insulated stand, is brought close to sphere **P**. As a result sphere **P** moves to a position where it is 20 cm from sphere **R**, as shown below. The system is in equilibrium and the angle between the string and the vertical is 7°.



Now the charged sphere **P** is suspended from a light, inextensible string. Another sphere, **R**, with a charge of – 0,9 μC, on an insulated stand, is brought close to sphere **P**. As a result sphere **P** moves to a position where it is 20 cm from sphere **R**, as shown below. The system is in equilibrium and the angle between the string and the vertical is 7°.



4.2 Draw a labelled free-body diagram showing ALL the forces acting on sphere **P**. (3)

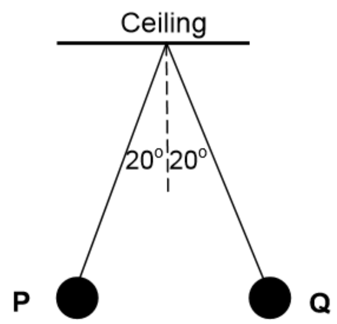
4.3 State Coulomb's law in words. (2)

4.4 Calculate the magnitude of the tension in the string. (5)

[13]

Question 5

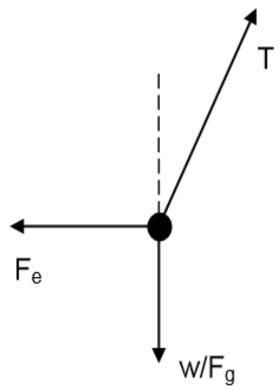
Two identical spherical balls, **P** and **Q**, each of mass 100 g, are suspended at the same point from a ceiling by means of identical light, inextensible insulating strings. Each ball carries a charge of +250 nC. The balls come to rest in the positions shown in the diagram below.



5.1 In the diagram, the angles between each string and the vertical are the same. Give a reason why the angles are the same. (1)

5.2 State Coulomb's law in words. (2)

5.3 The free-body diagram, not drawn to scale, of the forces acting on ball **P** is shown below.



Calculate the:

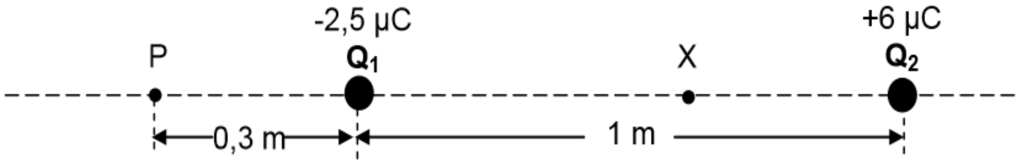
5.3.1 Magnitude of the tension (T) in the string (3)

5.3.2 Distance between balls **P** and **Q** (5)

[11]

Question 6

A sphere Q_1, with a charge of -2,5 μC, is placed 1 m away from a second sphere Q_2, with a charge +6 μC. The spheres lie along a straight line, as shown in the diagram below. Point **P** is located a distance of 0,3 m to the left of sphere Q_1, while point **X** is located between Q_1 and Q_2. The diagram is not drawn to scale.



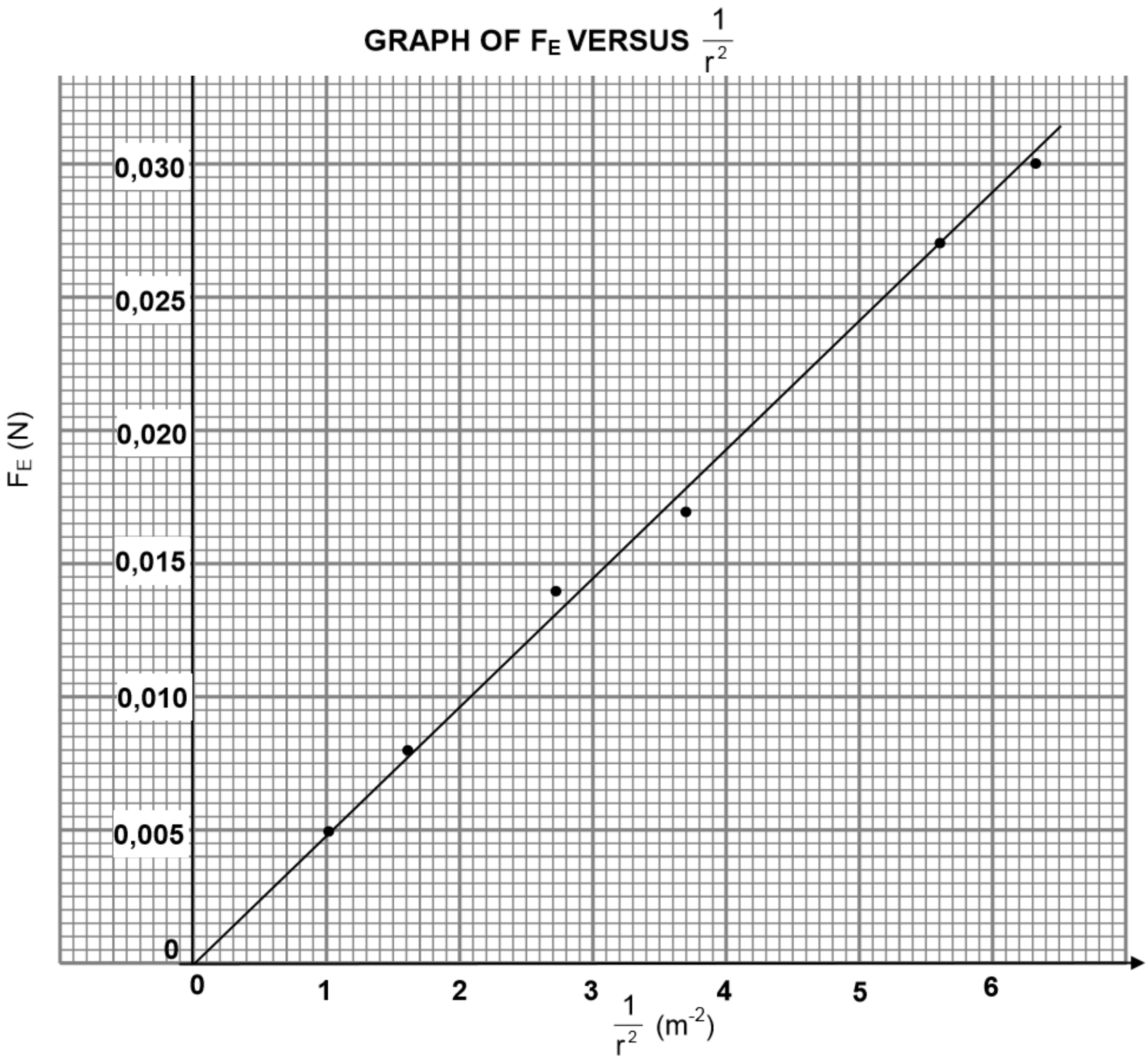
6.1 Show, with the aid of a VECTOR DIAGRAM, why the net electric field at point **X** *cannot be zero.* (4)

6.2 Calculate the net electric field at point **P**, due to the two charged spheres Q_1 and Q_2. (6)

[10]

Question 7

7.1 In an experiment to verify the relationship between the electrostatic force, F_E, and distance, r, between two **identical**, positively charged spheres, the graph below was obtained.



7.1.1 State Coulomb's law in words. (2)

7.1.2 Write down the dependent variable of the experiment. (1)

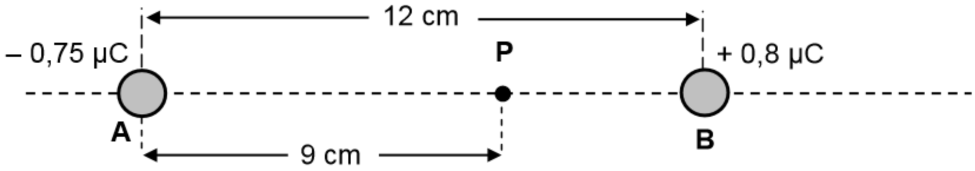
7.1.3 What relationship between the electrostatic force F_E and the square of the distance, r^2, between the charged spheres can be deduced from the graph? (1)

7.1.4 Use the information in the graph to calculate the charge on each sphere. (6)

7.2 A charged sphere, **A**, carries a charge of – 0,75 μC.

7.2.1 Draw a diagram showing the electric field lines surrounding sphere **A**. (2)

Sphere **A** is placed 12 cm away from another charged sphere, **B**, along a straight line in a vacuum, as shown below. Sphere **B** carries a charge of +0,8 μC. Point **P** is located 9 cm to the right of sphere **A**.



7.2.2 Calculate the magnitude of the net electric field at point **P**. (5)
[17]

4. Solutions

4.1 Multiple Choice

Question 1

1.1 A

1.2 A $E\alpha\frac{1}{r^2}\alpha\frac{1}{(2r)^2}\alpha\frac{1}{4r^2}\alpha\frac{1}{4}E$

1.3 A Newton's third law.

1.4 B

1.5 C

1.6 B

1.7 C

1.8 C $F\alpha 2Q2Q\alpha 4F$

1.9 B $F\alpha 1q3q\alpha 3F.......F=1q1q\alpha 1F.....F\alpha\frac{1}{3}F$

1.10 D Newton's third law

4.2 Structured Questions

Question 2

2.1 To ensure that charge does not leak to the ground/insulated. ✓

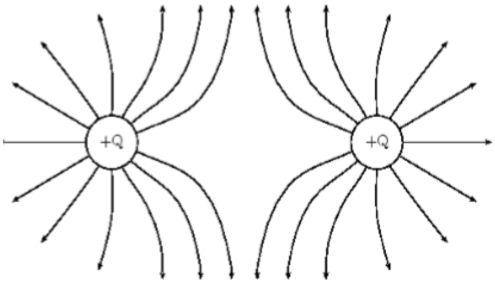
(1)

Notes Accept In order retain original charge✓/To insulate the charges.

2.2 Net charge $= \dfrac{Q_R + Q_S}{2} = \dfrac{+8 + (-4)}{2}$ ✓ $= 2\ \mu C$✓

(2)

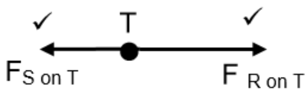
2.3



Criteria for sketch:	Marks
Correct direction of field lines	✓
Shape of the electric field	✓
No field line crossing each other / No field lines inside the spheres/	✓

(3)

2.4



(2)

2.5

$F = k\dfrac{Q_1Q_2}{r^2}$ ✓

$F_{ST} = (9\times10^9)\dfrac{(1\times10^{-6})(2\times10^{-6})}{(0,2)^2}$ ✓ ✓ $= 0,45\ N\ /\ 4,5 \times 10^{-1}\ N$

OR

$F_{TS} = \dfrac{1}{4}F_{RT} = \dfrac{1}{4}(1,8) = 0,45\ N$

$F_{RT} = 9\times10^9 \times \dfrac{(2\times10^{-6})(1\times10^{-6})}{(0,1)^2}$ ✓ $= 1,8\ N$ right

OR/*OF*

$F_{RT} = 4F_{ST} = 4(0,45) = 1,8\ N$ right

$F_{net} = F_{ST} + F_{RT} = \underline{1,8 + (-0,45)}$ ✓

$= \underline{1,35\ N}$ or towards sphere S or. right *S*✓

Right: both charges have equal magnitude but R has a smaller r therefore force exerted will be bigger.

(6)

2.6 Force experienced ✓per unit positive charge ✓placed at that point. (2)

2.7

OPTION 1
$E = \frac{F}{q}$ ✓ $= \frac{1{,}35}{1\times10^{-6}}$ ✓$= 1{,}35 \times 10^{6}\ N{\cdot}C^{-1}$ ✓

(3)

OPTION 2
$E_R = \frac{kQ}{r^2}$ ✓ $= \frac{(9\times10^{9})(2\times10^{-6})}{(0{,}1)^2}$ ✓$= 1{,}8 \times 10^{6}\ N{\cdot}C^{-1}$ right
$E_s = \frac{kQ}{r^2} = \frac{(9\times10^{9})(2\times10^{-6})}{(0{,}2)^2} = 4{,}5 \times 10^{5}\ N{\cdot}C^{-1}$ left
$E_{net} = 1{,}8 \times 10^{6} - 4{,}5 \times 10^{5} = 1{,}35 \times 10^{6}\ N{\cdot}C^{-1}$ ✓
OPTION 3
$E = \frac{F}{q}$ ✓ $= \frac{1{,}8}{1\times10^{-6}}$ ✓$= 1{,}8 \times 10^{6}\ N{\cdot}C^{-1}$
$E = \frac{F}{q} = \frac{0{,}45}{1\times10^{-6}} = 4{,}5 \times 10^{5}\ N{\cdot}C^{-1}$
$E_{net} = 1{,}8 \times 10^{6} - 4{,}5 \times 10^{5} = 1{,}35 \times 10^{6}\ N{\cdot}C^{-1}$ ✓

(3)

(3)
[19]

Question 3

3.1 The net electrostatic force on a charged particle due to the presence of another charged particle is directly proportional to the product of the charges✓and inversely proportional to the square of the distance between them ✓

3.2

3.2.1 $F = \frac{KQ_1Q_2}{r^2}$ ✓

$1{,}44 \times 10^{-1} = \frac{(9\times10^{9})Q^2}{(0{,}5)^2}$ ✓

$Q = 2 \times 10^{-6}$ C✓ (4)

3.2.2

Q = ne✓

$2 \times 10^{-6} = n(1{,}6 \times 10^{-19})$ ✓

$n = 1{,}25 \times 10^{13}$ electrons (3)

3.3

3.3.1 Left (west) ✓ (1)

3.3.2 Take right as positive

$E_{net} = E_A + E_B$ ✓

$$(3\times10^4) = -\frac{(9\times10^9)(2\times10^{-6})}{(1,5)^2} + \frac{(9\times10^9)Q_{final}}{(1)^2}$$ ✓ ✓

$Q_{final} = 4,22 \times 10^{-6}$ C ✓

Q = ne

$4,22 \times 10^{-6} = n(1,6\times10^{-19})$ ✓

$n_f = 2,64 \times 10^{13}$ electrons ✓

electrons removed

$= (2,64 \times 10^{13} + 1,25 \times 10^{13})$ ✓

$= 3,89 \times 10^{13}$ electrons ✓ (8)

[18]

Notes / *Aantekeninge*

No. electrons should be removed $= n_f - n_i$

allocate the 1 mark for the subtraction

Question 4

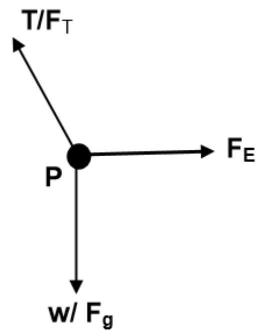
4.1

$$n = \frac{Q}{e}$$ ✓

$$n = \frac{0,5\times10^{-6}}{1,6\times10^{-19}}$$ ✓

$n = 3,13 \times 10^{12}$ ✓ electrons (3)

4.2



Accepted labels/*Aanvaarde benoemings*	
w	F_g / F_w / weight / mg / gravitational force
T	F_T / tension
F_E	Electrostatic force/F_C/ Coulombic force/F_Q /$F_{RP/PR}$

(3)

4.3 The magnitude of the electrostatic force exerted by one point charge (Q_1) on another point charge (Q_2) is directly proportional to the product of the (magnitudes of the) charges and inversely proportional to the square of the distance (r) between them. ✓✓ (2)

4.4

OPTION 1/*OPSIE 1*
$F_E = k\dfrac{Q_1Q_2}{r^2}$ ✓
$T\sin\theta/(T\cos\theta) = F_E$
$\therefore T\sin7^o/(T\cos83^o)$ ✓ $= \dfrac{(9\times10^9)(0,5\times10^{-6})(0,9\times10^{-6})}{(0,2)^2\ ✓}$ ✓
$\therefore T = 0,83$ N✓ (Accept)

(5)
[15]

Question 5

5.1 The magnitude of the charges are equal✓/ The balls repel each other with the same/identical force or force of equal magnitude✓ (1)

5.2 The electrostatic force of attraction between two point charges is <u>directly proportional to the product of the charges</u> ✓and <u>inversely proportional to the square of the distance between them</u>. ✓ (2)

5.3

5.3.1 $T\cos20^o = w$✓

$= mg$

$= (0,1)(9,8)$✓ $= 0,98$ N

$\therefore T = 1,04$ N✓ (3)

5.3.2 **POSITIVE MARKING FROM 7.3**

$F_{electrostatic} = T\sin20^o$✓

$\dfrac{kQ_1Q_2}{r^2}$ ✓$= (1,04)\sin20^o$

$\dfrac{kQ_1Q_2}{r^2} = 0,356$

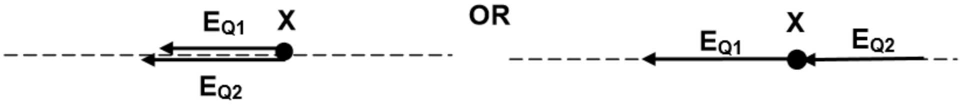
$\dfrac{(9\times10^9)(250\times10^{-9})(250\times10^{-9})}{r^2}$ ✓$= 0,356$✓

$\therefore r = 0,0397$ m ✓ (5)

[11]

Question 6

6.1



Vectors E_{Q1} and E_{Q2} in the same direction✓✓
Correct drawing of vectors E_{Q1} and E_{Q2}✓✓
The fields due to the two charges add up because they come from the same direction. Hence the field cannot be zero.

(4)

6.2 $E = k\frac{Q}{r^2}$ ✓

$E_{-2,5\mu C} = k\frac{Q}{r^2} = \frac{(9\times10^9)(2,5\times10^{-6})}{(0,3)^2}$✓ $= 250\ 000\ N.C^{-1}$ to the left

$E_{6\ \mu C} = k\frac{Q}{r^2} = \frac{(9\times10^9)(6\times10^{-6})}{(1,3)^2}$✓ $=31\ 952,66\ N.C^{-1}$ to the left

$E_P = E_{6\mu C} + E_{-2,5\mu C}$ ✓
$= 31\ 952,66 + 250\ 000$
$= 281\ 952,66\ N.C^{-1}$ ✓to the left ✓ (6)
[10]

Question 7

7.1.1 The (magnitude of the) electrostatic force exerted by one (point) charge on another is directly proportional to the product of the charges ✓ and inversely proportional to the square of the distance between their (centres) them. ✓ (2)

(1)

7.1.2 F_E/Electrostatic force ✓

7.1.3 The electrostatic force is inversely proportional to the square of the distance between the charges ✓

OR

The electrostatic force is directly proportional to the inverse of the square of the distance between the charged spheres (charges). ✓

OR

$F \alpha \frac{1}{r^2}$ ✓

OR

They are inversely proportional to each other (1)

7.1.4

OPTION 1

1 mark for using slope/

$$\text{Slope} = \frac{\Delta F_E}{\Delta \frac{1}{r^2}} ✓ = \frac{(0{,}027 - 0)}{(5{,}6 - 0)} ✓$$

$= 4{,}82 \times 10^{-3}\ N{\cdot}m^2$ $(4{,}76 \times 10^{-3} – 5 \times 10^{-3})$

Slope $= F_E r^2 = kQ_1Q_2 = kQ^2$ ✓

$4{,}82 \times 10^{-3}$ ✓ $= \underline{9 \times 10^9}\ \underline{Q^2}$ ✓

$\therefore Q = 7{,}32 \times 10^{-7} C$ ✓

OPTION 2

Accept any pair of points on the line

$$F = \frac{kQ_1Q_2}{r^2} ✓$$

$$(\quad) ✓ = \frac{(9 \times 10^9)Q^2}{(\quad)} ✓ ✓✓$$

$Q = 7{,}32 \times 10^{-7} C$ ✓ $(7{,}32 \times 10^{-7} – 7{,}45 \times 10^{-7}\ C)$

Examples

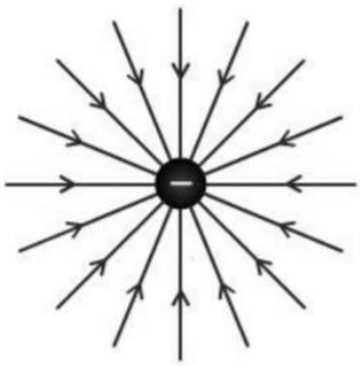
$$(0{,}005) ✓ = \frac{(9 \times 10^9)Q^2}{(1)} ✓ ✓✓$$

$Q = 7{,}45 \times 10^{-7}\ C$ ✓

$$(0{,}027) ✓ = \frac{(9 \times 10^9)Q^2}{\left(\frac{1}{5{,}6}\right)} ✓ ✓✓$$

$Q = 7{,}32 \times 10^{-7}\ C$ ✓ (6)

7.2



Criteria for drawing electric field: *Kriteria vir teken van elektriese veld:*	Marks/*Punte*
Direction /*Rigting*	✓
Field lines radially inward/*Veldlyne radiaal inwaarts*	✓

7.2.2 $E = \dfrac{kQ}{r^2}$ ✓

Take right as positive/*Neem regs as positief*

$E_{PA} = \dfrac{(9 \times 10^9)(0,75 \times 10^{-6})}{(0,09)^2}$ ✓

$= 8,33 \times 10^5\ N{\cdot}C^{-1}$ to the left/*na links*

$E_{PB} = \dfrac{(9 \times 10^9)(0,8 \times 10^{-6})}{(0,03)^2}$ ✓

$= 8 \times 10^6\ N{\cdot}C^{-1}$ to the left/*na links*

$E_{net} = E_{PA} + E_{PC}$

$= [-8,33 \times 10^5 + (-8 \times 10^6)]$ ✓

$= -8,83 \times 10^6$

$= 8,83 \times 10^6\ N{\cdot}C^{-1}$ ✓

1 mark for the addition of same signs/ *1 punt vir optelling van dieselfde tekens*

Take left as positive/*Neem links as positief*

Take left as positive/*Neem links as positief*

$E_{PA} = \dfrac{(9 \times 10^9)(0,75 \times 10^{-6})}{(0,09)^2}$ ✓

$= 8,33 \times 10^5\ N{\cdot}C^{-1}$ to the left/*na links*

$E_{PB} = \dfrac{(9 \times 10^9)(0,8 \times 10^{-6})}{(0,03)^2}$ ✓

$= 8 \times 10^6\ N{\cdot}C^{-1}$ to the left/*na links*

$E_{net} = E_{PA} + E_{PC}$

$= (\underline{8,33 \times 10^5} + \underline{8 \times 10^6})$ ✓

$= 8,83 \times 10^6\ N{\cdot}C^{-1}$ ✓

1 mark for the addition of same signs/ *1 punt vir optelling van dieselfde tekens*

(5)
[17]

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6 References

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