

$$Q = nq_e$$

Q = Charge

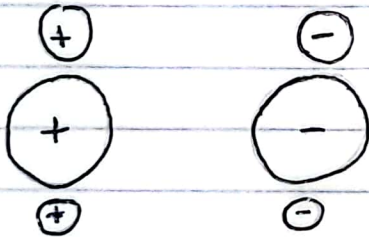
n = number of electrons

q_e = elementary charge ($-1,6 \times 10^{-19}$)

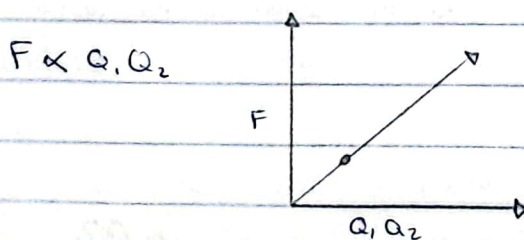
Charles de coulumb

Looked at the relationship between two charges (their magnitudes and distance between them.)

The magnitude of charges

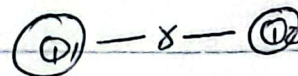


* The electrostatic force (Attraction / repulsion) is directly proportional to the product of the charges (Distance being constant)



Two charges Q_1 & Q_2 are ~~a distance~~ x distance apart as shown below.

Q One charge is doubled.



$$F = Q_1 Q_2$$

$$F = 2Q_1 Q_2$$

$$F = 2Q_1 Q_2$$

$$F = 2F$$

② Both charges are doubled

$$F = Q_1 Q_2$$

$$F = 2Q_1 2Q_2$$

$$F = 4Q_1 Q_2$$

$$F = 4F$$

③ Both charges halved

$$F = Q_1 Q_2$$

$$F = \frac{1}{2} Q_1 \frac{1}{2} Q_2$$

$$F = \frac{1}{4} Q_1 Q_2$$

$$F = \frac{1}{4} F$$

④ One charge is halved

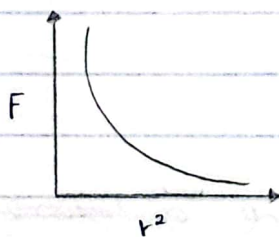
$$F \propto Q_1 Q_2 \propto \frac{1}{2} Q_1 Q_2 \propto \frac{1}{2} Q_1 Q_2$$

$$F = \frac{1}{2} F$$

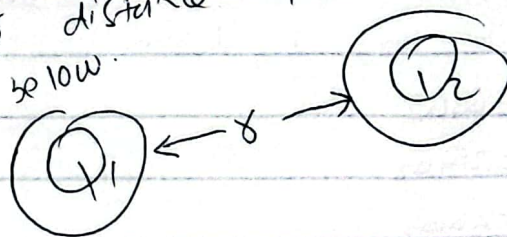
The magnitude of the distance between charges,

* Electrostatic force is inversely proportional to the square of the distance between them,

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



Two charges Q_1 & Q_2 are
at distance r apart as shown
below.



① The distance is doubled

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

$$= \frac{1}{(2r)^2}$$

$$= \frac{1}{4r^2}$$

$$= \frac{1}{4} \left(\frac{1}{r^2} \right) \quad F = \frac{1}{4} F$$

The distance is halved

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

$$= \frac{1}{(\frac{1}{2}r)^2}$$

$$F = \frac{1}{\frac{1}{4}r^2} = \frac{1}{\frac{1}{4}(\frac{1}{2}r)} = \frac{1}{\frac{1}{4}F}$$

$$F = 1 \times \frac{4}{1} F = 4F$$

From $F \propto Q_1 Q_2$ and $F \propto \frac{1}{r^2}$, we get $F = \frac{Q_1 Q_2}{r^2}$, We then include the proportionality constant k

$$F = \frac{k Q_1 Q_2}{r^2}$$

F = Electrostatic force (Attraction / repulsion) in Newtons (N)

Q_1, Q_2 = The magnitude of the charges in coulomb (C)

r = distance between the charges

k = Proportionality constant ($9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$)

Coulomb's law in words

The magnitude of the electrostatic force exerted by two point charges on each other is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance between them.

$$\text{Millicoulomb (mC)} = 1 \text{ mC} = 1 \times 10^{-3} \text{ C}$$

$$\text{Microcoulomb (μC)} = 1 \text{ μC} = 1 \times 10^{-6} \text{ C}$$

$$\text{nanocoulomb (nC)} = 1 \text{ nC} = 1 \times 10^{-9} \text{ C}$$

$$\text{Picocoulomb (pC)} = 1 \text{ pC} = 1 \times 10^{-12} \text{ C}$$

Coulomb's law

$$F = \frac{k Q_1 Q_2}{r^2}$$

Q = charge (C)

r = distance (m)

$$k = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

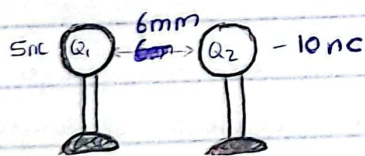
* Charge is not always measured in coulombs, but in a unit smaller than coulomb i.e. milli-, micro-, nano-, and picocoulomb.

How to solve coulomb's law questions

- ① Choose a direction why? Force is a vector quantity, it has direction.
- ② Draw a vector diagram
- ③ We don't use + and - in the equation $F = \frac{kQ_1Q_2}{r^2}$, NB
- ④ We use + and - when calculating the resultant / total / net electrostatic force.

Example 1

The centres of two spheres are a distance of 6 mm from each other. They carry a charge of 5 nC & -10 nC respectively as shown below.



- ① Calculate the magnitude of the electrostatic force between them.

$$\begin{aligned} F &= \frac{kQ_1Q_2}{r^2} \\ &= \frac{9 \times 10^9 \text{ N} \cdot \text{m}^2 \text{C}^{-2} \times 5 \times 10^{-9} \text{ C} \times 10 \times 10^{-9} \text{ C}}{(0,006 \text{ m})^2} \\ &= \frac{9 \times 10^9 \text{ N} \times 5 \times 10^{-9} \times 10 \times 10^{-9}}{0,006^2} \\ &= 0,0125 \text{ N} \quad \text{Attraction} \end{aligned}$$

- ② The spheres are allowed to touch one another and move back to their original position (calculate).

- ③ The new charge that the spheres have.

$$\begin{aligned}
 Q_{\text{new}} &= \frac{Q_1 + Q_2}{2} \\
 &= \frac{+5 \times 10^{-9} + (-10 \times 10^{-9})}{2} \\
 &= -2.5 \times 10^{-9} \text{ C}
 \end{aligned}$$

22. The new electrostatic force between them.

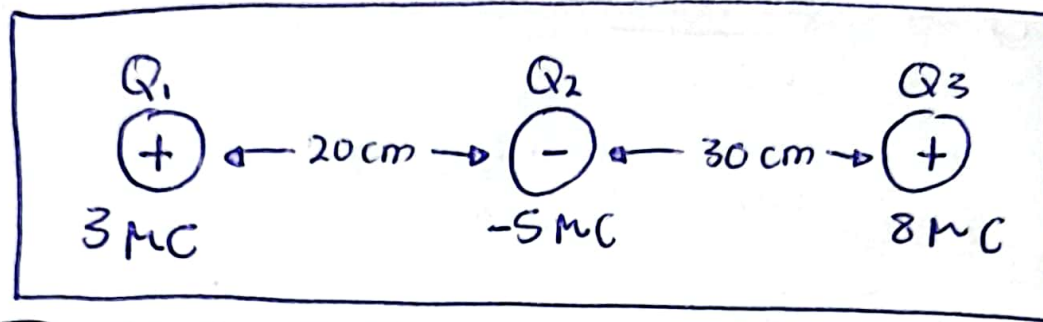
$$\begin{aligned}
 F &= \frac{k Q_1 Q_2}{r^2} \\
 &= \frac{9 \times 10^9 \times 2.5 \times 10^{-9} \times 2.5}{(0.006)^2} \\
 &= 1.56 \times 10^{-3} \text{ N, Repulsion}
 \end{aligned}$$

23 The number of electrons transferred

$$\begin{aligned}
 Q_{2\text{new}} &= Q_{\text{final}} - Q_{\text{initial}} \\
 &= -2.5 \times 10^{-9} - (-10 \times 10^{-9}) \\
 &= 7.5 \times 10^{-9} \\
 n &= \frac{Q}{q_e} = \frac{7.5 \times 10^{-9} \text{ C}}{-1.6 \times 10^{-19} \text{ C}} \\
 &= -4.69 \times 10^{10} / 4.69 \times 10^{10} \text{ electrons.}
 \end{aligned}$$

Example 2

Three charges Q_1 , Q_2 and Q_3 are placed as shown in the figure below. Calculate the net electrostatic force that is ~~ext~~ exerted by Q_2 and Q_3 on Q_1 .



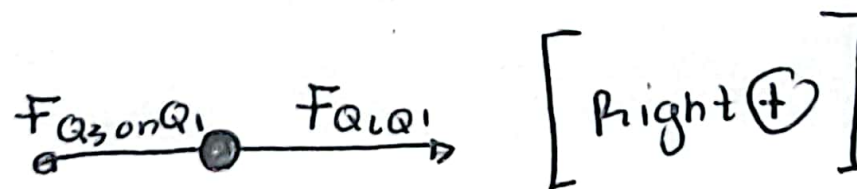
Rem: $\mu C = \text{micro Coulomb}$
 $(\times 10^{-6} \text{ C})$

$$F_{Q_2 \text{ on } Q_1} = \frac{k Q_2 Q_1}{r^2} = \frac{9 \times 10^9 \times 5 \times 10^{-6} \times 3 \times 10^{-6}}{(0,2)^2}$$

$$= 3,38 \text{ N}, \text{Attraction}$$

$$F_{Q_3 \text{ on } Q_1} = \frac{k Q_3 Q_1}{r^2} = \frac{9 \times 10^9 \times 8 \times 10^{-6} \times 3 \times 10^{-6}}{(0,5)^2}$$

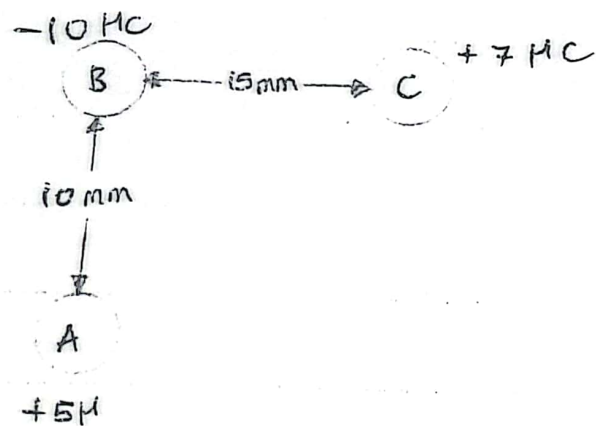
$$= 0,86 \text{ N}, \text{Repulsion}$$



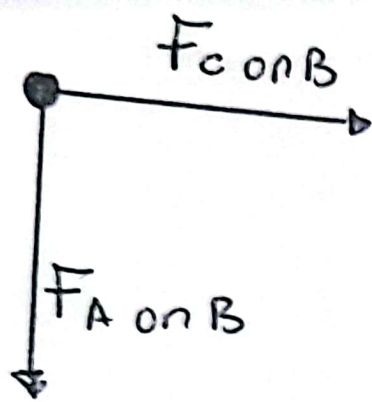
$$F_{\text{net}} = F_{Q_2 \text{ on } Q_1} + F_{Q_3 \text{ on } Q_1}$$

$$= -3,38 \text{ N} + 0,86 \text{ N}$$

$$= -2,52 \text{ N} \quad \text{to the left}$$



Determine the resultant electrostatic force on B, because of the electrostatic force A and C.



$$F_{A \text{ on } B} = \frac{k Q_A Q_B}{r^2}$$

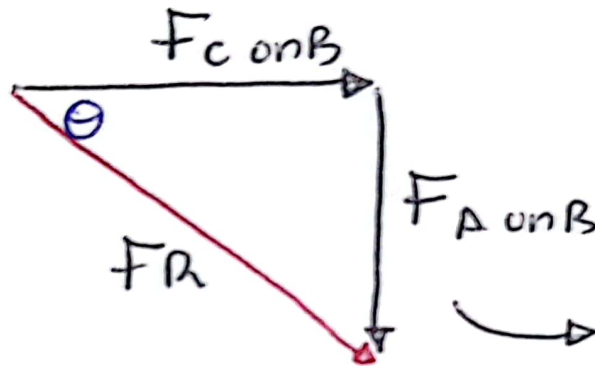
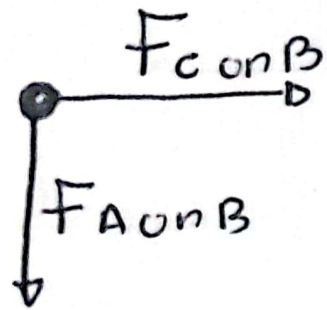
$$= \frac{9 \times 10^9 \times 5 \times 10^{-6} \times 10 \times 10^{-6}}{(0,01)^2}$$

$$= 4500 \text{ N, Attraction}$$

$$F_{C \text{ on } B} = \frac{k Q_C Q_B}{r^2}$$

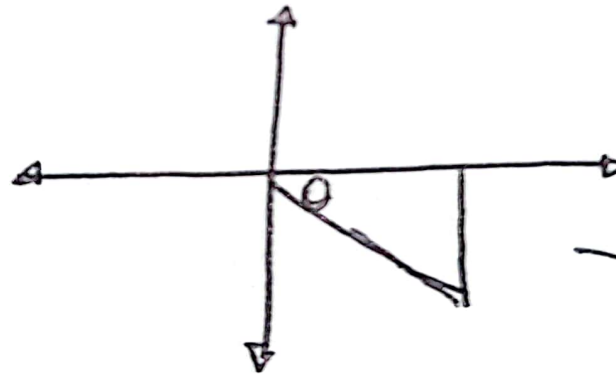
$$= \frac{9 \times 10^9 \times 7 \times 10^{-6} \times 10 \times 10^{-6}}{(0,015)^2}$$

$$= 2800 \text{ N, Attraction.}$$



Rem: F_R = Resultant Force

Right-angle triangle $\approx$ Pythagoras Theorem.



θ below the positive x-axis

$$F_R^2 = (F_{A \text{ on } B})^2 + (F_{C \text{ on } B})^2 \quad \} \quad r^2 = x^2 + y^2$$
$$\sqrt{F_R^2} = \sqrt{(4500)^2 + (2800)^2}$$

$$F_R = 5300 \text{ N}$$

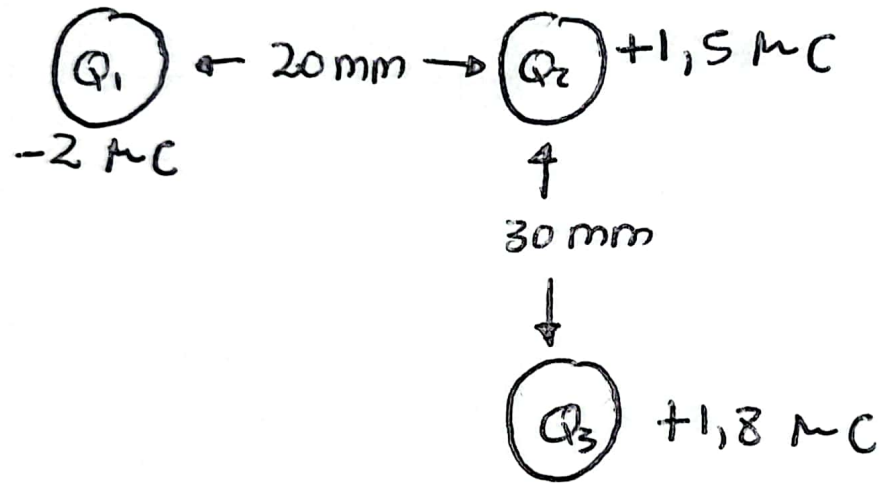
Hint: F_R is a vector quantity so both direction & magnitude

$$\begin{aligned}\tan \theta &= \frac{-4500}{-2800} \\ &= \tan^{-1} \left(\frac{4500}{2800} \right) \\ &= 58,11^\circ\end{aligned}$$

∴ The resultant electrostatic force is 5300 N in the direction of $58,11^\circ$ below the positive x-axis.

Example

Three charges Q_1, Q_2 & Q_3 are placed as shown in the Figure



Calculate the net electrostatic force that is exerted on charge Q_2 because of electrostatic force exerted by Q_1 & Q_3 .

Electric Field.

What is an electrical field?

- Region in space in which an electric charge experiences a force. The direction of the electrical field at a point is the direction that a positive test charge would move if placed at that point.

How do we test whether an electrical field exists around a charge or not?

- * Assume that we have a charged sphere with a positive charge $+Q$



- * We place a small positively charged object known as a small positive test charge ($+q$) at point D at a distance r from the centres of the spheres



- * The small positive test charge is repelled, because like charges repel. This can be calculated using Coulomb's law.

$$K = \frac{kQ_1Q_2}{r^2} \rightarrow F = \frac{kQq}{r^2}$$

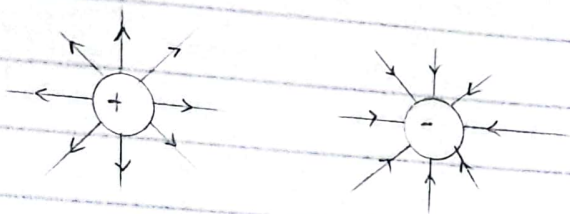
Electric field lines

- Are imaginary lines that indicate the direction and strength along which a positive test charge will move if it is placed at a specific point in the electrical field

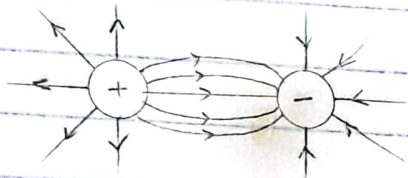
(NB) * They are the strongest closer to the charge

- Direction of the electric field lines

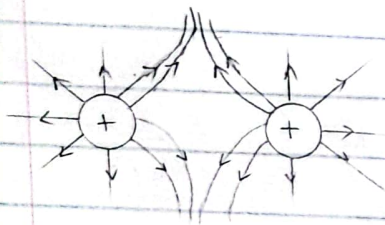
Lines run from a positively charged object to a negatively charged object.



Unlike charges.

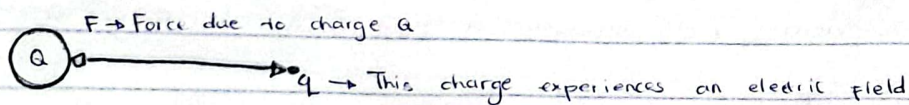


Like charges.



Electric field strength

- The electric field at a point is the electrostatic force experienced per unit positive charge placed at that point.



$$E = \frac{F_{\text{electrostatic force (N)}}}{q_{\text{charge experiencing force (C)}}$$

Electric field strength (N.C⁻¹)

6

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

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

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

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

E = Electric field strength ($N \cdot C^{-1}$)

k = proportionality constant ($9 \times 10^9 N \cdot m^2 \cdot C^{-2}$)

Q = Charge

r = Distance between objects (m)

Example 1

A
+2 Hc

B
-5 Hc

Charge B experiences a force of 2 N due to charge A.

Determine the electric field strength at point B.

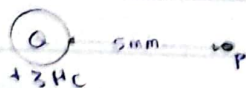
$$E = \frac{kQq}{r^2}$$

$$= \frac{2}{5 \times 10^{-6}}$$

$$= 4,10^5 N \cdot C^{-1} \text{ to the left}$$

Example 2

Determine the electric field strength at point P due to charge Q



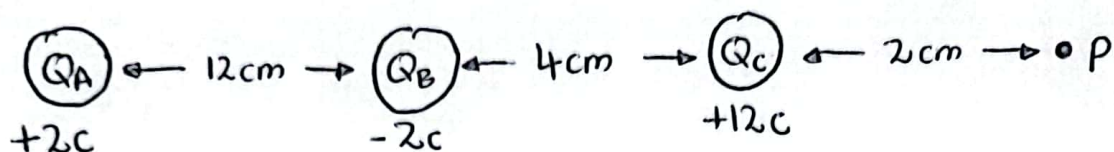
$$E = \frac{kQ}{r^2}$$

$$= \frac{3 \times 10^{-6} \times 9 \times 10^9}{(0,005)^2}$$

$$= 108\,000\,000 \text{ N.C}^{-1} \text{ to the right}$$

Example 3:

Examine the arrangement of charges where Q_A has a charge of $+2\text{C}$, $Q_B = -2\text{C}$ & $Q_C = +12\text{C}$



Calculate the net electric field as a result of these charges on point P , 2cm to the right of Q_C .

Solution:

$$E_{A \text{ on } P} = \frac{kQ_A}{r^2} = \frac{9 \times 10^9 \times 2}{(0,18)^2} = 5,56 \times 10^{11} \text{ N.C to the right}$$

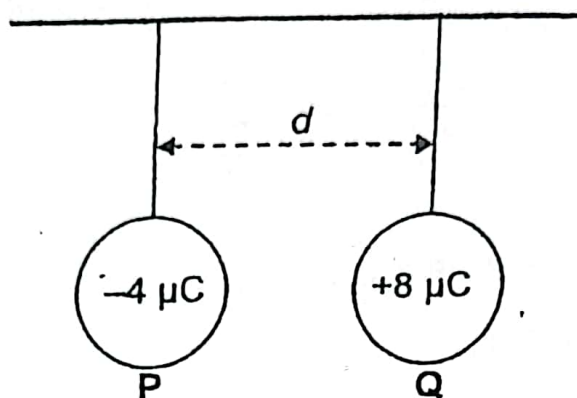
$$E_{B \text{ on } P} = \frac{kQ_B}{r^2} = \frac{9 \times 10^9 \times 2}{(0,06)^2} = 5 \times 10^{12} \text{ N.C to the left}$$

$$E_{C \text{ on } P} = \frac{kQ_C}{r^2} = \frac{9 \times 10^9 \times 12}{(0,02)^2} = 2,7 \times 10^{14} \text{ N.C to the right}$$

$$\begin{aligned} E_{\text{net}} &= E_{A \text{ on } P} + E_{B \text{ on } P} + E_{C \text{ on } P} \\ &= 5,56 \times 10^{11} + (-5 \times 10^{12}) + 2,7 \times 10^{14} \\ &= 2,66 \times 10^{14} \text{ N.C}^{-1} \text{ to the right.} \end{aligned}$$

QUESTION 9 (Start on a new page.)

- 9.1 Two identical metal spheres, P and Q, separated by a distance d , are suspended from an insulated rigid wooden bar, as shown in the diagram below. The charge on the spheres are $-4 \mu\text{C}$ and $+8 \mu\text{C}$ respectively.



- 9.1.1 Sphere Q experiences an electrostatic force.

In which direction will sphere Q move? Write down only TO THE LEFT or TO THE RIGHT. (1)

The spheres are now made to touch and are then separated.

- 9.1.2 Were electrons REMOVED FROM or TRANSFERRED TO P? Give a reason for the answer. (2)

- 9.1.3 Calculate the distance d between the two spheres if the magnitude of the force experienced by P is $0,8 \text{ N}$. (3)

- 9.2 Charges of $+4 \mu\text{C}$ and $-3 \mu\text{C}$ are placed a distance $0,2 \text{ m}$ apart on a straight line, as shown below. Point P is located $0,1 \text{ m}$ to the right of the $-3 \mu\text{C}$ charge.



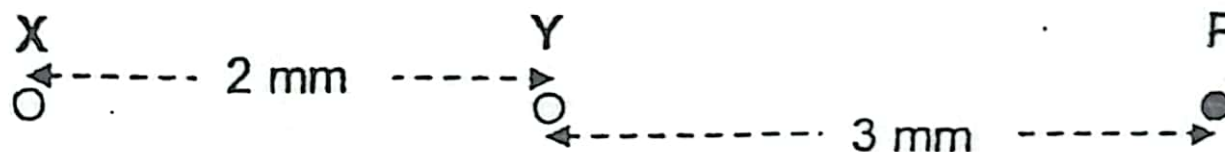
Calculate the:

- 9.2.1 Net electric field at point P (5)

- 9.2.2 Mass of a $+6 \mu\text{C}$ charge placed at P that will experience an acceleration of magnitude $5 \times 10^2 \text{ m}\cdot\text{s}^{-2}$ (3)
[14]

QUESTION 8 (Start on a new page.)

Two IDENTICAL point charges, X and Y, are placed 2 mm apart. Point P is 3 mm to the right of charge Y. The net electric field at point P is $5,44 \times 10^6 \text{ N}\cdot\text{C}^{-1}$ to the left.

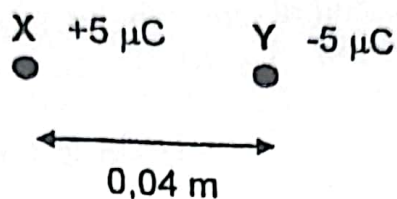


- 8.1 Define the term *electric field* at a point. (2)
- 8.2 Are the charges NEGATIVE or POSITIVE? (1)
- 8.3 Draw the resultant electric field pattern for charges X and Y. (3)
- 8.4 Calculate the magnitude of the charge X. (5)
- 8.5 Charge Y is now replaced by an identical oppositely charged point charge.
- How will the magnitude of the net electric field at point P be affected?
Choose from INCREASE, DECREASE or REMAIN THE SAME.
- Give a reason for the answer. (2)

[13]

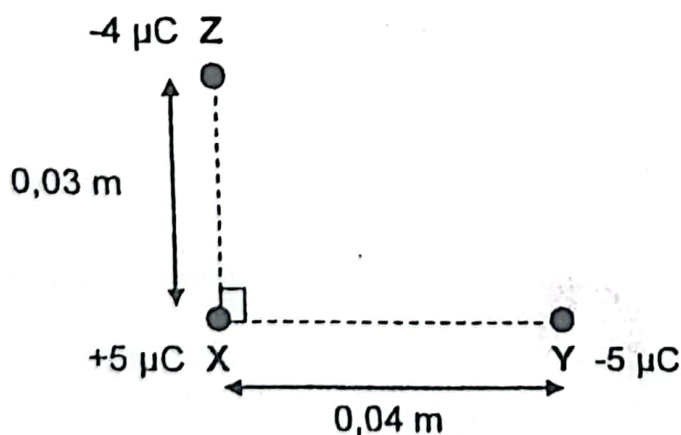
QUESTION 8 (Start on a new page.)

Two charged spheres, X and Y, are placed in a vacuum at a distance of 0,04 m apart.



- 8.1 Draw the resulting electric field pattern between the two charges. (3)
- 8.2 Calculate the electrostatic force sphere X experiences due to the charge on sphere Y. (4)
- 8.3 8.3.1 If sphere Y is at a fixed position and sphere X is free to move, will the acceleration experienced by sphere X towards sphere Y be constant? Write down YES or NO. (1)
- 8.3.2 Explain the answer to QUESTION 8.3.1 by referring to the electric field and the force. (2)

A third sphere, Z, with a charge of $-4 \mu\text{C}$, is placed at right angles to sphere X and at a distance of 0,03 m from sphere X.



- 8.4 Calculate the magnitude of the net force on sphere X due to sphere Y and sphere Z. (4)
- [14]