Dr. Bbosa Science

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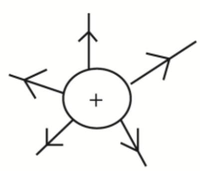
Electric field

Al electric field is a region around an electric charge where an electric force is experienced. This can be mapped out by electrostatic lines of force.

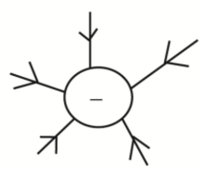
A line of force is a line such that the tangent to it at any point is in the direction of the force on a small positive charge at that point. Arrows are drawn the direction and these point from positive towards or inwards to the negative charge. A collection of lines of force is called an **electric flux.**

Electric field pattern

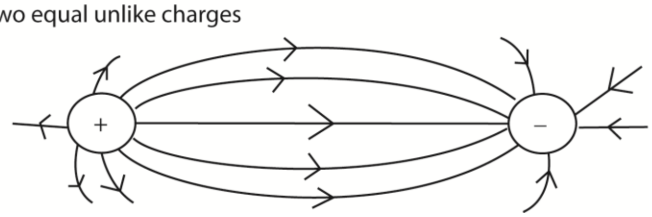
1. Isolated positive charge



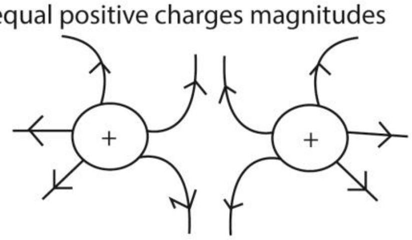
2. Isolated negative charge



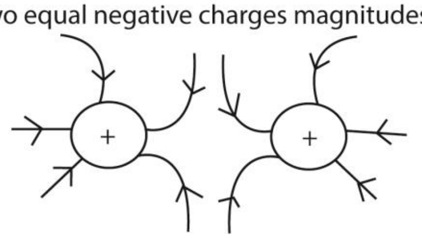
3. Two equal unlike charges



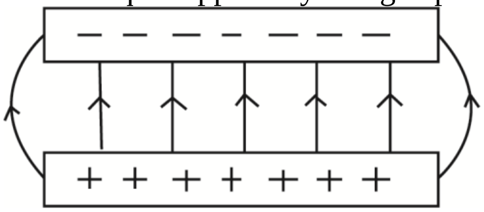
4. Two equal positive charges magnitudes



5. Two equal negative charges magnitudes



6. Two equal oppositely charged parallel plates

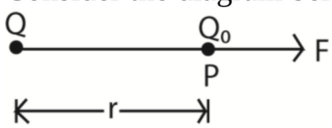


Definition

1. A neutral point in an electric field is a point where the resultant electric field field intensity is zero.

   The force exerted on the charged body in an electric field depends on the charge on the body and the intensity or strength of the field.
2. Electric field intensity or strength is defined as the force exerted on a positive charge of 1 coulomb placed at a point in electric field
   Therefore, electric field intensity, E is a vector quantity
   E = $\frac{F}{Q}$
   The S.I. unit of E is NC-1

Consider the diagram below



Placing a small charge Q_0 at point P, in an electric field, the force at P due to Q is given by

F= $\frac{1}{4\pi\varepsilon_0}$ x $\frac{QQ_0}{r^2}$

Electric field intensity, E, at P = $\frac{F}{Q_0}$

$= \frac{Q}{4\pi\varepsilon_0 r^2}$

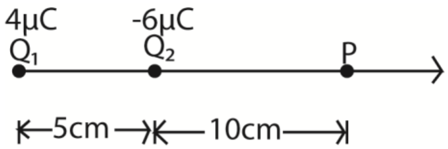
Therefore electric field intensity, E, at a point due to charge Q is given by

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

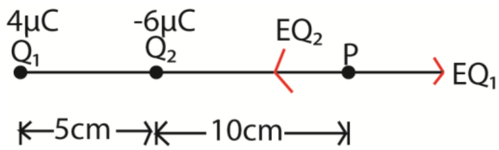
Note E is directed away from a positive charge and directed towards the negative charge.

Example 1

Find the electric field intensity at P



Solution



Solution

E at P due to Q_1

$EQ_1 = \frac{9.0\ x\ 10^9\ x\ 4\ x\ 10^{-6}}{(15\ x\ 10^{-2})^2}$ = 16 x $10^5 NC^{-1}$(→)

E at P due to Q_2

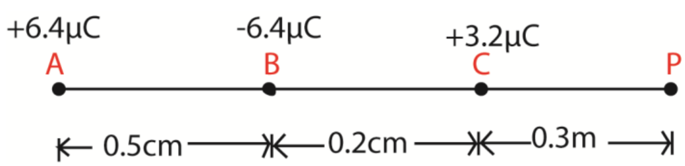
$EQ_2 = \frac{9.0\ x\ 10^9\ x\ 4\ x\ 10^{-6}}{(10\ x\ 10^{-2})^2}$ = 54 x $10^5 NC^{-1}$(←)

EP = EQ_1- EQ_2

= (16 x105 – 54 x 105)NC^{-1}

=38 x 10^5 NC^{-1}(←)

Example 2



Three point charges of +6.4μC, -6.4μC and +3.2μC are arranged in line at points A, B, and C respectively as shown in diagram above. Find the electric field intensity at P.

Solution

E at P due to A (+6.4μC)

$E_{AP} = \frac{9.0\ x\ 10^9\ x\ 6.4\ x\ 10^{-6}}{(1)^2}$ = 5.76 x $10^4 NC^{-1}$(→)(repulsive)

E at P due to A (- 6.4μC)

$E_{BP} = \frac{9.0\ x\ 10^9\ x\ 6.4\ x\ 10^{-6}}{(0.5)^2}$ = 2.304 x $10^5 NC^{-1}$(←)(attractive)

E at P due to A (+3.2μC)

$E_{CP} = \frac{9.0\ x\ 10^9\ x\ 3.2\ x\ 10^{-6}}{(0.3)^2}$ = 3.2 x $10^5 NC^{-1}$(→)(repulsive)

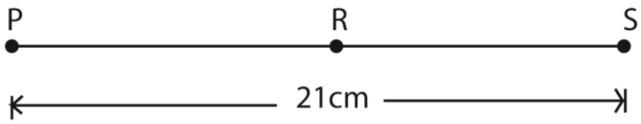
$E_P = E_{AP} - E_{BP} + E_{CP}$

= (5.76 x 10^4 -2.30 x 10^5 + 3.2 x 10^5)NC^{-1}

= 1.472x $0^5 NC^{-1}$(→)

Hence the electric field at P is 1.472x 0^5NC^{-1} to the right

Example 3



Two point Charges P and S of -17.6μC and -9.0μC respectively are placed in a vacuum at a distance of 21cm apart. When a 3rd charge R is placed midway between P and S as shown in figure above, then, the net force at S is zero

(i) Determine the charge on R
(ii) Calculate the electric potential at position R.
(iii) Sketch the electric field lines corresponding to charge distribution

Solution

Let the charge on R be Q

From

$F = \frac{1}{4\pi\varepsilon_0} x \frac{QQ_0}{r^2}$ where $\frac{1}{4\pi\varepsilon_0} = 9.0 \text{ x } 10^9$

Force on S due to R

$F_{SR} = \frac{9.0 \, x \, 10^9 \, x \, 9 \, x \, 10^{-6} \, x \, Q}{(10.5 \, x \, 10^{-2})^2}$

Force on S due to P

$F_{SP} = \frac{9.0 \, x \, 10^9 \, x \, 9 \, x \, 10^{-6} \, x \, 17.6 \, x \, 10^{-6}}{(21 \, x \, 10^{-2})^2}$

Resultant force on S = $F_{SP} - F_{SR} = 0$

⇨ $F_{SP} = F_{SR}$

$$\frac{9.0 \, x \, 10^9 \, x \, 9 \, x \, 10^{-6} \, x \, 17.6 \, x \, 10^{-6}}{(21 \, x \, 10^{-2})^2} = \frac{9.0 \, x \, 10^9 \, x \, 9 \, x \, 10^{-6} \, x \, Q}{(10.5 \, x \, 10^{-2})^2}$$

$Q = \frac{17.6 \, x \, 10^{-6} \, x \, (10.5 \, x \, 10^{-2})^2}{(21 \, x \, 10^{-2})^2} = 4.4 \text{ x } 10^{-6}$C

Hence the charge on R = +4.4x 10^{-6}C

(ii) Electric field potential, at a distance r fro charge D is given by

$V = \frac{Q}{4\pi\varepsilon_0 r}$

Electric potential at R due to S

$V_{RS} = \frac{9 \, x 10^9 \, x {-9} \, x \, 10^{-6}}{10.5 \, x \, 10^{-2}} = -7.71 \text{ x } 10^5$V

Electric potential at R due to P

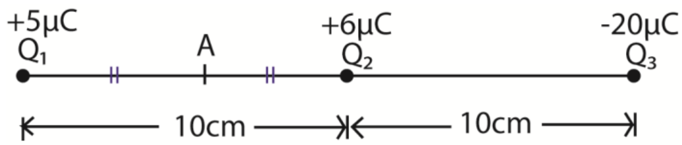
$$V_{RP} = \frac{9\,x10^{9}\,x{-17.6}\,x\,10^{-6}}{x\,10.5\,x\,10^{-2}} = -1.51 \text{ x } 10^{6}\text{V}$$

$V_R = V_{RS} + V_{RP}$

$= -\ 7.71 \text{ x } 10^{5} + -1.51 \text{ x } 10^{6}$

$= -2.28 \text{ x } 10^{6}\text{V}$

Example 4



Calculate the electric field intensity midway between Q1 and Q2

Solution

From $E = \frac{Q}{4\pi\varepsilon_0 r^2}$

E_{Q_1} at A due to Q_1 (= $\frac{9\,x10^{9}\,x5\,x\,10^{-6}}{(5\,x\,10^{-2})^2}$ = 1.8 x $10^{7}NC^{-1}$(→)

E_{Q_2} at A due to Q_2 = $\frac{9\,x10^{9}\,x\,6\,x\,10^{-6}}{(5\,x\,10^{-2})^2}$ = 2.16 x $10^{7}NC^{-1}$(←)

E_{Q_3} at A due to Q_3 = $\frac{9\,x10^{9}\,x\,20\,x\,10^{-6}}{(15\,x\,10^{-2})^2}$ = 8.0 x $10^{6}NC^{-1}$(→)

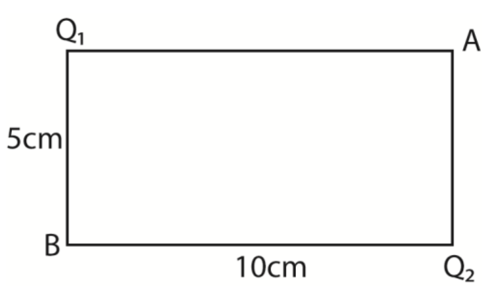
$E_A = E_{Q_1} - E_{Q_2} + E_{Q_3}$

$= 1.8 \text{ x } 10^{7} - 2.16 \text{ x } 10^{7} + 8.0 \text{ x } 10^{6}$

$= 4.4 \text{ x } 10^{6}NC^{-1}$(→)

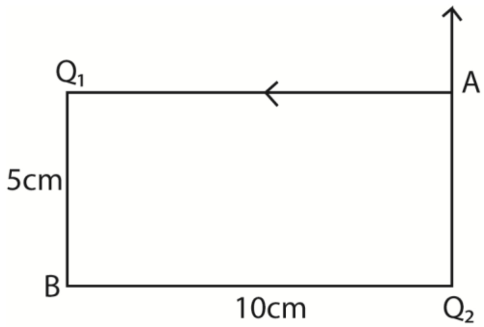
Example 5

Charges Q_1 and Q_2 of -5μC and +2.0μC respectively are placed at two opposite corners of a rectangle of sides 5.0cm and 10.0cm as shown below



Calculate the electric field at A

Solution



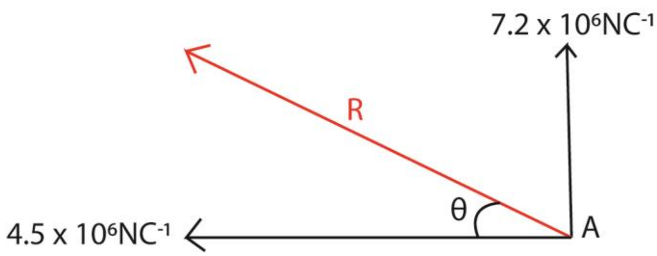
From $= \frac{Q}{4\pi\varepsilon_0 r^2}$, and $E = \frac{1}{4\pi\varepsilon_0} = 9.0\ x\ 10^9$

E at A due to Q1

$E_{Q_1} = \frac{9\ x 10^9\ x\ 5\ x\ 10^{-6}}{(10\ x\ 10^{-2})^2}$ = 4.5 x $10^6 NC^{-1}$

E at A due to Q_2

$E_{Q_2} = \frac{9\ x 10^9\ x\ 2\ x\ 10^{-6}}{(5\ x\ 10^{-2})^2}$ = 7.2 x $10^6 NC^{-1}$



$R^2 = (4.5 \text{ x } 10^6)^2 + (7.2 \text{ x } 10^6)^2$

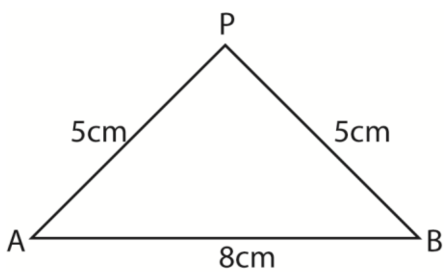
R = 8.49 x 10^6 NC^{-1}

$\tan\theta = \frac{7.2\ x\ 10^6}{4.5\ x\ 10^6}$

$\theta = 58^0$

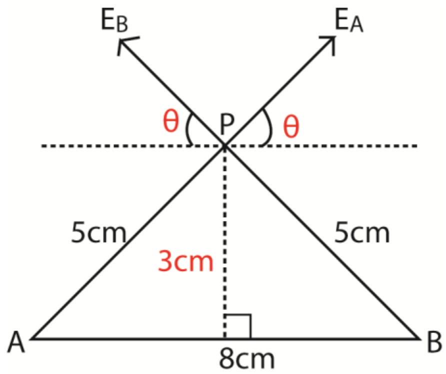
Hence the electric filed intensity at A is 8.49 x 10^6 NC^{-1} at 58^0 to the horizontal

Example 6



Two point charges A and B of +10μC and +0.05μC are separated by a distance of 8cm along the horizontal as shown above. Find the electric field intensity at P.

Solution



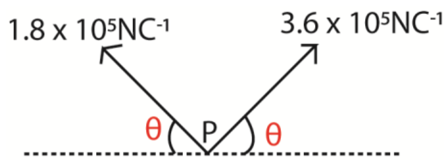
$\sin\theta^0 = \frac{3}{5} = 0.6;\ \cos\theta^0 = \frac{4}{5} = 0.8$

E at P due to charge at A

$E_{Q_1} = \frac{9\,x10^9\ x\ 0.1\ x\ 10^{-6}}{(5\ x\ 10^{-2})^2}$ = 3.6 x 10^5NC^{-1}

E at A due to charge at B

$E_{Q_2} = \frac{9\,x10^9\ x\ 0.05\ x\ 10^{-6}}{(5\ x\ 10^{-2})^2}$ = 1.8 x 10^5NC^{-1}



Resolving vertically

E_y = 3.6 x $10^5\sin\theta$ + 1.8 x $10^5\sin\theta$

= 5.4 x $10^5\sin\theta$

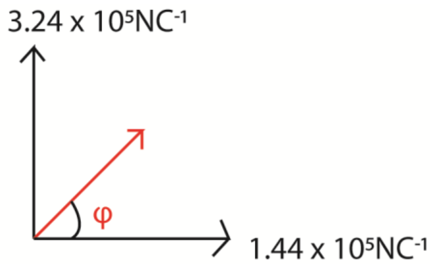
= 5.4 x 0.6 = 3.24 x 10^5 NC^{-1}

Resolving horizontally

E_x = 3.6 x $10^5\cos\theta$ - 1.8 x $10^5\cos\theta$

= 1.8 x 10^5 x 0.8

= 1.44 x 10^5 NC^{-1}



$R^2 = (1.44 \times 10^5)^2 + (3.24 \times 10^5)^2$

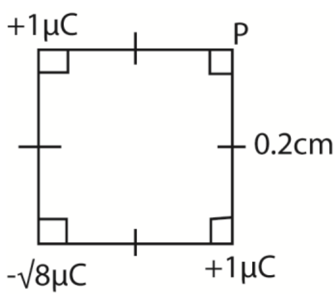
$R = 3.55 \times 10^5$ NC^{-1}

$\tan\theta = \frac{3.24 \times 10^6}{1.44 \times 10^6}$

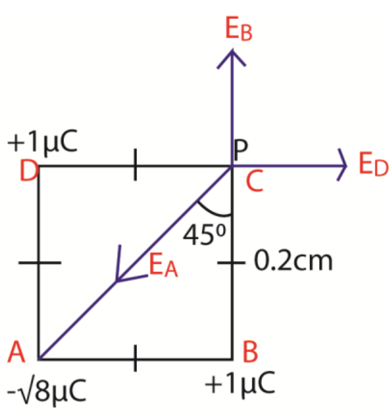
$\theta = 66^0$

Hence the electric field intensity at A is 3.55×10^5NC^{-1} at 66^0 to the horizontal

Example 7



Solution



$AP^2 = 0.2^2 + 0.2^2$

$AP = \sqrt{8} \times 10^{-1}$ m

E at P due to charge at A

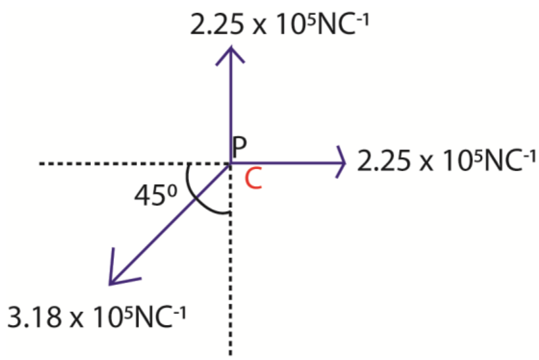
$E_A = \frac{9 \times 10^9 \times \sqrt{8} \times 10^{-6}}{(\sqrt{8} \times 10^{-1})^2} = 3.18 \times 10^5$NC^{-1}

E at P due to charge at B

$$E_{Q_2} = \frac{9 \, x 10^9 \, x \, 1 \, x \, 10^{-6}}{(0.2)^2} = 2.25 \text{ x } 10^5 \text{NC}^{-1}$$

E at P due to charge at D

$$E_{Q_2} = \frac{9 \, x 10^9 \, x \, 1 \, x \, 10^{-6}}{(0.2)^2} = 2.25 \text{ x } 10^5 \text{NC}^{-1}$$

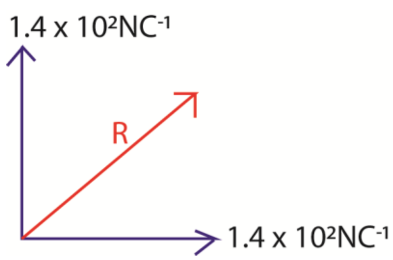


Resolving vertically

$E_y = 2.25 \text{ x } 10^5 – 3.18 \text{ x } 10^5 \sin 45^0 = 1.4 \text{ x } 10^2 \text{NC}^{-1}$

Resolving horizontally

$E_x = 2.25 \text{ x } 10^5 – 3.18 \text{ x } 10^5 \sin 45^0 = 1.4 \text{ x } 10^2 \text{NC}^{-1}$



$R^2 = (1.4 \text{ x } 10^2)^2 + (1.4 \text{ x } 10^2)^2$

$R = 1.98 \text{ x } 10^2 \text{ NC}^{-1}$

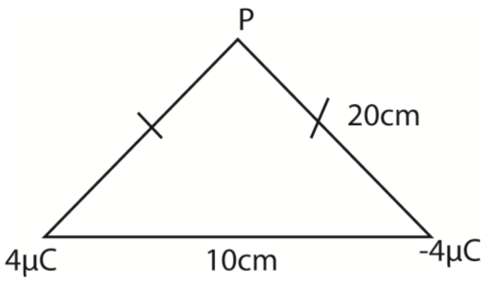
$\tan \theta = \frac{1.4 \, x \, 10^2}{1.4 \, x \, 10^2}$

$\theta = 45^0$

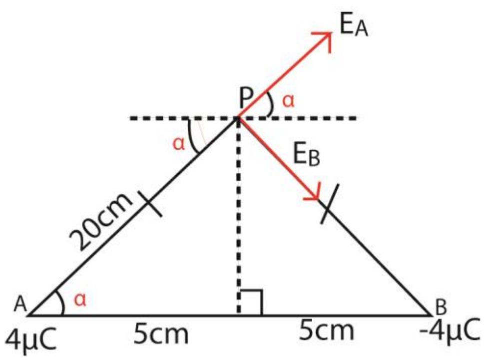
Hence the electric field intensity at P is $1.98 \text{ x } 10^2 \text{ NC}^{-1}$ at 450 to horizontal

Example 8

Two point charges are separated by 10cm in air as shown



Solution

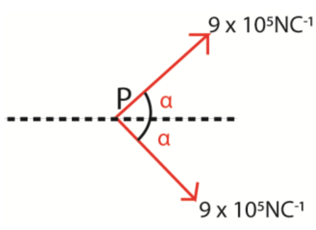


E at P due to charge at A

$E_A = \frac{9\,x10^9\,x\,4\,x\,10^{-6}}{(20\,x\,10^{-2})^2}$ = 9 x 10^5NC^{-1}

E at P due to charge at B

$E_B = \frac{9\,x10^9\,x\,4\,x\,10^{-6}}{(20\,x\,10^{-2})^2}$ = 9 x 10^5NC^{-1}



Sinα = $\frac{\sqrt{375}}{20}$; cos α = $\frac{5}{20} = 0.25$

Resolving vertically

E_y = 9 x 10^5NC^{-1}sinα - 9 x 10^5NC^{-1}sinα = 0

Resolving horizontally

E_x = 9 x 10^5NC^{-1}cosα + 9 x 10^5NC^{-1}cosα

$= 18 \times 10^5 \times .25 = 4.5 \times 10^5 NC^{-1}$

$R^2 = (4.5 \times 10^5)^2 + (0)^2$

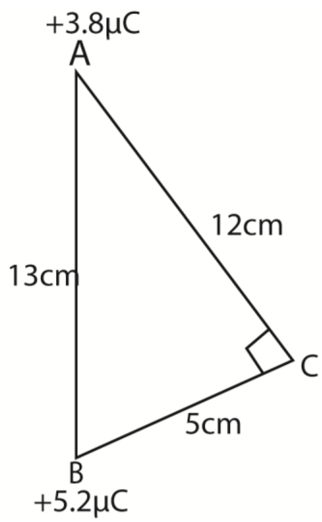
$R = 4.5 \times 10^5\ NC^{-1}$

$\tan\theta = \frac{0}{4.5 \times 105}$

$\theta = 0^0$

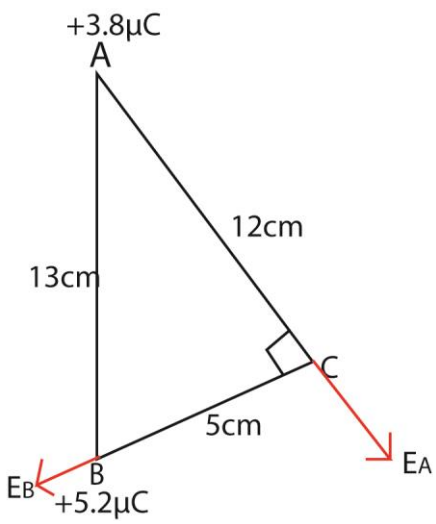
Hence the electric field intensity at P is $4.5 \times 10^5\ NC^{-1}$ at 0^0 to the horizontal

Example 9



Two points +3.8μC and -5.2μC are place in air at points A and B as shown. Determine the electric field intensity at C

Solution

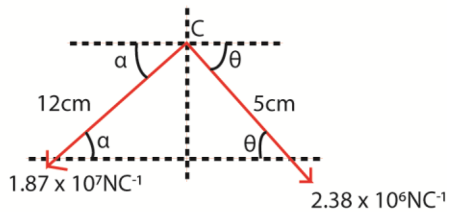


E at C due to charge at A

$E_A = \frac{9 x 10^9 \ x \ 3.8 \ x \ 10^{-6}}{(12 \ x \ 10^{-2})^2}$ = 2.38 x 10^5NC^{-1}

E at C due to charge at B

$E_B = \frac{9 x 10^9 \ x \ 5.2 \ x \ 10^{-6}}{(5 \ x \ 10^{-2})^2}$ = 1.87 x 10^7NC^{-1}



tan α = $\frac{5}{12}$; α = 22.6   tan θ =$\frac{12}{5}$; θ =67.4

Resolving vertically;

E_y = 1.87 x 10^7sin 22.6 + 2.38 x 10^6sin 67.4

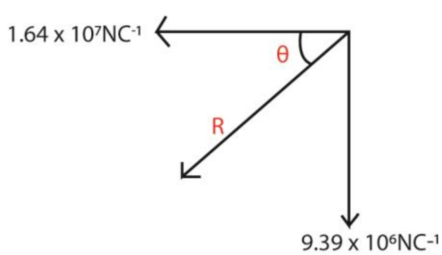
= 9.39 x 10^6NC^{-1}

Resolving horizontally

E_x = 2.38 x 10^6cos67.4 - 1.87 x 10^7cos 22.6

= 9.16 x 106 – 1.73x107

= -1.64 x 10^7NC^{-1}



$R^2 = (1.64 \ x \ 10^7)^2 + (9.39 \ x \ 10^6)^2$

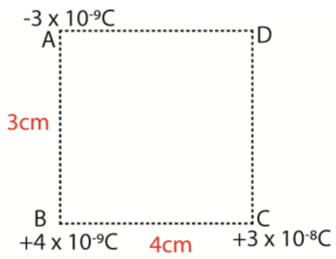
R = 1.89 x 10^7NC^{-1}

tan θ = $\frac{9.39 \ x \ 10^6}{1.64 \ x \ 10^7}$

θ = 29.79^0

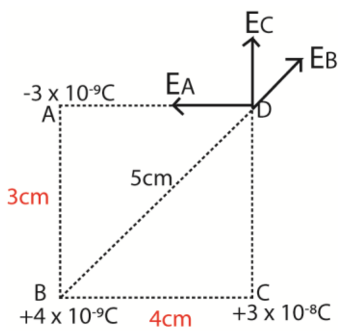
Hence the electric field intensity at C is 1.89 x 10^7NC^{-1} acting at 29.7^0 to horizontal.

Example 10



Three charges of -3 x 10^{-9}C, +4 x 10^{-9}C and +3 x 10^{-9}C are placed at vertices A, B, C respectively of a rectangle ABCD of side 3cm x 4cm as shown. Calculate the resultant electric field intensity at D

Solution



E at D due to charge at A

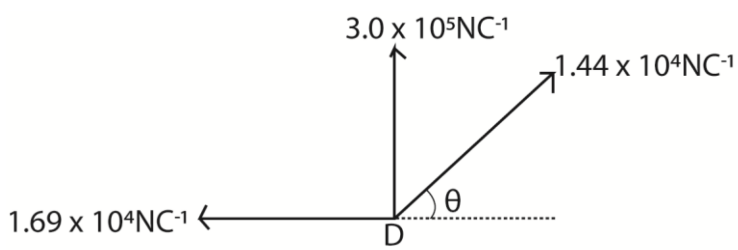
$$E_A = \frac{9\,x10^9\;x\;3\;x\;10^{-9}}{(4\;x\;10^{-2})^2} = 1.69 \text{ x } 10^4 NC^{-1}$$

E at D due to charge at B

$$E_B = \frac{9\,x10^9\;x\;4\;x\;10^{-9}}{(5\;x\;10^{-2})^2} = 1.44 \text{ x } 10^4 NC^{-1}$$

E at D due to charge at C

$$E_C = \frac{9\,x10^9\;x\;3\;x\;10^{-8}}{(3\;x\;10^{-2})^2} = 3.0 \text{ x } 10^5 NC^{-1}$$



$\sin\theta = \frac{3}{5} = 0.6$; $\cos\theta = \frac{4}{5} = 0.8$

Resolving vertically;

$E_y = 3.0 \times 10^5 + 1.44 \times 10^4 \sin\theta$

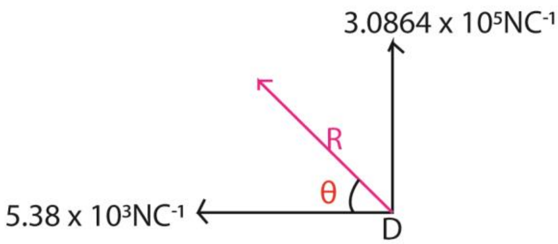
$= 3.0864 \times 10^5\ NC^{-1}$

Resolving horizontally

$E_x = -1.69 \times 10^4 + 1.44 \times 10^4 \cos\theta$

$= -1.69 \times 10^4 + 1.44 \times 10^4 \times 0.8$

$= -5380 NC^{-1}$



$R^2 = (3.0864 \times 10^5)^2 + (5380)^2$

$R = 3.09 \times 10^5 NC^{-1}$

$\tan\theta = \frac{3.0864 \times 10^5}{5380}$

$\theta = 89^0$

Hence electric field intensity at D = $3.09 \times 10^5 NC^{-1}$ at 89^0 to horizontal

Field strength and charge density

