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Term 2221

Welcome
to
PHYS 212: Physics

Chapter#22

Electric Fields

Topics

- Electric Field.
- Electric Field lines.
- The electric field due to a charge particle.
- The electric field due to a electric dipole.
- Applications :
  - Inkjet printing
  - CRT

22-1 The Electric Field

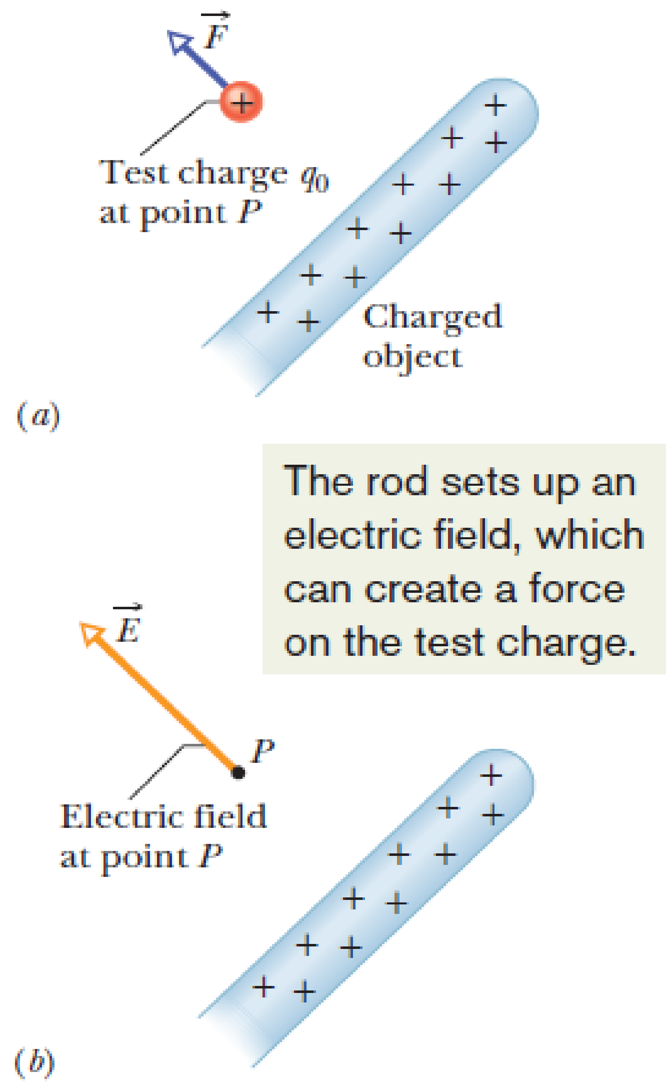
- When there are two charges q_1 and q_2 at a distance, then if q1 and q2 have the same charge, they repel and if they have different charges, they attract.

How does q_1 know that q_2 is near ???
It feels it through something called an Electric Field.

- *An Electric field is a vector field.*

Explanation of the Electric Field:

Fig. 22-1 (a) A positive test charge q_0 placed at point P near a charged object. An electrostatic force $\vec{F}$ acts on the test charge. (b) The electric field $\vec{E}$ at point P produced by the charged object.



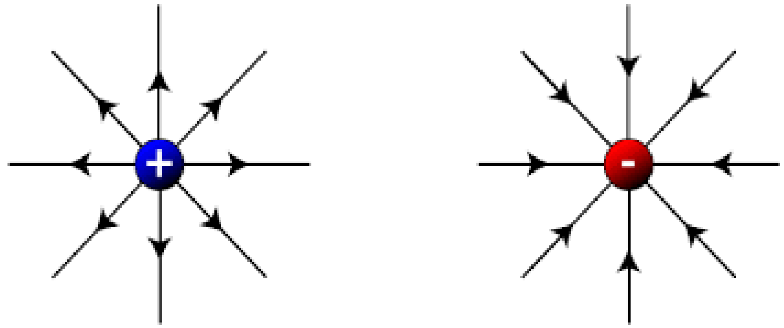
Defining the Intensity of Electric Field

- The electric field $\vec{E}$ at point P due to a charged object can be defined as :

$$\vec{E} = \frac{\vec{F}}{q_0} \qquad \text{(electric field).}$$

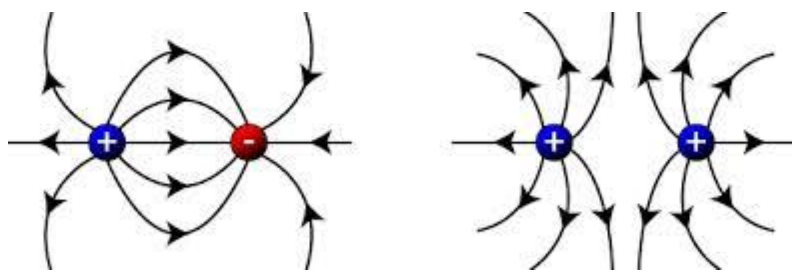
The SI unit for the electric field is newton per coulomb (N/C).

22-1 Electric Field Lines



- Electric field lines due to isolated positive and negative charges.

Electric field lines extend away from positive charge (where they originate) and toward negative charge (where they terminate).

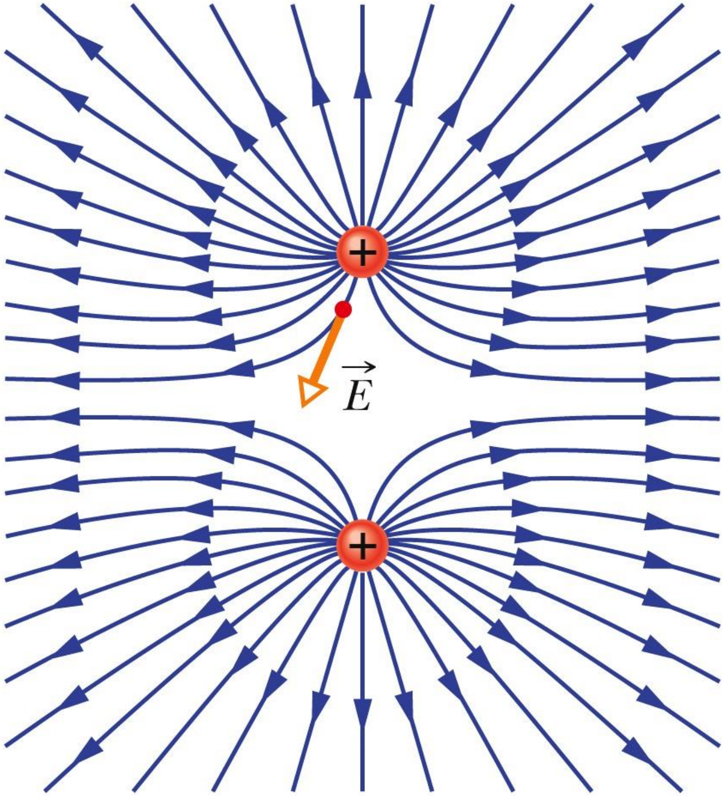


Electric field lines due to attraction and repulsion of charges.

Electric Field lines

(1)The electric field vector at any given point must be tangent to the field line at that point and in the same direction, as shown for one vector.

(2) A closer spacing means a larger field magnitude.



22-2 The Electric Field due to a Charged Particle

- In the electric field due to a point charge q (or charged particle) at any point a distance r from the point charge, the direction of $\vec{F}$ is directly away from the point charge if q is positive, and directly toward the point charge if q is negative. Thze electric field vector is

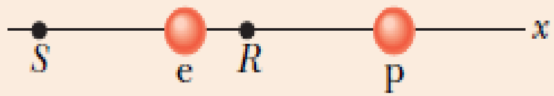
$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{\mathrm{r}} \quad \text{(point charge).}$$

- Also, the net Electric field at the position of the test charge is

$$\vec{E} = \overrightarrow{E_1} + \overrightarrow{E_2} + \overrightarrow{E_3} + \overrightarrow{E_4} \ldots\ldots + \overrightarrow{E_n}$$

- If more than one charged particle sets up an electric field at a point, the net electric field is the vector **sum** of the individual electric fields—**electric fields obey the superposition principle**.

CHECKPOINT 1



The figure here shows a proton p and an electron e on an x axis. What is the direction of the electric field due to the electron at (a) point S and (b) point R? What is the direction of the net electric field at (c) point R and (d) point S?

Hint : Electric field lines go ***in*** a negative charge and ***out*** of a positive charge. Also, p and e have the same magnitude but p is farther.

Problem-1:

A charged particle produces an electric field with a magnitude of 2.0 N/C at a point that is 50 cm away from the particle. What is the magnitude of the particle's charge?

Answer:

$$|q| = 5.6\times10^{-11}\,\text{C}.$$

Problem-2:

A charge $q_1 = 7.0\ \mu C$ is located at the origin, and a second charge $q_2 = -5.0\ \mu C$ is located on the x axis, 0.30 m from the origin (Fig. 23.14). Find the electric field at the point P, which has coordinates (0, 0.40) m.

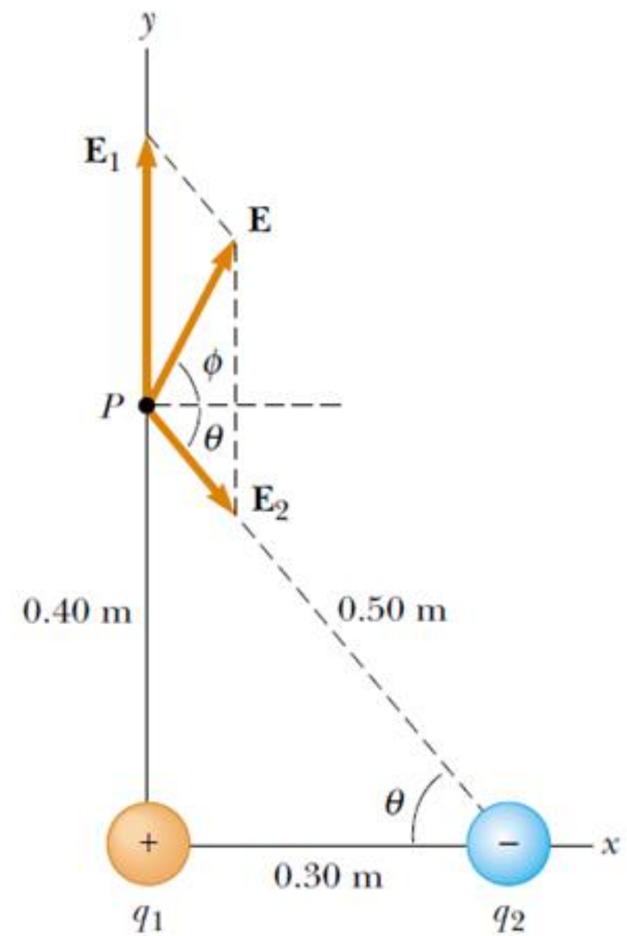


Figure 23.14 (Example 23.5) The total electric field **E** at P equals the vector sum $\mathbf{E}_1 + \mathbf{E}_2$, where $\mathbf{E}_1$ is the field due to the positive charge q_1 and $\mathbf{E}_2$ is the field due to the negative

Solution First, let us find the magnitude of the electric field at P due to each charge. The fields $\mathbf{E}_1$ due to the 7.0-μC charge and $\mathbf{E}_2$ due to the -5.0-μC charge are shown in Figure 23.14. Their magnitudes are

$$E_1 = k_e \frac{|q_1|}{r_1^2} = (8.99 \times 10^9 \ \mathrm{N \cdot m^2/C^2}) \frac{(7.0 \times 10^{-6} \ \mathrm{C})}{(0.40 \ \mathrm{m})^2}$$
$$= 3.9 \times 10^5 \ \mathrm{N/C}$$

$$E_2 = k_e \frac{|q_2|}{r_2^2} = (8.99 \times 10^9 \ \mathrm{N \cdot m^2/C^2}) \frac{(5.0 \times 10^{-6} \ \mathrm{C})}{(0.50 \ \mathrm{m})^2}$$
$$= 1.8 \times 10^5 \ \mathrm{N/C}$$

The vector $\mathbf{E}_1$ has only a y component. The vector $\mathbf{E}_2$ has an x component given by $E_2 \cos\theta = \frac{3}{5}E_2$ and a negative y component given by $-E_2 \sin\theta = -\frac{4}{5}E_2$. Hence, we can express the vectors as

$$\mathbf{E}_1 = 3.9 \times 10^5 \hat{\mathbf{j}} \ \mathrm{N/C}$$

$$\mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} - 1.4 \times 10^5 \hat{\mathbf{j}}) \ \mathrm{N/C}$$

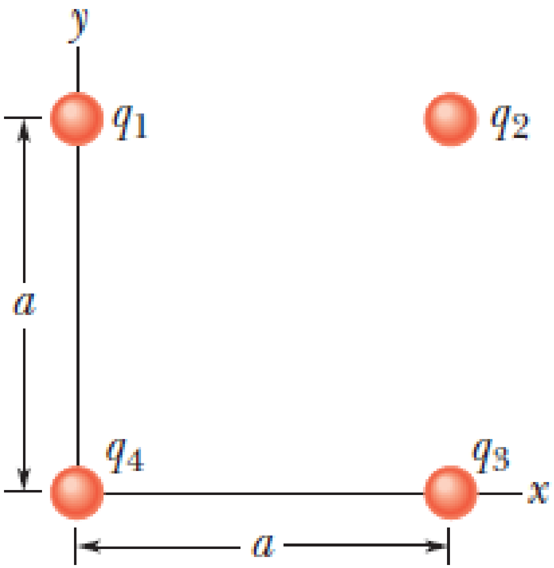
The resultant field $\mathbf{E}$ at P is the superposition of $\mathbf{E}_1$ and $\mathbf{E}_2$:

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 = \boxed{(1.1 \times 10^5 \hat{\mathbf{i}} + 2.5 \times 10^5 \hat{\mathbf{j}}) \ \mathrm{N/C}}$$

From this result, we find that $\mathbf{E}$ makes an angle ϕ of 66° with the positive x axis and has a magnitude of 2.7×10^5 N/C.

Problem-3:

••7 SSM ILW WWW In Fig. 22-35, the four particles form a square of edge length $a = 5.00$ cm and have charges $q_1 = +10.0$ nC, $q_2 = -20.0$ nC, $q_3 = +20.0$ nC, and $q_4 = -10.0$ nC. In unit-vector notation, what net electric field do the particles produce at the square's center?

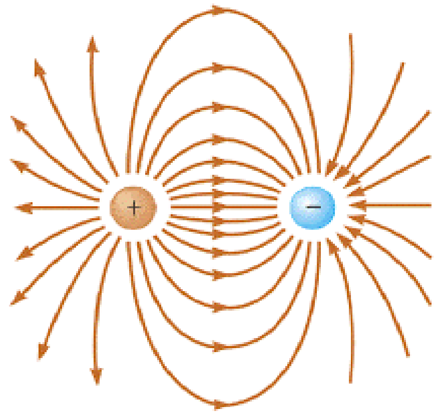


Answer:

$\vec{E} = (1.02\times10^5 \text{ N/C})\hat{\mathrm{j}}$

22-3 The Electric Field due to an Electric Dipole

- An electric dipole can be described as two charged particles of magnitude *q* but of opposite sign, separated by a distance *d.*



An Electric dipole is given by the formula

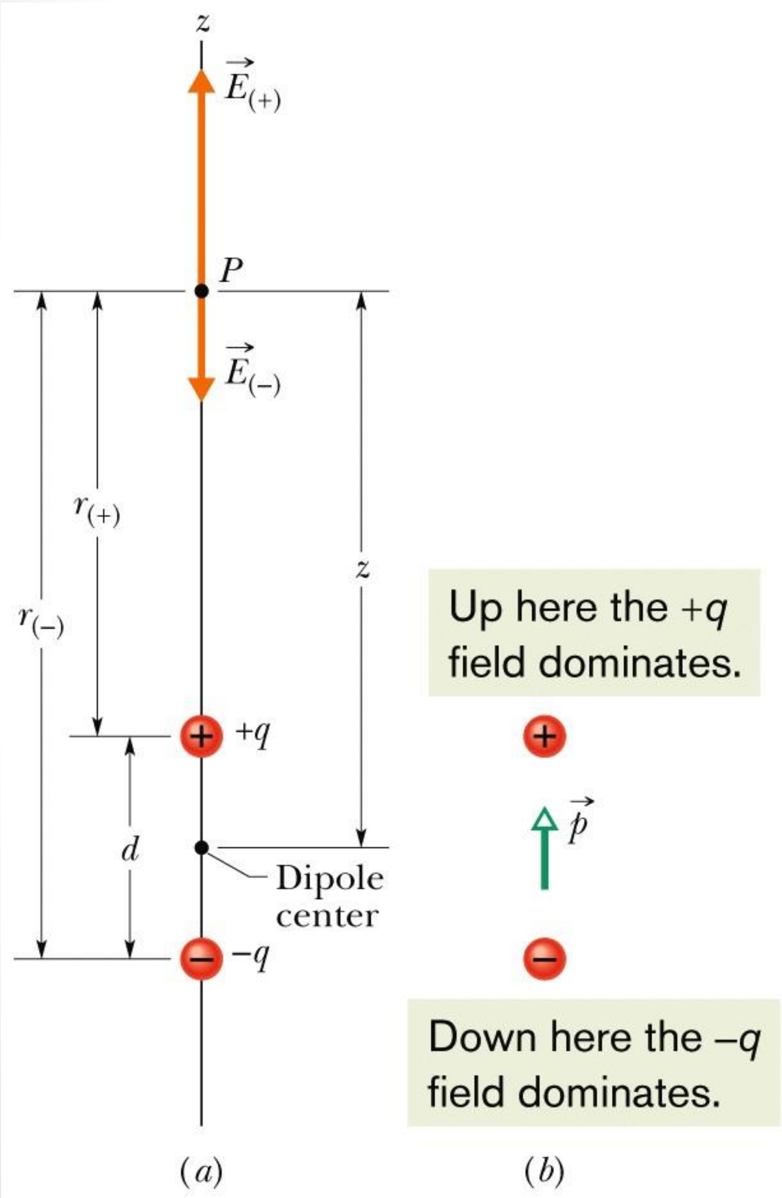
$$p = qd$$

Where p =electric dipole, q= magnitude of the charges,

d = distance between the charges.

The SI unit of the electric dipole is **C-m**.

The Electric Field due to an Electric Dipole



- The electric field due to a dipole p is given by the formula

$$E = \frac{1}{2\pi\varepsilon_0}\frac{p}{z^3}$$

Where z = the distance from the center of the dipole to a point P.

Another way of writing this formula is

$$E = \frac{2kp}{z^3} \text{ (k= 8.99x}10^{-9}\text{ Nm}^2/\text{C}^2\text{)}$$

In simple words,

E for a dipole is inversely proportional to z^3

Dipole in an Electric Field

❖ ***Dipole in an Electric Field***: When an electric dipole of dipole moment is placed in an electric field ,the field exerts a torque on the dipole:

$$\overrightarrow{\tau} = \overrightarrow{P} \times \overrightarrow{E}$$

❖ The dipole has a potential energy **U** associated with its orientation in the field:

$$U = -\overrightarrow{P}.\overrightarrow{E}$$

❖ This potential energy is defined to be zero when $\overrightarrow{P}$ is perpendicular to $\overrightarrow{E}$; it is least ($U = -pE$) when $\overrightarrow{P}$ is aligned with $\overrightarrow{E}$ and greatest ($U = pE$) when $\overrightarrow{P}$ is directed opposite $\overrightarrow{E}$.

Problem-4:

•56 An electric dipole consists of charges $+2e$ and $-2e$ separated by 0.78 nm. It is in an electric field of strength 3.4×10^6 N/C. Calculate the magnitude of the torque on the dipole when the dipole moment is (a) parallel to, (b) perpendicular to, and (c) antiparallel to the electric field.

Answer:

(a) $\tau = 0$

(b) $\tau = 8.5 \times 10^{-22}\ \mathrm{N \cdot m}$

(c) $\tau = 0$

Problem-5:

83 SSM An electric dipole with dipole moment

$$\vec{p} = (3.00\hat{\text{i}} + 4.00\hat{\text{j}})(1.24 \times 10^{-30}\ \text{C}\cdot\text{m})$$

is in an electric field $\vec{E} = (4000\ \text{N/C})\hat{\text{i}}$. (a) What is the potential energy of the electric dipole? (b) What is the torque acting on it? (c) If an external agent turns the dipole until its electric dipole moment is

$$\vec{p} = (-4.00\hat{\text{i}} + 3.00\hat{\text{j}})(1.24 \times 10^{-30}\ \text{C}\cdot\text{m}),$$

how much work is done by the agent?

Answer:

(a) $U = -1.49 \times 10^{-26}$ J.

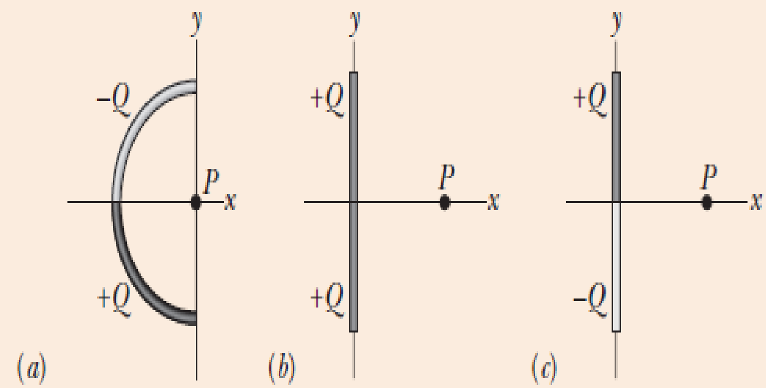
(b) $\vec{\tau} = \left(-1.98 \times 10^{-26}\,\text{N}\cdot\text{m}\right)\hat{\text{k}}$.

(c) The work done is

$$W = 3.47 \times 10^{-26}\ \text{J}.$$

CHECKPOINT 2

The figure here shows three nonconducting rods, one circular and two straight. Each has a uniform charge of magnitude Q along its top half and another along its bottom half. For each rod, what is the direction of the net electric field at point P?



Answers:

(a)

(b)

(c)

<u>Hints</u>:

- The electric dipole moment $\vec{p}$ of an electric dipole is a vector that points from the negative to the positive end of the dipole.

- Dipole fields are much smaller than the fields of isolated charges, but in dielectric where there are no free charges, the dipole effects are principal.

22-6 A Point charge in an Electric Field

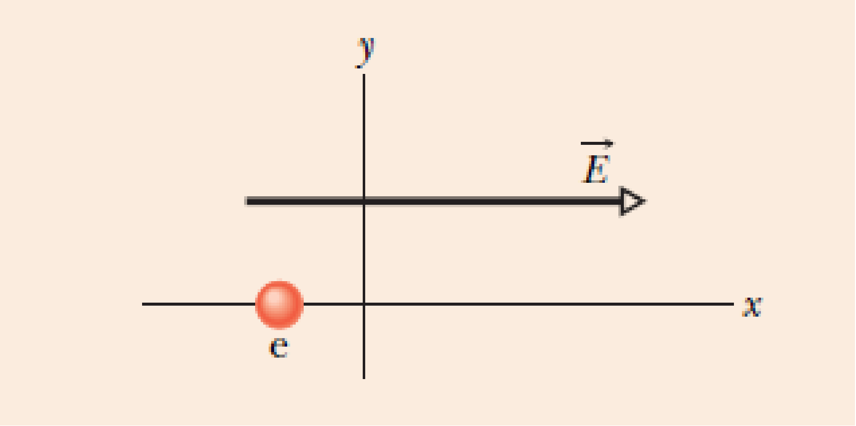
If a particle with charge ***q*** is placed in an external electric field ***E***, an electrostatic force ***F*** acts on the particle:

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

The electrostatic force $\vec{F}$ acting on a charged particle located in an external electric field $\vec{E}$ has the direction of $\vec{E}$ if the charge q of the particle is positive and has the opposite direction if q is negative.

CHECKPOINT 3

(a) In the figure, what is the direction of the electrostatic force on the electron due to the external electric field shown?



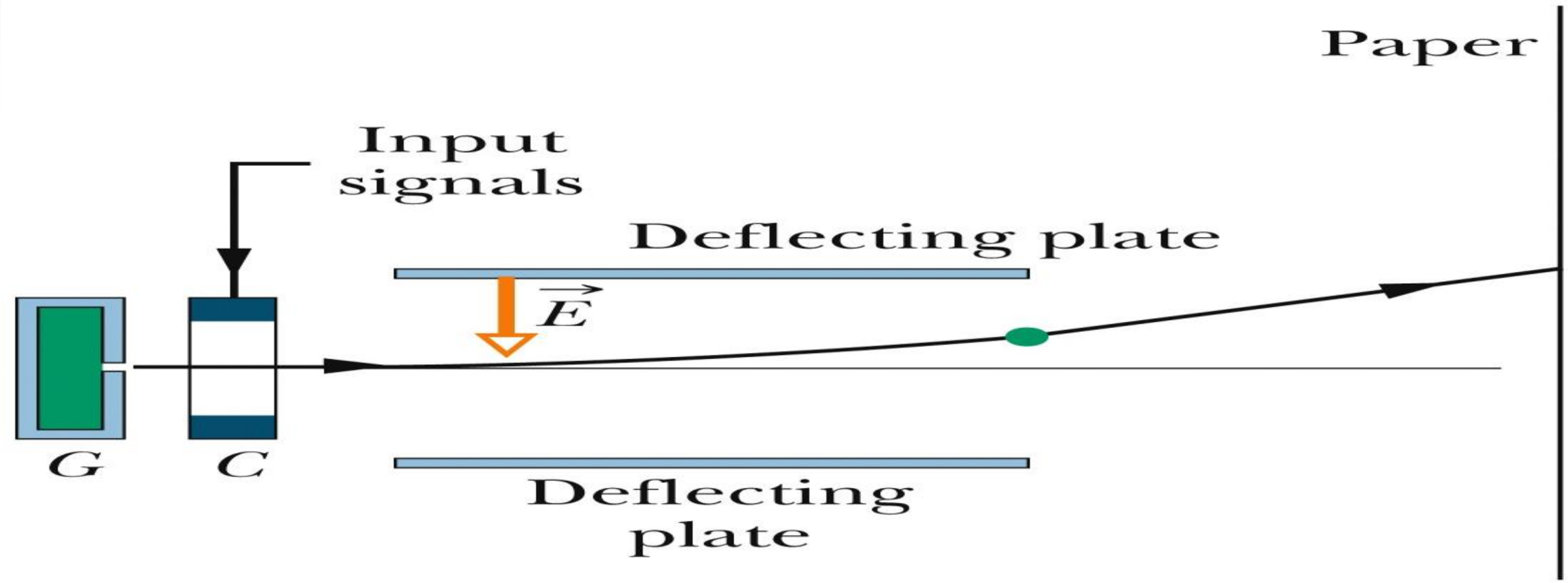
Answer:

Hint:

If it's a positive charge then the force will be in the direction the Electric field

and it will be in the opposite direction of the electric field if it's a negative charge.

Application: Inkjet Printing



Ink-jet printer: Drops shot from generator ***G*** receive a charge in charging unit ***C***. An input signal from a computer controls the charge and thus the effect of field ***E*** on where the drop lands on the paper.

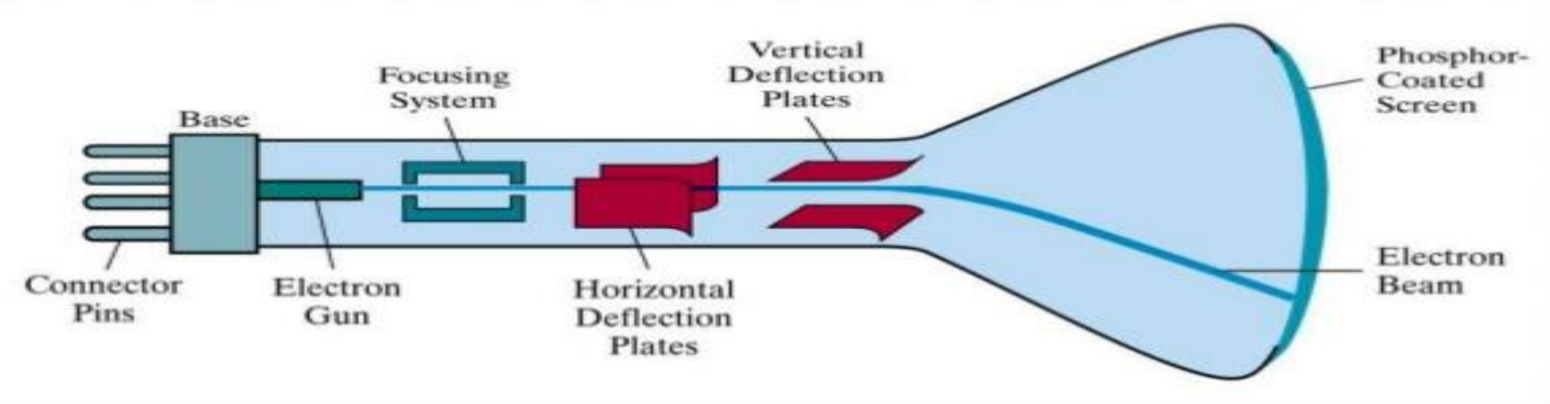
Application: Inkjet Printing

Ink-jet printer:

Figure shows a **negatively charged drop** moving between two conducting deflecting plates, between which a uniform downward-directed electric field $\vec{\mathbf{E}}$ has been set up.

The drop is deflected upward according to $\vec{\mathbf{F}} = \mathbf{q}\,\vec{\mathbf{E}}$ and then strikes the paper at a position that is determined by the magnitudes of $\vec{\mathbf{E}}$ and the charge **q** of the drop.

Application: The Cathode Ray Tube (CRT)



The **CRT** tube, is used to obtain a visual display of electronic information in oscilloscopes, radar systems, television receivers, and computer monitors.

The **CRT** is a vacuum tube in which a beam of electrons is accelerated and deflected under the effect of electric or magnetic fields.