

# 2.6 Force due to an electric charge

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2024-09-22

# Quick review:

**02:00**

A charge of  $1.34 \times 10^{-15}$  is distributed over a plane with dimensions of 3 m per side. What is the charge density of the plane?

**Answer:**

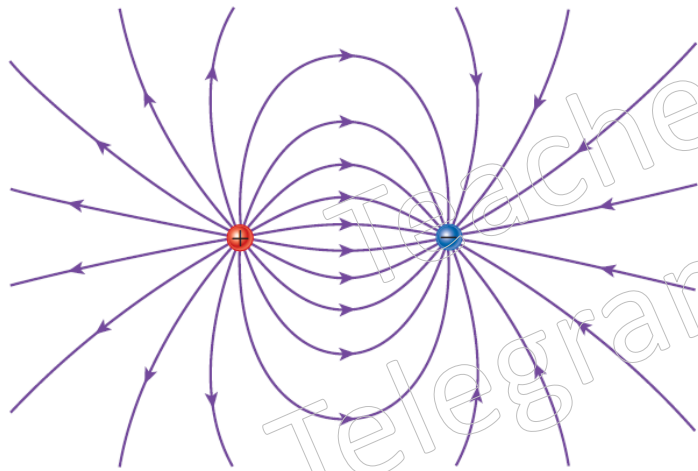
$$\sigma = \frac{q}{A}$$

$$A = 3 \times 3 = 9m^2$$

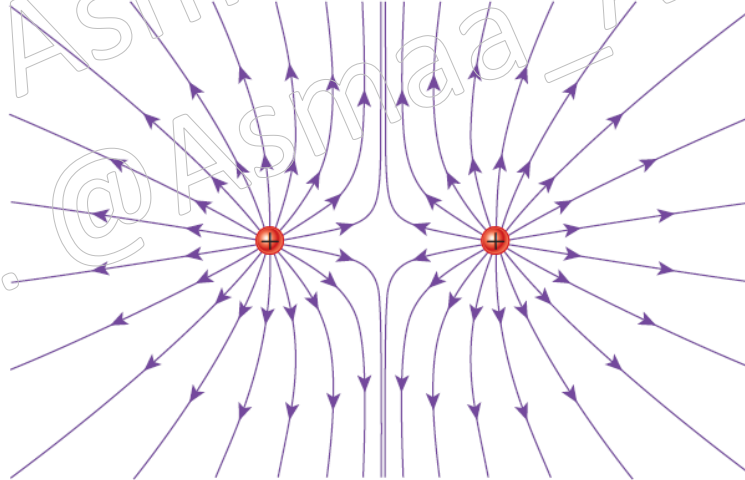
$$\sigma = \frac{q}{A} = \frac{1.34 \times 10^{-15} \text{ C}}{9 \text{ m}^2} = 1.49 \times 10^{-16} \frac{\text{C}}{\text{m}^2}$$

# Force due to an electric field

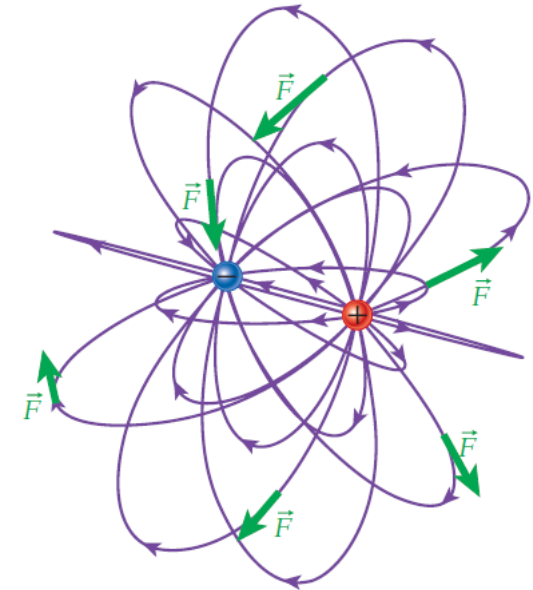
The force  $\vec{F}$  exerted by an electric field on a point charge  $q$  is given by  $\vec{F} = q\vec{E}$ .



2D



2D

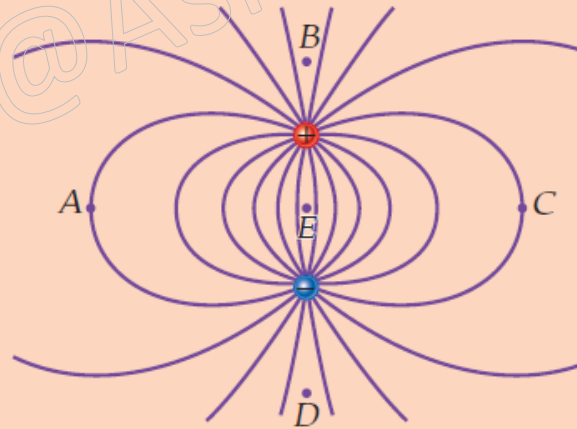


3D

# Activity: Page 37:

## Self-Test Opportunity 2.1

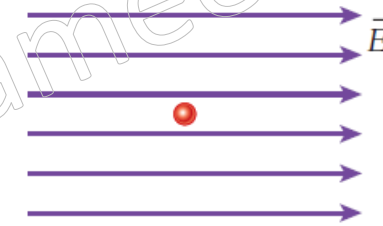
The figure shows a two-dimensional view of electric field lines due to two opposite charges. What is the direction of the electric field at the five points  $A$ ,  $B$ ,  $C$ ,  $D$ , and  $E$ ? At which of the five points is the magnitude of the electric field the largest?



**2.1** The direction of the electric field is downward at points  $A$ ,  $C$ , and  $E$  and upward at points  $B$  and  $D$ . (There is an electric field at point  $E$ , even though there is no line drawn there; the field lines are only sample representations of the electric field, which also exists between the field lines.) The field is largest in magnitude at point  $E$ , which can be inferred from the fact that it is located where the field lines have the highest density.

## Concept Check 2.5

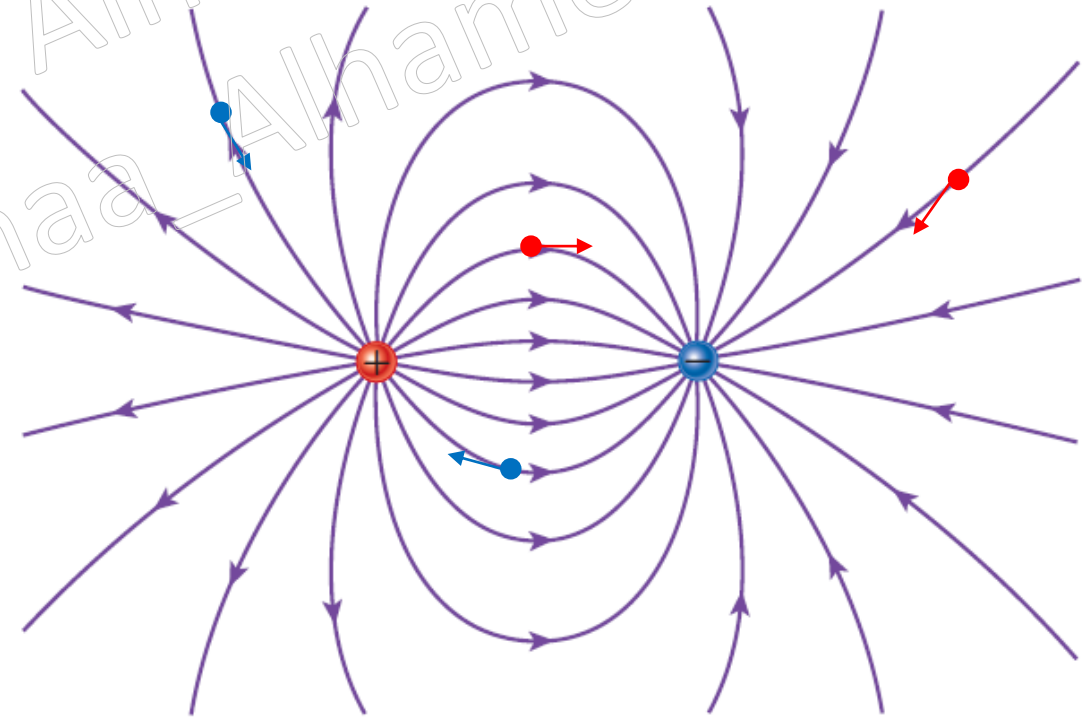
A small positively charged object is placed at rest in a uniform electric field as shown in the figure. When the object is released, it will



- a) not move.
- b) begin to move with a constant speed.
- c) begin to move with a constant acceleration.**
- d) begin to move with an increasing acceleration.
- e) move back and forth in simple harmonic motion.

# Force due to an electric field

- You can see that the **force** on the **positive charge** is always tangent to the field lines and points **in the same direction as the electric field**.
- The force on the **negative charge** would point **in the opposite direction**.



Direction of the forces

# Force due to an electric field (page 37):

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**Read at home**

## **EXAMPLE 2.4**

### **Time Projection Chamber**

Nuclear physicists study new forms of matter by colliding gold nuclei at very high energies. In particle physics, new elementary particles are created and studied by colliding protons and antiprotons at the highest energies. These collisions create many particles that stream away from the interaction point at high speeds. A simple particle detector is not sufficient to identify these particles. A device that helps physicists study these collisions is a time projection chamber (TPC), found in most large particle detectors.

# Force due to an electric field: Example

## SOLVED PROBLEM 2.2

### Electron Moving over a Charged Plate

#### PROBLEM

An electron with a kinetic energy of 2.00 keV ( $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$ ) is fired horizontally across a horizontally oriented charged conducting plate with a surface charge density of  $+4.00 \times 10^{-6} \text{ C/m}^2$ . Taking the positive direction to be upward (away from the plate), what is the vertical deflection of the electron after it has traveled a horizontal distance of 4.00 cm?

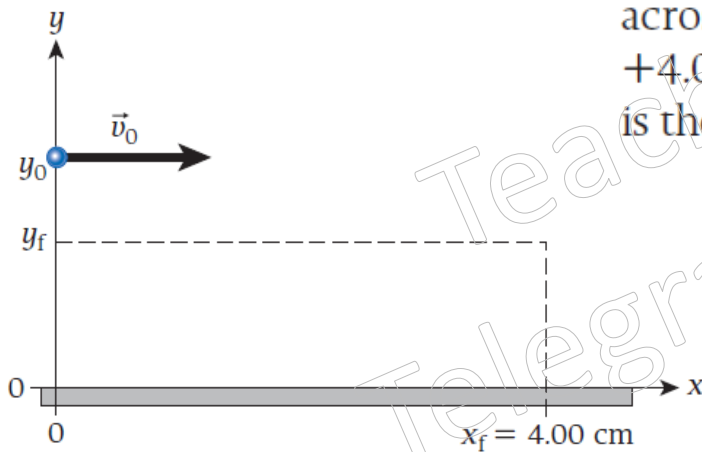


**FIGURE 2.18** An electron moving to the right with initial velocity  $\vec{v}_0$  over a charged conducting plate.

# Force due to an electric field:

## SOLUTION

**THINK** The initial velocity of the electron is horizontal. During its motion, the electron experiences a constant attractive force from the positively charged plate, which causes a constant acceleration downward. We can calculate the time it takes the electron to travel 4.00 cm in the horizontal direction and use this time to calculate the vertical deflection of the electron.

**SKETCH** Figure 2.18 shows the electron with initial velocity  $\vec{v}_0$  in the horizontal direction. The initial position of the electron is taken to be at  $x_0 = 0$  and  $y = y_0$ .

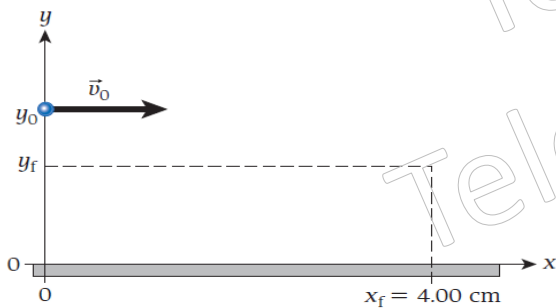


**FIGURE 2.18** An electron moving to the right with initial velocity  $\vec{v}_0$  over a charged conducting plate.

# Force due to an electric field:

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The magnitude of the electric field can be calculated using:

$$E = \frac{q}{4\pi\epsilon_0 r^2}$$

If you consider the sphere to be hollow, all of its charge will be concentrated on its surface. The surface area of a sphere is equal to  $4\pi r^2$ . The density of charge on this sphere's surface is:

$$\sigma = \frac{q}{A}$$

$$\sigma = \frac{q}{4\pi r^2}$$

Therefore, the electric field can also be calculated using:

$$E = \frac{\sigma}{\epsilon_0}$$

where  $\sigma$  is the charge density on the conducting plate and  $e$  is the charge of an electron. This force causes a constant acceleration in the downward direction whose magnitude is given by  $a = F/m$ , where  $m$  is the mass of the electron. Using the expression for the force from equation (ii), we can express the magnitude of this acceleration as

$$a = \frac{F}{m} = \frac{e\sigma}{m\epsilon_0} \quad (\text{iii})$$

Note that this acceleration is constant. Thus, the vertical position of the electron as a function of time is given by

$$y_f = y_0 - \frac{1}{2}at^2 \Rightarrow y_f - y_0 = -\frac{1}{2}at^2 \quad (\text{iv})$$

Finally, we can relate the electron's initial kinetic energy to its initial velocity through

$$K = \frac{1}{2}mv_0^2 \Rightarrow v_0^2 = \frac{2K}{m} \quad (\text{v})$$

**SIMPLIFY** We substitute the expressions for the time and the acceleration from equations (i) and (iii) into equation (iv) and obtain

$$y_f - y_0 = -\frac{1}{2}at^2 = -\frac{1}{2}\left(\frac{e\sigma}{m\varepsilon_0}\right)\left(\frac{x_f}{v_0}\right)^2 = -\frac{e\sigma x_f^2}{2m\varepsilon_0 v_0^2} \quad (\text{vi})$$

Now substituting the expression for the square of the initial speed from equation (v) into the right-hand side of equation (vi) gives us

$$y_f - y_0 = -\frac{e\sigma x_f^2}{2m\varepsilon_0 \left(\frac{2K}{m}\right)} = -\frac{e\sigma x_f^2}{4\varepsilon_0 K} \quad (\text{vii})$$

**CALCULATE** We first convert the kinetic energy of the electron from electron-volts to joules:

$$K = (2.00 \text{ keV}) \frac{1.602 \times 10^{-19} \text{ J}}{1 \text{ eV}} = 3.204 \times 10^{-16} \text{ J}$$

Putting the numerical values into equation (vii), we get

$$y_f - y_0 = -\frac{e\sigma x_f^2}{4\varepsilon_0 K} = -\frac{(1.602 \times 10^{-19} \text{ C})(4.00 \times 10^{-6} \text{ C/m}^2)(0.0400 \text{ m})^2}{4(8.85 \times 10^{-12} \text{ C}^2/(\text{N m}^2))(3.204 \times 10^{-16} \text{ J})} = -0.0903955 \text{ m}$$

**ROUND** We report our result to three significant figures:

$$y_f - y_0 = -0.0904 \text{ m} = -9.04 \text{ cm}$$

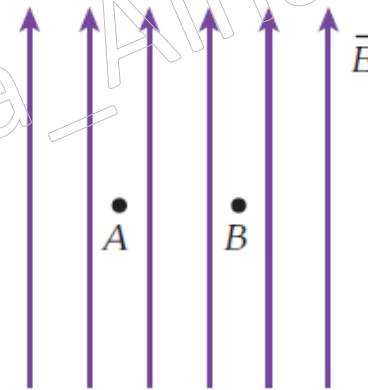
# Activity: Page 37:

**02:00**

## Concept Check 2.6

A small positively charged object could be placed in a uniform electric field at position *A* or position *B* in the figure. How do the electric forces on the object at the two positions compare?

- a) The magnitude of the electric force on the object is greater at position *A*.
- b) The magnitude of the electric force on the object is greater at position *B*.
- c) There is no electric force on the object at either position *A* or position *B*.
- d) The electric force on the object at position *A* has the same magnitude as the force on the object at position *B* but is in the opposite direction.



- e) The electric force on the object at position *A* is the same nonzero electric force as that on the object at position *B*.