Static electricity

EP0605

PRE-CLASS (1 TO 14)

IN-CLASS (16 ONWARDS)

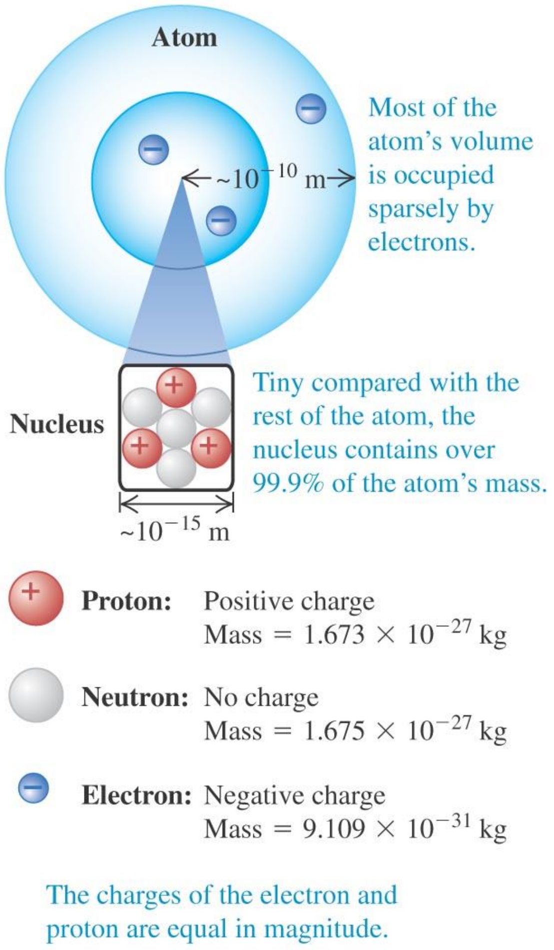
Learning objectives

At the end of this chapter, student should be able to:

- state Coulomb’s law for forces between point charges.
- calculate the electric force on a point charge due to several point charges.
- determine the electric field at a point due to several point charges.

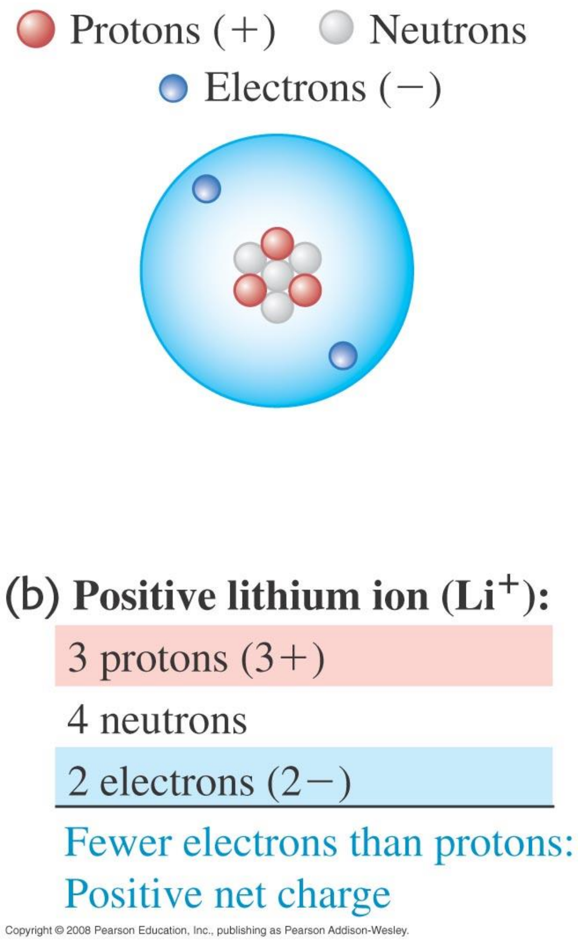
Atoms

- Atoms are made up of :
  - electrons
  - protons
  - neutrons
- The number of protons and electrons are equal when the atom is neutral.
- An electron has a charge of -1.6×10^{-19} C.
- A proton has a charge of $+1.6 \times 10^{-19}$ C.



Ions

- A lithium atom gas 3 protons and 3 electrons.
- A positive lithium ion has 3 protons and 2 electrons and a net charge of $+1.6 \times 10^{-19}$ C.
- A negative lithium ion has 3 protons and 4 electrons and a net charge of -1.6×10^{-19} C
- Transfer of electrons between the atoms of objects can result in the objects either acquiring a net positive or negative charge.



Example 1

How many electrons will give you a charge of -32×10^{-6} C?

Solution:

Number of electrons:

$$n = \frac{Q}{e} = \frac{-32 \times 10^{-6}}{-1.6 \times 10^{-19}} = 2.0 \times 10^{14}$$

Example 2

If you transfer 10^6 electrons from object A to object B, what is their net charge? Charge of an electron is -1.6×10^{-19} C.

Amount of charge transferred is $q = 10^6 \times (-1.6 \times 10^{-19}) = -1.6 \times 10^{-13}$ C

Hence A becomes $+1.6 \times 10^{-13}$ C and B becomes -1.6×10^{-13} C.

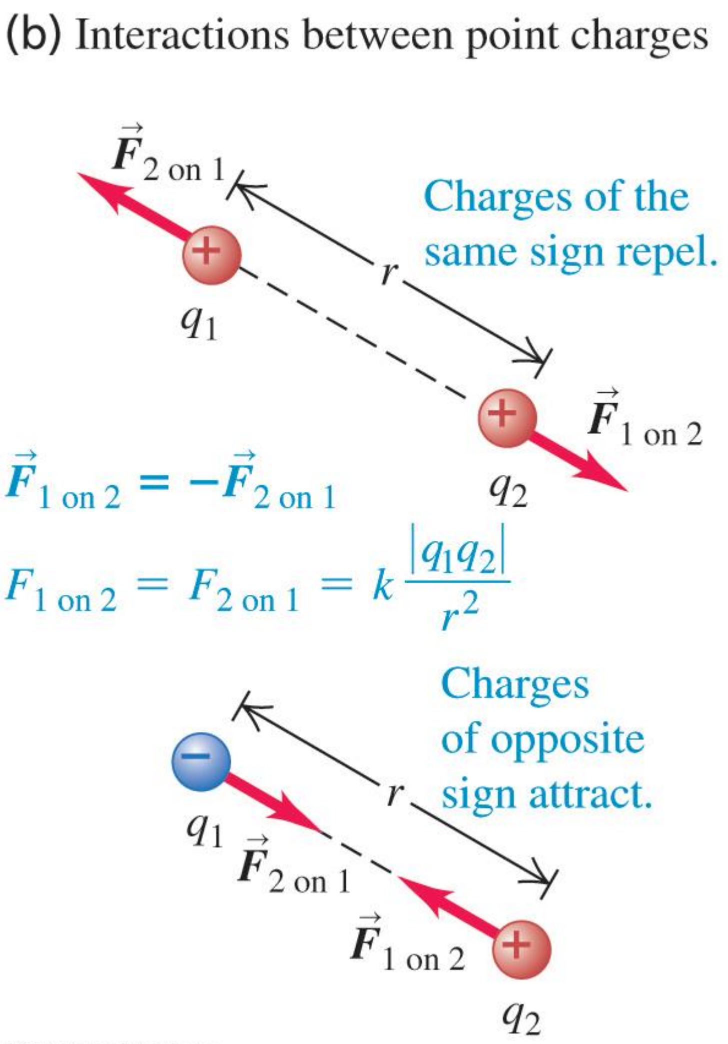
Coulomb's Law for point charges

- The force between two point charges is given by Coulomb's law.
- The magnitude of the force between q_1 and q_2 is

$$F = k\frac{|q_1 q_2|}{r^2}$$

where $k = 8.9876 \times 10^9$ N m^2/ C^2 is the Coulomb constant, q_1 and q_2 are in coulombs (C) and r is the distance between them in metres (m).

- The absolute sign is required because the product of q_1 and q_2 can be negative.



Permittivity

- Coulomb's constant can be written as

$$k = \frac{1}{4\pi\epsilon_0}$$

where ϵ_0 is the permittivity of free space (or vacuum) and has a value of $8.854 \times 10^{-12}\ C^2/N\,m^2$.

- If the charges are in some medium, then

$$k = \frac{1}{4\pi\epsilon}$$

where ϵ is the permittivity of the medium.

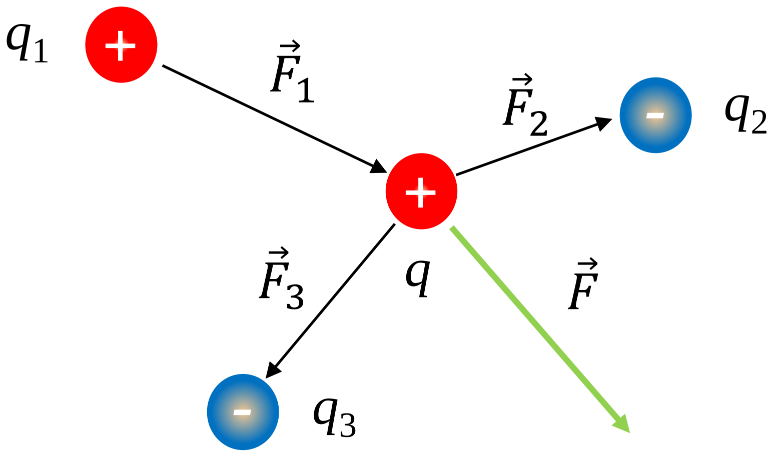
Relative permittivity

- The ratio $\epsilon_r = \frac{\epsilon}{\epsilon_0}$ is known as relative permittivity.
- The relative permittivity ϵ_r of water is 80.
- Hence ϵ for water = $80\epsilon_0$
- When common salt or sodium chloride (NaCl) is put into water, the force between the sodium and chloride ions is reduced by 80 times.
- This explains the high solubility of common salt in water.

Superposition of forces

- The superposition of forces principle states that the resultant force on any one charge equals the vector sum of all the forces exerted by the other individual charges that are present, i.e.,

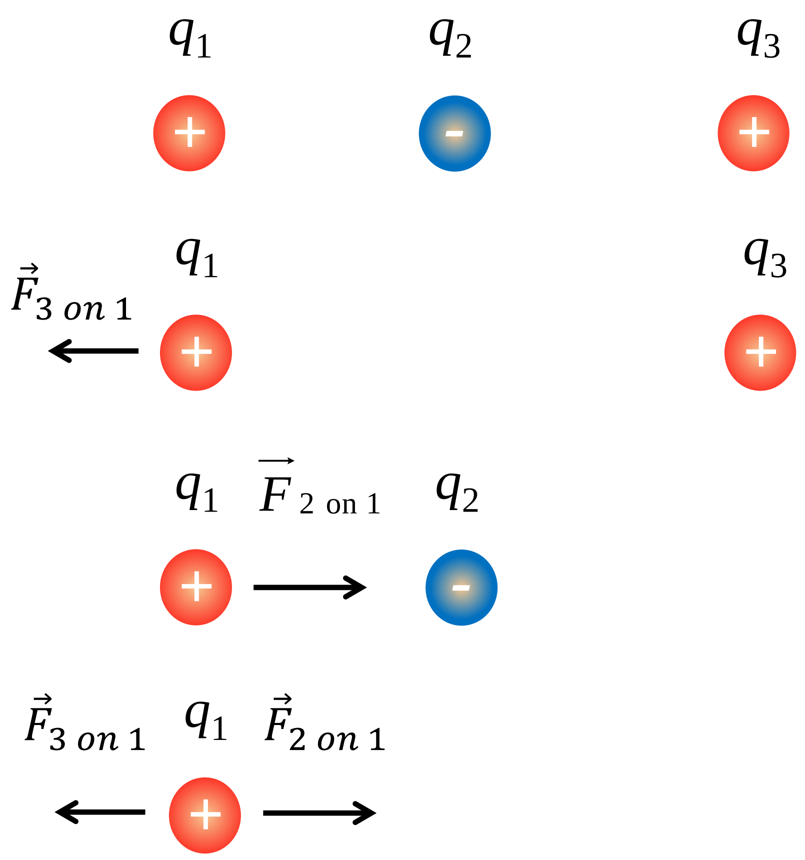
$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$$



Force on point charge due to other point charges

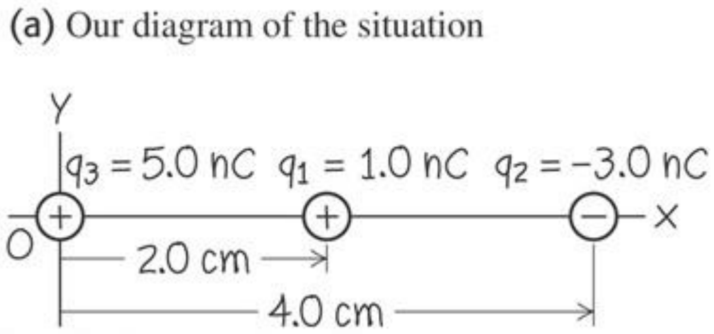
- Consider the three charges shown.
- Suppose we want the force on q_1 due to q_2 and q_3.
- Imagine only q_1 and q_3 are present and draw the force $\vec{F}_{3\ on\ 1}$.
- Next imagine only q_1 and q_2 are present and draw the force $\vec{F}_{2\ on\ 1}$.
- The net force on q_1 is the vector sum of the two forces,

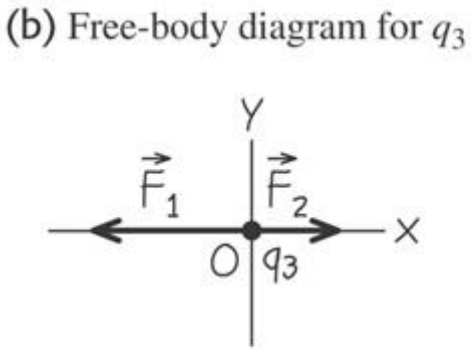
$$\vec{F}_{net} = \vec{F}_{3\ on\ 1} + \vec{F}_{2\ on\ 1}$$



Example 3

Two point charges are located on the x-axis of a coordinate system: $q_1 = 1.0$ nC is at $x = +2.0$ cm and $q_2 = -3.0$ nC is at $x = +4.0$ cm. What is the total electric force exerted by q_1 and q_2 on a charge $q_3 = 5.0$ nC at $x = 0$? Take $k = 8.9876 \times 10^9$ N m^2/ C^2 .





The magnitude of $\vec{F}_1$ and $\vec{F}_2$ acting on q_3 are:

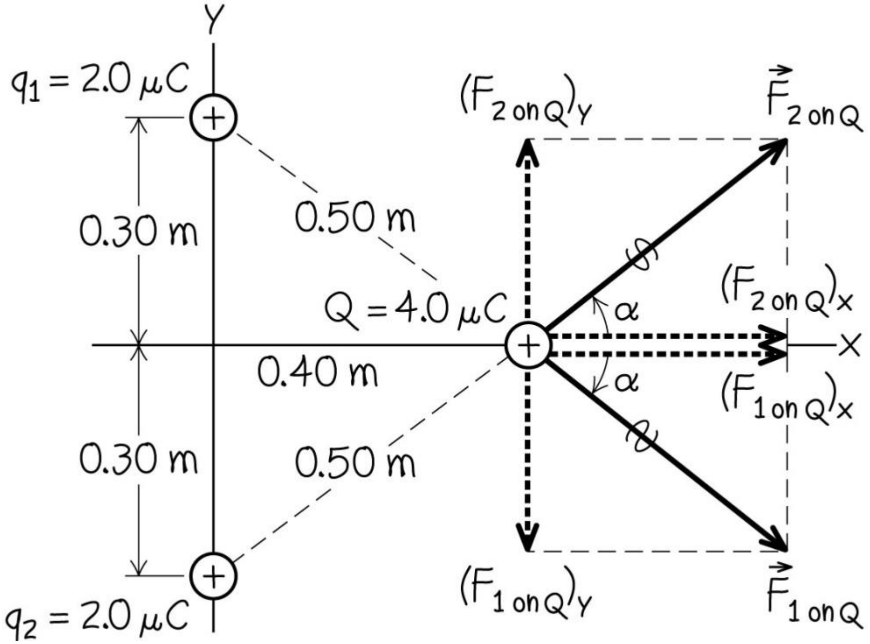
$$F_1 = k\frac{|(1.0 \times 10^{-9})(5.0 \times 10^{-9})|}{0.02^2} = 112 \times 10^{-6}\text{ N}$$

$$F_2 = k\frac{|(-3.0 \times 10^{-9})(5.0 \times 10^{-9})|}{0.04^2} = 84 \times 10^{-6}\text{ N}$$

$$\vec{F} = \vec{F}_1 + \vec{F}_2 = -112 \times 10^{-6}\,\hat{\imath} + 84 \times 10^{-6}\,\hat{\imath} = -28 \times 10^{-6}\,\hat{\imath}\text{ N}$$

Example 4

Two equal positive charges point charges $q_1 = q_2 = 2.0\ \mu\text{C}$ are located at $x = 0$, $y = 0.30$ m and $x = 0$, $y = -0.30$ m respectively. What are the magnitude and direction of the total electric force that q_1 and q_2 exert on a third charge $Q = 4.0\ \mu\text{C}$ located at $x = 0.4$ m, $y = 0$?



Due to the symmetrical positions of q_1 and q_2 with respect to Q, there is no net y-component force on Q.

$$F_{1\ on\ Q} = k\frac{(2.0\times10^{-6})(4.0\times10^{-6})}{0.05^2} = 0.29\ \text{N}$$

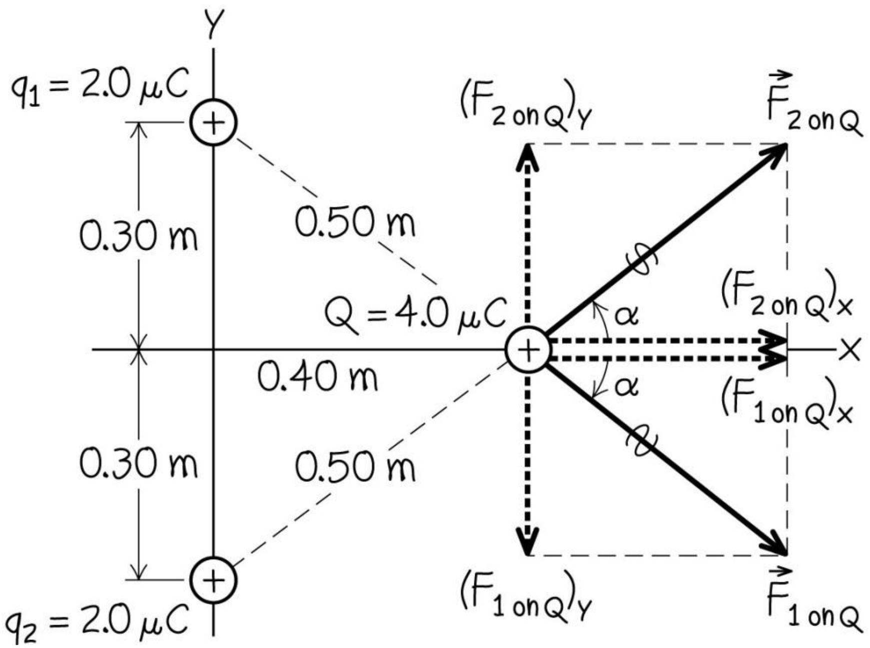
From the figure, $\cos\alpha = \frac{0.4}{0.5} = 0.8$

The x-component of $F_{1\ on\ Q}$ is

$$\left(F_{1\ on\ Q}\right)_x = F_{1\ on\ Q}\cos\alpha = 0.29(0.8) = 0.23\ \text{N}$$

Example 4 - cont

Two equal positive charges point charges $q_1 = q_2 = 2.0\ \mu\text{C}$ are located at $x = 0$, $y = 0.30$ m and $x = 0$, $y = -0.30$ m respectively. What are the magnitude and direction of the total electric force that q_1 and q_2 exert on a third charge $Q = 4.0\ \mu\text{C}$ located at $x = 0.4$ m, $y = 0$?



$$\left(\vec{F}_{1\,on\,Q}\right)_x = 0.23\ \hat{\imath}\ \text{N}$$

$$\left(\vec{F}_{2\,on\,Q}\right)_x = 0.23\ \hat{\imath}\ \text{N}$$

$$\vec{F}_{net} = 2\left(\vec{F}_{1\,on\,Q}\right)_x = 2\left(\vec{F}_{2\,on\,Q}\right)_x = 0.46\ \hat{\imath}\ \text{N}$$

End of pre-class slides

Class Exercise

Two small plastic spheres are given positive electric charges. When they are 15.0 cm apart, the repulsive force between them has magnitude 0.220 N. What is the charge on each sphere

(a) if the two charges are equal and

(b) if one sphere has four times the charge of the other?

Electric field

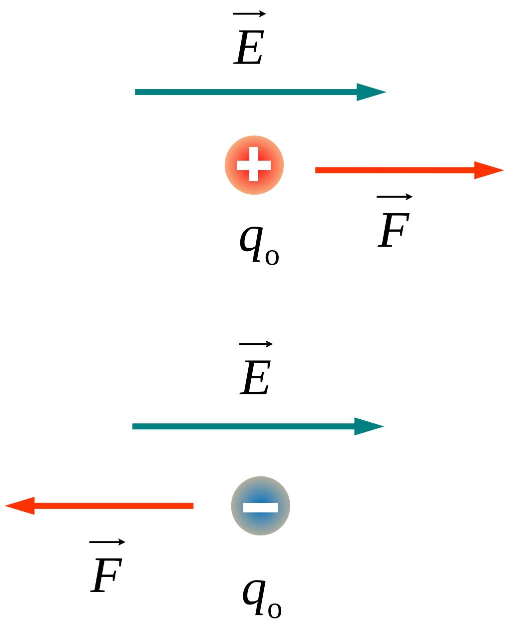
- An electric field is a region where an electric charge experiences an electric force.
- The charge may be either stationary or moving.
- The direction of electric field is defined as the direction of the electric force on a positive test charge.
- Electric fields are represented by imaginary field lines.
- The stronger the field, the denser the lines.

Mathematical definition of electric field

- Suppose we require the electric field $\vec{E}$ at the position of a point charge q_0. By definition,

$$\vec{E} = \frac{\vec{F}}{q_0}$$

- In words, it is the force per unit charge experience by the charge at that position.
- The SI unit of electric field is therefore N/C.
- If q_0 is positive, $\vec{E}$ is in the same direction as $\vec{F}$.
- If q_0 is negative, $\vec{E}$ is opposite to $\vec{F}$.



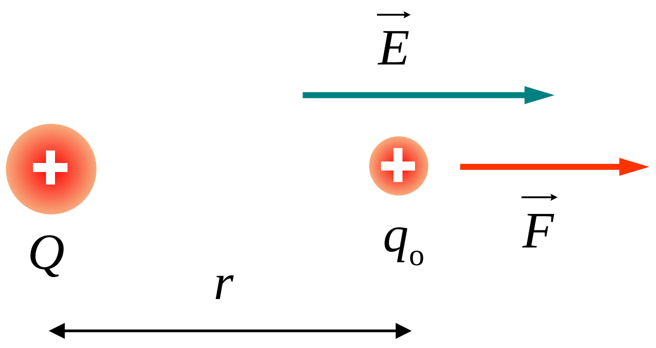
Electric field due to a point charge

- From Coulomb's law, the force exerted by Q on q_0 is

$$\vec{F} = k\frac{Qq_0}{r^2}\,\hat{r}$$

- Dividing both sides by q_0, we get

$$\vec{E} = \frac{\vec{F}}{q_0} = k\frac{Q}{r^2}\,\hat{r}$$



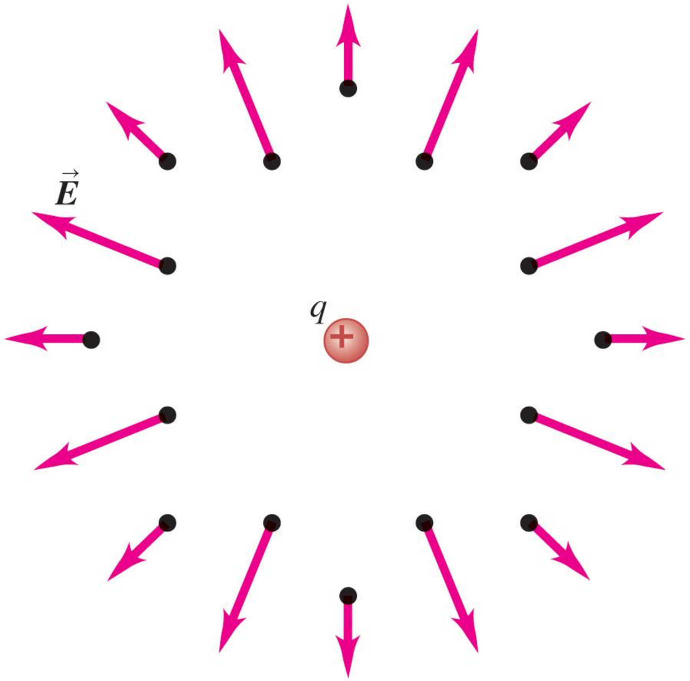
- Note that this formula is correct only for fields due to point charges.

- Also note that we do not need to know q_0 when we are finding fields.

Electric field of point charges

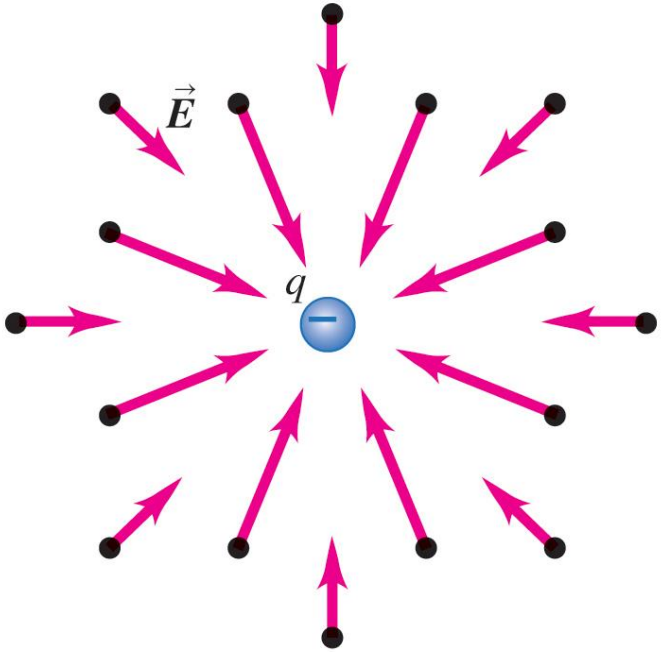
For a single isolated **positive** point charge, the field lines are straight lines pointing **away** from the positive charge.

(a) The field produced by a positive point charge points *away from* the charge.



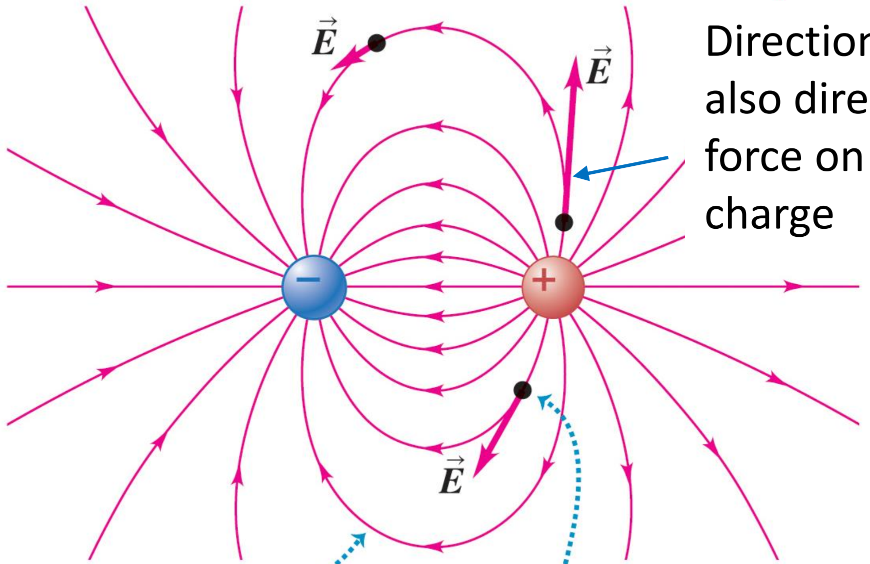
For a single isolated **negative** point charge, the field lines are straight lines pointing **towards** the negative charge.

(b) The field produced by a negative point charge points *toward* the charge.



Electric field due to two point charges

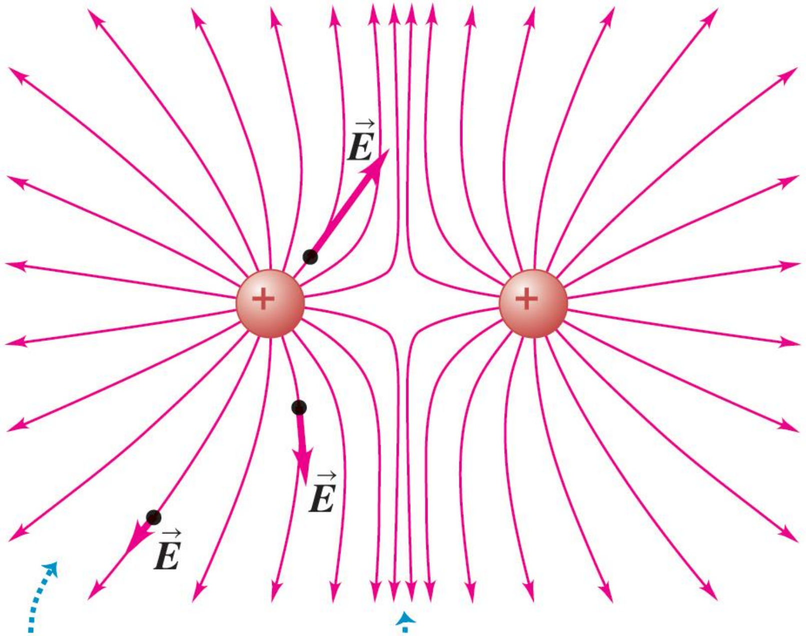
- The electric field of two point charges is the resultant of their individual fields.
- The shapes of the field lines are such that the tangent to the curves at any point is the direction of the electric force on a positive charge at that point.



Direction of E is also direction of force on positive charge

Field lines always point *away from* (+) charges and *toward* (−) charges.

At each point in space, the electric field vector is *tangent* to the field line passing through that point.



Field lines are close together where the field is strong, farther apart where it is weaker.

Example 5

A point charge $Q = 12$ μC is located at the origin. Find the electric field at the points $x = 1.2$ m, $y = 0$ m and at $x = -1.2$ m, $y = 0$ m .

Solution:

It is easier to find the magnitude of the electric field first, then determine its direction.

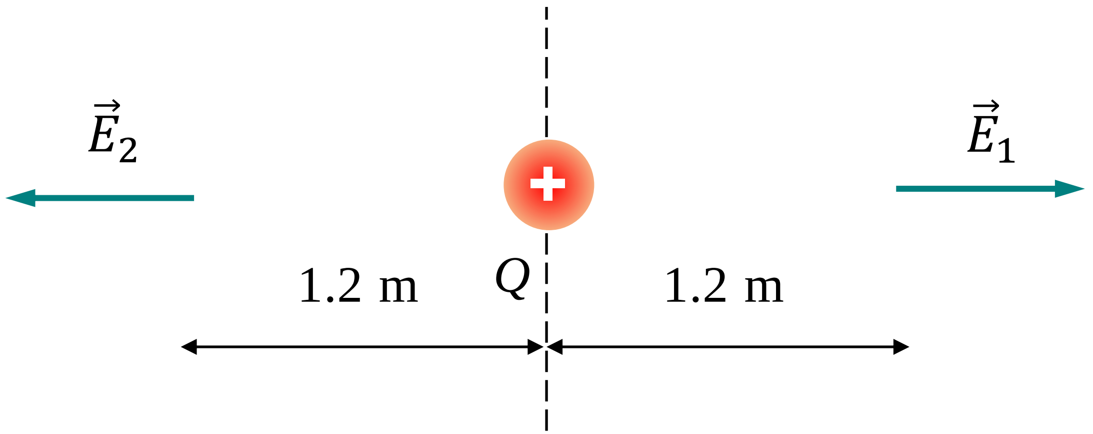
The force per unit charge on q_0 distance r from Q is

$$E = \frac{F}{q_o} = k\frac{Q}{r^2}$$

$$E = 8.99 \times 10^9 \times \frac{12 \times 10^{-6}}{1.2^2} = 75 \text{ kN/C}$$

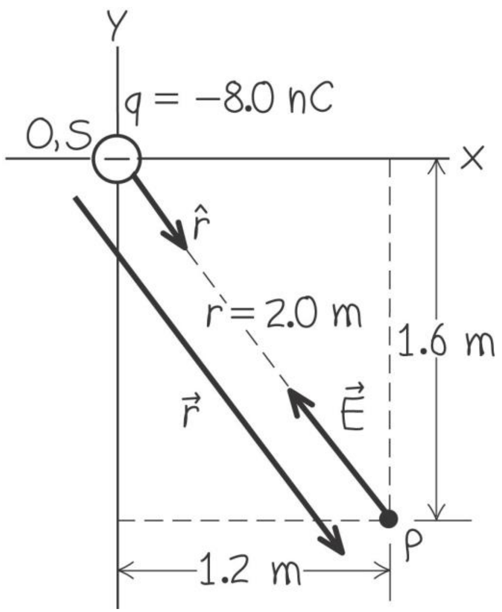
At $x = 1.2$ m, $\vec{E}_1 = 75\ \hat{\imath}$ kN/C

At $x = -1.2$ m, $\vec{E}_2 = -75\ \hat{\imath}$ kN/C



Example 6

A point charge $q = -8.0\ \mathrm{nC}$ is located at the origin. Find the electric field vector at the point $x = 1.2\ \mathrm{m}$, $y = -1.6\ \mathrm{m}$.



Superposition of electric fields

- If we have a distribution of charge, we can imagine it to be made up of many point charges.

- The total force on a charge q_0 due to the fields of all the point charges is

$$\vec{F}_0 = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$$

$$\vec{F}_0 = q_0\vec{E}_1 + q_0\vec{E}_2 + q_0\vec{E}_3 + \cdots$$

- Hence, the net field is the superposition of electric fields which is

$$\vec{E} = \frac{\vec{F}_0}{q_0} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$$

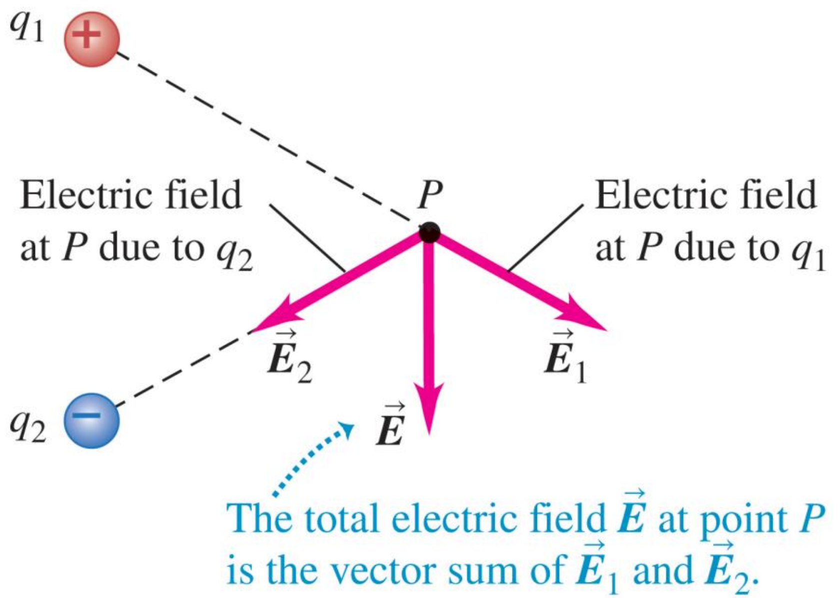
Field due to two equal point charges of opposite signs

- The total field at P is $\vec{E} = \vec{E}_1 + \vec{E}_2$

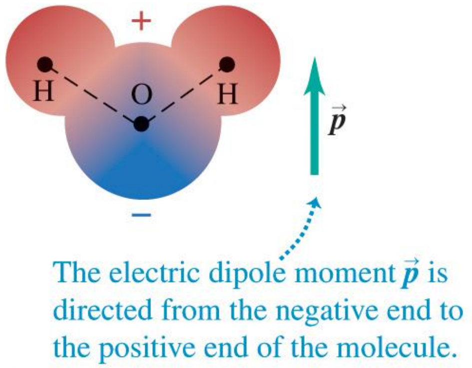
  where $\vec{E}_1 = k\frac{q_1}{a^2+x^2}\,\hat{r}_1$

  and $\vec{E}_2 = -k\frac{q_2}{a^2+x^2}\,\hat{r}_2$

- Since $q_1 = q_2$, there is only $\vec{E}_y$.
- Such an arrangement of two charges is known as an electric dipole.
- The water molecule is a natural dipole.

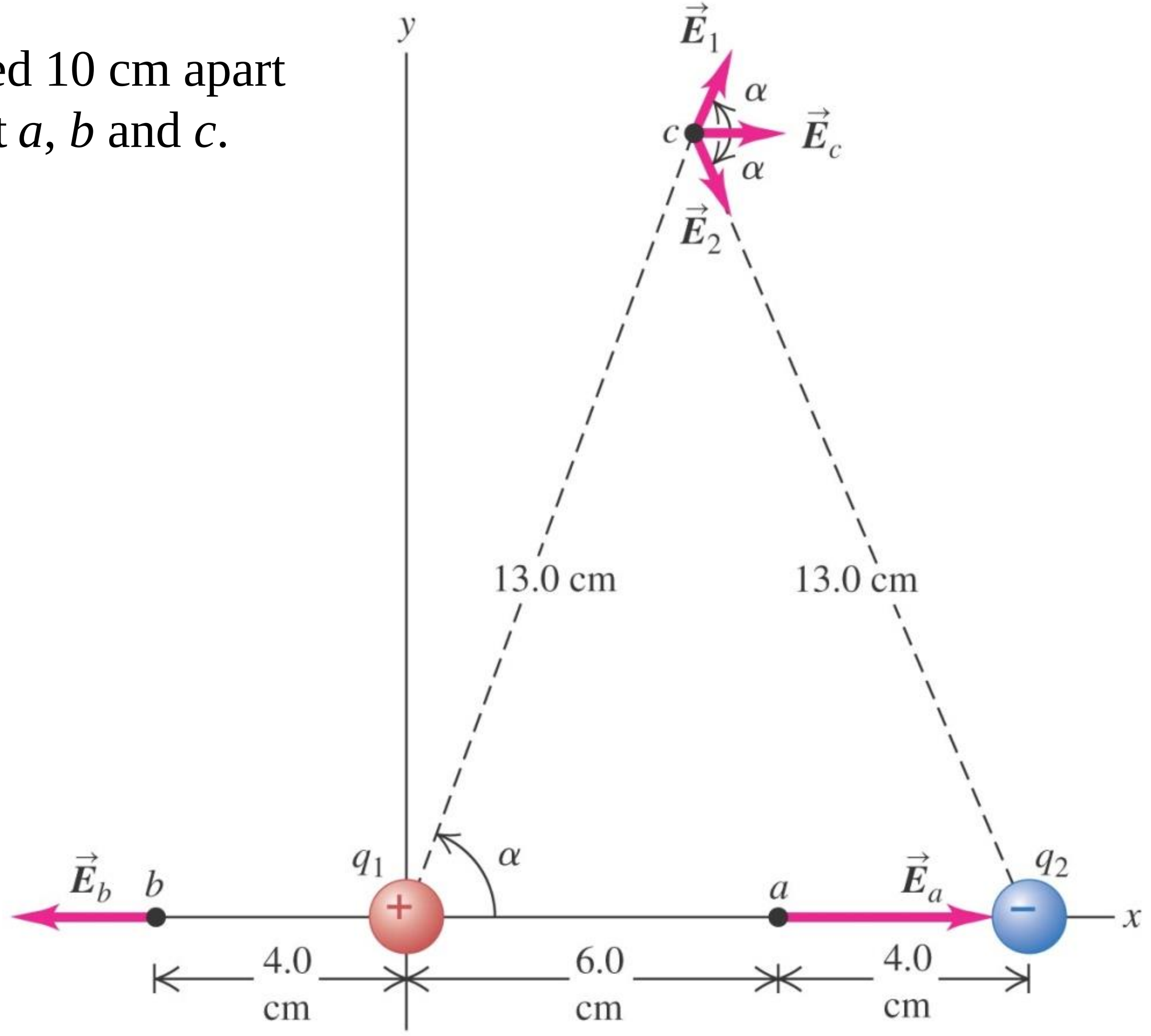


(a) A water molecule, showing positive charge as red and negative charge as blue



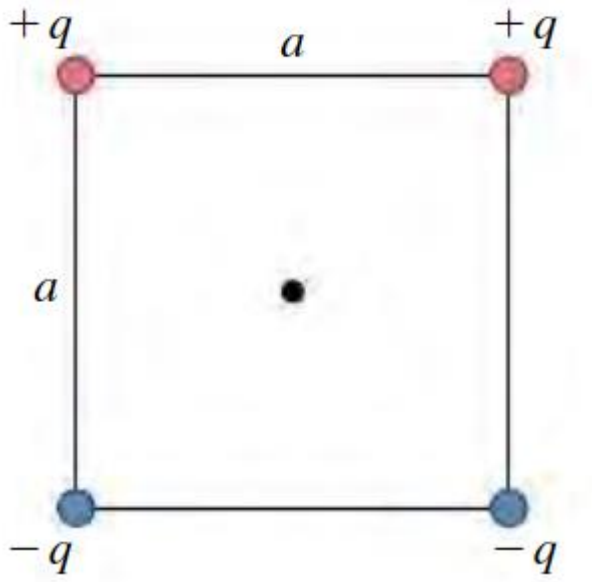
Example 7

Point charges, $q_1 = +12$ nC and $q_2 = -12$ nC, placed 10 cm apart (see figure). Compute the total electric field at point a, b and c.



Class Exercise

A point charge is placed at each corner of a square with side length a. All charges have magnitude q. Two of the charges are positive and two are negative. What is the direction of the net electric field at the center of the square due to the four charges, and what is its magnitude in terms of q and a?

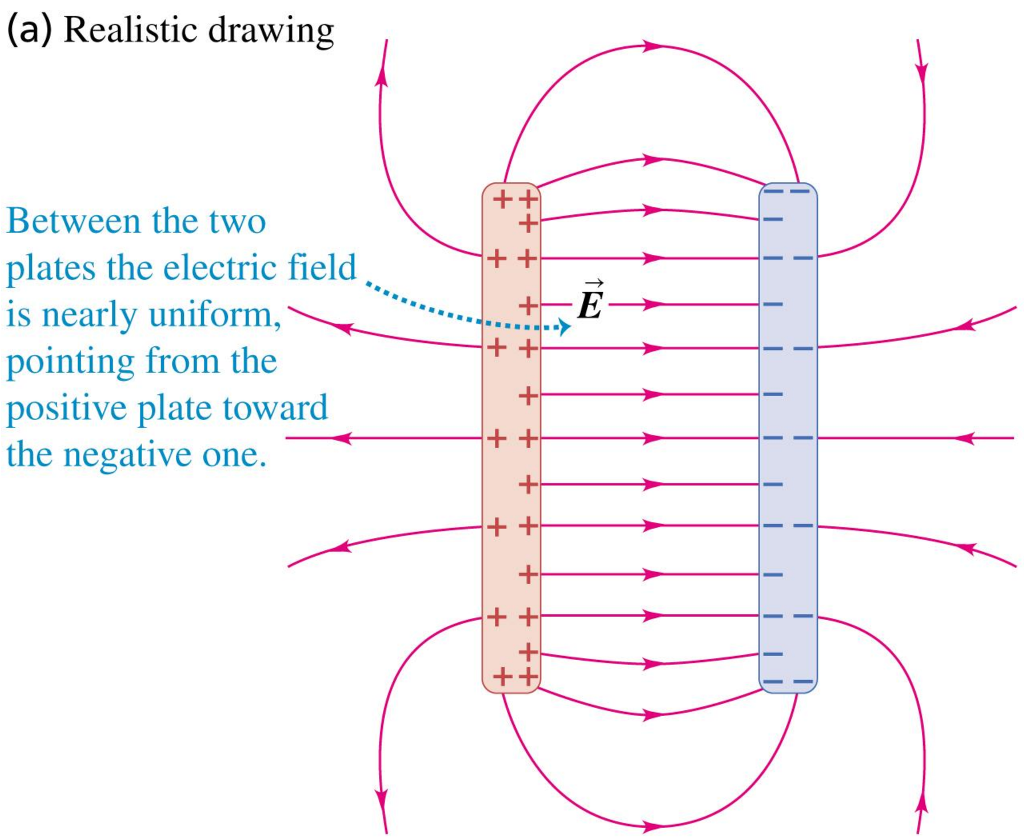


Electric field between two parallel plates

- The electric field between two parallel plates is uniform except near the edges of the plates.

- From $\vec{E} = \frac{\vec{F}_0}{q_0}$, we have $\vec{F}_0 = q_0\vec{E}$.

- A charge in a uniform field will experience the same force regardless of where it is placed.



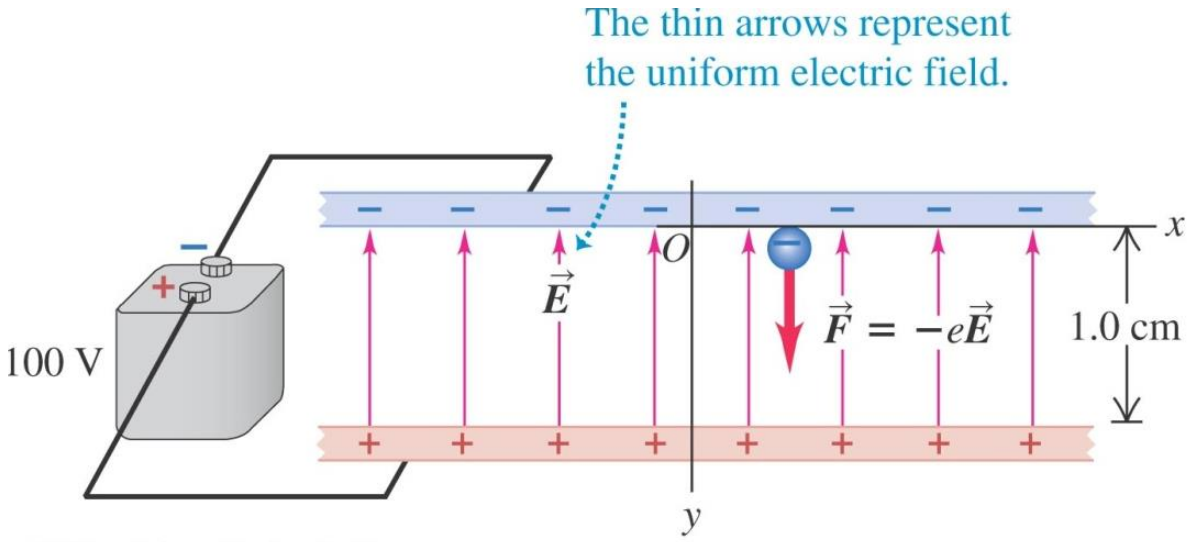
Example 8

The diagram shows a uniform electric field of magnitude $E = 1.00 \times 10^{4}$ N/C. Mass of an electron is 9.11×10^{-31} kg. If an electron is released from rest at the upper plate,

a) What is its acceleration?

b) What speed and kinetic energy does the electron acquire travelling 1.0 cm to the lower plate?

c) How much time is required for it to reach the lower plate?

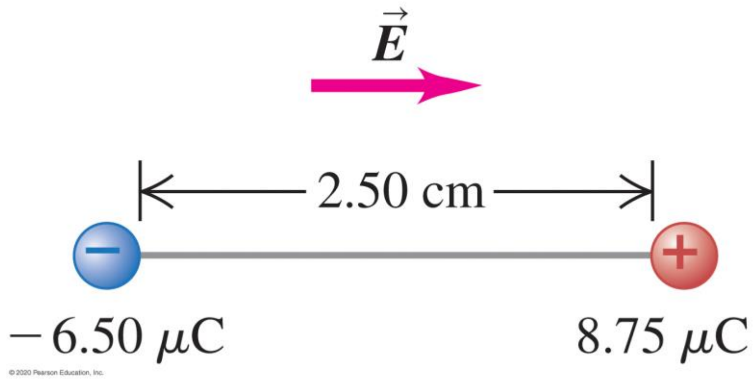


Problem solving strategy involving electric forces and electric field

<table>
<tr><th>Steps</th><th>Electric force on a charge</th><th>Electric field at a point</th></tr>
<tr><td>1</td><td>Draw free-body diagram showing the direction of the electric forces acting on the charge
• Like charges repel, unlike charges attract
• Uniform field – positive charge (same direction as $\vec{E}$), negative charge (opposite $\vec{E}$)</td><td>Draw the electric field vectors at a point due to different charges
• Field due to positive charge: radially away
• Field due to negative charge: radially toward</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Use formula to calculate the magnitudes of forces or electric fields. Sum the vectors. Resolve the vectors into its x and y components if necessary.</td></tr>
<tr><td>$F_{net,x} = F_{1x} + F_{2x} + F_{3x} + \cdots$
$F_{net,y} = F_{1y} + F_{2y} + F_{3y} + \cdots$</td><td>$E_{net,x} = E_{1x} + E_{2x} + E_{3x} + \cdots$
$E_{net,y} = E_{1y} + E_{2y} + E_{3y} + \cdots$</td></tr>
<tr><td>3</td><td colspan="2">Find the magnitude of the resultant force or electric field using Pythagoras theorem.</td></tr>
<tr><td>4</td><td colspan="2">Draw out the vector and calculate a suitable angle to describe its direction.</td></tr>
</table>

Class Exercise

A +8.75 μC point charge is glued down on a horizontal frictionless table. It is tied to a -6.50 μC point charge by a light, non-conducting 2.50 cm wire. A uniform electric field of magnitude 1.85×10^8 N/C is directed parallel to the wire, as shown.



(a) Find the tension in the wire.

(b) What would the tension be if both charges were negative?

Summary of Electric Force and Electric Field

Physical quantities	**Formula**
Coulomb's law (Electric force between two point charges)	$F = k\dfrac{Qq}{r^2}$
Electric field	$\vec{E} = \dfrac{\vec{F}}{q_0}$
Electric field due to point charge	$E = \dfrac{kQ}{r^2}$
Superposition of electric force and electric fields	$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$ $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$

Note: Newton's laws are still applicable in electrostatics situations.

Electric potential and electric potential energy

Learning outcomes

At the end of this lesson, students should be able to

- define electric potential energy and electric potential
- solve electrostatic problems using ideas of conservation of energy and electric potential energy
- recognize that electrostatic force is a conservative force
- appreciate the relationship between electric field and electric potential

Electric potential energy – uniform field

- If the upper plate is positive and lower plate is negative, a positive charge q_0 will experience a constant downward force

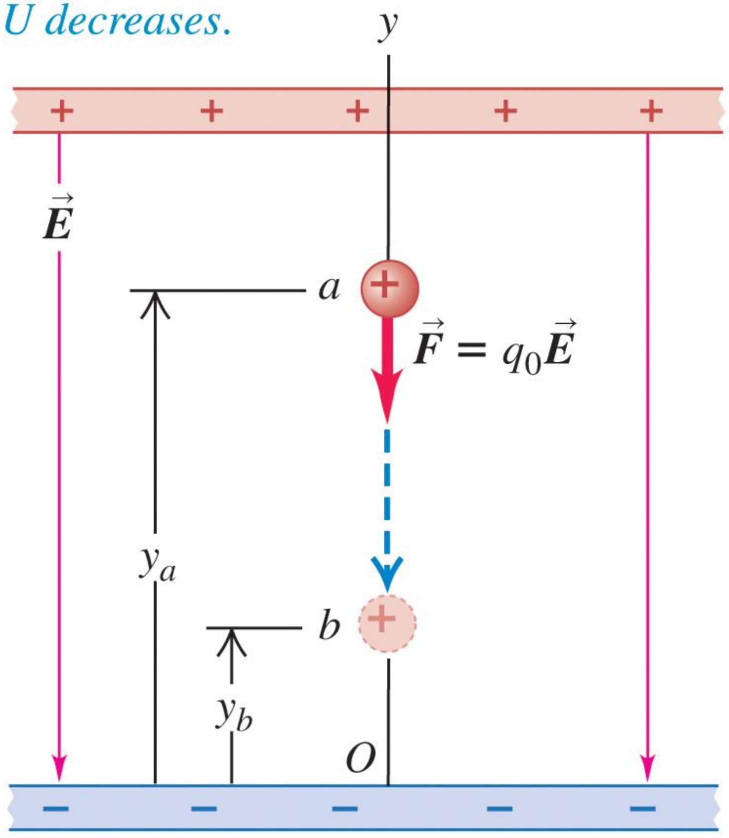
$$F = q_0 E$$

- The work done by this force to bring q_0 from a to b is

$$W_{a \to b} = F\Delta d = -\Delta U$$

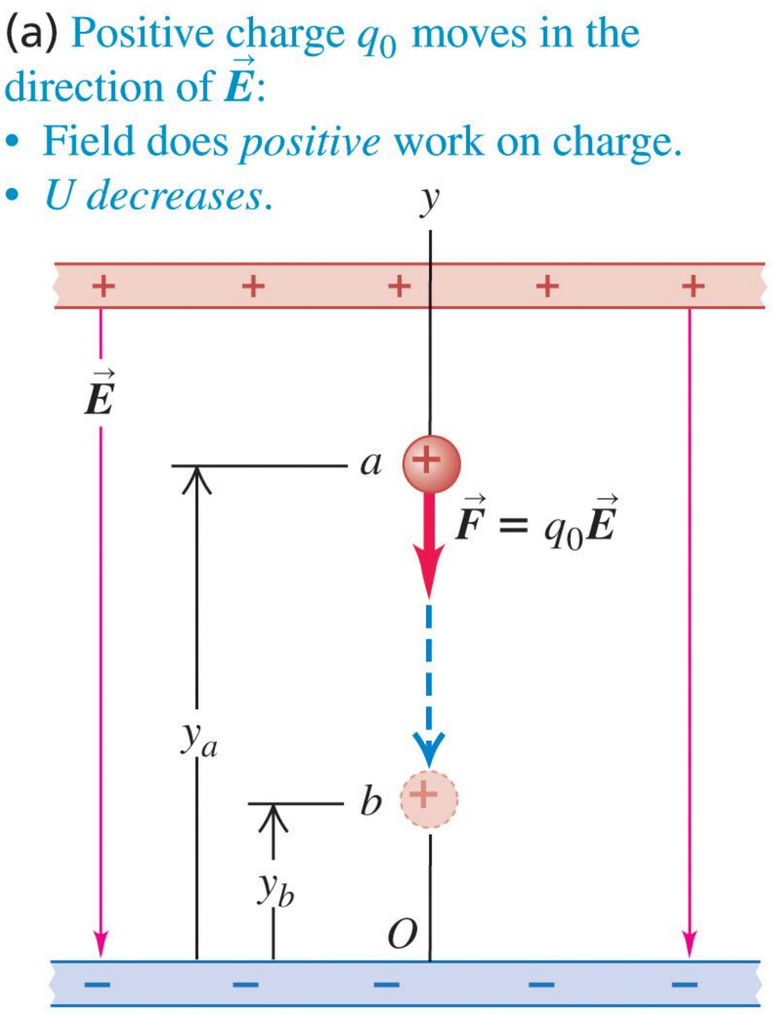
- The negative sign indicates the potential energy U of the charge decreases, i.e., $U_b < U_a$.

(a) Positive charge q_0 moves in the direction of $\vec{E}$:
- Field does *positive* work on charge.
- *U decreases.*



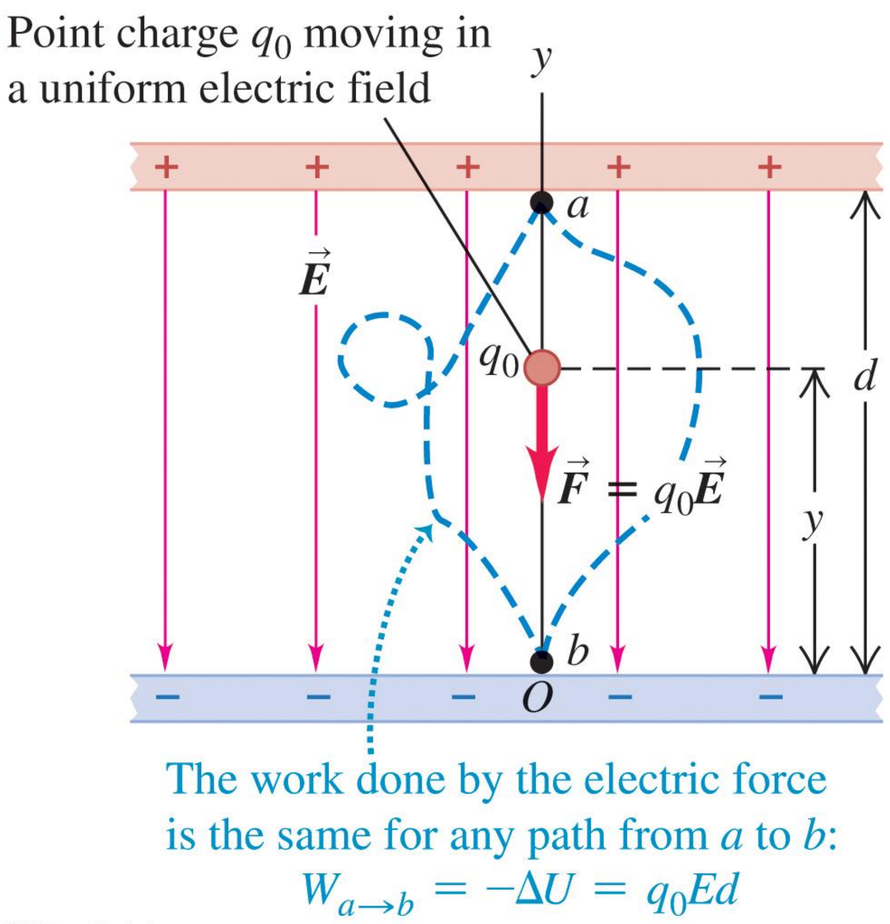
Electric potential energy – uniform field

- The negative sign indicates the potential energy U of the charge decreases, i.e., $U_b < U_a$.
- Setting the bottom plate as the zero potential energy line, then the electric potential energy in the uniform field is defined as $q_0 E y$.
- Since $y_b < y_a$, so $U_b < U_a$.



Electric potential energy – uniform field

- The electrostatic force is a conservative force.
- The work done by the electric force is the same for any path from *a* to *b*.
- The work done by the electric force is independent of path.



Electric potential energy

- Suppose q and q_0 are positive point charges. The force on q_0 due to q is

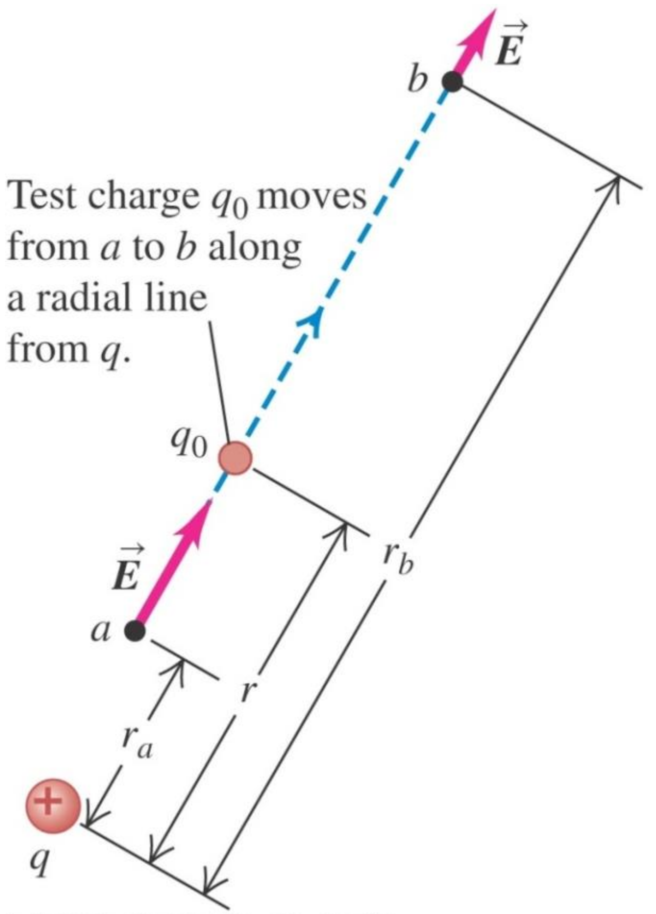
$$\vec{F} = k\frac{qq_0}{r^2}\hat{r}$$

- The work done in moving q_0 from a to b is

$$W_{a\to b} = \int \vec{F}\cdot d\vec{r} = \int_{r_a}^{r_b} k\frac{qq_0}{r^2}\hat{r}\cdot d\vec{r} = kqq_0\int_{r_a}^{r_b}\frac{1}{r^2}dr$$

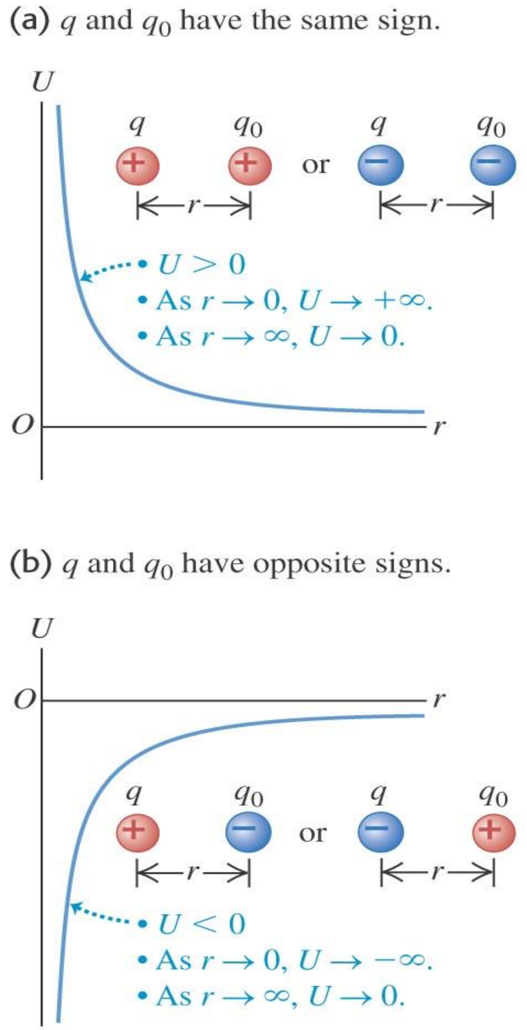
$$W_{a\to b} = kqq_0\left(\frac{1}{r_a}-\frac{1}{r_b}\right) = -\Delta U = -(U_b - U_a) = U_a - U_b$$

$$U_a = \frac{kqq_0}{r_a} \text{ and } U_b = \frac{kqq_0}{r_b}, \qquad U = \frac{kqq_0}{r}$$



Electric potential energy

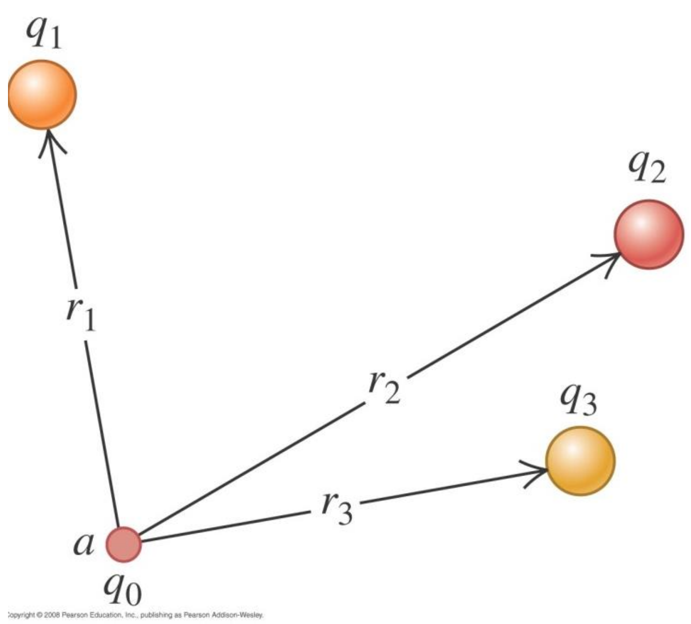
- If q and q_0 have the same sign, then $U > 0$.
- When $r \to 0$, $U \to +\infty$. When $r \to \infty$, $U \to 0$
- Hence, like charges repel to reduce their potential energy.
- If q and q_0 have opposite signs, then $U < 0$.
- When $r \to 0$, $U \to -\infty$. When $r \to \infty$, $U \to 0$
- Hence, unlike charges attract to reduce their potential energy.



Electric potential energy of several point charges

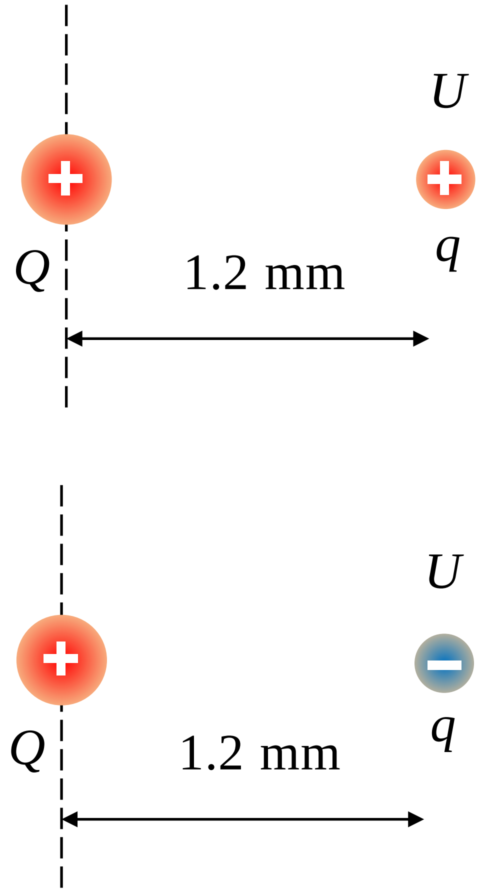
- When there are several point charges around q_0, the electric potential energy of q_0 is the algebraic sum of all the electric potential energy due to the individual point charges, i.e.,

$$U = U_1 + U_2 + U_3 + \cdots = kq_0\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \cdots\right)$$



Example 9

The diagram shows a positive charge $Q = 1.0$ µC at the origin. Find the electric potential energy U of q if a) $q = 1.0$ µC and b) if $q = –1.0$ µC.



Solution:

Using $U = \frac{kQq}{r}$,

$$(a)\ U = \frac{kQq}{r} = 8.99 \times 10^9 \frac{(1.0 \times 10^{-6})^2}{1.2 \times 10^{-3}} = 7.49\ \text{J}$$

$$(b)\ U = \frac{kQq}{r} = -8.99 \times 10^9 \frac{(1.0 \times 10^{-6})^2}{1.2 \times 10^{-3}} = -7.49\ \text{J}$$

Conservation of energy in system of charges

- Since electrostatic force is conservative, we only need to care about the initial and final states of situation.
- Step 1: Draw out the initial and final states of the situation. List the kinetic energies and electric potential energies of the initial and final situations.
- Step 2: Write the energy conservation equation: $K_i + U_i = K_f + U_f$
- Step 3: Solve for unknown

Example 10

Two protons are released from rest when they are 0.750 nm apart.

(a) What is the maximum speed they will reach? When does this speed occur?

(b) What is the maximum acceleration they will achieve? When does this acceleration occur?

Class exercise

Two protons, starting several meters apart, are aimed directly at each other with speeds of 2.00×10^5 m/s, measured relative to the earth. Find the maximum electric force that these protons will exert on each other.

Electric potential

- The electric potential (V) at q_0 is defined as the electric potential energy (U) per unit charge q_0 at that point, i.e.

$$V = \frac{U}{q_0}$$

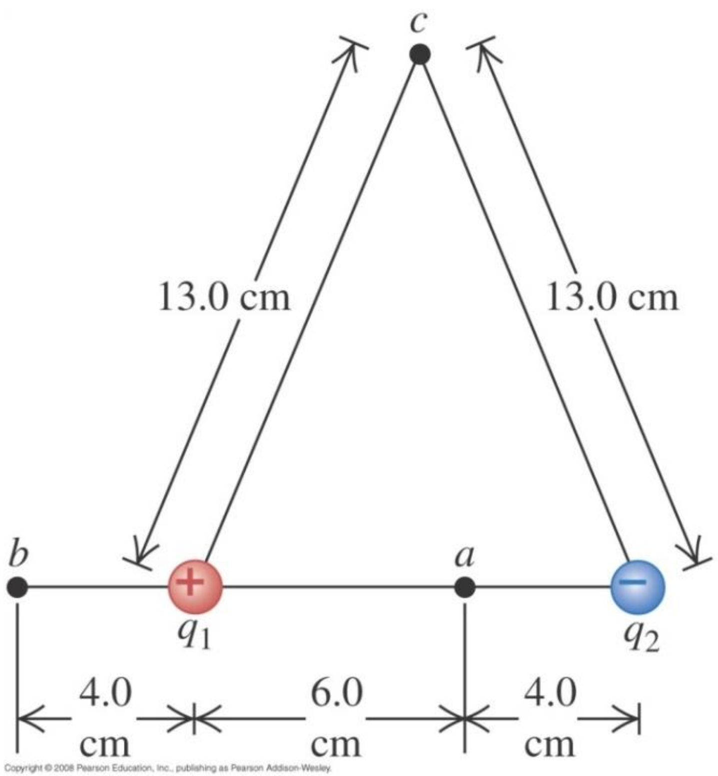
- The SI unit of electric potential is joule per coulomb (J/C) or volt (V).

- Since the potential energy at any point r from a point charge q is $U = \frac{kqq_0}{r}$, the potential V at that point is $V = \frac{U}{q_0} = \frac{kq}{r}$.

- Unlike electric potential energy, we need not know q_0 if we are calculating the electric potential.

Example 11

An electric dipole consists of two point charges, $q_1 = +12$ nC and $q_2 = -12$ nC, placed 10 cm apart. Compute the potentials at point a, b and c by adding potentials due to either charge.



Electric potential – uniform field

- From the diagram at right, we have $\vec{F} = -q_0 E\hat{y}$. The electric potential energy is $U = q_0 E y$.

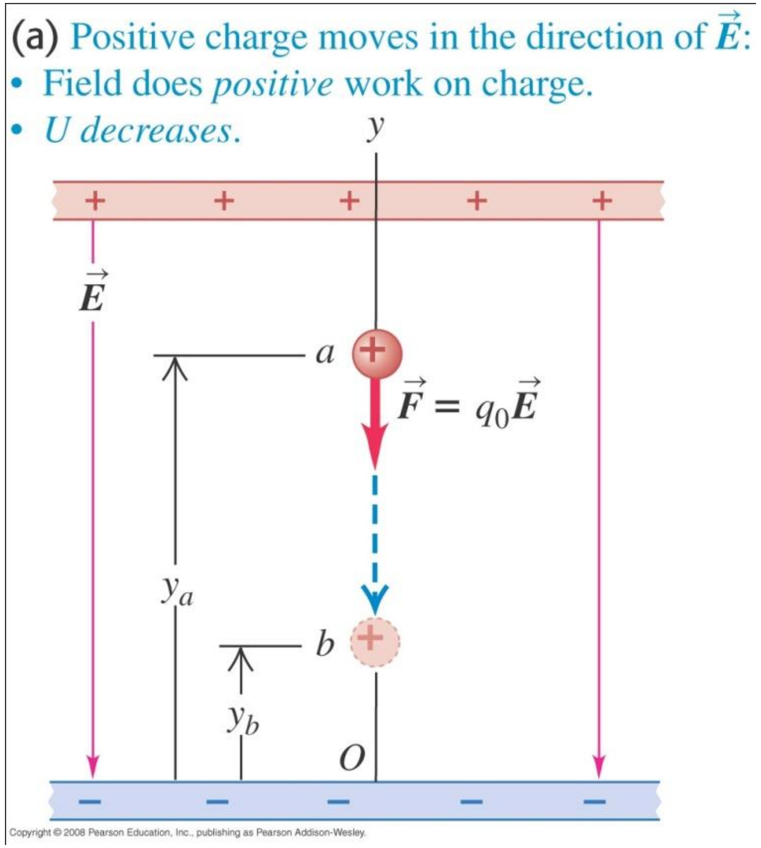
- We can therefore write $F = -\frac{\Delta U}{\Delta y}$.

- Since $F = q_0 E$, dividing both sides by q_0, we have

$$E = \frac{F}{q_0} = -\frac{\Delta U}{q_0 \Delta y} = -\frac{\Delta V}{\Delta y}$$

- The electric field is therefore also equal to the negative of the electric potential gradient.

- Another unit of electric field is V/m.



Example 12

A proton of charge 1.60×10^{-19} C, moves in a straight line from point a to point b inside a linear accelerator, a total distance $d = 0.50$ m. The electric field is uniform along this line, with magnitude $E = 1.5 \times 10^7$ V/m in the direction from a to b. Determine

a) the force on the proton

b) the work done on it by the field

c) the potential difference $V_a - V_b$

The electron-volt (eV) as a unit of energy

- From $V = \frac{U}{q_0}$, we have $U = q_0 V$
- If $q_0 = e = 1.6 \times 10^{-19}$ coulomb and V is 1 volt, then

  $U = q_0 V = eV = 1.6 \times 10^{-19}\ \mathrm{C} \times 1\ \mathrm{V} = 1.6 \times 10^{-19}\ \mathrm{J}.$
- By definition, this amount of energy is called 1 electron-volt (eV).
- Hence 1 eV = 1.6×10^{-19} J.
- The unit of eV is widely used in atomic physics.

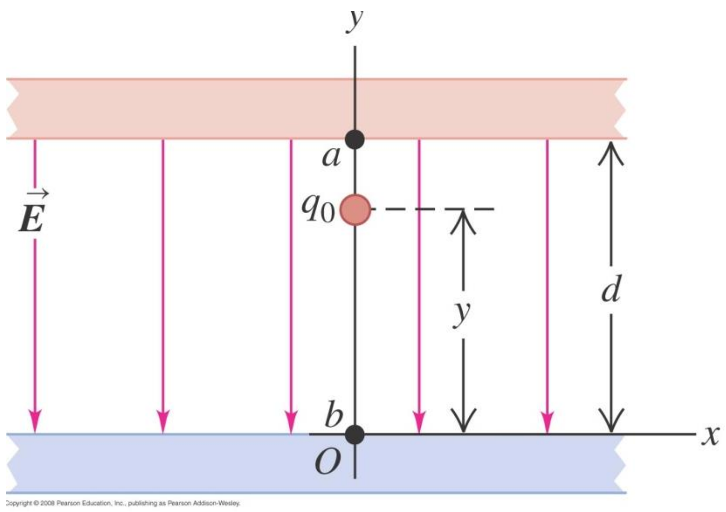
Example 13

An electric potential difference of 2000 V is applied to a pair of plates that is separated by 1 cm. If a particle of charge 6.40×10^{-19} C is released from the upper plate

a) What is the electric field (that is uniform) in the region between the plates?

b) Find the kinetic energy of the particle in eV when it reaches the bottom plate.

c) If the mass of the particle is 1.92×10^{-16} kg, what is the speed of the particle as it reaches the bottom plate?



Electric potential from electric field of point charge

- From the definition of work and potential,

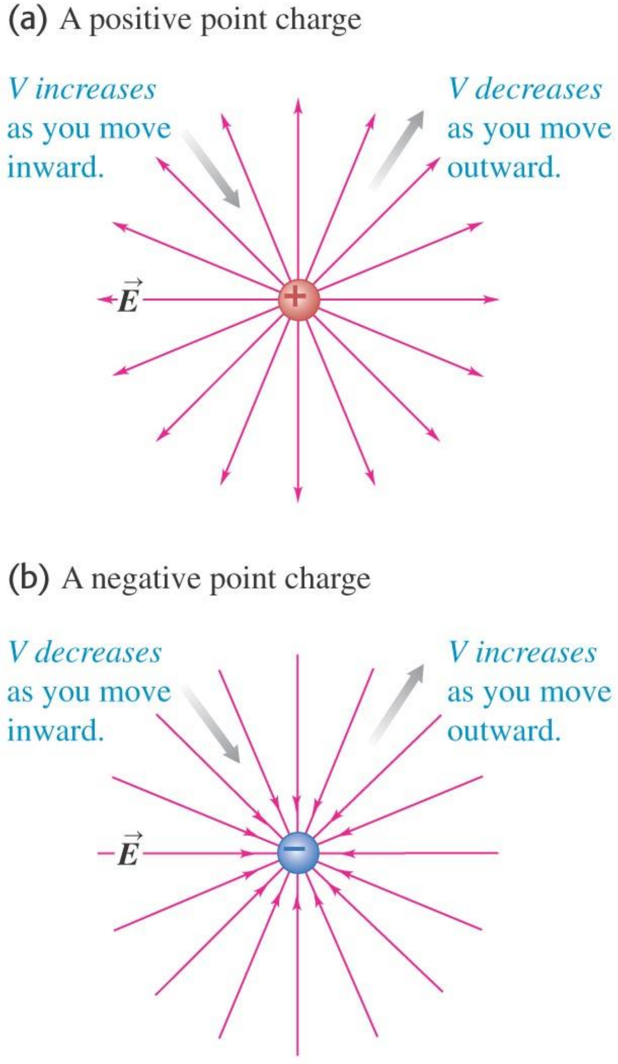
$$W_{a\to b} = \int_a^b \vec{F}\cdot d\vec{l} = \int_a^b q_0\vec{E}\cdot d\vec{l} = -\Delta U = -q_0\Delta V$$

$$\Delta V = V_b - V_a = -\frac{1}{q_0}\int_a^b q_0\vec{E}\cdot d\vec{l} = -\int_a^b \vec{E}\cdot d\vec{l}$$

- For a point charge, $\vec{E} = \frac{q}{4\pi\epsilon_0 r^2}\hat{r}$.

- Since the field is radial, $d\vec{l} = d\vec{r}$, the integral becomes

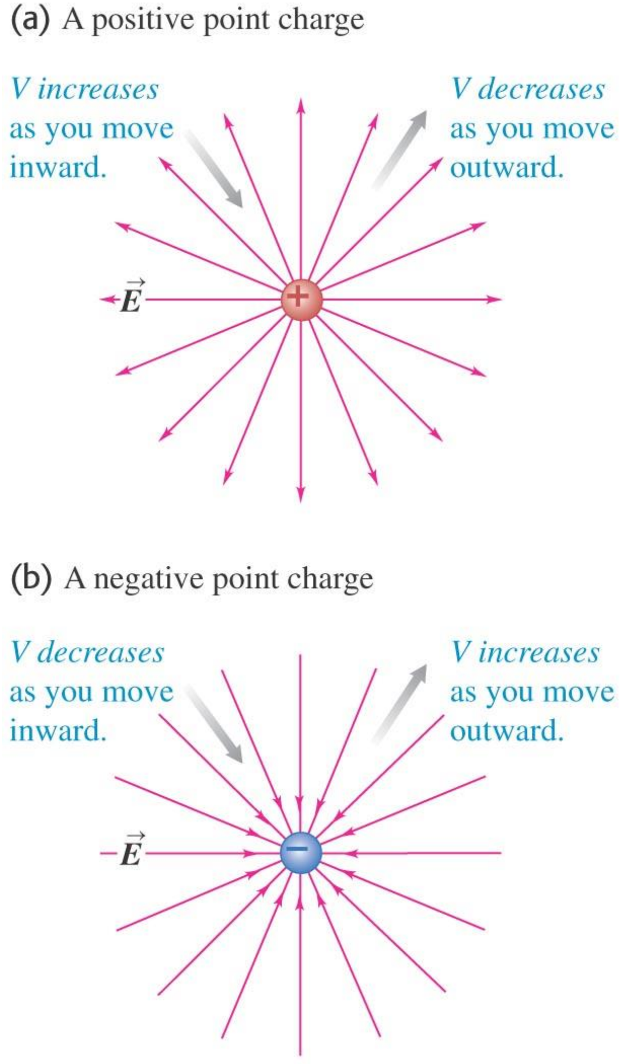
$$V_b - V_a = -\int_a^b \frac{q}{4\pi\epsilon_0 r^2}dr = \frac{q}{4\pi\epsilon_0}\left(\frac{1}{b} - \frac{1}{a}\right)$$



Electric potential from electric field of point charge

$$V_b - V_a = -\int_a^b \frac{q}{4\pi\epsilon_0 r^2} dr = \frac{q}{4\pi\epsilon_0}\left(\frac{1}{b} - \frac{1}{a}\right)$$

- **Positive** charge ($q > 0$): as you move outward ($b > a$), $V_b < V_a$, electric potential **decreases**. Electric field points radially **outward**.
- **Negative** charge ($q < 0$): as you move outward ($b > a$), $V_b > V_a$, electric potential **increases**. Electric field points radially **inward**.
- Note: The electric field points in the direction of **decreasing** electric potential.



Chapter summary

Physical quantities	Formula
Coulomb's law (Electric force between two point charges)	$F = k\frac{Qq}{r^2}$
Electric field	$\vec{E} = \frac{\vec{F}}{q_0}$
Electric field due to point charge	$E = \frac{kQ}{r^2}$
Superposition of electric force and electric fields	$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$ $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$

Chapter summary

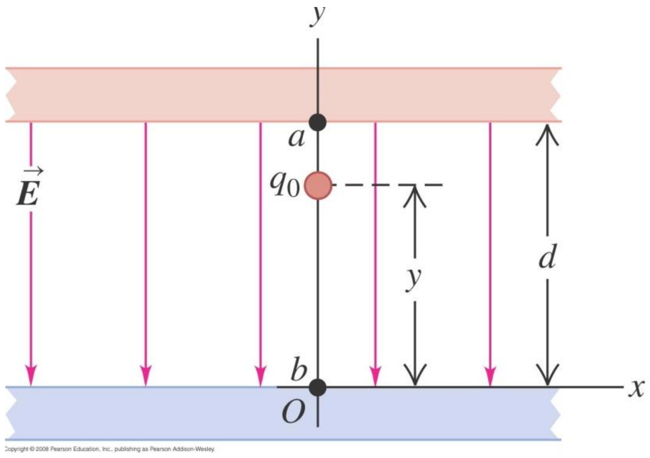
Physical quantities	Formula
Electric potential energy for system of two point charges	$U = k\dfrac{Qq}{r}$
Work done due to electrostatic force	$W = \int \vec{F} \cdot d\vec{r} = -\Delta U_E$
Electric potential	$V = \dfrac{U}{q_0}$
Electric potential due to point charge	$V = \dfrac{kQ}{r}$
Superposition of electric potential energy and electric potential	$U_{tot} = U_1 + U_2 + U_3 + \cdots$ $V_{tot} = V_1 + V_2 + V_3 + \cdots$

Chapter summary

- Electric field is uniform in parallel plate setup.

- Magnitude of electric field:

$$E = \frac{\Delta V}{d}$$



- The direction of electric field points from the positive plate to the negative plate.

- $1 \text{ eV} = 1.6 \times 10^{-19}$ J

- The electric field points in the direction of **decreasing** electric potential.

Class Exercise

For each of the following arrangements of two point charges, find all the points along the line passing through both charges for which the electric potential V is zero and for which the electric field E is zero:

(a) charges $+Q$ and $+2Q$ separated by a distance d, and

(b) charges $-Q$ and $+2Q$ separated by a distance d.

(c) Are both V and E zero at the same places? Explain.

End of chapter