Feb 20

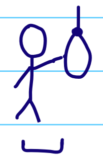
Electric Fields

$F = \frac{kQ_1Q_2}{r^2}$

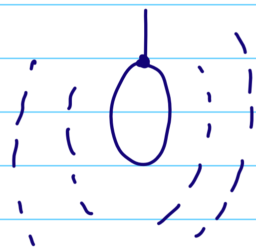
$k = 9\times10^9 \ \frac{Nm^2}{C^2}$

C ← measure of charge

Q_1 Q_2 — charge



r distance



An electric field is a property of the space around an electric charge

If a charge enters that field, it will experience a force

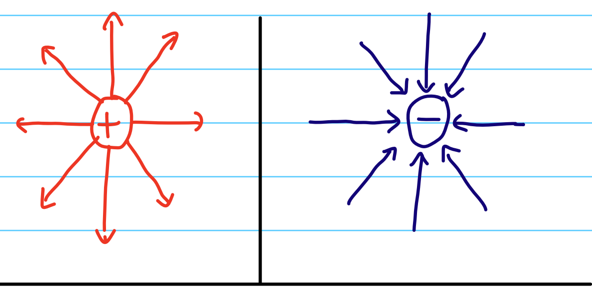
$\vec{E} = \frac{F}{q}$ unit: N/C

The field is a vector visualized by "field lines"

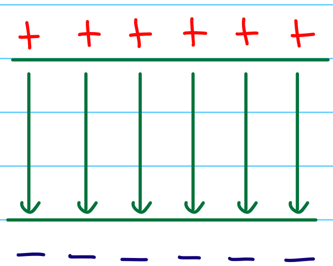
→ drawn in the direction of a positive test charge's motion

If $\vec{E} = \frac{\vec{F}}{q}$ for single point charges,

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

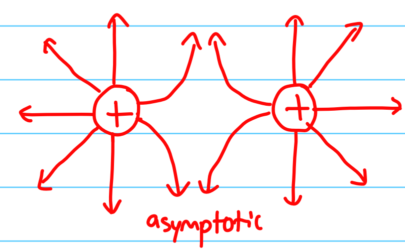


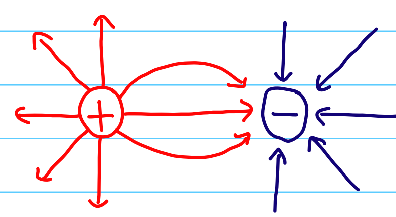
Uniform Electric Fields



The electric field is the same value everywhere between the two places

$q_{electron} = 1.602\times10^{-19}$ C





* field lines never overlap

Ex ① What is the acceleration of an electron in a uniform field $\vec{E} = 600\ N/C$

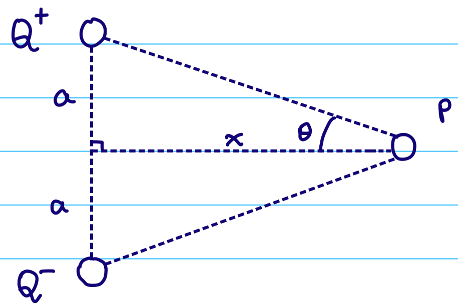
$$\vec{E} = \frac{F}{q}$$

$$600 = \frac{ma}{1.6\times10^{-19}}$$

$$600 = \frac{9.11\times10^{-31}\,a}{1.6\times10^{-19}}$$

$$a = 1.1\times10^{14}\ m/s^2$$

Ex ②



What is the electric field at point P

$\vec{E} = \frac{kq}{r^2}$ positive in the x direction

horizontal component

$E_{(+)} \cos\theta$

$= \frac{kq}{a^2+x^2} \cdot \frac{x}{\sqrt{a^2+x^2}}$ right

$E_{(-)} \cos\theta$

$= \frac{kq}{a^2+x^2} \cdot \frac{x}{\sqrt{a^2+x^2}}$ left

vertical component

$E_{(+)} \sin\theta$

$= \frac{kq}{a^2+x^2} \cdot \frac{a}{\sqrt{a^2+x^2}}$ down

$E_{(-)} \sin\theta$

$= \frac{kq}{a^2+x^2} \cdot \frac{a}{\sqrt{a^2+x^2}}$ down

E_y net

$= \frac{2kqa}{(a^2+x^2)^{3/2}}$ down

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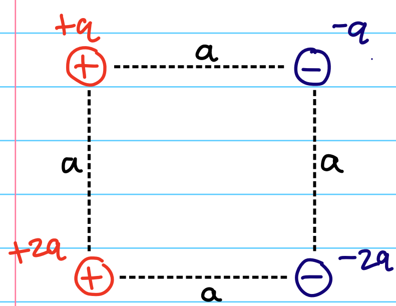
Electric field example

Ex 0.5 If $q = 10\mu C$ what is the magnitude of force on $+q$



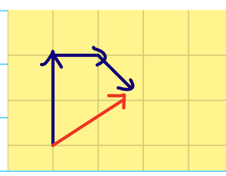
calculate with absolute value of charge then use the diagram to find direction

$$F_{+2q} = \uparrow \frac{kq(2q)}{a^2} = \frac{9\times10^9 \times 10 \times 2\times 10}{a^2} = \frac{18\times10^{11}}{a^2}$$

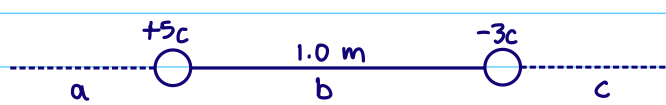
$$F_{-q} = \longrightarrow \frac{kq(q)}{a^2} = \frac{9\times10^9\times10\times10}{a^2} = \frac{9\times10^{11}}{a^2}$$

$$F_{-2q} = \searrow \frac{kq(2q)}{2a^2} = \frac{9\times10^9\times10\times2\times10}{2a^2} = \frac{9\times10^{11}}{a^2}$$

resultant



Ex② Find the region where the electric field is zero



$r_5 = r_{-3} + 1$

a: E is always $\leftarrow$

b: Both make E $\rightarrow$

c: $\vec{E}_5$ is going $\rightarrow$

$\vec{E}_{-3}$ is going $\leftarrow$

$$F_5 = \frac{kqQ}{r^2} \qquad F_{-3} = \frac{kqQ}{r^2}$$

$$\frac{\cancel{kq}Q_5}{r_5^2} = \frac{\cancel{kq}Q_{-3}}{r_{-3}^2}$$

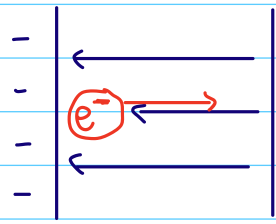
$$\frac{5}{(r_{-3}+1)^2} = \frac{3}{r_{-3}^2}$$

$$5r^2 = 3(r+1)^2$$

$$0 = 2r^2 - 6r - 3$$

$$r = 3.436 \text{ m} \quad \text{from } r_3$$

Ex ③ An electron is placed at one end of a uniform electric field. ($\vec{E} = 1.85\times10^4$ N/c) What is its final velocity?



1.2cm

$$V_f = ?$$

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

$$E_k = \frac{1}{2}mv^2$$

$$Fd = \frac{1}{2}mv^2$$

$$q\vec{E}d = \frac{1}{2}mv^2$$

$$(1.6\times10^{-19})(1.85\times10^4)(0.012) = \frac{1}{2}(9.11\times10^{-31})v^2$$

$$v = 8.8\times10^6 \text{ m/s}$$

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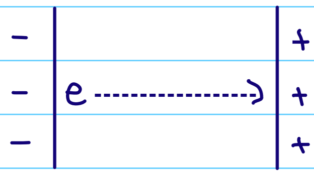


Electric potential energy

If a charge is in an electric field
It has electric potential energy (E_p)

- In a uniform electric field:

$$\Delta E_p = Fd$$

$$\Delta E_p = \frac{kQ_1Q_2}{r^2}\times r$$

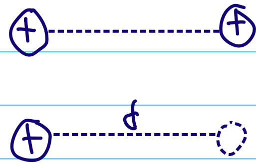
$$E_p = \frac{kQ_1Q_2}{r}$$

2) Electric potential (also known as voltage V)

- electric potential energy per electric charge

$$V = \frac{E_p}{q} \qquad \text{units: } [V] = \frac{[J]}{[C]}$$

For point charge $\quad V = \frac{kQq}{r} \Big/ q$

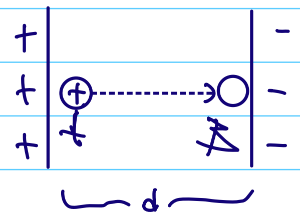


$V = \frac{kQ}{r}$

change in potential energy

$\Delta E_p = q \Delta V$

3) Electric potential in uniform electric field (E)



$E_p = Fd$

$E_p = q\vec{E}d$

$\frac{E_p}{q} = \vec{E}d$

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

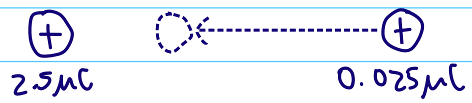
Comparing the potential at two points is called the potential difference

Summary: At all times $\quad E_p = qV \quad\quad V = \frac{E_p}{q}$

point charges: $\quad E_p = \frac{kQq}{r} \quad\quad V = \frac{kq}{r}$

uniform field: $\quad E_p = q\vec{E}d \quad\quad V = E\vec{d}$

Ex② How much work is done against an electric field given by a $2.5\,\mu C$ charge when a smaller $0.025\,\mu C$ charge is moved from $r = 3$ cm $\rightarrow r = 1$ cm



$$\Delta E_p = \frac{kQq}{R} - \frac{kQq}{r}$$

$$= \frac{(10\times10^9)(2.5\times10^{-6})(0.025\times10^{-6})}{0.01} - \frac{(10\times10^9)(2.5\times10^{-6})(0.025\times10^{-6})}{0.03}$$

$$= 0.0375\ J$$

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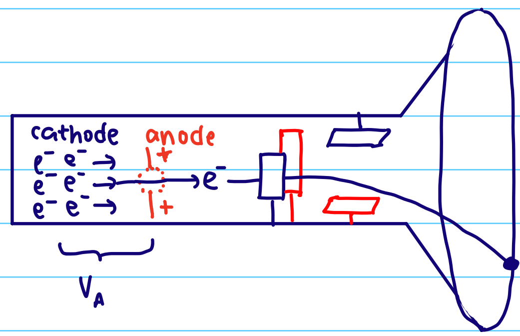
Cathode Ray Tube

CRT → sends electrons to all parts of the tube

e^- hit a fluorescent screen to light up

ex. older TV, monitors, oscilloscope



electron accelerated by a high voltage (V_A)
it changes electric potential energy to kinetic energy

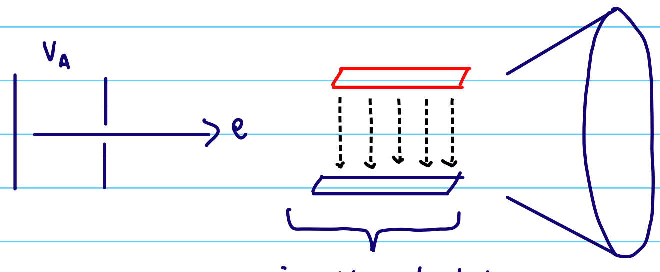
$$E_p = E_k$$
$$q_e V_A = \frac{1}{2} m_e v^2$$

Deflecting the beam of electrons (V_{def})

2 horizontal & 2 vertical plates

↕ high voltage → e^- goes to edge of one side
Ø voltage → e^- goes to middle
high ⊖ voltage → e^- goes to other edge

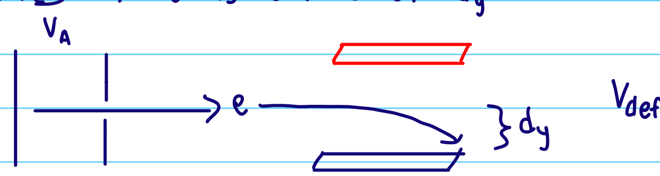
Ex ① If in a CRT you decrease V_A what will happen to vertical deflection



If V_A is less, the velocity of e^- is less

it deflects longer & further

Ex ② How is deflection d_y



related to V_{def} & V_A ?

$$d_y = V_i t + \frac{1}{2}at^2$$

$$d_y = \frac{1}{2}at^2$$

$$F = ma$$

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

$$V = \vec{E}d$$

distance between the plates

$$q\frac{V_{def}}{h} = ma$$

$$a = \frac{qV_{def}}{mh}$$

$$t = \frac{d_x}{\vec{V}_x}$$

$$t = \frac{\ell}{V_x}$$

$$t^2 = \frac{\ell^2}{V_x^2}$$

$$t^2 = \frac{\ell^2 m}{2qV_A}$$

$$E_p = \frac{1}{2}mv_x^2$$

$$qV_A = \frac{1}{2}mv_x^2$$

$$\frac{2qV_A}{m} = v_x^2$$

$$d_y = \frac{1}{2}\left(\frac{qV_{def}}{mh}\right)\left(\frac{\ell^2 m}{2qV_A}\right)$$

$$d_y = \frac{\ell^2 V_{def}}{4hV_A}$$