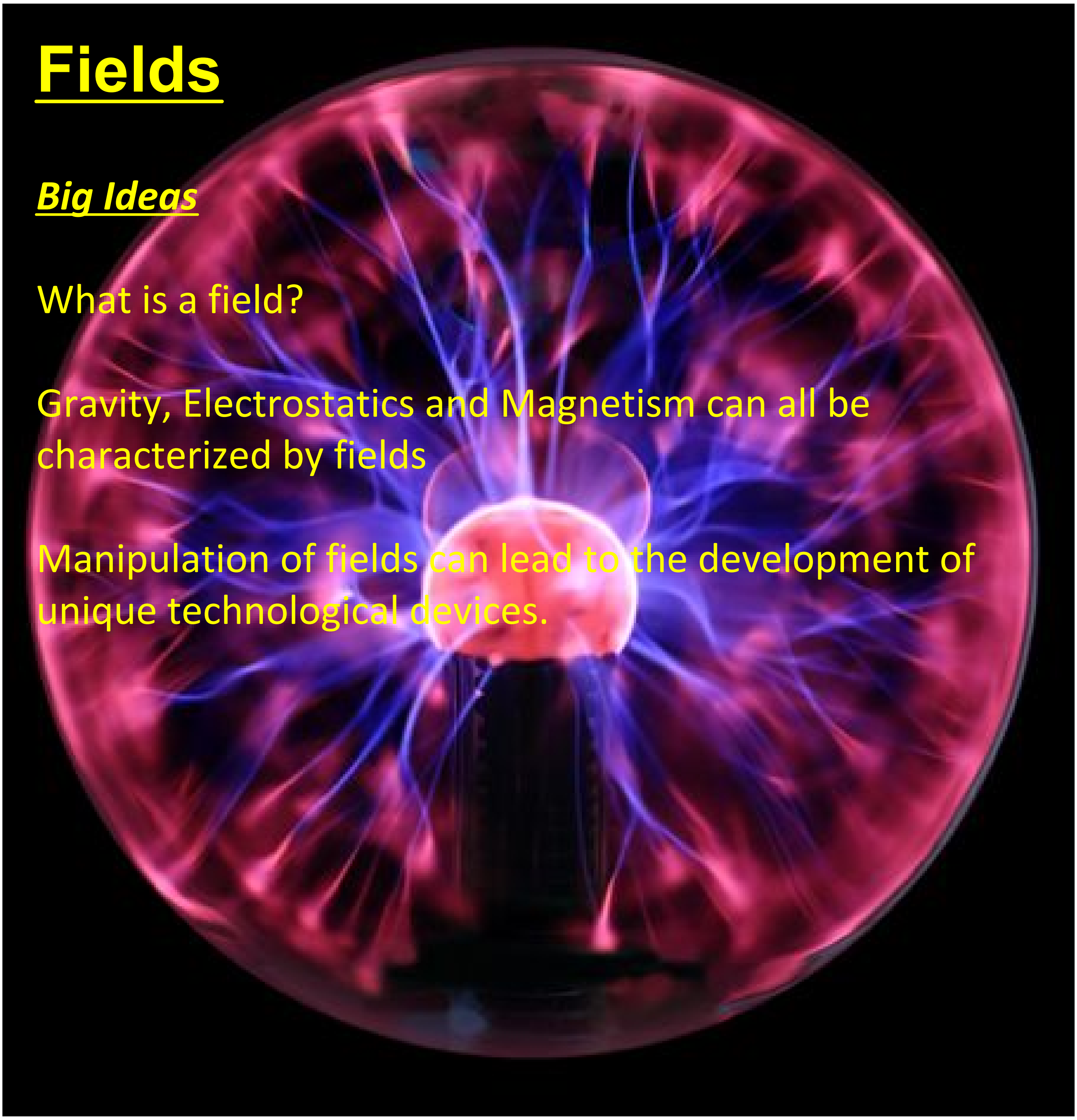


Fields

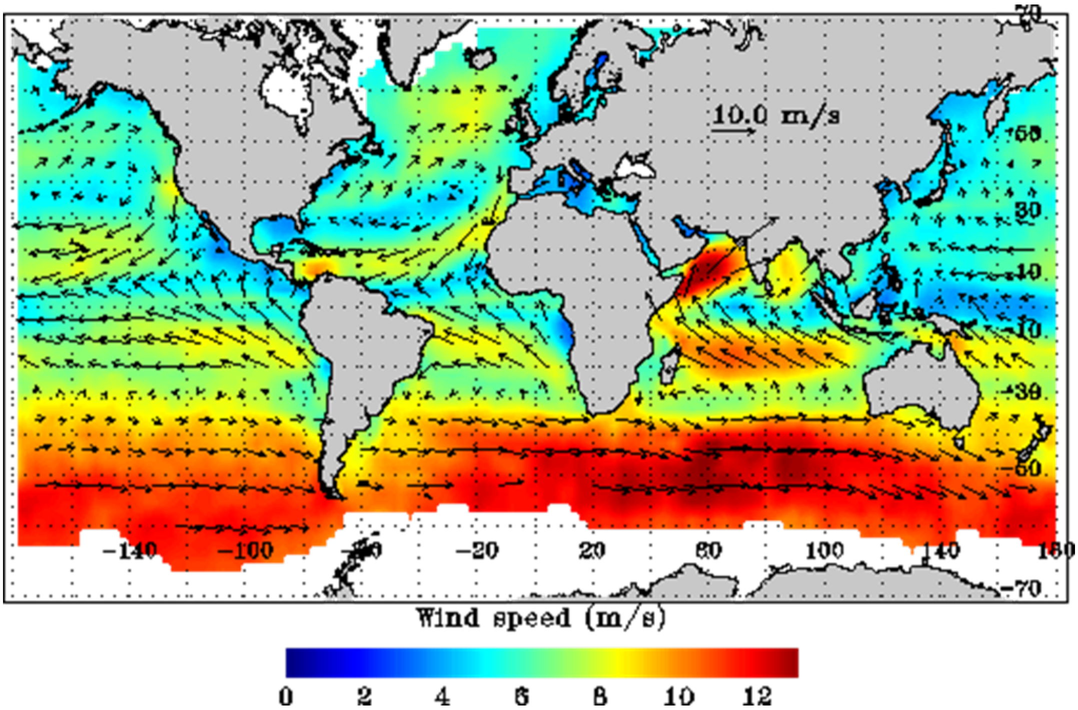
Big Ideas

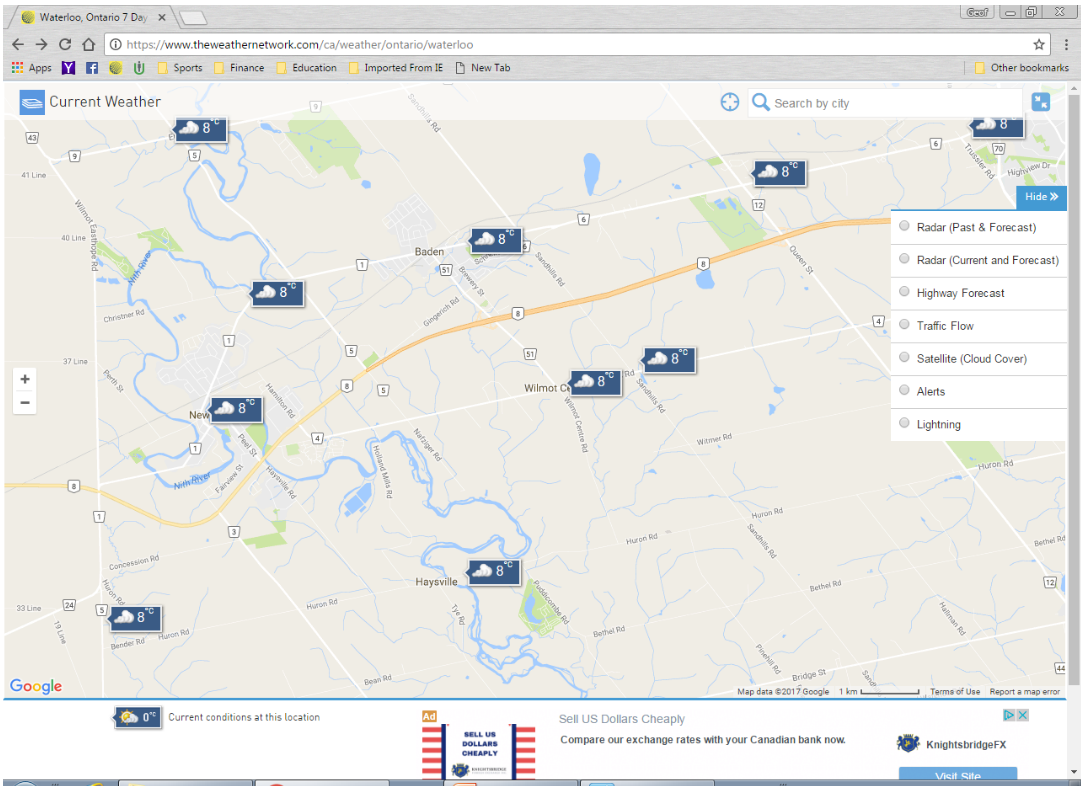
What is a field?

Gravity, Electrostatics and Magnetism can all be characterized by fields

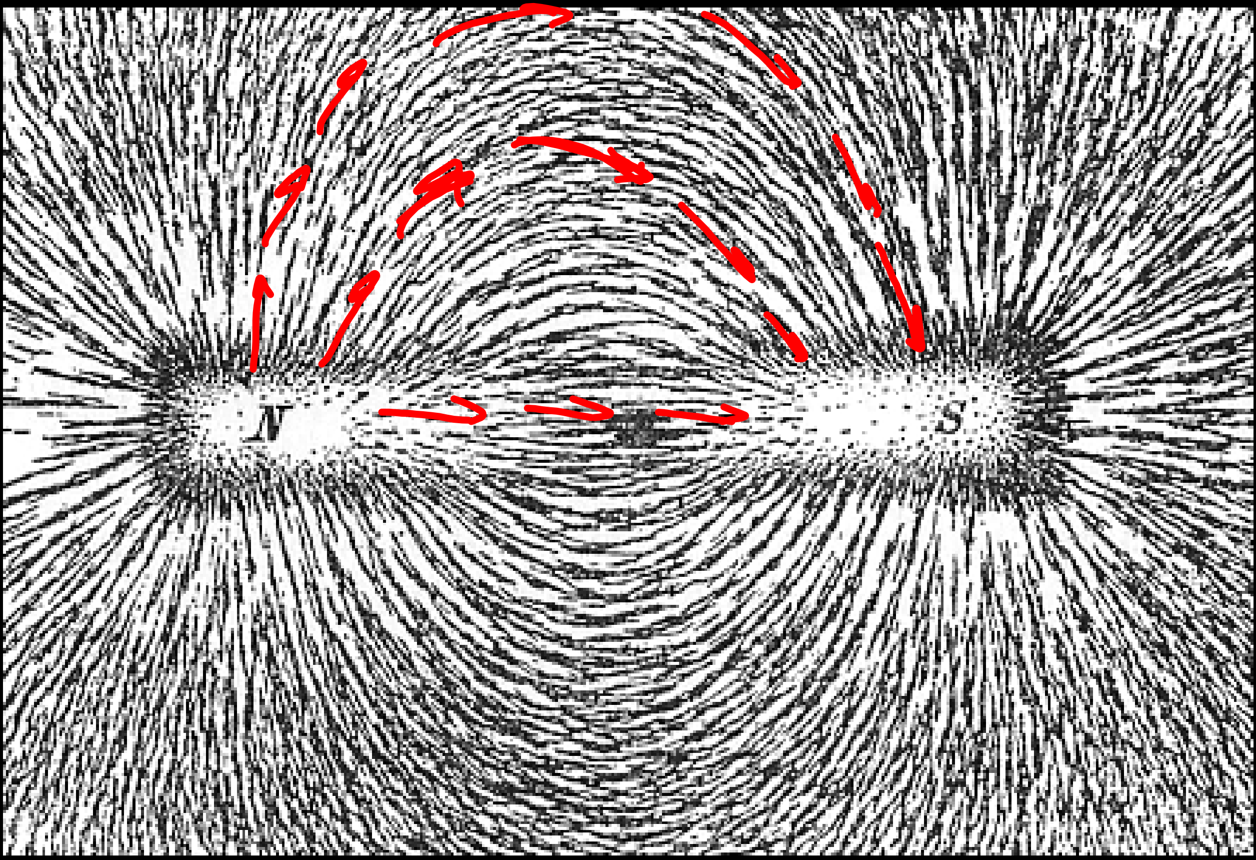
Manipulation of fields can lead to the development of unique technological devices.

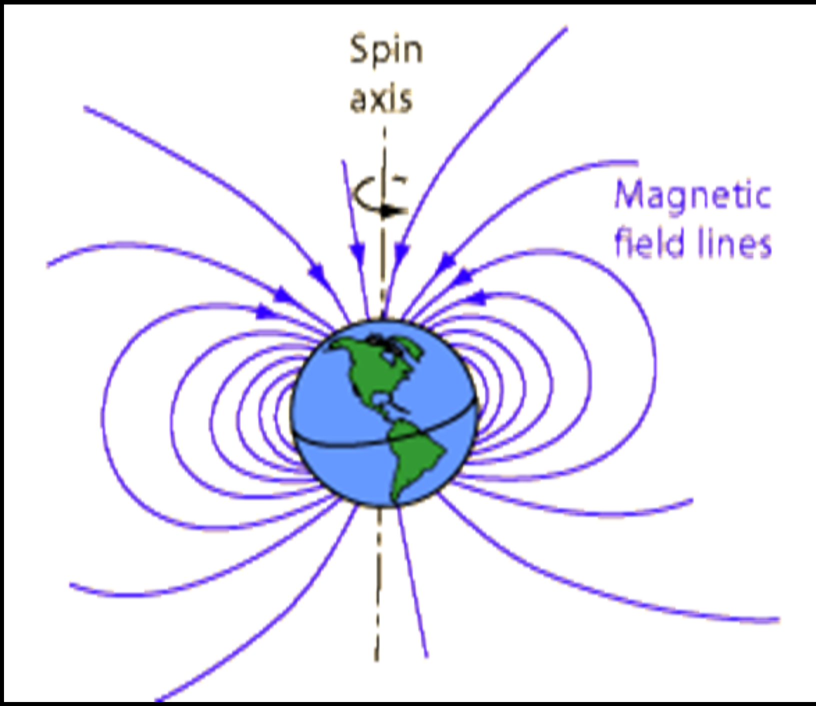
Examples of Fields



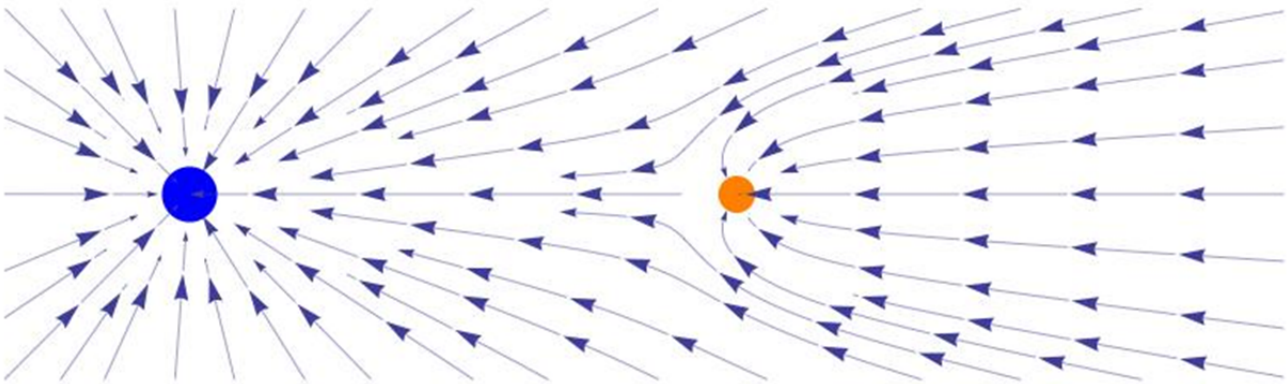


Examples of Fields - cont'd

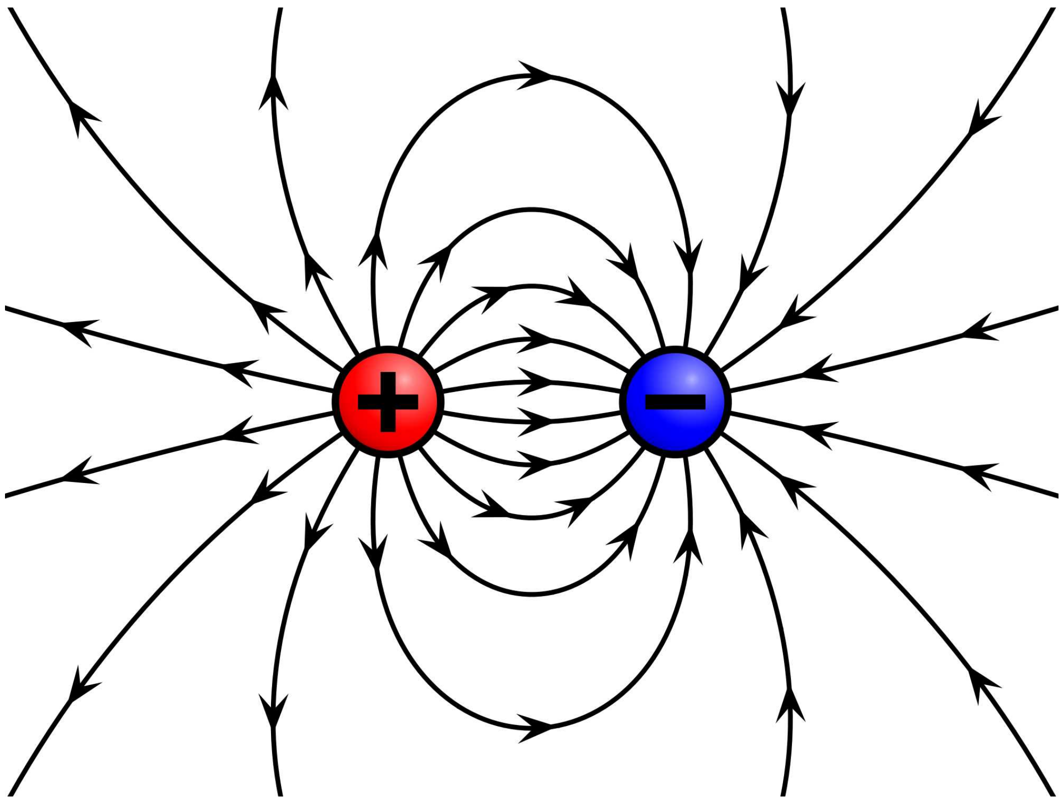




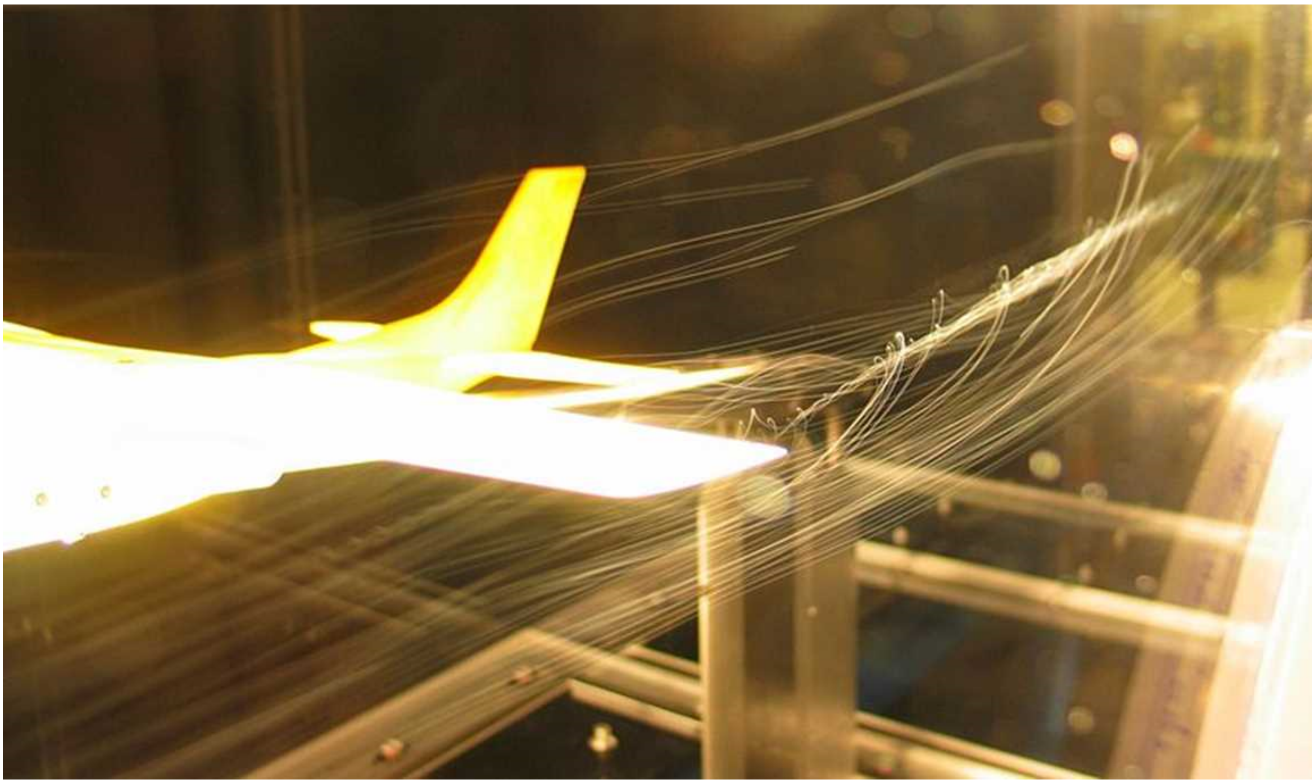
Examples of Fields - cont'd



Examples of Fields - cont'd



Examples of Fields - cont'd



Fields

ordered set of numbers

What is a Field

- a field is an array of values that specify a numeric property to each point in "space"

Types of Fields

- Scalar Field – a scalar field associates a scalar value to every point in space
- Vector Field - a vector field associates a vector value (magnitude and direction) to every point in space

---

Examples of Fields

Scalar	**Vector**
temperature	gravity
air pressure	electrostatic
Higgs field	magnetic

→ responsible for mass of elementary particles.

Activity :

Calculate the force of gravity between a 1kg object and the earth at the following altitudes:

- Zero metres (i.e. on the surface of the the earth)
- 6,380km
- 12,760km
- 19,140km
- 25,520km

$$F_g = \frac{G m_1 m_2}{r^2}$$

let $m_1 = 1kg$.

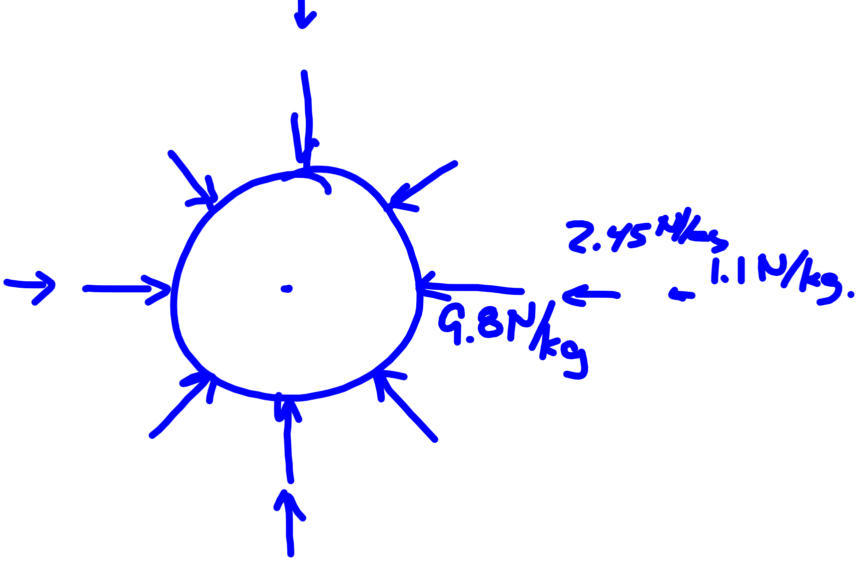
Variables Required:
- Mass of earth, $M_e = 5.97 \times 10^{24}$kg
- Radius of Earth, $R_e = 6.38 \times 10^6$m
- $G = 6.67 \times 10^{-11}$ N·m²/kg²

r (m)	F (N)
6.38×10^6	9.8
12.76×10^6	2.45
19.14×10^6	1.1
25.52×10^6	0.61
31.90×10^6	0.39

×2 → ÷4

×3 → ÷9

Gravitational Field Map of Earth



Gravitational Field Strength

Gravitational Field Strength is the force of gravity on a 1 kg test mass at a particular location.

$$F_g = \frac{Gm_1m_2}{r^2}$$ let $m_1 = 1\,kg$.

$$= \frac{Gm_2}{r^2}$$ call $m_2 \rightarrow M$ (object creating the field)

$$\boxed{g = \frac{GM}{r^2}}$$

$$\frac{6.67\times10^{-11}\cdot 5.98\times10^{24}}{(6.38\times10^{6})^2} = 9.78\ldots$$

units on g

$$\frac{N\cdot m^2/kg^2\cdot kg}{m^2} = N/kg$$

$$m/s^2 = N/kg$$

$$9.8\,m/s^2 = 9.8\,N/kg$$

Homework

Calculate the gravitational field strength of the moon

Next Day

- Electromagnetic Fields & Uniform Electric Fields

Homework:

Calculate the gravitational field strength of the moon at distances of 1, 2, 3 and 4 times the moon radius

Variables Required

- Mass of moon, M_m = 7.3×10^{22}kg
- Radius of moon, R_m= 1.74×10^{6}m
- G=6.67×10^{-11} $N \cdot m^2/kg^2$

$$\vec{g} = \frac{GM}{r^2}$$

r	g_m (N/kg or m/s^2)
1.74×10^6m	1.6
×2	0.40 ÷4 (2^2)
×3	0.18 ÷9 (3^2)
×4	0.10 ÷16 (4^2)

Field Strength N/kg.

Force of Gravity = N

$F = mg$

Fields

Today's Plan

1. Complete discussion on gravitational fields
2. Learn about electrostatic fields

Electric Fields

1. Electric Force

1. F_e varies directly with magnitude of the chorge.

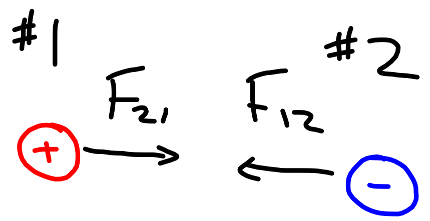
$$F_e \propto q$$

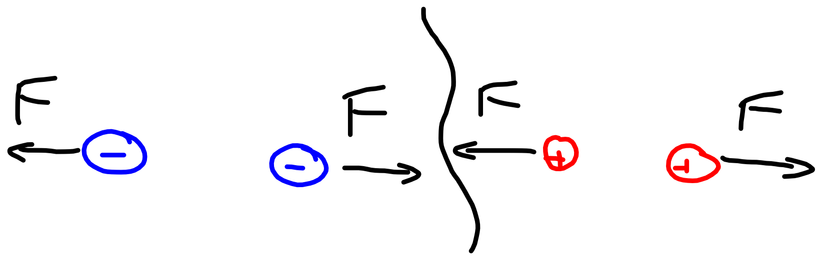
q → quantity of charge

2. F_e varies indirectly with squore of distance.

$$F_e \propto \frac{1}{r^2}$$

r → distance between objects.





electric charge is measured in Coulomb (C)

1 electron = -1.602×10^{-19} C

1 proton = $+1.602 \times 10^{-19}$ C

Electric Fields (cont'd)

Calculating Electric Force

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

k → Coulombs Constant

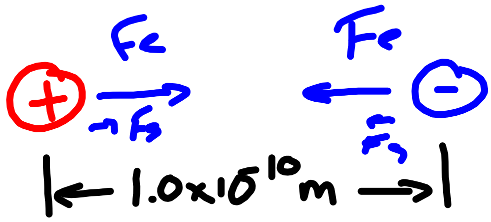
$k = 9.0 \times 10^9 \; N \cdot m^2 / C^2$

r → meters

q → Coulombs

example:
Compare Electric Forces to Gravitational Forces

$q = 1.602\times10^{-19}\,C$
$m_p = 1.67\times10^{-27}\,kg$



$q = -1.602\times10^{-19}\,C$
$m_e = 9.11\times10^{-31}\,kg$

Calculate & compare F_g & F_e.

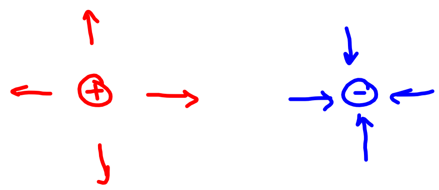
$$F_g = 1.0\times10^{-47}\,N$$

$$F_e = 2.3\times10^{-8}\,N$$

$F_e \sim 2.3\times10^{39}$ x's bigger.

2. Electric Fields

* An electric field is the force a 1 C charge would feel if placed in the field.
* the electric field points in the direction a positive charge would move.



Calculating the Electric Field

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

let $q_1 = 1\,C$ (test charge)
let $q_2 = q$ (charge creating the field)

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

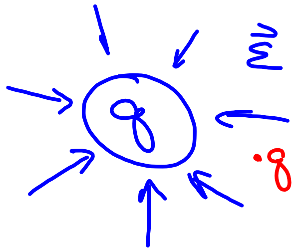
units on $\vec{\varepsilon}$

$$= \frac{N \cdot m^2/C^2 \cdot C}{m^2}$$

$$= N/C$$

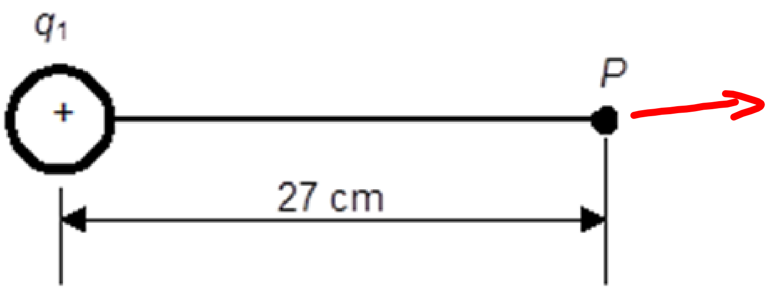
$\vec{\varepsilon}$ → strength of the electric field

$$\vec{F_e} = q\vec{\varepsilon}$$



Practice Problems

1a. Calculate the electric field at point P, 27 cm from a point charge q_1 that is $3.3\text{x}10^{-9}$C.



$$\vec{E} = \frac{kq}{r^2} = 407\ \text{N/C}\ [\rightarrow]$$

1b. How many excess protons are required to create a charge of $+3.3\text{x}10^{-9}$C.

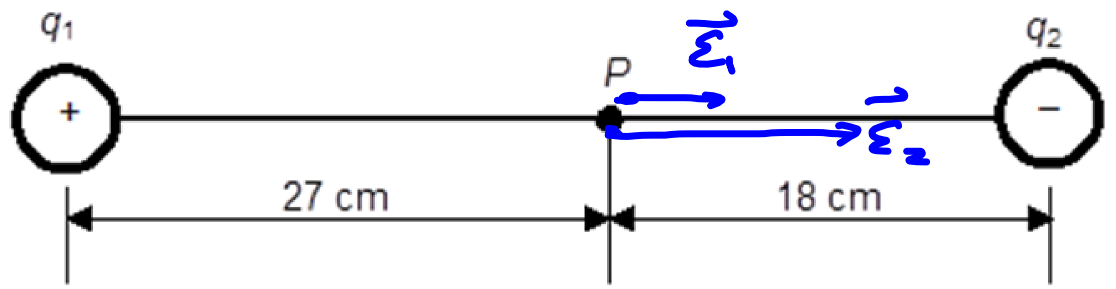
$$1\ \text{proton} = +1.602\times10^{-19}\ \text{C}$$

$$\frac{3.3\times10^{-9}\ \text{C}}{1.602\times10^{-19}\ \text{C/proton}} = 2\times10^{10}\ \text{protons}$$

~ 20 billion

Practice Problems

2. Two point charges are 45 cm apart. The charge on q_1 is $3.3\text{x}10^{-9}$C and the charge on q_2 is $-1.00\text{x}10^{-8}$C. Find the net electric field at point P. (hint – electric fields are additive, you can simply calculate the fields from each point charge and add them together).



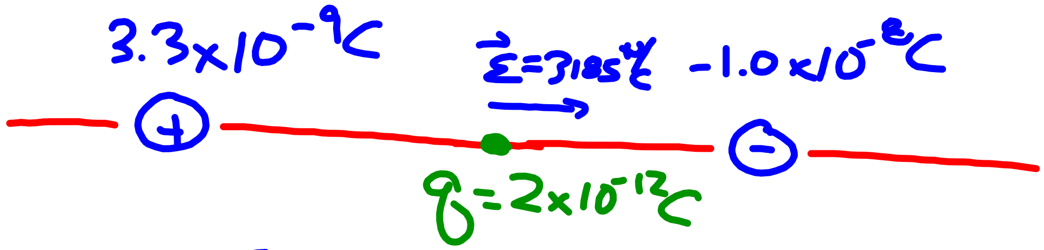
$$\vec{\varepsilon} = \vec{\varepsilon}_1 + \vec{\varepsilon}_2$$

$$\vec{\varepsilon}_1 = 407 \text{ N/C} [\rightarrow]$$

$$\vec{\varepsilon}_2 = 2778 \text{ N/C} [\rightarrow]$$

$$\vec{\varepsilon}_{TOT} = 3185 \text{ N/C} [\rightarrow]$$

3. In the above scenario, a new charge of $+2.0\text{x}10^{-12}$C is placed at point P. Determine the net electric force acting on this charge.



$$F = q\vec{\varepsilon}$$

$$= 2\times10^{-12}\text{C} \times 3185 \text{ N/C} [\rightarrow]$$

$$= 6.37\times10^{-9} \text{ N} [\rightarrow]$$

Comparison : Gravitational vs. Electric Field Formulas

Gravity

$$\vec{F}_g = \frac{G m_1 m_2}{r^2}$$

Electric

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

Field Strength

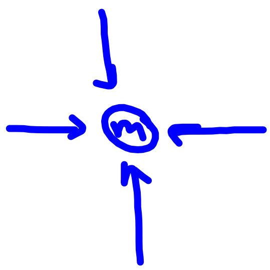
$$\vec{g} = \frac{Gm}{r^2} \quad (N/kg) \quad (m/s^2)$$

$$\vec{\varepsilon} = \frac{kq}{r^2} \quad (N/C)$$

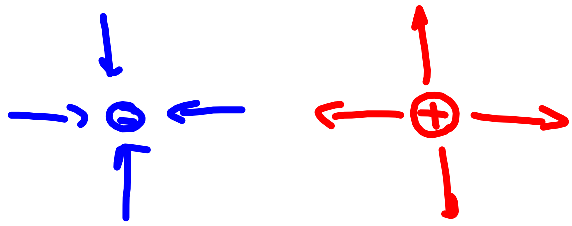
$$\vec{F} = m\vec{g}$$

$$\vec{F}_e = q\vec{\varepsilon}$$

point mass

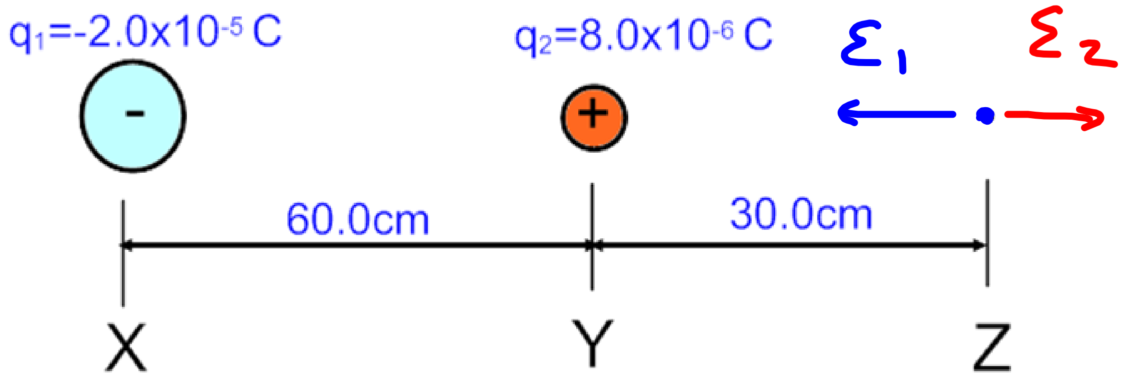


point charge



Extra Practice (try this one on your own)

1. What is the magnitude and direction of the electric field strength at point Z in the diagram below? What would be the force on a particle of charge -5.0×10^{-6}C that was placed at point Z?



$r_1 = 0.9\,m$ $\quad r_2 = 0.3\,m$

$\varepsilon_1 = \frac{kq_1}{r^2} = 2.2\times10^{5}\,N/C\ [\leftarrow]$

$\varepsilon_2 = \frac{kq_2}{r^2} = 8.0\times10^{5}\,N/C\ [\rightarrow]$

$\varepsilon_{TOT} = \varepsilon_1 + \varepsilon_2 = 5.8\times10^{5}\,N/C\ [\rightarrow]$

$F = q\varepsilon \qquad q = -5.0\times10^{-6}\,C$

$F = (-5\times10^{-6}\,C)(5.8\times10^{5}\,N/C)$

$= 2.9\,N\ [\leftarrow]$

2. A ping pong ball of mass 3.0x10^{-4}kg hangs from a light thread 1.0m long between two vertical parallel plates 10.0cm apart. When the potential difference across the plates is 420V, the ball comes to an equilibrium position 1.0cm to one side of it original position.

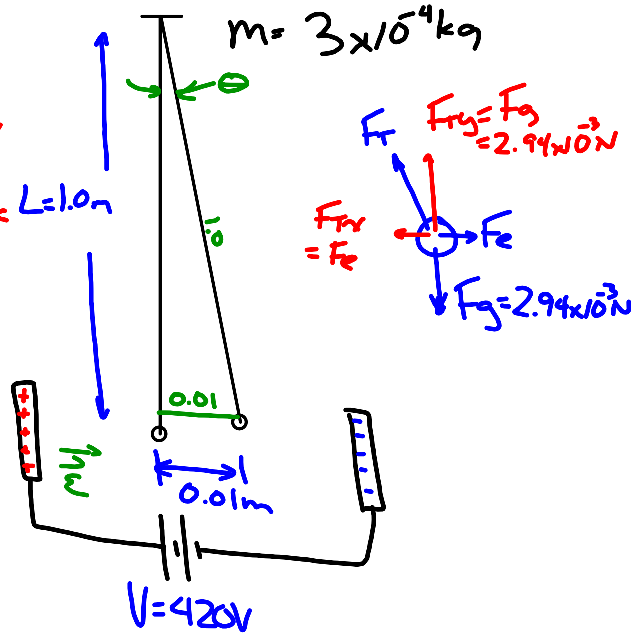
a. Calculate the electric field strength between the plates.

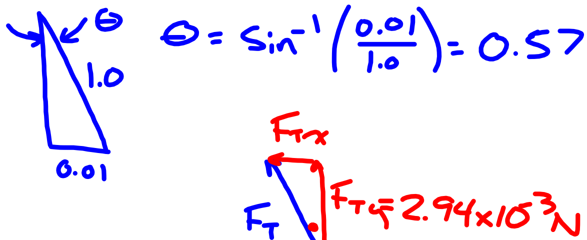
b. Calculate the tension in the thread.

c. Calculate the magnitude of the electric force deflecting the ball.

d. What is the magnitude of the excess charge on the ping pong ball?

a. $\vec{\mathcal{E}} = \frac{V}{d} = \frac{420V}{0.1m} = 4200 N/C$





$\theta = \sin^{-1}\left(\frac{0.01}{1.0}\right) = 0.572967$

b. $F_{Ty} = F_T \cos\theta$

$F_T = F_{Ty}/\cos\theta = 2.94\times10^{-3}N$

c. $F_e = F_{Tx} = F_T \sin\theta$

$= 2.94\times10^{-5}N$

d. $\vec{F_e} = q\vec{\mathcal{E}}$

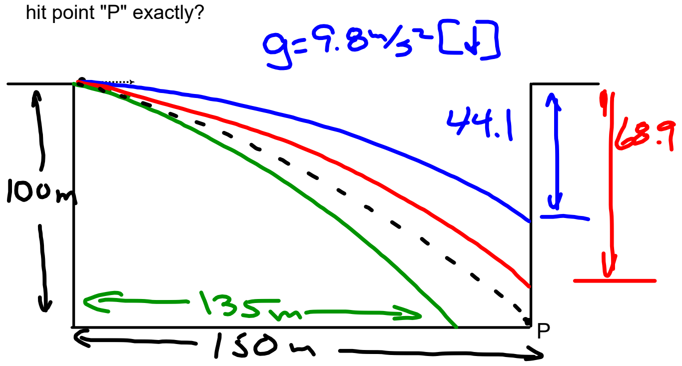
$\vec{q} = \vec{F_e}/\vec{\mathcal{E}} = 2.94\times10^{-5} N / 4200 N/C$

$= 7.0\times10^{-9} C$

Uniform Fields - Gravity Warmup / Review

A 5.0 kg cannon ball is fired horizontally across a 150m canyon that is 100m deep (assume 2 sig figs). Where will it hit the opposite wall if it is fired at 30m/s, 40m/s, 50m/s? *(if it doesn't hit the wall how close does it come?)*

Challenge - what velocity would the cannon ball need to be fired at, to hit point "P" exactly?



Vertical

$v_{v1} = 0\ m/s$

$a = 9.8\ m/s^2$

$\Delta d = 100$

③ $t = \sqrt{\frac{2\Delta d}{a}} = 4.5\ s$

Horiz

$v_H = 50\ m/s$

$\Delta t = 3\ s$

$t = \frac{\Delta d_H}{v_H}$

$v_{v1} = 0,\ \Delta t = 3,\ a = 9.8$

$\Delta d = \cancel{v_1 \Delta t} + \frac{1}{2} a \Delta t^2$

$= 44.1\ m$

$v_H = 40\ m/s$

$\Delta t = 3.75\ s$

$v_{v1} = 0,\ \Delta t = 3.75,\ a = 9.8$

$\Delta d = 68.9\ m$

$v_H = 30\ m/s$

$\Delta t = 5\ s$

$\Delta d_H = v_H \Delta t$

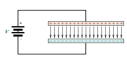
$= 30\ m/s \cdot 4.5\ s$

$= 135\ m$

to hit Point P

$\Delta d_H = 150\ m,\ \Delta t = 4.5\ s$

$v_H = \frac{\Delta d_H}{\Delta t} = \frac{150\ m}{4.5\ s} = 33.3\ m/s$

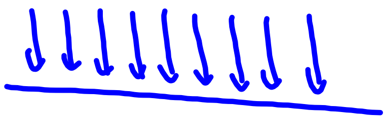


Uniform Fields

→ uniform in magnitude

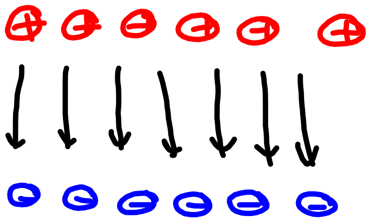
→ uniform in direction

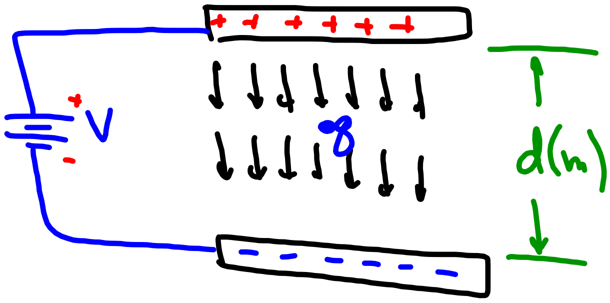
Gravity (assume earth is flat)



$g = 9.8\ N/kg$

Electric





$$\vec{E} = \frac{V}{d} \quad \left(V/m\right)$$

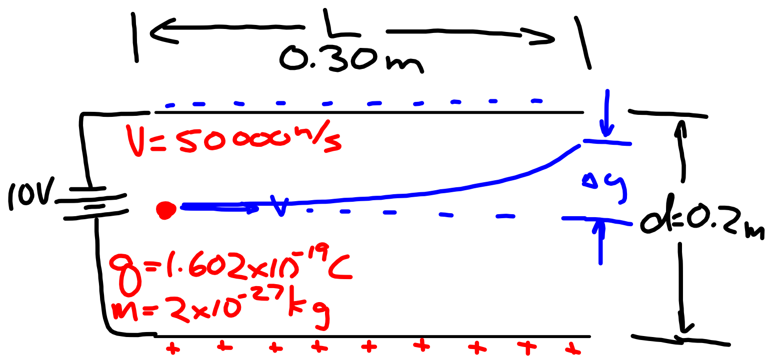
$\frac{V}{m}$ equivalent to N/C.

Force on a particle in a charged field.

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

Parallel Plate Simulator (the charged particle gun)

Find the displacement of the charged particle in the electric field shown below.



1. find $\vec{\varepsilon}$ $\quad \vec{\varepsilon} = \frac{V}{d} = \frac{10\,V}{0.2\,m} = 50\,N/C \uparrow$

2. find force on particle

$$\vec{F} = q\vec{\varepsilon}$$

$$= 1.602\times10^{-9}\,C \times 50\,N/C$$

$$= 8.01\times10^{-18}\,N \uparrow$$

3. find acceleration

$$\vec{a} = \vec{F}/m = \frac{8.01\times10^{-18}\,N}{2\times10^{-27}\,kg}$$

$$= 4.00\times10^{9}\,m/s^2 \uparrow$$

4 find Δt

$$\Delta t = \frac{L}{V_H} = \frac{0.3\,m}{50\,000\,m/s}$$

$$= 6\times10^{-6}\,s$$

5 find vertical displacement

$V_{v_1} = 0$, $a = 4.0\times10^{9}\,m/s^2$

$\Delta t = 6\times10^{-6}\,s$

(3) $\Delta d_v = \frac{1}{2}(4.0\times10^{9}\,m/s^2)(6\times10^{-6}\,s)^2$

$= 7.2\,cm$

$(0.072\,m)$

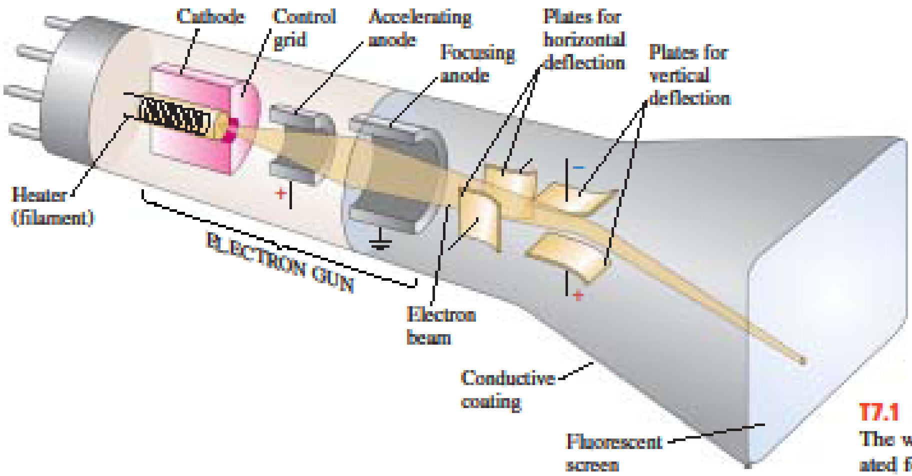
Topic 7 | The Cathode-Ray Tube

Let's look at how the concept of potential is applied to an important class of devices called **cathode-ray tubes,** or "CRTs" for short. Cathode-ray tubes are found in oscilloscopes, and similar devices are used in TV picture tubes and computer displays. The name goes back to the early 1900s. Cathode-ray tubes use an electron beam; before the basic nature of the beam was understood, it was called a cathode ray because it emanated from the cathode (negative electrode) of a vacuum tube.

Figure T7.1 is a schematic diagram of the principal elements of a cathode-ray tube. The interior of the tube is a very good vacuum, with a pressure of around 0.01 Pa (10^{-7} atm) or less. At any greater pressure, collisions of electrons with air molecules would scatter the electron beam excessively. The *cathode,* at the left end in the figure, is raised to a high temperature by the *heater,* and electrons evaporate from the surface of the cathode. The *accelerating anode,* with a small hole at its center, is maintained at a high positive potential V_1, of the order of 1 to 20 kV, relative to the cathode. This potential difference gives rise to an electric field directed from right to left in the region between the accelerating anode and the cathode. Electrons passing through the hole in the anode form a narrow beam and travel with constant horizontal velocity from the anode to the *fluorescent screen.* The area where the electrons strike the screen glows brightly.

The *control grid* regulates the number of electrons that reach the anode and hence the brightness of the spot on the screen. The *focusing anode* ensures that electrons leaving the cathode in slightly different directions are focused down to a narrow beam and all arrive at the same spot on the screen. We won't need to worry about the control grid or focusing anode in the following analysis. The assembly of cathode, control grid, focusing anode, and accelerating electrode is called the *electron gun.*

The beam of electrons passes between two pairs of *deflecting plates.* An electric field between the first pair of plates deflects the electrons horizontally, and an electric field between the second pair deflects them vertically. If no deflecting fields are present, the electrons travel in a straight line from the hole in the accelerating anode to the center of the screen, where they produce a bright spot.

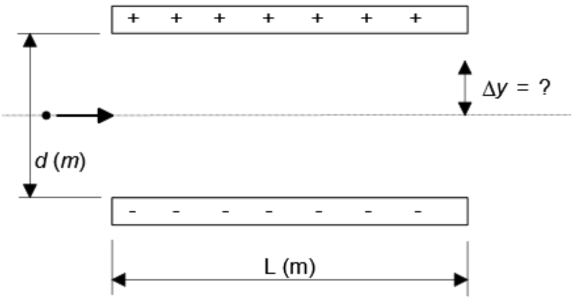


T7.1 Basic elements of a cathode-ray tube. The width of the electron beam is exaggerated for clarity.

$$V = \sqrt{\frac{2E_k}{m}}$$

Electric Field Between Parallel Plates

Homework / Practice



Parameters:

Particle : proton Mass = 1.67×10^{-27} kg Charge = $+1.602 \times 10^{-19}$ C Starting Kinetic Energy $E_k = 2.5 \times 10^{-18}$ J	Distance Between Plates, d= .20m Length of Plates, L = .10m Voltage Between Plates, V= 125V

Determine the vertical deflection of the particle as it travels through the electric field.

$$V_H = \sqrt{\frac{2E_k}{m}} = 54717\ m/s$$

$$\vec{\varepsilon} = \frac{V}{d} = 625\ V/m \Rightarrow 625\ N/C \downarrow$$

$$\vec{F} = q\vec{\varepsilon} = 1.00 \times 10^{-16}\ N \downarrow$$

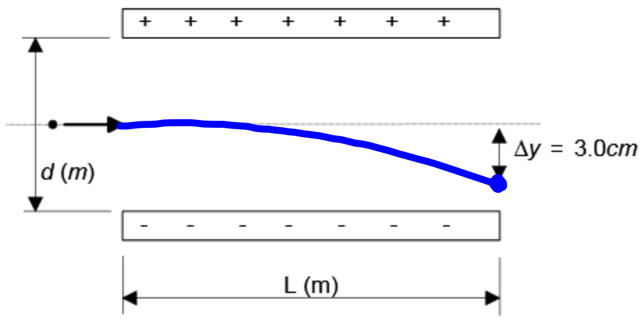
$$\vec{a} = \vec{F}/m = 6.0 \times 10^{10}\ m/s^2 \downarrow$$

$$t_H = \frac{d_H}{V_H} = \frac{L}{V_H} = 1.83 \times 10^{-6}\ s$$

$a = 6.0 \times 10^{10}\ m/s^2$, $V_{1v} = 0$, $t = 1.83 \times 10^{-6}\ s$, $\Delta d_v = ?$

③ $\Delta d_v = \cancel{V_{1v}\Delta t} + \frac{1}{2}a\Delta t^2$

$= 0.10\ m$ or $10\ cm$ ↓



Parameters:

Particle : helium nucleus Mass = 6.64×10^{-27}kg Charge = $+3.2\times10^{-19}$C Horizontal Velocity = 4.0×10^{5}m/s	Distance Between Plates, d= ???cm Length of Plates, L = 10cm Voltage Between Plates, V= 1,500V (1.5kV)

Determine the plate separation "d" to make the particle deflect 3cm downwards.

$$t_H = \frac{d_H}{V_H} = \frac{L}{V_H} = \frac{0.10m}{400000 m/s} = 2.5\times10^{7} s$$

$$\Delta d_v = 0.03m \qquad \vec{a} = \frac{2\Delta d_v}{t^2} \text{ (from eqn 3)}$$

$$= 9.6\times10^{11} m/s^2$$

$$\vec{F} = ma = 6.37\times10^{-15} N$$

$$F = q\varepsilon \Rightarrow \vec{\varepsilon} = \vec{F}/q = 19920\ N/C\ (V/m)$$

$$\vec{\varepsilon} = \frac{V}{d} \Rightarrow d = \frac{V}{\varepsilon} = 0.075 m$$

∴ plate separation = 7.5cm