Electric and Magnetic Fields

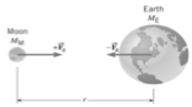
Gravitational Force

Gravitational Mass - the property of an object that determines how much gravitational force it feels when near another object with mass

Types: one type only

Symbol: m **Units:** kg

1 kg = the mass of a standard cylinder of platinum-iridium alloy kept at the International Bureau of Weights and Measures in Sèvres, France



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

Universal Gravitational Constant :
$G = 6.77 \times 10^{-11}\ \mathrm{N\ m^2/kg^2}$

Newton's Universal Law of Gravitation
The force of gravity between two objects is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them and acts along a line joining their centers. (Note: The masses act as point masses.)

Electric Force

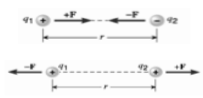
Electric Charge - the property of an object that determines how much electric force it feels when near another object with charge

Types: two types – positive and negative

Symbol: q **Units:** e or C

e = elementary unit of charge (magnitude of charge on electron)

1 e = 1.60×10^{-19} C



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

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Coulomb constant (electrostatic constant):
$k = 1/(4\pi\varepsilon_0) = 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}$

ε_0 = permittivity of free space
$= 8.85 \times 10^{-12}\ \mathrm{C^2/(N\ m^2)}$

Coulomb's Law – The electric force between two point charges is directly proportional to the product of the two charges and inversely proportional to square of the distance between them, and acts along the line joining the two charges. (Note: The charges act as point charges.)

Conservation of Electric Charge: The total electric charge of an isolated system remains constant.

Example: Find the gravitational force of attraction between the proton and the electron in a hydrogen atom.

$$\frac{GMm}{r^2} \qquad \frac{10^{-11}\ 10^{-27}\ 10^{-30}}{(10^{-10})^2} = 10^{-48} \qquad \sim 1\,\mathring{A} \approx 10^{-10}\ m$$

Example: Find the Coulomb force of attraction between the proton and the electron in a hydrogen atom.

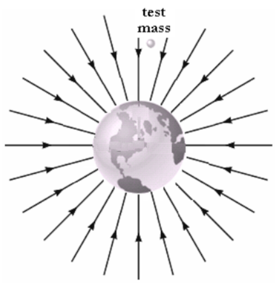
$$\frac{kQq}{r^2} \qquad \frac{10^{10}\ 10^{-19}\ 10^{19}}{(10^{-10})^2} = 10^{-8}$$

Force Fields

Force field (field of force): a region of space where a mass or charge experiences a force

Gravitational Field

Gravitational Field Strength (g) – gravitational force per unit mass on a point mass



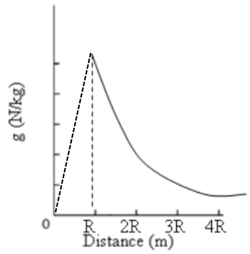
Formula:

$$g = \frac{F_g}{m}$$

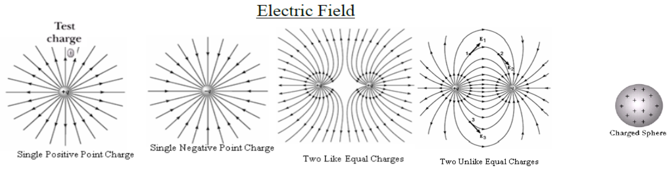
$$g = \frac{G \cdot M}{r^2}$$

Units:

$$\frac{N}{kg} \text{ or } \frac{m}{s^2}$$



Electric Field



Electric Field Strength (intensity) (E) - electric force exerted per unit charge on a small positive test charge

Electric Field Lines

1. Never cross
2. Show the direction of force on a small positive test charge
3. Out of positive, into negative
4. Direction of electric field is tangent to the field lines
5. Density of field lines is proportional to field strength (density = intensity)
6. Perpendicular to surface
7. **Radial field**: field lines are extensions of radii

Formula:

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

Units:

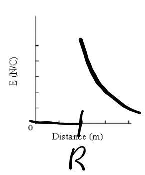
$$[N/C]$$

Electric Force:

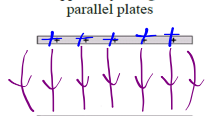
$$\vec{F}_e = q\vec{E}$$

For point charges:

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



Oppositely charged parallel plates



Uniform Field: field has same intensity at all spots*

Formula:

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

2

Units:

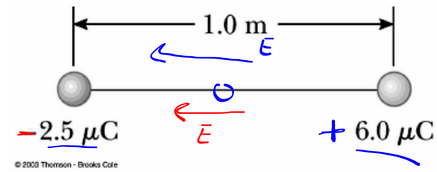
$$\left[\frac{V}{m}\right]$$

1. a) Find the magnitude and direction of the net electric field halfway between the two charges shown below.

$$\vec{E} = \frac{KQ}{r^2} + \frac{KQ}{r^2}$$

(+) (+)

$$= 3.1\times10^{5}\ N/C$$



+ ⟵⟶

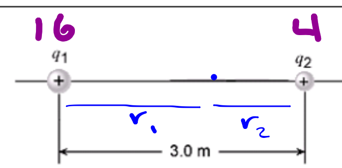
b) Determine the electric force on a proton placed at this spot.

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

$$= 1.6\times10^{-19}\,C \cdot 3.1\times10^{5}\,\frac{N}{C}$$

$$= 4.9\times10^{-19}\,N$$ left

2. Two positive point charges, $q_1 = +16\ \mu C$ and $q_2 = +4.0\ \mu C$, are separated in a vacuum by a distance of 3.0 m. Find the spot on the line between the charges where the net electric field is zero.



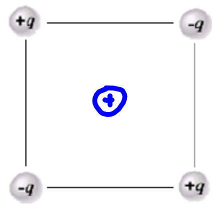
$$\frac{KQ_1}{r_1^2} = \frac{KQ_2}{r_2^2}$$

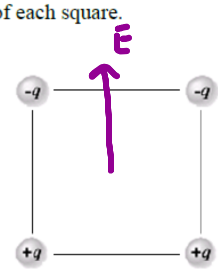
$$\frac{Q_1}{Q_2} = \frac{r_1^2}{r_2^2} = \frac{4}{1}$$

$$r_1 = 2r_2$$

$$r_1 + r_2 = 3m$$

3. Determine the direction of the net electric field at the center of each square.





Potential Energy and Potential

Gravitational Potential Energy: work done bringing a small point mass in from infinity to a point in a gravitational field

Gravitational potential: work done per unit mass bringing a small point mass in from infinity to a point in a gravitational field

Gravitational Potential Energy

Units: J
Type: scalar

$$E_p = -\frac{GMm}{r}$$

Gravitational Potential

Units: J/kg
Type: scalar

$$V = -\frac{GM}{r}$$

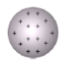
Relationships:

$$E_p = mV$$

$$W = \Delta E_p = m\Delta V$$

Electric Potential Energy: work done bringing a small positive test charge in from infinity to a point in an electric field

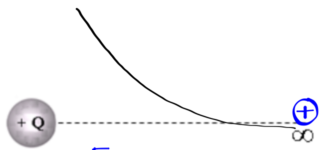
Electric Potential: work done per unit charge bringing a small positive test charge in from infinity to a point in an electric field



	Electric Potential Energy	Electric Potential	Relationships:
Units:	[J]	[J/C]	$E_p = qV$
Type:	scalar	scalar	
	$E_p = \frac{kQq}{r}$	$V = \frac{kQ}{r}$	

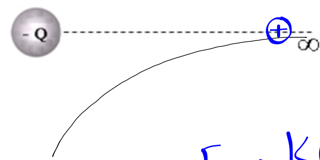
NOTE: 1) use the signs of the charges with these formulas

2) electric potential at infinity is zero



$+E_p$

$-E_p$



$W = \int F \cdot dr = \int \frac{kQq}{r^2} \cdot dr$

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

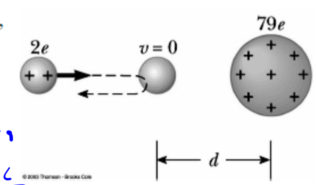
1. a) Calculate the potential at a point 2.50 cm away from a +4.8 μC charge.

$V = \frac{kQ}{r} = 1.7 \times 10^{6}\ \frac{J}{C}$

b) How much potential energy will an electron have if it is at this spot? A proton?

$E_p = qV = \pm 2.8 \times 10^{-13}\ J$

2. In Rutherford's famous scattering experiments (which led to the planetary model of the atom), alpha particles were fired toward a gold nucleus with charge +79*e*. An alpha particle, initially very far from the gold nucleus, is fired at 2.00 × 10[7] m/s directly toward the gold nucleus. Assume the gold nucleus remains stationary. How close does the alpha particle get to the gold nucleus before turning around? (the "distance of closest approach")



$KE \to E_p$

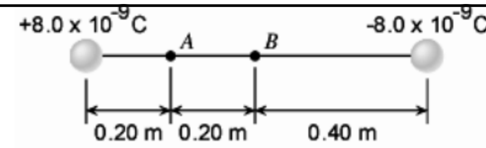
$\frac{1}{2}mv^2 = \frac{kQq}{r}$

$r = \frac{kQq}{\frac{1}{2}mv^2} = \frac{8.77 \times 10^{9}\ N\frac{m^2}{C^2} \cdot 2 \cdot 1.6 \cdot 10^{-19} C \cdot 79 \cdot 1.6 \cdot 10^{-19} C}{\frac{1}{2} \cdot 4 \cdot 1.66 \times 10^{-27} kg\,(2 \times 10^{7}\ m/s)^2}$

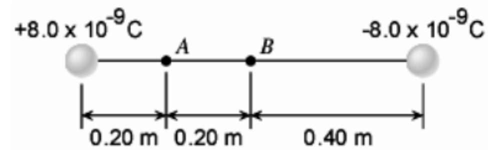
$m_\alpha \sim 4u$

$\sim 2.7 \times 10^{-14}\ m$

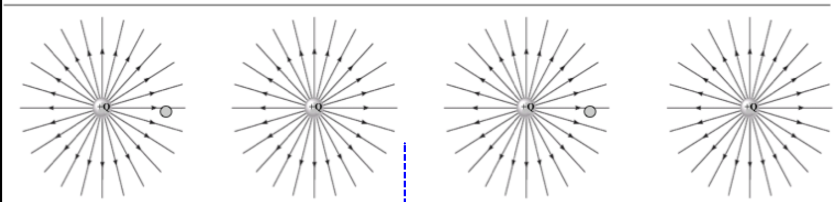
3. a) Find the magnitude and direction of the net electric field at each point (A and B).



4. Calculate the net electric potential at each spot (A and B):



Point Charges



Electric Force	Electric Field	Electric Potential Energy	Electric Potential
$\vec{F}_e = \frac{KQq}{r^2}$	$\vec{E} = \frac{KQ}{r^2}$	$E_p = \frac{KQq}{r}$	$V = \frac{KQ}{r}$
$\vec{F} = q\vec{E}$		$E = qV$	

vector →

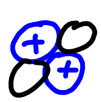
scalar →

Do Not plug in +/−
check F.O.R.

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

use q + or −

$M_e = 9.11 \times 10^{-31}$ kg
$M_p = 1.673 \times 10^{-27}$ kg
$q_e = q_p = 1.6 \times 10^{-19}$ C = 1 e.c.
$u = 1.66 \times 10^{-27}$ kg



$\alpha_{particle}$

2p, 2n