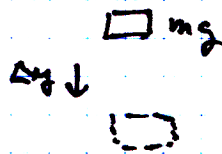


$$W_K = mg \Delta y \underbrace{\cos 180}_{-1}$$

$$= -mg \Delta y = \Delta U$$

$$\Delta U > 0$$



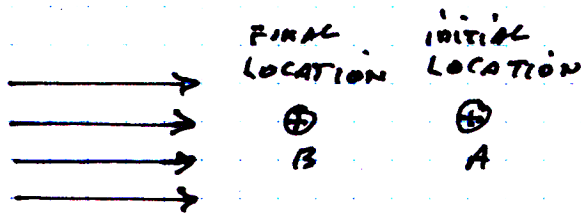
$$W_K = mg \Delta y \underbrace{\cos 0}_{+1}$$

$$= mg \Delta y = -\Delta U$$

$$\Delta U < 0$$

ELECTRIC POTENTIAL - VOLTAGE

ONE OF THE PROBLEMS IN CALCULATING $\vec{E} = \vec{F}/q$ IS THAT IT DEPENDS ON q AT LEAST AT FIRST GLANCE. WE ARE LOOKING FOR A WAY OF MEASURING THE EFFECT OF \vec{E} THAT DOES NOT DEPEND ON q



ΔU OF THE CHARGE = - WORK DONE ON THE CHARGE BY THE E FIELD FORCE

$$F_C = qE$$

$$\Delta U_{AB} = -F_C \Delta x_{AB} = -E q \Delta x_{AB} \underbrace{\cos 180}_{-1}$$

$$\frac{U_B}{q} - \frac{U_A}{q} = E x_B - E x_A = (x_B - x_A) E^{-1}$$

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

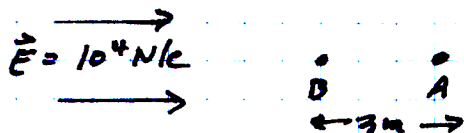
$$V_B - V_A = (x_B - x_A) E$$

$$V = - \int_i^{P_2} \vec{E} \cdot d\vec{s}$$

EXAMPLE I - A CHARGE MOVES 3m in an

ELECTRIC FIELD OF 10^4 N/C . If $q = 1 \mu\text{C}$ find
the difference in the electric potential over
the 3 m distance

$$q = 1 \times 10^{-6} \text{ C}$$



THE ELECTRIC POTENTIAL ENERGY } $\Delta U_{AB} = -W_{AB} = -\vec{F} \Delta x \cos 180^\circ$

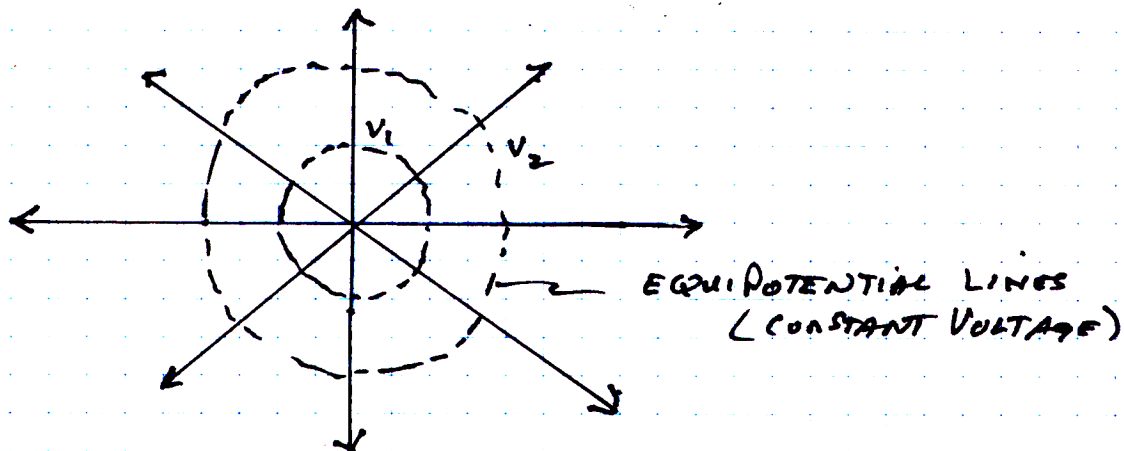
$$= Eq \Delta x = 10^4 (1 \times 10^{-6}) (3) = 3 \times 10^{-2} \text{ J}$$

ELECTRIC POTENTIAL } = { VOLTAGE }
DIFFERENCE } $\Delta V = \frac{\Delta U}{q} = \frac{3 \times 10^{-2}}{1 \times 10^{-6}} = 3 \times 10^4 \text{ J/C}$

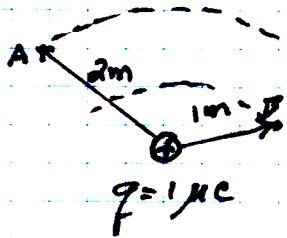
THE VOLTAGE AT ANY POINT IN AN \vec{E} IS A SCALAR
QUANTITY & THUS IT HAS NO DIRECTION

EQUIPOTENTIAL SURFACES

$$E = \frac{F}{q} = \frac{kqQ_1}{r^2 q} = \frac{kQ_1}{r^2}$$



$$V = - \int \vec{E} \cdot d\vec{s} = - \int \frac{kq}{r^2} dr = -kq \left\{ \frac{1}{\infty} - \frac{1}{r} \right\} = \frac{kq}{r}$$



$$V_a = \frac{kq}{r_a} = \frac{9 \times 10^9 (1 \times 10^{-6})}{2} = 4500 \text{ V}$$

$$V_b = \frac{kq}{r_b} = \frac{9 \times 10^9 (1 \times 10^{-6})}{1} = 9000 \text{ V}$$

$$V_b - V_a = 9000 - 4500 = 4500 \text{ Volts}$$

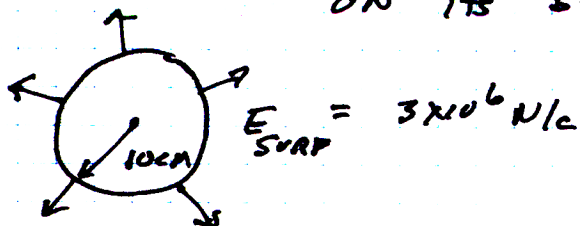
IMPORTANT RELATIONSHIPS

$$F = \frac{kq_1 q_2}{r^2}$$

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

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

EXAMPLE III - A SPHERE OF RADIUS 10CM HAS AN ELECTRIC FIELD ON ITS SURFACE OF $3 \times 10^6 \text{ N/C}$



a) find THE TOTAL CHARGE ON THE SPHERE

$$\vec{E} = \frac{kq}{r^2} \quad q = \frac{E r^2}{k} = \frac{3 \times 10^6 (0.1)^2}{9 \times 10^9} = 3.33 \times 10^{-6} \text{ C}$$

b) WHAT IS THE CHARGE DENSITY ON THE SPHERE

$$\sigma = \frac{q}{4\pi r^2} = \frac{3.33 \times 10^{-6}}{4\pi (0.1)^2} = 26.5 \mu\text{C/m}^2$$

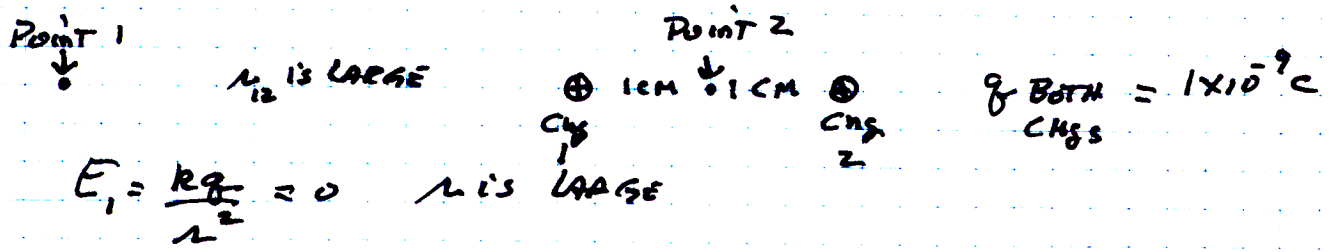
c) find the VOLTAGE DIFF BETWEEN THE SPHERE'S SURFACE & A FAR AWAY GROUND

$$V_{\text{SURF}} = \frac{kq}{r} = \frac{9 \times 10^9 (3.33 \times 10^{-6})}{0.1} = 300,000 \text{ Volts}$$

$$V_{\infty} = 0$$

$$\Delta V = 300,000 - 0 = 300,000 \text{ Volts}$$

DETERMINE $V_1 - V_2$

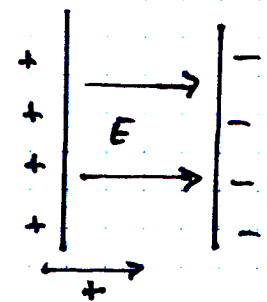


$$E_1 = \frac{kq}{r^2} = 0$$

$$V_2 = \frac{kq}{r} + \frac{kq}{r} = \frac{2kq}{.01} = \frac{2(9 \times 10^9)(1 \times 10^{-9})}{.01} = 1800 \text{ V}$$

$$V_1 - V_2 = 0 - 1800 = -1800 \text{ VOLTS}$$

POTENTIAL DIFFERENCE BETWEEN CHARGED CONDUCTING SURFACES



$$E_{\text{CONDUCTING SURFACES}} = \frac{\sigma}{\epsilon_0}$$

IF THE PLATES HAVE $\sigma = 1 \text{ nAmp C/m}^2 = 1 \times 10^{-9} \text{ C/m}^2$

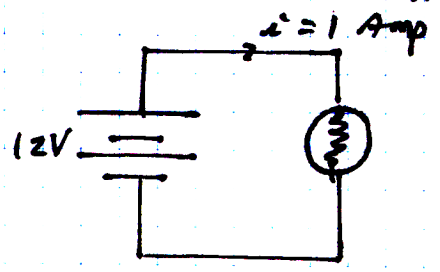
$\Delta x = 1 \text{ cm}$ DETERMINE ΔV

$$\Delta V = -\vec{E} \cdot \vec{\Delta x} \quad E = \frac{\sigma}{\epsilon_0} = \frac{1 \times 10^{-9}}{8.85 \times 10^{-12}} = 113 \text{ N/C}$$

$$\Delta V = -|E| |\Delta x| \cos \theta = -(113)(.01) = -1.13 \text{ Volts}$$

$$V_- - V_+ = -1.13 \text{ Volts}$$

CURRENT FLOWS IN A CIRCUIT AS SHOWN FOR 1 MINUTE. BY HOW MUCH IS THE ELECTRICAL POTENTIAL ENERGY OF THE BATTERY CHANGED



$$i = \frac{\Delta q}{\Delta t}$$

$$\Delta q = i \Delta t = 1 \text{ Amp} \left(1 \text{ min} \times \frac{60 \text{ Sec}}{1 \text{ min}} \right)$$

$$\Delta U = q \Delta V = 60(12) = 720 \text{ J}$$

↑
ENERGY LOST BY THE BATTERY

EXAMPLE VI

A HOLLOW CONDUCTING SPHERE HAS 15,000 VOLTS ON ITS SURFACE & THE SPHERE HAS A RADIUS OF 10CM DETERMINE $V_A - V_B$



$$V_{\text{SURF}} = 15000 \text{ VOLTS}$$

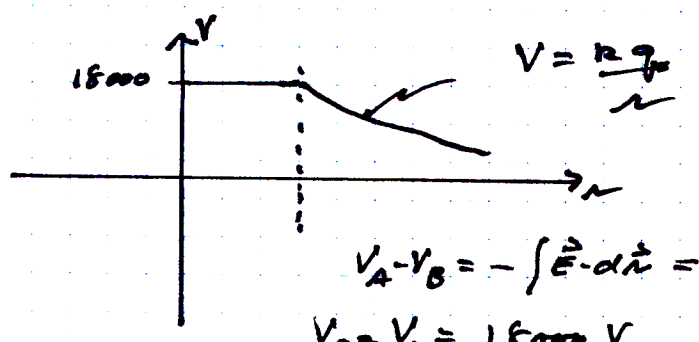
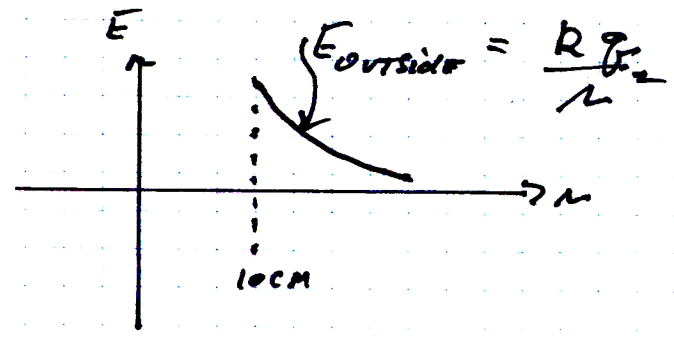
$$\Delta V = - \int \vec{E} \cdot d\vec{n}$$

USE GAUSS'S LAW FOR INSIDE THE SPHERE

$$\epsilon_0 \oint \vec{E} \cdot d\vec{A} = q_{\text{enclosed}}$$

USING THE DOTTED SURFACE

$$q_{\text{enc}} = 0 \quad E_{\text{inside}} = 0 \text{ SPHERE}$$



TWO SPHERES OF RADII'S 10 CM & 20 CM ARE INITIALLY ISOLATED FROM EACH OTHER. THE SMALLER 10 CM SPHERE HAS AN INITIAL VOLTAGE ON IT OF 90,000 V & THE 20 CM SPHERE HAS 0 VOLTS. THE SPHERES ARE THEN CONNECTED & YOU MUST DETERMINE THE FINAL VOLTAGE ON BOTH SPHERES.

INITIALLY $q_{20\text{cm}} = \frac{V_{\text{initial}}}{k} = 0$ SINCE $V_{\text{initial}} = 0$

& $q_{10\text{cm}} = \frac{90,000(0.1)}{9 \times 10^9} = 10^{-6} \text{ C}$

WHEN THE SPHERES ARE PUT TOGETHER

$$V_{10} = V_{20} \quad q_{10} + q_{20} = 1 \times 10^{-6}$$

$$\frac{k q_{10}}{0.1} = \frac{k (1 \times 10^{-6} - q_{10})}{0.2}$$

$$q_{10} = 0.33 \mu\text{C} \quad \& \quad q_{20} = 0.67 \mu\text{C}$$

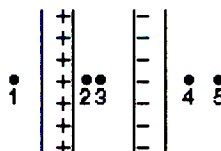
$$V_{10} = V_{20} = \frac{k q_{20}}{r} = \frac{9 \times 10^9 (.67 \times 10^{-6})}{0.2} = 30,000 \text{ V}$$

1. A total charge of 6.3×10^{-8} C is placed on a 2.7-cm radius isolated conducting sphere. The surface charge density is:
 - A) 3.7×10^{-7} C/m²
 - B) 6.9×10^{-6} C/m²
 - C) 2.5×10^{-4} C/m³
 - D) 7.6×10^{-4} C/m²
 - E) 7.6×10^{-4} C/m³

2. A point charge is placed at the center of a spherical Gaussian surface. The electric flux Φ_E is changed:
 - A) if the sphere is replaced by a cube of the same volume
 - B) if the sphere is replaced by a cube of one-tenth the volume
 - C) if the point charge is moved off center (but still inside the original sphere)
 - D) if the point charge is moved to just outside the sphere
 - E) if a second point charge is placed just outside the sphere

3. A conducting sphere of radius 0.01 m has a charge of 1.0×10^{-9} C deposited on it. The magnitude of the electric field in N/C just outside the surface of the sphere is:
 - A) zero
 - B) 450
 - C) 900
 - D) 4500
 - E) 90,000

4. Two large parallel plates carry charge of equal magnitude, one positive and the other negative, that is distributed uniformly over their inner surfaces. Rank the points 1 through 5 according to the magnitude of the electric field at the points, least to greatest.



- A) 2 and 3 tie, then 1, 4, and 5 tie
 B) 1, 4, and 5 tie, then 2 and 3 tie
 C) 1, 2, 3, 4, 5
 D) 2 and 3 tie, then 1 and 4 tie, then 5
 E) 5, 4, 3, 2, 1

5. Electric field lines:

- A) are trajectories of a test charge
 B) are vectors in the direction of the electric field
 C) cross each other in the region between two point charges
 D) form closed loops
 E) are none of the above

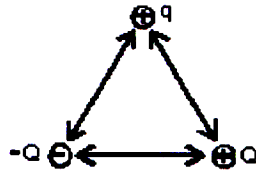
6. The electric field due to a uniform distribution of charge on a spherical shell is zero:

- A) everywhere
 B) nowhere
 C) only at the center of the shell
 D) only inside the shell
 E) only outside the shell

7. An electron traveling north enters a region where the electric field is uniform and points north. The electron:
- A) speeds up
 - B) slows down
 - C) veers east
 - D) veers west
 - E) continues with the same speed in the same direction
8. A point charge is placed in an electric field that varies with location. No force is exerted on this charge:
- A) at locations where the electric field is zero
 - B) at locations where the electric field strength is $1/(1.6 \times 10^{-19})$ N/C
 - C) if the charge is moving along a field line
 - D) if the charge is moving perpendicular to a field line
 - E) if the field is caused by an equal amount of positive and negative charge
9. The magnitude of the force on a 0.02 C point charge due to an electric field of 4000 N/C is:
- A) 80 N
 - B) 8×10^{-5} N
 - C) 8×10^{-3} N
 - D) 0.08 N
 - E) 2×10^{11} N
10. To make an uncharged object have a negative charge we must:
- A) add some atoms
 - B) remove some atoms
 - C) add some electrons
 - D) remove some electrons
 - E) write down a negative sign

11. A small object has charge Q . Charge q is removed from it and placed on a second small object. The two objects are placed 1 m apart. For the force that each object exerts on the other to be a maximum, q should be:
- A) $2Q$
 - B) Q
 - C) $Q/2$
 - D) $Q/4$
 - E) 0
12. A 5.0-coulomb charge is 10 m from a -2.0-coulomb charge. The electrostatic force is on the positive charge is:
- A) 9.0×10^9 N toward the negative charge
 - B) none of these
 - C) 9.0×10^8 N toward the negative charge
 - D) 9.0×10^9 N away from the negative charge
 - E) 9.0×10^8 N away from the negative charge
13. Charges q_1 and q_2 are on the x axis, with q_1 at $x = a$ and q_2 at $x = 2a$. For the net force on a another charge at the origin to be zero q_1 and q_2 must be related by $q_2 =$:
- A) $2q_1$
 - B) $4q_1$
 - C) $-2q_1$
 - D) $-4q_1$
 - E) $-q_1/4$

14. Charges Q , $-Q$, and q are placed at the vertices of an equilateral triangle as shown. The total force exerted on the charge q is:



- A) toward charge Q
- B) toward charge $-Q$
- C) away from charge Q
- D) at right angles to the line joining Q and $-Q$
- E) parallel to the line joining Q and $-Q$

Answer Key

1. B
2. D
3. ~~C~~ E
4. B
5. E
6. D
7. B
8. A
9. ~~B~~ A
10. C
11. C
12. C
13. D
14. E