Electric Forces and Fields

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Summary - This unit covered 6 major topics - Electric Charges and Coulomb's Law; Electric Fields, Charge Distribution; Drawing Electric Field Lines; and Motion of a Charge in an Electric Field. Electric forces are both fundamental to our life by keeping atoms together, and vastly used, governing our everyday processes.

Important formula:

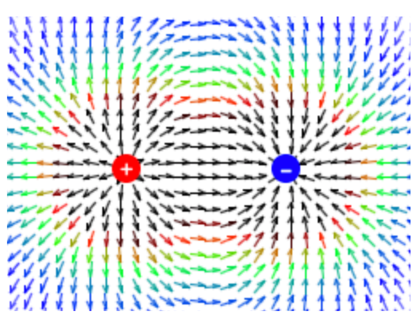
- $\vec{F} = \frac{1}{4\pi\epsilon} \cdot \frac{q_1 q_2}{r^2}$
- F = QE

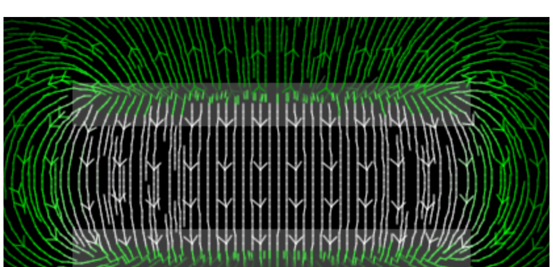
Key terms:

- Conductor - material that allows charges to move about freely within it
- Insulator - material that holds electrons securely within their atomic orbits
- Coulomb's law - calculates the electrostatic force vector between two charged particles
- electric field - physical phenomenon created by a charge; it "transmits" a force between two charge

Major topics

1. Electric Charges and Coulomb's Law:
    a. like charges repel, opposite charges attract
    b. Conductors are metals (copper, gold, aluminum, etc.), which conduct charges easily
    c. Non-conductors, or insulators such as rubber, plastic, or wood, don't easily conduct charge
    d. "Charging by conduction" occurs when a charged conductor (metal) touches another conductor with a different amount of charge: some free electrons pass from one object to the other.
    e. "Charging by induction" occurs when a charged object is brought near a neutral conductor. Charges in the conductor become polarized in response to the nearby rod.
    f. Coulomb's law describes the force of attraction or repulsion between two charges
2. Electric Fields, Charge Distribution
    a. Two opposite charges





   b. Parallel plates
   c. If electric charge is distributed continuously over a larger region of space, we'll usually need a calculus-based strategy to identify the electric field.
3. Drawing Electric Field Lines
   a. The number of lines starting on a positive charge or ending on a negative charge is proportional to the magnitude of the charge.
   b. The closer the lines are together in a region, the stronger the electric field is in that region.
   c. Field lines indicate the direction of the electric field, because the E field at any position points in a direction tangent to the field line at that point.

FRQs

Questions:

1. A charge –Q and mass m is fired into a cavity bounded by two metallic plates of length L. The plates are d units apart. The charge initially moves along the cavity's central x-axis with velocity (see sketch). Assuming gravity acts downward:
   a. Q will move straight along the x-axis even though gravity is acting upon the mass. An E-fld is placed between the plates to counteract gravity. In what direction must that field be? Also, what kind of charge must exist on the top and bottom plate to effect that field?
   b. What must be the electric field magnitude to effect this straight-line motion?
   c. Given this E-fld, if this experiment had been carried out in space
      i. What path would the charge take after the firing?
      ii. Given the electric field as calculated, what velocity would the charge require to just barely clear the cavity without crashing into its wall?
2. Two point charges, and C12, are fixed in place on the x-axis at positions Xl = —1.00 m and x2 = +0.50 m, respectively. Charge has a value of +2.0 nC. Values of electric potential are illustrated by the given equipotentials in the diagram shown above, which is drawn to scale.
   a. Calculate the value of qi .
   b. At point C on the diagram, draw a Vector representing the direction of the electric field at that point.
   c. Calculate the approximate magnitude of the electric field strength at point D on the diagram.

d. The equipotential labeled 0 V is the cross section of a nearly spherical surface. Calculate the electric flux for this surface.
e. A proton is placed at point A and then released from rest.
    i. Calculate the work done by the electric field on the proton as it moves from point A to point E.
    ii. Calculate the speed of the proton when it reaches point E.
f. An electron is released from rest at point B. Which of the following indicates the direction of the initial acceleration, if any, of the electron? Justify your answer.

3. Two students stand 1.5 meters apart from each other. One has long hair, and in recent brushing he removed 5,000 electrons from his body. The other student has short hair, and brushing her hair removed 1,300 electrons.
    a. What is the net charge of each student?
    b. Are they electrically attracted or repelled?
    c. What is the magnitude of the electric force between them?

Answers:

1. a)Downwards. The electric field must counteract the force of gravity and the force of an electric field runs opposite of a negative charge.

b)

ΣF_x:

$Q|E| - mg = ma$ (= 0)

$|E| = \frac{mg}{Q}$

c) i)The particle would follow an upwards trajectory

ii)→

ΣF_y:

$Q|E| = ma_y$

$\Rightarrow Q(mg/Q) = ma_y$

$\Rightarrow a_y = g$

$y_2 = y_1 + v_{1,y}\Delta t + \frac{1}{2}a_y(\Delta t)^2$

$(\Delta t) = (d/g)^{1/2}$

$x_2 = x_1 + v_{1x}\Delta t + \frac{1}{2}a(\Delta t)^2$

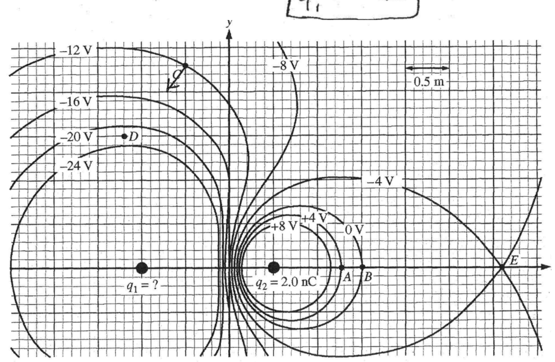
$L = v_0 \Delta t$

$v_0 = L/\Delta t$

$= L/(d/g)^{1/2} = L(g/d)^{1/2}$

2. a) $\frac{kq_2}{(1m)} - \frac{kq_1}{(2.5m)} = 0$ $\quad \frac{k(2E\text{-}9)}{1} = \frac{kq_1}{2.5}$ $\quad \boxed{q_1 = -5nC}$

b)



c)

$E = \frac{dV}{dx} = \frac{24-20}{1.4-1.6} = \boxed{20\ V/m}$

d)

$$\phi_E = \oint E \cdot dA = \frac{Q}{\epsilon_0}$$

$$Q = 2nC$$

$$\phi_E = \frac{(2E\text{-}9\ C)}{(8.85E\text{-}12)} = \boxed{225.99\ \frac{N\cdot m^2}{C}}$$

e) i) $W = q\Delta V = (1.6E\text{-}19)(-4-4) = \boxed{+1.28E\text{-}18\ J}$

ii)

$$W = \Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \quad v_i = 0$$

$$1.28\times10^{-18} = \frac{1}{2}m\cdot v_f^2$$

$$\boxed{V = 39152.7\ m/s}$$

f) left. Electric field lines are always perpendicular to voltage lines and go from high to low voltage. That means the E. Field points to the right at point B, and electrons accelerate opposite the direction of the field.

3. a) The first student has lost electrons, and so has a net positive charge. To identify the amount of that charge:

$$q = \frac{5000\ electrons}{1} \cdot \frac{-1.602e-19C}{1\ electron}$$

$$q = 8.01e - 16C$$

b) The other student, using a similar calculation, has a charge of 2.08e-16 C, and because they are both positively charged, they experience an electrical force of repulsion.

c)

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

$$F = (8.99e9)\frac{(8.01e-16C)(2.08e-16C)}{(1.5m)^2}$$

F = 6.66 e -22 N