Lab: AP Review Sheet

Chapter 23: Electric Fields

AP Physics

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Background: The electromagnetic force between charged particles is one of the fundamental forces of nature. One manifestation of the electromagnetic force is the electric force. Coulomb's law is the fundamental law governing the electric force between any two charged particles. This chapter describes how an electric field associated with a charge distribution can affect other charged particles.

Vocabulary:

electrical conductor: a material in which some of the electrons are free electrons that are not bound to atoms and can move relatively freely through the material

electrical insulator: material in which all electrons are bound to atoms and cannot move freely through the material

semiconductor: material whose electrical properties are between those of insulators and those of conductors

induction: charged object causes electrons in the neutral conductor to migrate away from the charged object, leaving an effective positive charge in the side of the conductor near the charged object

ground: reservoir that can accept or provide electrons freely with negligible effect on its electrical characteristics

point charge: charged particle of zero size

electric field: field existing in region of space around a charged object, called the **source charge**. When another charged object, the **test charge**, enters this electric field, and **electric force** acts on it.

Major Topics:

- Properties of Electric Charges
- Charging Objects by Induction
- Coulomb's Law
- Electric Fields

Formulae:

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

$$\vec{F}_e = k_e \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

$$\vec{E} \equiv \frac{\vec{F}_e}{q_0}$$

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

$$\vec{E} = k_e \sum_i \frac{q_i}{r_i^2} \hat{r}_i$$

$$\vec{E} = k_e \int \frac{dq}{r^2} \hat{r}$$

Charge Density Formulae:

$$\rho \equiv \frac{Q}{V}$$

$$\sigma \equiv \frac{Q}{A}$$

$$\lambda \equiv \frac{Q}{\ell}$$

$$dq = \rho dV$$

$$dq = \sigma dA$$

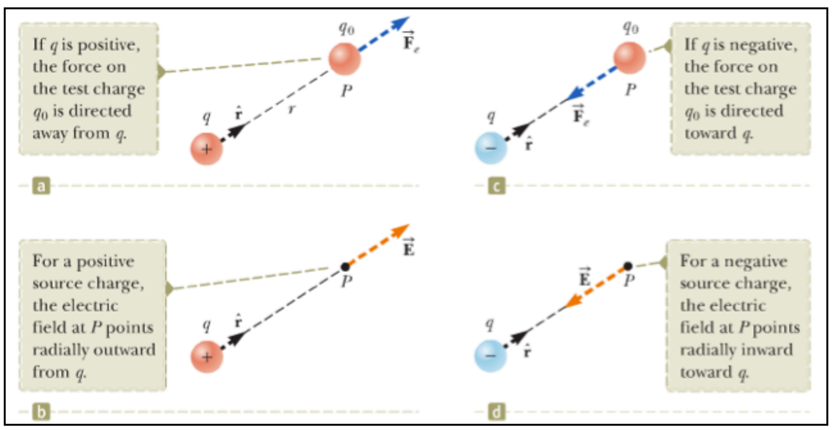
$$dq = \lambda d\ell$$

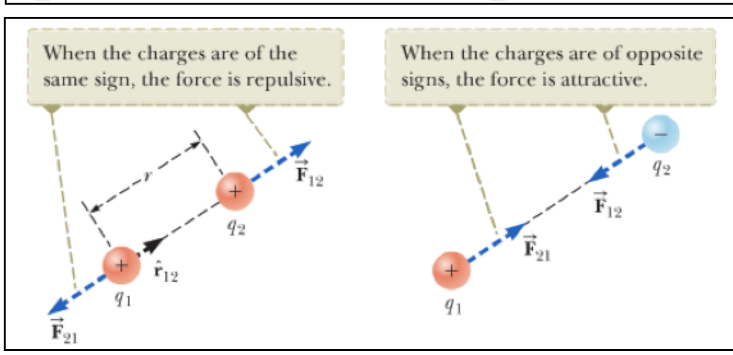
Diagrams:

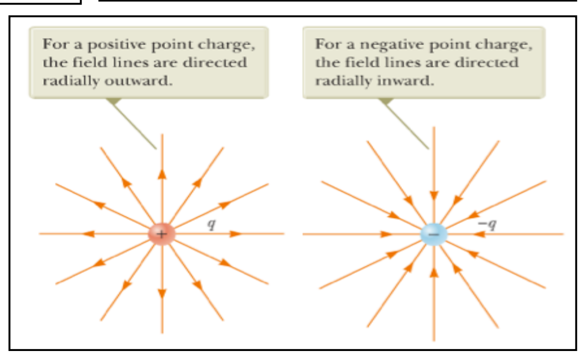
Electric field, test charge, and point charge (directly left)

Coulomb's law (down and left)

Electric field lines (below)







Problems

1. [Easy]

A 7.50-nC point charge is located 1.80 m from a 4.20-nC point charge. (a) Find the magnitude of the electric force that one particle exerts on the other. (b) Is the force attractive or repulsive?

SOLUTION:

(a)

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

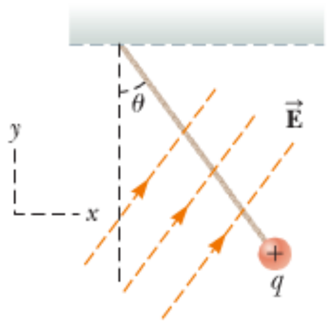
$$F = \left(8.99 \times 10^9 N \cdot m^2/C^2\right)\left(\frac{(7.50 \times 10^{-9} C)(4.20 \times 10^{-9} C)}{(1.80 m)^2}\right)$$

$$\boxed{F = 8.74 \times 10^{-8} N}$$

(b)

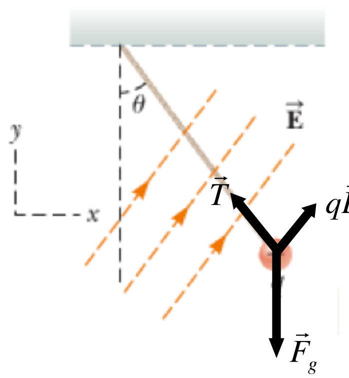
The force is repulsive because the point charges are both positively charged. Opposite charges attract each other, while charges of the same sign repulse one another.

Problems (cont'd)
2. [Medium]



A charged cork ball of mass 1.00 g is suspended on a light string in the presence of a uniform electric field. When $\vec{E} = \left(3.00\hat{i} + 5.00\hat{j}\right) \times 10^5 N/C$, the ball is in equilibrium at $\theta = 37.0^\circ$. Find (a) the charge on the ball and (b) the tension in the string.

SOLUTION:



Begin with force analysis.

$$\sum \vec{F} = \vec{T} + q\vec{E} + \vec{F}_g = 0$$

We are given: $E_x = 3.00 \times 10^5 N/C$ and $E_y = 5.00 \times 10^5 N/C$

Applying Newton's second law:

$$\sum F_x = qE_x - T\sin 37.0^\circ = 0 \qquad \text{Eq. 1}$$
$$\sum F_y = qEy - T\cos 37.0^\circ - mg = 0 \qquad \text{Eq. 2}$$

(a) Substitute T from Eq. 1 into Eq. 2

$$q = \frac{mg}{E_y + \dfrac{E_x}{\tan 37.0^\circ}} = \frac{(1.00 \times 10^{-3} kg)(9.80 m/s^2)}{5.00 \times 10^5 N/C + \dfrac{3.00 \times 10^5 N/C}{\tan 37.0^\circ}}$$

$$\boxed{q = 1.09 \times 10^{-8} C}$$

(b) Using solved q, substitute into Eq. 1 to find tension:

$$T = \frac{qE_x}{\sin 37.0^\circ} = \boxed{5.44 \times 10^{-3} N}$$

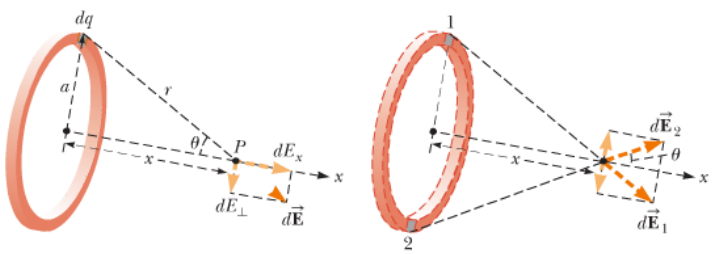
Problems (cont'd)

3. [Hard]

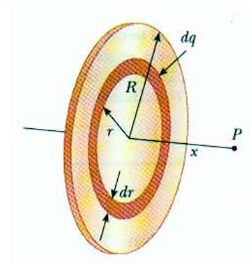
(a) A ring of radius *a* carries a uniformly distributed positive total charge *Q*. Calculate the electric field due to the ring at a point *P* lying a distance *x* from its center along the central axis perpendicular to the plane of the ring.

(b) Use answer from part (a) to calculate the electric field at a point *P* that lies along the central perpendicular axis of a disk and a distance *x* from the center of the disk. The disk is a uniformly charged disk of radius R that has a uniform surface charge density σ.

(a)



(b)



SOLUTION:

(a) Evaluate parallel component of an electric field contribution from a segment of charge *dq* on ring (Note: all dE_y's cancel each other out.):

$$dE_x = k_e \frac{dq}{r^2}\cos\theta = k_e \frac{dq}{a^2 + x^2}\cos\theta \qquad \text{Eq. 1}$$

From the geometry in the figure above, evaluate $\cos\theta$:

$$\cos\theta = \frac{x}{r} = \frac{x}{\left(a^2 + x^2\right)^{1/2}} \qquad \text{Eq. 2}$$

Substitute Eq. 2 into Eq. 1.

$$E_x = \int \frac{k_e x}{\left(a^2 + x^2\right)^{3/2}} dq = \frac{k_e x}{\left(a^2 + x^2\right)^{3/2}} \int dq$$

$$\boxed{E = \frac{k_e x}{\left(a^2 + x^2\right)^{3/2}} Q}$$

(b) Find the amount of charge *dq* on a ring of radius *r* and width *dr*:

$$dq = \sigma dA = \sigma(2\pi r dr) = 2\pi\sigma r dr$$

Use the above result combined with answer (a) to find field due to the ring:

$$dE_x = \frac{k_e x}{\left(r^2 + x^2\right)^{3/2}} (2\pi\sigma r dr)$$

To obtain total field at *P*, integrate this expression over the limits *r* = 0 to *r* = R (*x* is constant):

$$E_x = k_e x\pi\sigma \int_0^R \frac{2r dr}{\left(r^2 + x^2\right)^{3/2}} = k_e x\pi\sigma \int_0^R \left(r^2 + x^2\right)^{-3/2} d\left(r^2\right) = k_e x\pi\sigma \left[\frac{\left(r^2 + x^2\right)^{-1/2}}{-1/2}\right]_0^R$$

$$\boxed{E = 2\pi k_e \sigma \left[1 - \frac{x}{\left(R^2 + x^2\right)^{1/2}}\right]}$$