PHYSICS II

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Problem Solutions for Coulomb's Law, Electrostatic Potential, Electric Charges & Electric Fields

Problem 1

A helium nucleus has charge $+2e$, and a neon nucleus $+10e$, where e is the quantum of charge, 1.60×10^{-19} C. Find the repulsive force exerted on one by the other when they are 3.0 nanometers (1 nm $= 10^{-9}$ m) apart. Assume the system to be in vacuum.

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$$F_E = k\frac{qq'}{r^2} = (9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})\frac{(2)(10)(1.6 \times 10^{-19}\ \mathrm{C})^2}{(3.0 \times 10^{-9}\ \mathrm{m})^2} = 5.1 \times 10^{-10}\ \mathrm{N} = 0.51\ \mathrm{nN}$$

Problem 2

In the Bohr model of the hydrogen atom, an electron ($q = -e$) circles a proton ($q' = e$) in an orbit of radius 5.3×10^{-11} m. The attraction of the proton for the electron furnishes the centripetal force needed to hold the electron in orbit. Find (*a*) the force of electrical attraction between the particles and (*b*) the electron's speed. The electron mass is 9.1×10^{-31} kg.

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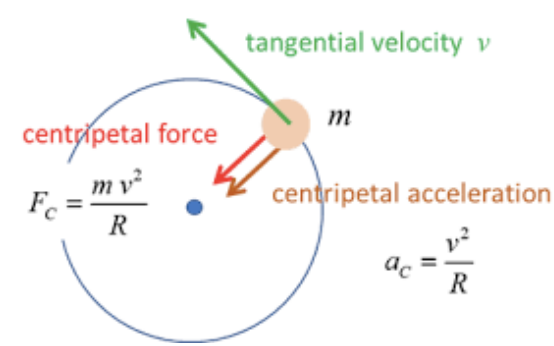
(*a*) $$F_E = k\frac{qq'}{r^2} = (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{(1.6 \times 10^{-19}\ \text{C})^2}{(5.3 \times 10^{-11}\ \text{m})^2} = 8.2 \times 10^{-8}\ \text{N} = 82\ \text{nN}$$

(*b*) The force found in (*a*) is the centripetal force, mv^2/r. Therefore,

$$8.2 \times 10^{-8}\ \text{N} = \frac{mv^2}{r}$$

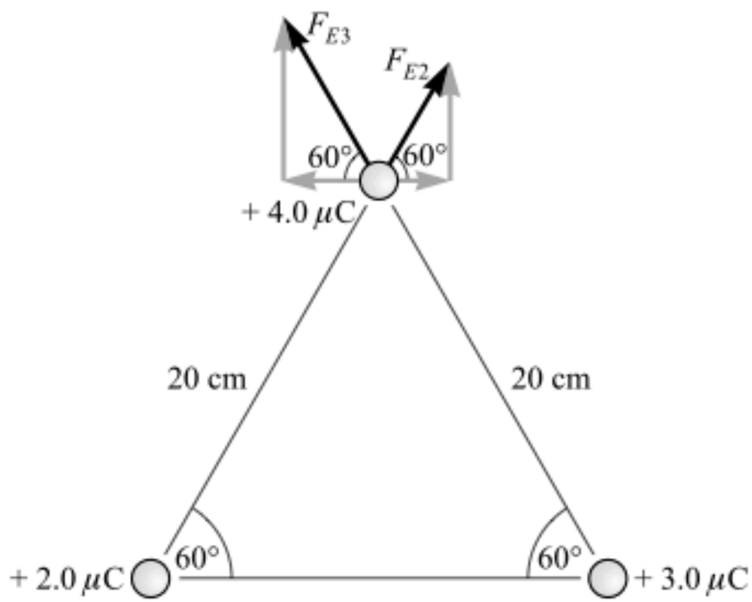
from which

$$v = \sqrt{\frac{(8.2 \times 10^{-8}\ \text{N})(r)}{m}} = \sqrt{\frac{(8.2 \times 10^{-8}\ \text{N})(5.3 \times 10^{-11}\ \text{m})}{9.1 \times 10^{-31}\ \text{kg}}} = 2.2 \times 10^6\ \text{m/s}$$

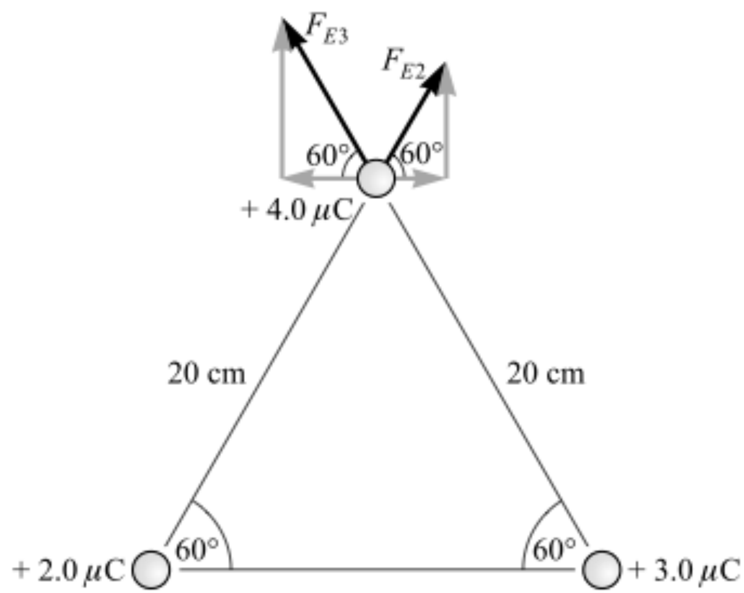


Problem 3

The charges shown in figure are stationary. Find the force on the 4.0 μC charge due to the other two.



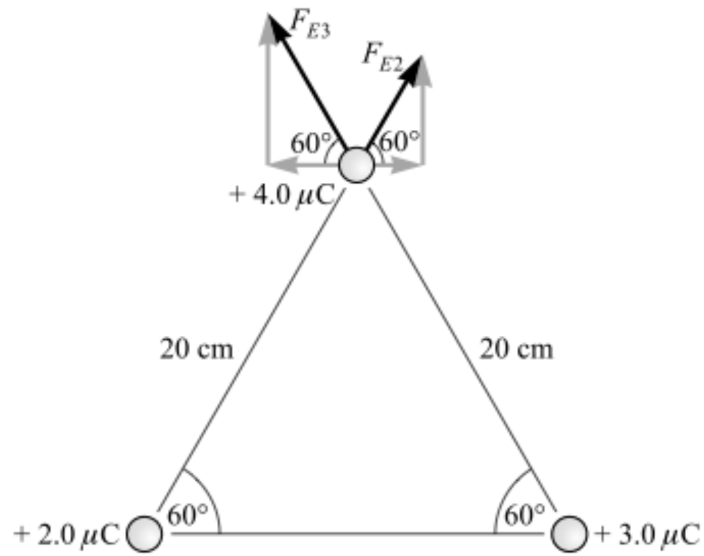
Problem 3



$$F_{E2} = k\frac{qq'}{r^2} = (9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})\frac{(2.0 \times 10^{-6}\ \mathrm{C})(4.0 \times 10^{-6}\ \mathrm{C})}{(0.20\ \mathrm{m})^2} = 1.8\ \mathrm{N}$$

$$F_{E3} = k\frac{qq'}{r^2} = (9.0 \times 10^9\ \mathrm{N \cdot m^2/C^2})\frac{(3.0 \times 10^{-6}\ \mathrm{C})(4.0 \times 10^{-6}\ \mathrm{C})}{(0.20\ \mathrm{m})^2} = 2.7\ \mathrm{N}$$

Problem 3



$$F_{Ex} = F_{E2}\cos 60^\circ - F_{E3}\cos 60^\circ = (1.8 - 2.7)(0.50)\,\mathrm{N} = -0.45\,\mathrm{N}$$

$$F_{Ey} = F_{E2}\sin 60^\circ + F_{E3}\sin 60^\circ = (1.8 + 2.7)(0.866)\,\mathrm{N} = 3.9\,\mathrm{N}$$

$$F_E = \sqrt{F_{Ex}^2 + F_{Ey}^2} = \sqrt{(0.45)^2 + (3.9)^2}\,\mathrm{N} = 3.9\,\mathrm{N}$$

The resultant makes an angle of $\tan^{-1}(0.45/3.9) = 7^\circ$ with the positive y-axis, that is, $\theta = 97^\circ$.

Problem 4

Compute (*a*) the electric field E in air at a distance of 30 cm from a point charge $q_1 = 5.0 \times 10^{-9}$ C, (*b*) the force on a charge $q_2 = 4.0 \times 10^{-10}$ C placed 30 cm from q_1, and (*c*) the force on a charge $q_3 = -4.0 \times 10^{-10}$ C placed 30 cm from q_1 (in the absence of q_2).

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(*a*)
$$E = k\frac{q_1}{r^2} = (9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)\frac{5.0 \times 10^{-9}\ \text{C}}{(0.30\ \text{m})^2} = 0.50\ \text{kN/C}$$

directed away from q_1.

(*b*)
$$F_E = Eq_2 = (500\ \text{N/C})(4.0 \times 10^{-10}\ \text{C}) = 2.0 \times 10^{-7}\ \text{N} = 0.20\ \mu\text{N}$$

directed away from q_1.

(*c*)
$$F_E = Eq_3 = (500\ \text{N/C})(-4.0 \times 10^{-10}\ \text{C}) = -0.20\ \mu\text{N}$$

This force is directed toward q_1.

Problem 5

An electric field is most directly related to:

A. the momentum of a test charge
B. the kinetic energy of a test charge
C. the potential energy of a test charge
D. the force acting on a test charge
E. the charge carried by a test charge

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the force acting on a test charge
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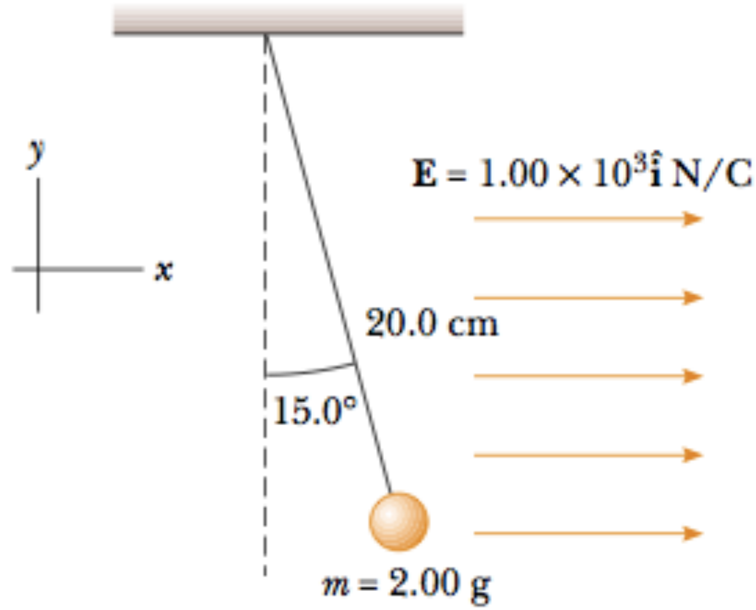
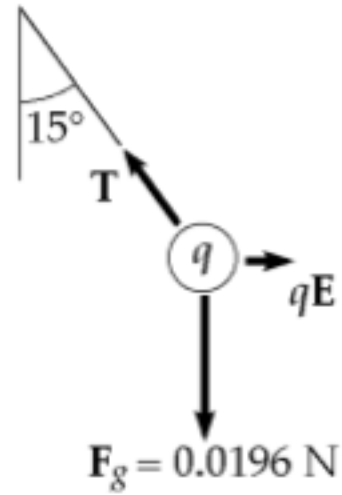
Problem 6

A small, 2.00-g plastic ball is suspended by a 20.0-cm-long string in a uniform electric field as shown in Figure P23.54. If the ball is in equilibrium when the string makes a 15.0° angle with the vertical, what is the net charge on the ball?



Problem 6



From the free-body diagram shown,

$\sum F_y = 0$: $\quad T\cos 15.0° = 1.96 \times 10^{-2}$ N.

So $\quad T = 2.03 \times 10^{-2}$ N.

From $\sum F_x = 0$, we have $\quad qE = T\sin 15.0°$

or $$q = \frac{T\sin 15.0°}{E} = \frac{(2.03 \times 10^{-2}\ \text{N})\sin 15.0°}{1.00 \times 10^{3}\ \text{N/C}} = 5.25 \times 10^{-6}\ \text{C} = \boxed{5.25\ \mu\text{C}}.$$

Problem 7

A uniformly charged, straight filament 7.00 m in length has a total positive charge of 2.00 μC. An uncharged cardboard cylinder 2.00 cm in length and 10.0 cm in radius surrounds the filament at its center, with the filament as the axis of the cylinder. Using reasonable approximations, find (a) the electric field at the surface of the cylinder and (b) the total electric flux through the cylinder.

Problem 7

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(a) $$E = \frac{2k_e\lambda}{r} = \frac{2\left(8.99\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left[\left(2.00\times10^{-6}\ \text{C}\right)/7.00\ \text{m}\right]}{0.100\ \text{m}}$$

$$E = \boxed{51.4\ \text{kN/C, radially outward}}$$

(b) $$\Phi_E = EA\cos\theta = E(2\pi r\ell)\cos 0^\circ$$

$$\Phi_E = \left(5.14\times10^{4}\ \text{N/C}\right)2\pi(0.100\ \text{m})(0.020\,0\ \text{m})(1.00) = \boxed{646\ \text{N}\cdot\text{m}^2/\text{C}}$$

Problem 8

On a clear, sunny day, a vertical electric field of about 130 N/C points down over flat ground. What is the surface charge density on the ground for these conditions?

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From Gauss's Law, $EA = \dfrac{Q}{\epsilon_0}$

$$\sigma = \frac{Q}{A} = \epsilon_0 E = \left(8.85 \times 10^{-12}\right)(-130) = -1.15 \times 10^{-9}\ \text{C/m}^2 = \boxed{-1.15\ \text{nC/m}^2}$$

Problem 9

A square plate of copper with 50.0-cm sides has no net charge and is placed in a region of uniform electric field of 80.0 kN/C directed perpendicularly to the plate. Find (a) the charge density of each face of the plate and (b) the total charge on each face.

Problem 9

A square plate of copper with 50.0-cm sides has no net charge and is placed in a region of uniform electric field of 80.0 kN/C directed perpendicularly to the plate. Find (a) the charge density of each face of the plate and (b) the total charge on each face.

(a) $E = \dfrac{\sigma}{\epsilon_0}$ $\qquad \sigma = \left(8.00\times10^{4}\right)\left(8.85\times10^{-12}\right) = 7.08\times10^{-7}\ \text{C/m}^2$

$\sigma = \boxed{708\ \text{nC/m}^2}$, positive on one face and negative on the other.

(b) $\sigma = \dfrac{Q}{A}$ $\qquad Q = \sigma A = \left(7.08\times10^{-7}\right)(0.500)^2\ \text{C}$

$Q = 1.77\times10^{-7}\ \text{C} = \boxed{177\ \text{nC}}$, positive on one face and negative on the other.

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What potential difference is needed to stop an electron having an initial speed of 4.20 X 105 m/s?

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$$W = \Delta K = -q\Delta V$$

$$0 - \frac{1}{2}\left(9.11\times10^{-31}\ \text{kg}\right)\left(4.20\times10^{5}\ \text{m/s}\right)^2 = -\left(-1.60\times10^{-19}\ \text{C}\right)\Delta V$$

From which, $\Delta V = \boxed{-0.502\ \text{V}}$.

References for this lecture: