

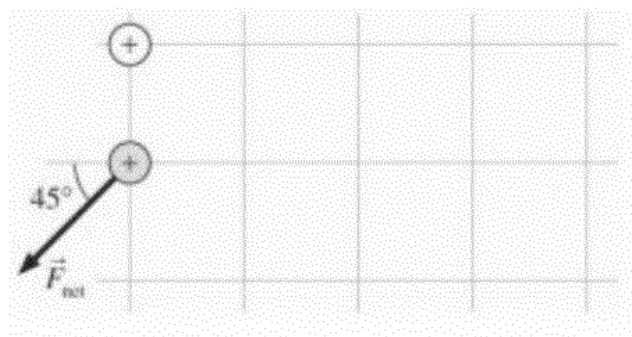
Physics 223&: Engineering Physics III Midterm

The purpose of the following questions is meant to assess the student's understanding of and skills in applying the following concepts:

- Charges & Forces: the charge model, electric insulators & conductors, Coulomb's Law and the electric force
- The Electric Field: the electric field of a due to multiple point charges, the parallel-plate capacitor, motion of a charged particle in an electric field
- Gauss's Law: symmetry, electric flux
- The Electric Potential: the potential energy of point charges, the electric potential inside a parallel-plate capacitor
- Potential & Field: finding the electric field from the potential

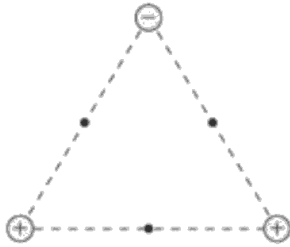
During this exam you are allowed access to both the textbook and your notes. Good luck.

- 1) One end of a **neutral** rod is brought into close proximity to, but does not touch, an object with charge $Q \neq 0$.
 - a) Draw the final charge distribution of the rod if it is made of a **conducting** material such as copper? Describe the motion of the charges before getting there.
 - b) Draw the final charge distribution of the rod if it is made of an **insulating** material such as rubber? Describe the motion of the charges before getting there.
 - c) Draw the final charge distribution of the rod after it is been pulled away from the charged object. Does this depend on if the rod is a conductor or an insulator?
 - d) The charged object is said to _____ the rod?
 - a. Charge
 - b. Electrify
 - c. Polarize
 - d. Magnetize
- 2) The gray positive charge experiences a net force due to two other charges: the +1 charge that is seen and a +4 charge that is not seen. Add the +4 charge to the figure at the correct position and explain why you chose that position.

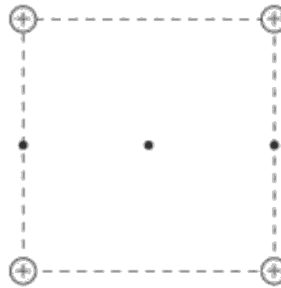


- 3) For each figure, draw and label the net electric field vector \vec{E}_{net} at each of the points marked with a dot or, if appropriate, label the dot $\vec{E}_{\text{net}} = \vec{0}$. The lengths of your vectors should indicate the magnitude of \vec{E} at each point.

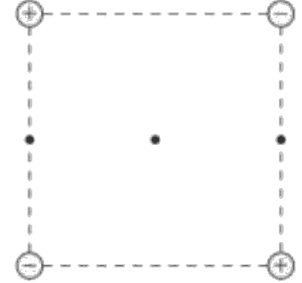
a.



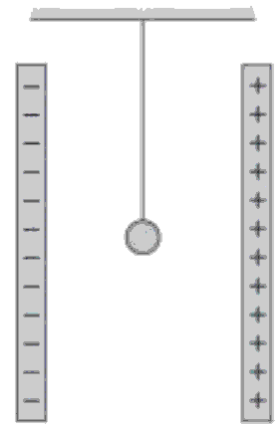
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c.

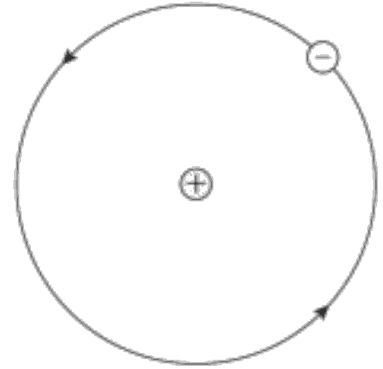


- 4) A ball hangs from a thread between two vertical capacitor plates. Initially, the ball hangs straight down. The capacitor plates are charged as shown, then **the ball is given a small negative charge**. The ball moves to one side, but not enough to touch a capacitor plate.
- Draw the ball and thread in the ball's new equilibrium position.
 - In the space below, draw a free-body diagram of the ball when in its new position.



- 5) Ionized Helium He^+ has two protons and two neutrons in its nucleus $Q_n = 2e$ while only a single electron orbiting $Q_e = -e$. The Bohr model of the atom states that electrons can only exist at certain distances from the nucleus in order to “quantize” its electrostatic potential energy. These distances form concentric circular “rails” upon which the electrons travel, otherwise known as *electron shells* or *energy levels*, with the “lowest energy level” being closest to the nucleus.

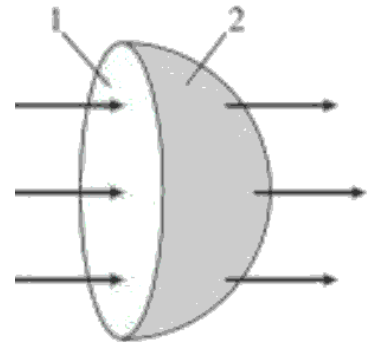
Draw and label the following vectors on a diagram of the He^+ ion with the electron in the lowest energy level: the electron's velocity \vec{v} and acceleration \vec{a} , the net force \vec{F} on the electron, and the electric field \vec{E} at the position of the electron. **Note: Don't worry about magnitude and length, just focus on direction.**



- 6) Consider a uniform electric field $\vec{E} = E\hat{x}$ and a hemisphere of radius R oriented such that the area vector of the base points in the $-\hat{x}$ direction.
- What is the electric flux through the base of the hemisphere?
 - What is the electric flux through the dome of the hemisphere? Note: for a hemisphere, the area element $d\vec{A}$ is such that

$$d\vec{A} = R^2 \sin(\theta) [\sin(\theta) \cos(\varphi) \hat{x} + \sin(\theta) \sin(\varphi) \hat{y} + \cos(\theta) \hat{z}] d\theta d\varphi.$$

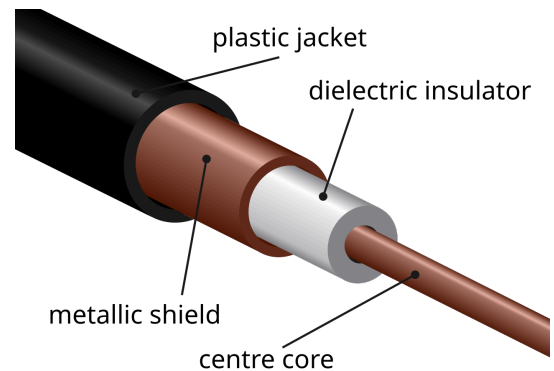
where $0 \leq \theta \leq \pi$ and $-\frac{\pi}{2} \leq \varphi \leq \frac{\pi}{2}$. *Hint:* $\int_0^\pi \sin^2(\theta) d\theta = \frac{\pi}{2}$.



- What is the electric flux through the entire hemisphere?

- 7) Consider a coaxial cable of length L with a conducting hollow core of radius R_c with uniform surface charge density η and an outer conducting shield of radius $R_s > R_c$ with uniform surface charge density $-\eta$. **Note: the space between the core and the shield is empty.**

- a) What is the electric flux Φ_i through a Gaussian cylinder of radius $R_G < R_c$ and length $L_G < L$ that is coaxial with the cable?



- a) What is the electric flux Φ_b through a Gaussian cylinder of radius $R_c < R_G < R_s$ and length $L_G < L$ that is coaxial with the cable?
- b) What is the electric flux Φ_o through a Gaussian cylinder of radius $R_s < R_G$ and length $L_G < L$ that is coaxial with the cable?
- c) Graph the electric flux through a Gaussian cylinder of radius $R_c < R_G < R_s$ that is coaxial with the cable as its length L_G increases from $0L$ to $2L$.
- 8) Consider a ring of radius R with a total charge $Q > 0$, and an object with mass m and charge $q > 0$ at a distance d_0 along the central axis of the ring moving with velocity $\vec{v} = -v\hat{d}$ along the axis toward the ring. The electric field $\vec{E}(d)$ at a point on the central axis at a distance d away from the center of the ring is given by

$$\vec{E}(d) = \frac{1}{4\pi\epsilon_0} \frac{Qd}{(d^2 + R^2)^{3/2}} \hat{d}.$$

- a) What is the work done by the electric force on the object as it moves from its initial point to the center of the ring?
- b) What is the change in potential energy of the object between its initial position and the center of the ring?
- c) What initial speed does the object need to have in order to come to rest at the center of the ring?
Hint: The electric force conserves mechanical energy.
- 9) Given two atoms separated by a great distance, they will naturally move toward each other due to the electro-static attraction between the electrons and the protons. At some point though, the electro-static repulsion between the electrons and between the protons becomes stronger. This competition results in an optimal distance between the atoms known as the *bond length*. For two Hydrogen atoms, known as *molecular Hydrogen* H_2 , this optimal distance is 74 pm (1 pm = 1 picometer = 10^{-12} m).

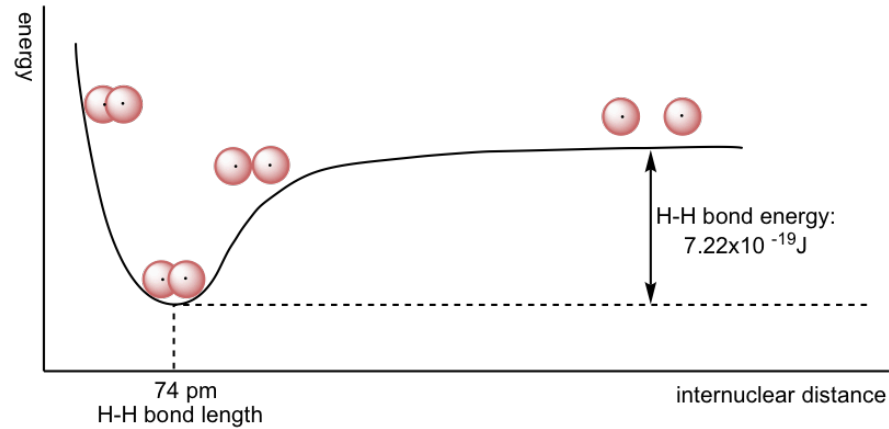
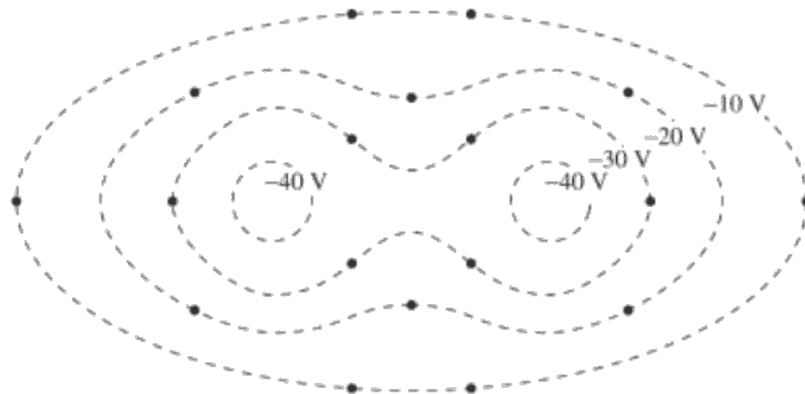


Figure 2: The dependence of molecular Hydrogen's potential energy on the separation distance results in an optimal distance of 74 pm.

- a) Is the electric potential at the location of each Hydrogen atom greater than, less than, or equal to the electric potential around it?
 - b) What is the expression for the electric potential at a point far away, but not infinitely so, from a H_2 molecule?
- 10) The figure below shows the equipotential lines for some hidden distribution of charge.



- a) Draw the electric field vectors at the dots on this contour map. The length of each vector should be proportional to the field strength at that point.
- b) Rank the strength of the electric field at [this position] in [this direction]