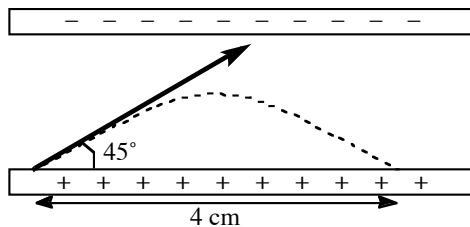


Problem Session

Motion of electric charges in a uniform electric field

- A proton moves at 4.50×10^5 m/s in the horizontal direction. It enters a uniform vertical electric field with a magnitude of 9.60×10^3 N/C. Ignoring any gravitational effects, find
 - the time interval required for the proton to travel 5.00 cm horizontally,
 - its vertical displacement during the time interval in which it travels 5.00 cm horizontally, and
 - the horizontal and vertical components of its velocity after it has traveled 5.00 cm horizontally.
- An electron is launched at a 45° angle and a speed 5.0×10^6 m/s from a positive conducting plate in the following figure. The electron touches the positive plate again 4 cm away.

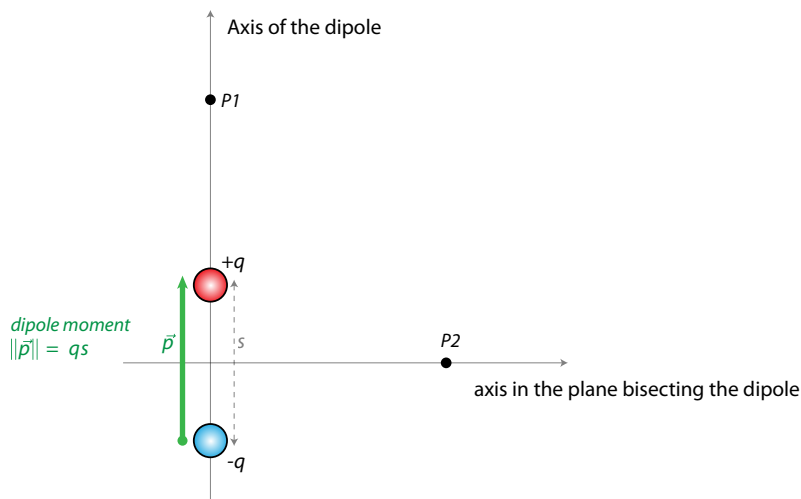


- What is the electric field strength between the conducting plates?
- What is the minimum spacing between the plates?

Electric Dipoles

3. **REVIEW:**

- Calculate the electric field of the following dipole for the point $P1$ a distance r from the center of the dipole along its axis.
- Calculate the electric field at the point $P2$ a distance r from the center of the dipole on the axis in the plane bisecting the dipole.
- Rewrite the fields at $P1$ and $P2$ calculated above assuming that $r \gg s$.



4. A point charge Q is a distance r from the center of a dipole consisting of charges $\pm q$ separated by a distance s . The charge is located in the plane that bisects the dipole. At this instant, assuming $r \gg s$, what are
- the force on the dipole? *Hint: Remember Newton's third law.*
 - the torque on the dipole? *Hint: Find the field due to the proton in the center of the dipole, then use $\vec{\tau} = \vec{p} \times \vec{E}$.*
5. An ammonia molecule (NH_3) has a permanent electric dipole moment 5×10^{-30} Cm. A proton is 2.0 nm from the molecule in the plane that bisects the dipole. What is the electric force of the molecule on the proton? *Hint: the size of a molecule is ≈ 0.1 nm, you can therefore use $r \gg s$.*
6. The permanent electric dipole moment of a water molecule (H_2O) is 6.2×10^{-30} Cm. What is the maximum possible torque on a water molecule in a 5.0×10^8 N/C electric field? *Hint: Remember that torque is $\vec{\tau} = \vec{p} \times \vec{E}$ and use the approximation found in problem 2c).*

Answers

- 111 ns
 - 5.68 mm
 - $v_x = 4.5 \times 10^5$ m/s, $v_y = 1.02 \times 10^5$ m/s
- 3559 N/C, b) 1 cm
- $E_{(P1)} = kq \left[\frac{2rs}{(r - s/2)^2(r + s/2)^2} \right]$, pointing in the same direction as the dipole moment.
 - $E_{(P2)} = \frac{kqs}{[r^2 + (s/2)^2]^{3/2}}$, pointing in the opposite direction as the dipole moment.
 - when $r \gg s$: $E_{(P1)} \approx \frac{2kqs}{r^3}$ and, $E_{(P2)} \approx \frac{kqs}{r^3}$.
Note that the field at point P2, is half the one at point P1, and in the opposite direction.
- $\vec{F}_Q \text{ on dipole} = \left(\frac{kqQs}{r^3}, \text{ direction of } \vec{p} \right)$
 - $\tau = \left(\frac{kqQs}{r^2} \right)$
- $\vec{F}_{\text{dipole on proton}} = (9.0 \times 10^{-13} \text{ N, opposite } \vec{p})$
- $\tau = 3.1 \times 10^{-21} \text{ Nm}$