PHY-112 | Principles of Physics-2

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Summer 2025 | Class #3

Department of Mathematics & Natural Sciences

Recap of the previous class!

What we studied in Class #2

Refer to Class #2 slides for details!

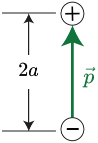
- What Electric Field Lines are and how they describe electric fields.
- How do electric charges accelerate in electric fields.
- 1D motion of charged particles in uniform electric fields.
- 2D motion of charged particles in uniform electric fields.

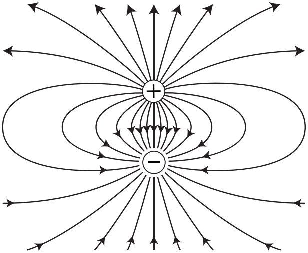
The Curious Case of Electric Dipoles

Electric Dipole

Two in a One system DEAL

A system consisting of two equal and opposite point charges, typically denoted as $q_+ = +ne$ and $q_- = -ne$, separated by a distance $d = 2a$.



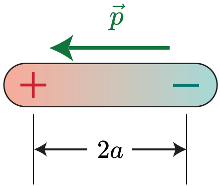


For calculation purposes, we write $\vec{d} = (2a)\hat{d}$.

Some commonly known dipoles are water molecules, polar molecules in general, dielectric materials, capacitor plates, etc.

Electric Dipole Moment
Measurement of the Dipole strength

The direction of $\vec{p}$ indicates the orientation of the dipole.
The magnitude of $\vec{p}$ measures the strength/polarity of the dipole.



$$\vec{p} = q\vec{d} = q(2a)\hat{a}.$$

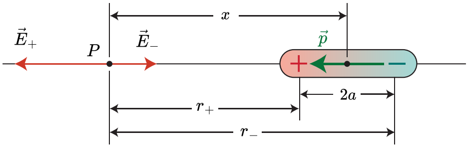
Note: $\vec{p}$ points from the $-$ve side to the $+$ve side of the dipole system.

Electric Field of an Electric Dipole

Electric Dipole's Electric Field

Measurement of the field strength of a dipole

An electric dipole generates an electric field that follows an *inverse cube law* (see the derivation provided with the slides).



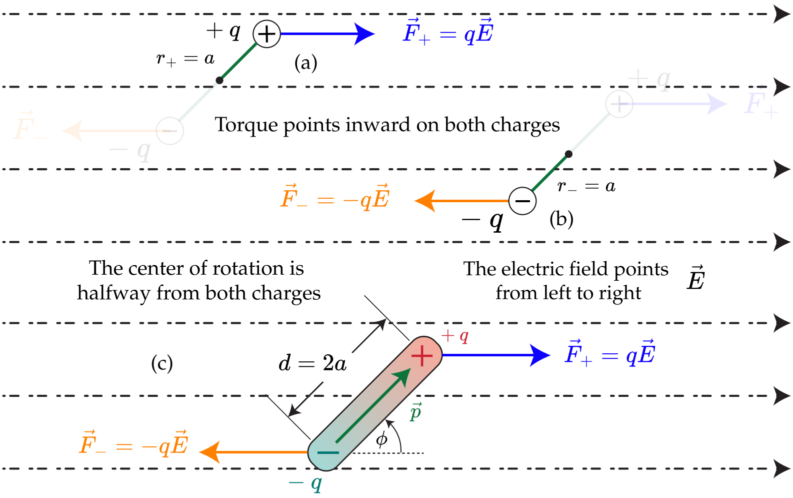
$$\vec{E} = \frac{1}{2\pi\epsilon_0}\frac{p}{r^3}\hat{r}.$$

where r is the distance (parallel to the dipole axis) from the center of the dipole to the observation point.

Note: Try the case when the observation is done perpendicular to the dipole axis.

Motion of an Electric Dipole in Electric field

Forces on Electric Dipole in a Uniform $\vec{E}$-field
Move it!



Forces on Electric Dipole in a Uniform $\vec{E}$-field
Move it!

- The positive charge experiences a Coulomb force $\vec{F}_+ = +q\vec{E}$ that points along $\vec{E}$
- The negative charge of the dipole also feels an equal but opposite force $\vec{F}_- = -q\vec{E}$ that points opposite to $\vec{E}$
- The net force on the dipole thus $\vec{F}_{\text{net}} = \vec{F}_+ + \vec{F}_- = 0$
- This does not mean the dipole is motionless

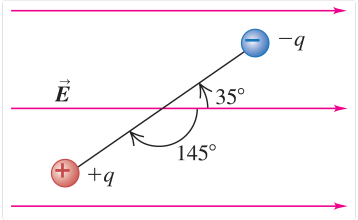
Torque on Electric Dipole in a Uniform $\vec{E}$-field
Roll it!

- The torque for the positive charge would be
$$\vec{\tau}_+ = \vec{r}_+ \times \vec{F}_+ = a\hat{d} \times q\vec{E} = (qa)\hat{d} \times \vec{E} = \frac{1}{2}\vec{p} \times \vec{E}$$
- The torque for the negative charge would be
$$\vec{\tau}_- = \vec{r}_- \times \vec{F}_- = \left(-L\hat{d}\right) \times \left(-q\vec{E}\right) = (qa)\hat{d} \times \vec{E} = \frac{1}{2}\vec{p} \times \vec{E}$$
- The total torque of the dipole system
$$\vec{\tau} = \vec{\tau}_+ + \vec{\tau}_- = \frac{1}{2}\vec{p} \times \vec{E} + \frac{1}{2}\vec{p} \times \vec{E} = \vec{p} \times \vec{E}$$

Incepting Ideas (1)

Hint: Try the extremum cases for Cross Product

Q: An electric dipole in a uniform electric field of magnitude 5.0×10^5 N C^{-1} that is directed parallel to the plane of the figure. The charges are 1.6×10^{-19} C; both lie in the plane and are separated by 0.125 nm (0.125×10^{-9} m). Find (a)] the net force exerted by the field on the dipole; (b) the magnitude and direction of the electric dipole moment; (c) the magnitude and direction of the torque; (d) the potential energy of the system in the position shown.



Incepting Ideas (2)

Hint: Try the extremum cases for Cross Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the MAXIMUM possible torque on the molecule in a 8.0×10^{8} N C^{-1} field?

Incepting Ideas (2)

Hint: Try the extremum cases for Cross Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the MAXIMUM possible torque on the molecule in a 8.0×10^{8} N C^{-1} field?
- $\longrightarrow$ Take $\theta = 90^{\circ}$

Incepting Ideas (2)

Hint: Try the extremum cases for Cross Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the MAXIMUM possible torque on the molecule in a 8.0×10^{8} N C^{-1} field?
- $\longrightarrow$ Take $\theta = 90^\circ$
- Q: Find the MINIMUM torque

Incepting Ideas (2)

Hint: Try the extremum cases for Cross Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the MAXIMUM possible torque on the molecule in a 8.0×10^{8} N C^{-1} field?
- $\longrightarrow$ Take $\theta = 90°$
- Q: Find the MINIMUM torque
- $\longrightarrow$ Take $\theta = 0°$

Potential Energy stored by an Electric Dipole
Rotational work done explains this energy

$$
\begin{aligned}
U_{\text{dipole}} &= -\int \tau d\theta \\
&= -\int pE\sin\theta \; d\theta \\
&= -pE\cos\theta \\
&= -\vec{p}\cdot\vec{E}
\end{aligned}
$$

Incepting Ideas (3)

Hint: Try the extremum cases for Dot Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the stored energy on the molecule (when placed parallel) in a 8.0×10^{8} N C^{-1}?

Incepting Ideas (3)

Hint: Try the extremum cases for Dot Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the stored energy on the molecule (when placed parallel) in a 8.0×10^{8} N C^{-1}?
- $\longrightarrow$ Take $\theta = 0^{\circ}$

Incepting Ideas (3)

Hint: Try the extremum cases for Dot Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the stored energy on the molecule (when placed parallel) in a 8.0×10^{8} N C^{-1}?
- $\longrightarrow$ Take $\theta = 0^\circ$
- Q: What is the stored energy on the molecule (when placed perpendicular)

Incepting Ideas (3)

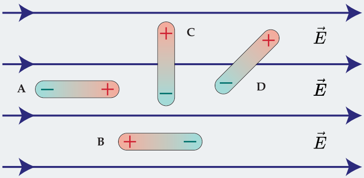
Hint: Try the extremum cases for Dot Product

- Q: The permanent electric dipole moment of a particular molecule is 1.1×10^{-30} C m. What is the stored energy on the molecule (when placed parallel) in a 8.0×10^{8} N C^{-1}?
- $\longrightarrow$ Take $\theta = 0^{\circ}$
- Q: What is the stored energy on the molecule (when placed perpendicular)
- $\longrightarrow$ Take $\theta = 90^{\circ}$

Incepting Ideas (4)

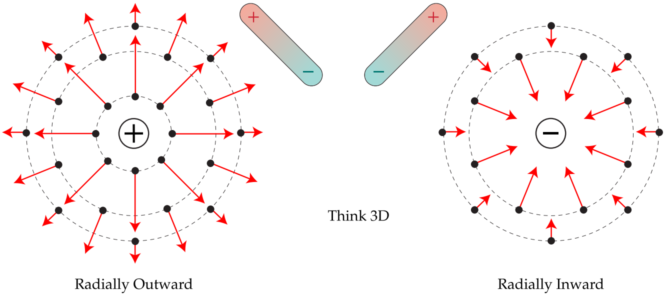
Hint: Find $\vec{p}$ and the angle between it and $\vec{E}$

Homework Practice Problem: Try it Yourself



- Q: Rank the $\vec{F}_{\text{net}}$ experienced by the dipoles in descending order.
- Q: Rank the $\vec{\tau}_{\text{net}}$ experienced by the dipoles in descending order.
- Q: Rank the U_{dipole} stored by the dipoles in descending order.

Electric Dipoles in a Non-Uniform $\vec{E}$-field
Magic? No. Physics? Yes



- Step-1: Orient $\vec{p}$ to $\vec{E}$
- Step-2: Apply Force $\vec{F}_E$ (push/pull) accordingly

Incepting Ideas (5)

Hint: Practice! Practice! Practice!

Some Problems to Practice at Home on Electric Dipole

Example Problem 21.13, p-732, 21.14, p-733 | Young-Freedman
Exercise Problem 21.51, 21.55, p-740 | YF
Checkpoint 4, p-649 | Resnick-Halliday
Sample Problem 22.02, p-637, 22.05, p-650 | RH
Exercise Problem 56, 57, 59 p-657 | RH

YouTube:

- https://youtu.be/VDFCF1zBY7E

That is it for today!