Chapter 26

1

Capacitance And Dielectrics

1

Lecture 03

2

Electric Dipole

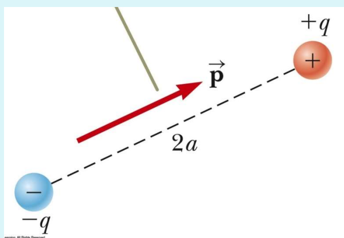
2

Electric Dipole

3

An electric dipole consists of two charges of equal magnitude and opposite signs.

The charges are separated by $2a$.



The electric dipole moment $\vec{p}$ is **directed** along the line joining the charges from $-q$ to $+q$.

The electric dipole moment has a **magnitude** of:

$$\boxed{p = 2aq}$$

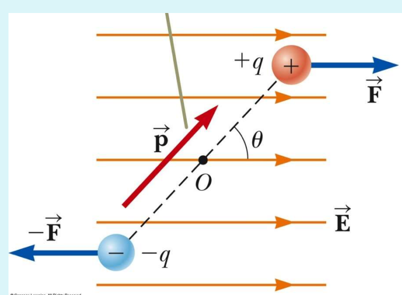
SI units: $C.m$

3

Electric Dipole, …

4

- Assume the dipole is placed in a uniform external field, $\boldsymbol{E}$.
- Assume the dipole makes an angle θ with the field
- Each charge has a force of ($F = qE$) acting on it.
- The net force on the dipole is zero.
- The forces produce a **net torque** on the dipole.



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Electric Dipole, …

5

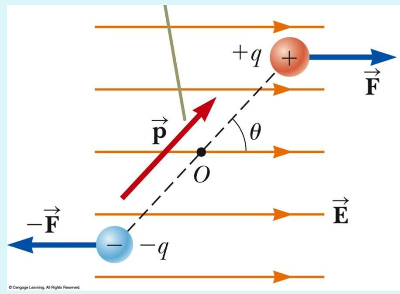
- The dipole is a rigid object under a net torque.
- The magnitude of the torque is:

$$\tau = rFsin\theta = 2aFsin\theta$$
$$\tau = 2aqEsin\theta$$

$$\boxed{\tau = pEsin\theta}$$

- The torque can also be expressed as the cross product of the moment and the field:

$$\boxed{\vec{\tau} = \vec{p} \times \vec{E}}$$



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5

Electric Dipole, …

6

- The change in the potential energy can be expressed as a function of the orientation of the dipole with the field:

$$\boxed{U_f - U_i = -pE\left(cos\theta_f - cos\theta_i\right)}$$

- Choose $U_i = 0$ at $\theta_i = 90^{\circ}$ as reference point for measuring U, then:

$$\boxed{U = -pEcos\theta}$$

$$\boxed{U = -\vec{p} \cdot \vec{E}}$$

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6

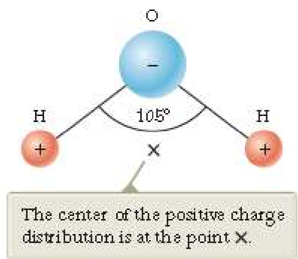
The H_2O Molecule

Tuesday, 2 February, 2021 16:55

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- [x] R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
- [ ] J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
- [ ] H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
- [ ] H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

The water (H_2O) molecule has an electric dipole moment of $6.3 \times 10^{-30}\ C.m$. A sample contains 10^{21} water molecules, with the dipole moments all oriented in the direction of an electric field of magnitude $2.5 \times 10^5\ N/C$. How much work is required to rotate the dipoles from this orientation $(\theta = 0^o)$ to one in which all the moments are perpendicular to the field $(\theta = 90^o)$?



SOLUTION

When all the dipoles are aligned with the electric field, the dipoles–electric field system has the minimum potential energy. This energy has a negative value given by the product of the right side of $(U = -pE\cos\theta)$, evaluated at $0°$, and the number N of dipoles. Work must be done to rotate all the dipoles of the system by $90°$ because the system's potential energy is raised to a higher value of zero.

Write the appropriate reduction of the conservation of energy equation for this situation:

$$(1)\Delta U = W$$

Use $(U = -pE\cos\theta)$ to evaluate the initial and final potential energies of the system and Equation (1) to calculate the work required to rotate the dipoles:

$$W = U_{90°} - U_{0°} = (-NpE\ cos\ 9\ 0°) - (-NpE\ cos\ 0\ °)$$

$$= NpE = (10^{21})(6.3 \times 10^{-30} C \cdot m)(2.5 \times 10^5 N/C)$$

$$= 1.6 \times 10^{-3} J$$

Notice that the work done on the system is positive because the potential energy of the system has been raised from a negative value to a value of zero.

An electric dipole

Wednesday, 14 April, 2021 14:11

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.

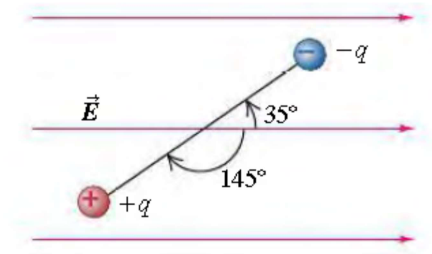
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.

H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.

H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

The figure shows an electric dipole in a uniform electric field of magnitude $5 \times 10^5\ N/C$ that is directed parallel to the plane of the figure. The charges are $\mp 1.6 \times 10^{-19}\ C$; both lie in the plane and are separated by $0.125\ nm$. Find:

- the net force exerted by the field on the dipole;
- the magnitude and direction of the electric dipole moment;
- the magnitude and direction of the torque;
- the potential energy of the system in the position shown.



The field is uniform, so the forces on the two charges are equal and opposite. Hence the total force on the dipole is zero.

$$\sum \vec{F} = 0$$

The magnitude p of the electric dipole moment is:

$$p = 2aq = 0 \cdot 125 \times 10^{-9} \times 1.6 \times 10^{-19} = 2 \times 10^{-29} C \cdot m$$

The direction of $\vec{p}$ is from the negative to the positive charge, $145°$ clockwise from the electric-field direction.

The magnitude of the torque is:

$$\tau = pE \sin\theta = 2 \times 10^{-29} \times 5 \times 10^5 \times \sin 145° = 5 \cdot 7 \times 10^{-24} N \cdot m$$

From the right-hand rule for vector products, the direction of the torque $\vec{\tau} = \vec{p} \times \vec{E}$ is out of the page. This corresponds to a counterclockwise torque that tends to align $\vec{p}$ with $\vec{E}$.

The potential energy is:

$$U = -pE\cos\theta = -2 \times 10^{-29} \times 5 \times 10^5 \times \cos 145° = 8.2 \times 10^{-24} J$$

The charge magnitude, the distance between the charges, the dipole moment, and the potential energy are all very small, but are all typical of molecules.

Or, using unit vectors, write $\vec{E}$ in unit vector notation:

$\vec{E} = 5 \times 10^5 \hat{\imath}\, N/C$

Calculate the magnitude of the electric dipole moment p:

$p = 2aq = 0 \cdot 125 \times 10^{-9} \times 1.6 \times 10^{-19} = 2 \times 10^{-29} C \cdot m$

Write the electric dipole moment in unit vector notation $\vec{p}$, noting that $\theta = 215°$, when measured counter clockwise from the +ve x-axis:

$$\vec{p} = 2 \times 10^{-29} \cos 215° \,\hat{\imath} + 2 \times 10^{-29} \sin 215° \,\hat{\jmath}$$

$$\vec{p} = (-1.64 \times 10^{-29}\hat{\imath} - 1.15 \times 10^{-29}\hat{\jmath}) C.m$$

The torque is:

$$\vec{\tau} = \vec{p} \times \vec{E} = (-1.64 \times 10^{-29}\hat{\imath} - 1.15 \times 10^{-29}\hat{\jmath}) \times (5 \times 10^{5}\hat{\imath})$$

$$\vec{\tau} = \left(5.74 \times 10^{-24}\hat{k}\right) N.m$$

The potential energy is:

$$U = -\vec{p} \cdot \vec{E} = (-1.64 \times 10^{-29}\hat{\imath} - 1.15 \times 10^{-29}\hat{\jmath}) \cdot (5 \times 10^{5}\hat{\imath}) = 8.2 \times 10^{-24} J$$