Torque on an Electric Dipole in Uniform Electric Field

Science is a strange subject that never ceases to amaze you as new subjects are presented. We're all aware that charge occurs everywhere around us and that its existence causes a variety of natural events. Furthermore, positive and negative charges exist in many forms, displaying various characteristics in the presence of a stimulating field.

Have you ever come across the term "electric dipole"? This unusual configuration of electric charges, i.e., positive and negative charges, creates an intriguing physics idea. To be more specific, Electric Dipole is a separation of positive and negative charges.

Consider a pair of electric charges with opposite signs but equal magnitude that are separated by a much smaller distance. The behavior of an Electric Dipole in the presence of an external field is now our main focus. Let's review the characteristics of the torque acting on an electric dipole in a uniform electric field before moving on to the properties of the torque acting on an electric dipole in a uniform electric field.

Torque

Torque is the measurement of the force that causes an item to rotate around an axis.

Torque is a vector quantity whose direction is determined by the force acting on the axis. The torque vector's magnitude is determined as follows:

$\boldsymbol{\tau = F\ r\ \sin\theta}$
where

- F is the force acting on the axis,
- r is the length of moment arm,
- θ is the angle between the force vector and moment arm, &
- τ is the torque vector

Electric Dipole

An electric dipole is a pair of equal and opposite electric charges separated by a distance d.

The product of the magnitude of these charges and the distance between them is the electric dipole moment. The electric dipole moment is a vector that has a clear direction from negative to positive charge.

The electric dipole moment,

p = q d
where

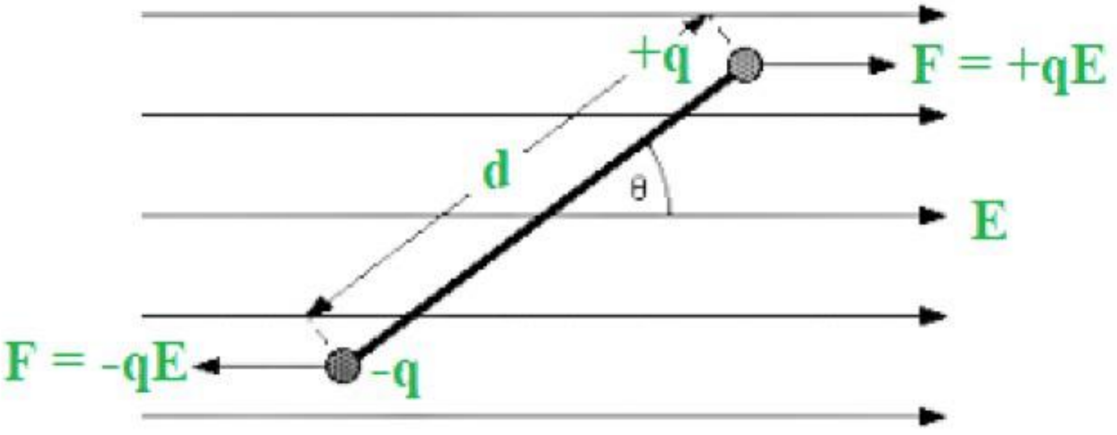
- q is the magnitude of charge &
- d is the separating distance.

Torque on an electric dipole

Consider a dipole that is placed in a uniform external field 'E' to calculate the torque experienced by the dipole when placed in an external field. The positive charge will be subjected to an electric force of 'qE' magnitude in the upward direction, while the negative charge will be subjected to an electric force of 'qE' magnitude in the downward direction.

Because the net force is zero, it can be observed that the dipole is in transitional equilibrium. What is, however, the rotational equilibrium? In this scenario, the dipole may remain fixed but rotates with a certain angular velocity. This fact has been demonstrated experimentally, and it indicates that both electrostatic forces (qE) behave as clockwise torque. As a result, when the dipole is put in a uniform external electric field, it rotates. Always keep in mind that torque always works in pairs. Furthermore, its magnitude is the resulting product of force and its arm. The arm may be thought of as the distance between the point where force is applied and the point where rotation occurs for the dipole.

Derivation of Torque
Consider a dipole with charges +q and –q that form a dipole because they are separated by a distance of d. Place it in a homogeneous electric field of strength E, with the dipole's axis forming an angle θ with the electric field.



Electric Dipole in External Field

The force on the charges, $\mathbf{F = \pm q E}$
The components of the force perpendicular to the dipole, $\mathbf{F = \pm q E \sin\theta}$
Since these components are equal and are separated by a distance d, the torque on the dipole is:

Torque = Force × distance between forces
$\boldsymbol{\tau = (q E \sin\theta)\, d = q d E \sin\theta}$

Since 'qd' is the magnitude of dipole moment (p), and the direction of dipole moment is from positive to negative charge; torque is the cross product of dipole moment and electric field. If the direction of an electric field is positive, the torque is in the clockwise direction (therefore negative) in the above figure.

Thus,

$\boldsymbol{\tau = -p E \sin\theta}$
The negative sign shows that torque is in the clockwise direction.