Applied Physics for Engineers

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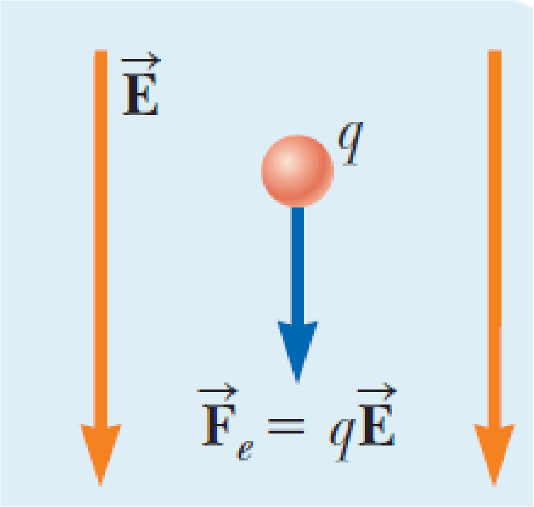
A point charge and a dipole in an electric field

A point charge in an electric field

- When a charged particle is placed in an electric field set up by other stationary charges, an electric force acts on it, that is

$$\vec{F} = q\vec{E}$$

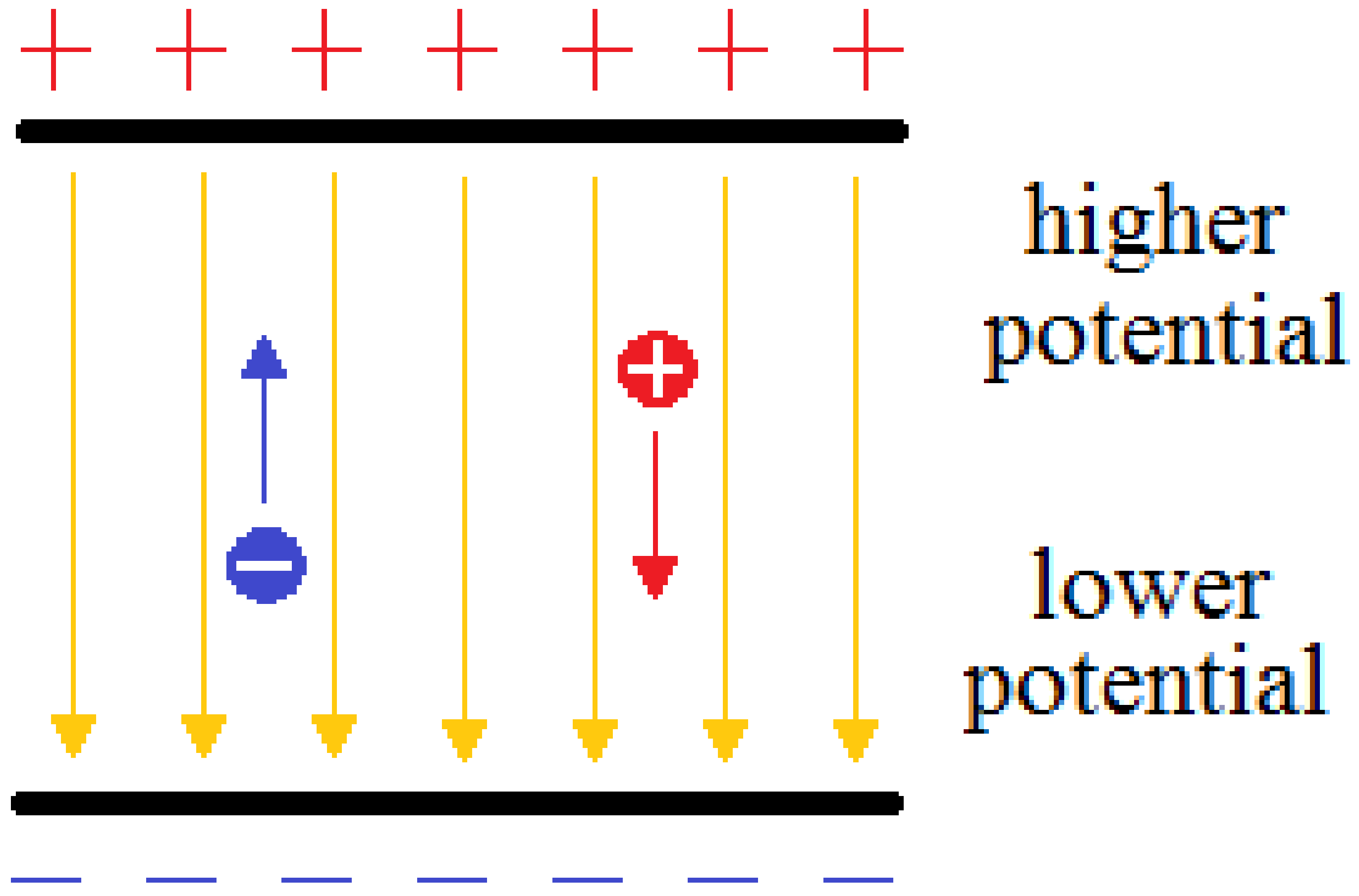


q is the charge of the particle

$\vec{E}$ is the electric field produced by other charges

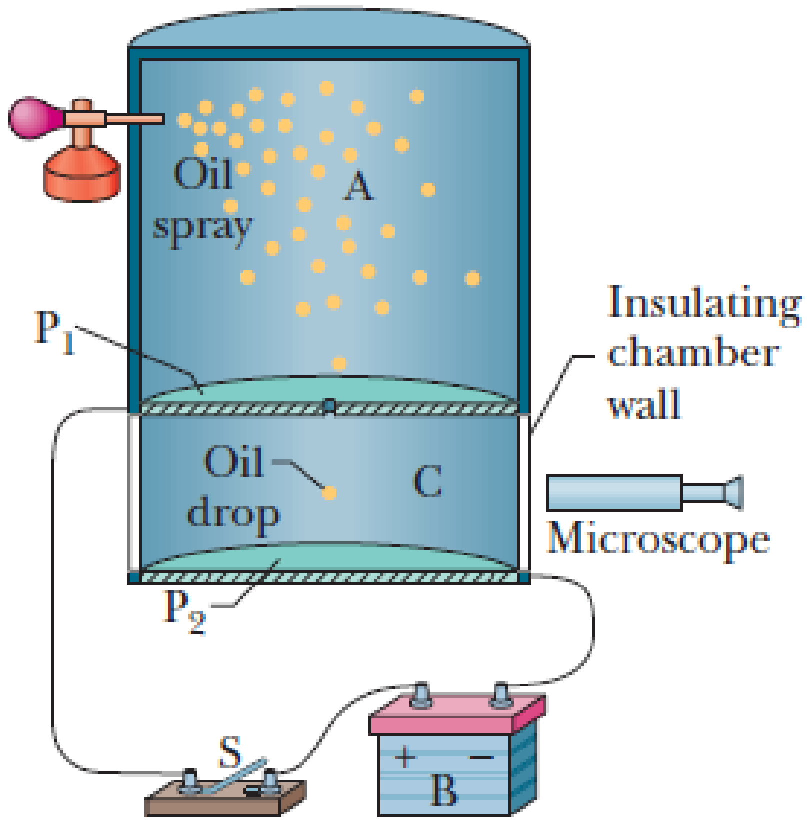
- If charge *q* is positive, the force vector is in the same direction as the field vector. If charge *q* is negative, the force vector is in the opposite direction

Positive and negative charges in an external electric field



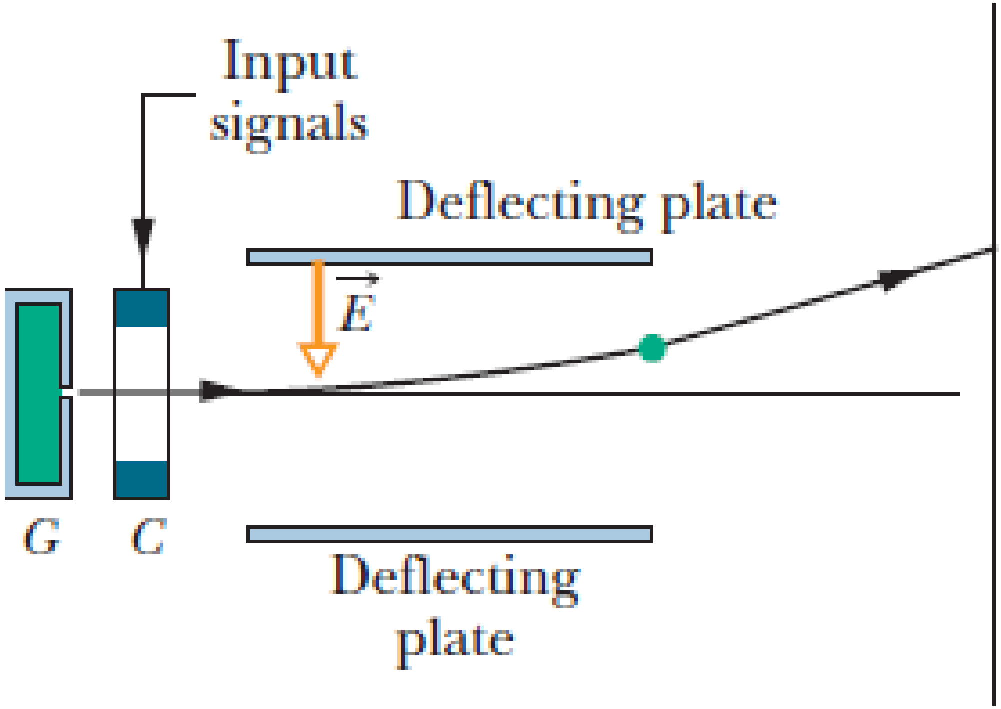
Measuring the Elementary Charge

The Millikan oil-drop apparatus for measuring the elementary charge e. When a charged oil drop drifted into chamber C through the hole in plate P1, its motion could be controlled by closing and opening switch S and thereby setting up or eliminating an electric field in chamber C



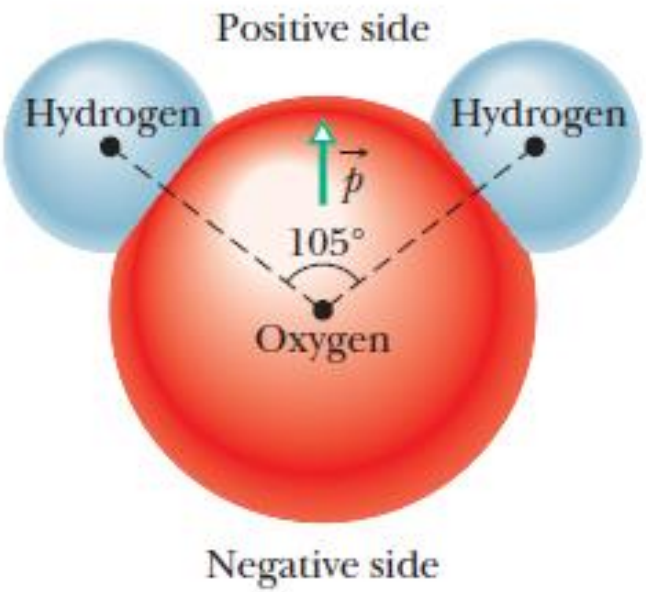
Ink-Jet Printing

Ink-jet printer. Drops shot from generator G receive a charge in charging unit C. An input signal from a computer controls the charge and thus the effect of field on where the drop lands on the paper



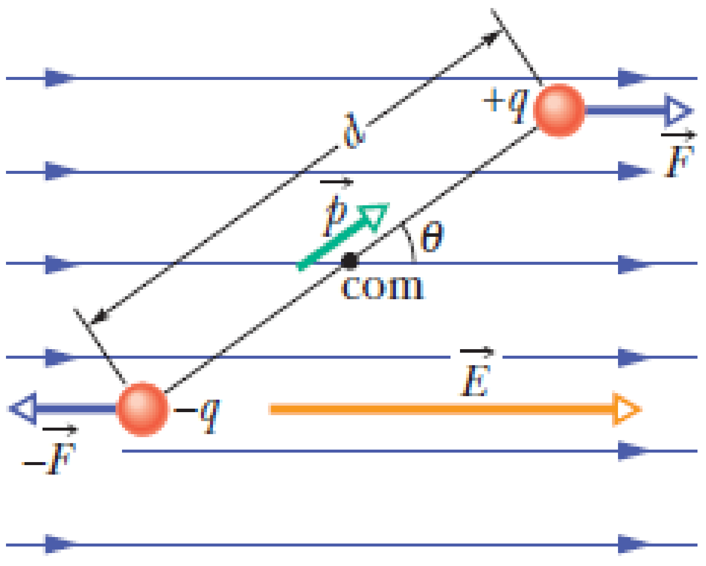
A DIPOLE IN AN ELECTRIC FIELD

- Electric dipole moment of an electric dipole to be a vector that points from the negative to the positive end of the dipole
- A molecule of water (H_2O) is an electric dipole
- Showing in figure the three nuclei (represented by dots) and the regions in which the electrons can be located. The electric dipole moment *p*: points from the (negative) oxygen side to the (positive) hydrogen side of the molecule.



A DIPOLE IN AN ELECTRIC FIELD

- In fig (a) an electric dipole is placed in a uniform electric field **E.** The dipole is a rigid structure that consists of two centers of opposite charge, each of magnitude q, separated by a distance d. The dipole moment makes an angle θ with field.
- Net force on the dipole from the field **F**=q**E** is zero and center of mass of the dipole does not move.
- However, the forces on the charged ends do produce a net torque $\boldsymbol{\tau}$ on the dipole about its center of mass



(a)

We know that

$$\tau = rF \sin\theta$$

The magnitude of net torque will be

$$\tau = Fx \sin\theta + F(d-x)\sin\theta = Fd \sin\theta$$

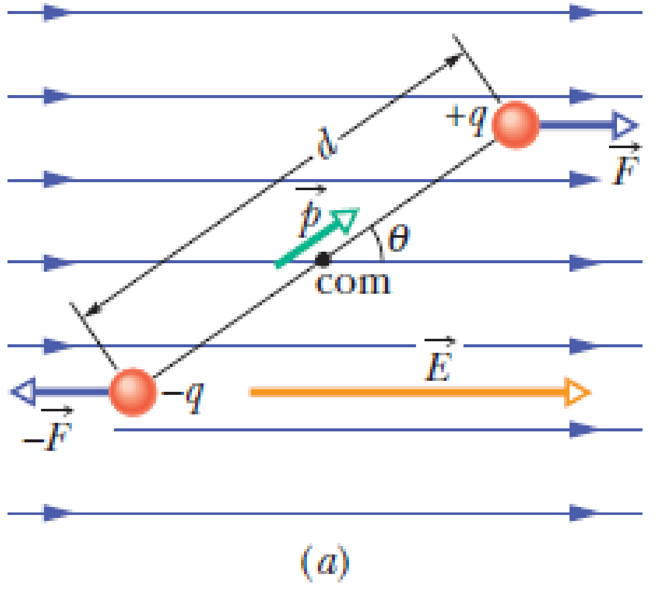
$$\boxed{\tau = Fd \sin\theta}$$

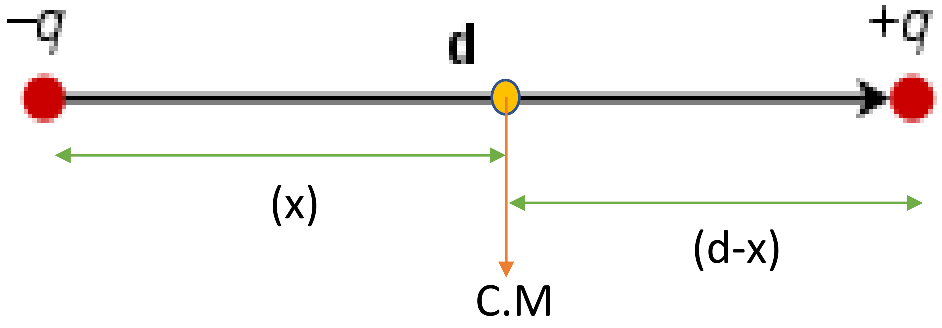
Put F = qE, d = p/q as p=qd

$$\tau = qE \times p/q \sin\theta$$

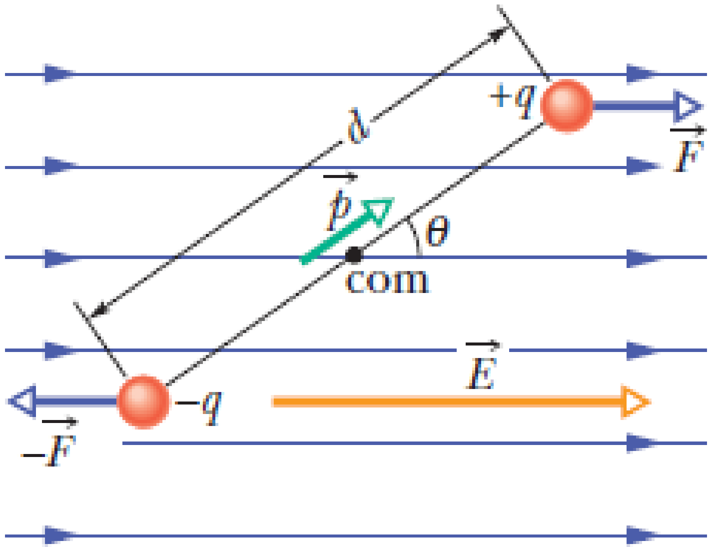
$$\tau = pE \sin\theta$$

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





- The torque acting on a dipole tends to rotate ***p*** (hence the dipole) into the direction of field , thereby reducing θ
- Such rotation is clockwise
- a torque that gives rise to a clockwise rotation by including a minus sign with the magnitude of the torque.



(a)

$$\tau = -pE \sin \theta.$$

POTENTIAL ENERGY OF AN ELECTRIC DIPOLE

- Potential energy can be associated with the orientation of an electric dipole in an electric field. The dipole has its least potential energy when it is in its equilibrium orientation, which is when its moment **p** is lined up with the field **E**. It has greater potential energy in all other orientations.
- the potential energy U at any angle θ is

$$U = -W = -\int_{90^\circ}^{\theta} \tau \, d\theta = \int_{90^\circ}^{\theta} pE \sin\theta \, d\theta.$$

Evaluating the integral leads to

$$U = -pE\cos\theta.$$

$$U = -\vec{p}\cdot\vec{E} \quad \text{(potential energy of a dipole).}$$

- the potential energy of the dipole is least $(U = -pE)$ when $\theta = 0$ (**p** and **E** are in the same direction);
- the potential energy is greatest $(U = pE)$ when $\theta = 180^\circ$ (**p** and **E** are in opposite directions).

When a dipole rotates from an initial orientation θ_i to another orientation θ_f, the work W done on the dipole by the electric field is

$$W = -\Delta U = -(U_f - U_i), \tag{22-39}$$

- If the change in orientation is caused by an applied torque (commonly said to be due to an external agent), then the work 'W' done on the dipole by the applied torque is the negative of the work done on the dipole by the field; that is,

$$W_a = -W = (U_f - U_i).$$