ELECTRIC DIPOLE

An electric dipole is a **pair** of **equal** and **opposite** point charges q and –q, separated by a distance 2a. The line connecting the two charges defines a direction in space. By **convention**, the direction **from –q** to **q** is said to be the direction of the dipole. The mid-point of locations of –q and q is called the centre of the dipole.

The **total charge** of the electric dipole is obviously **zero**. This does **not** mean that the **field** of the electric dipole is zero. Since the charge q and –q are separated by some distance, the electric fields due to them, when added, do not exactly cancel out.

Electric Dipole Moment

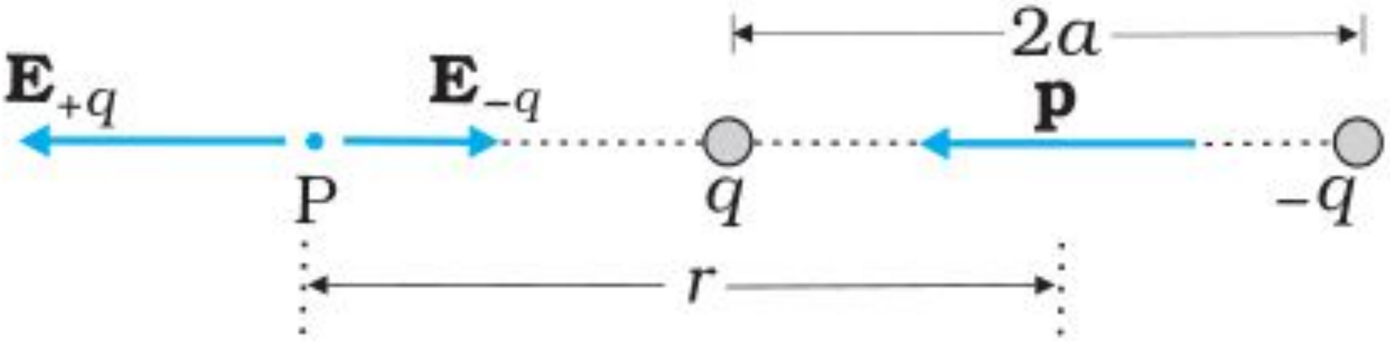
If q is the magnitude of each charge and 2a is the distance between the charges,

the dipole moment p = 2a X q

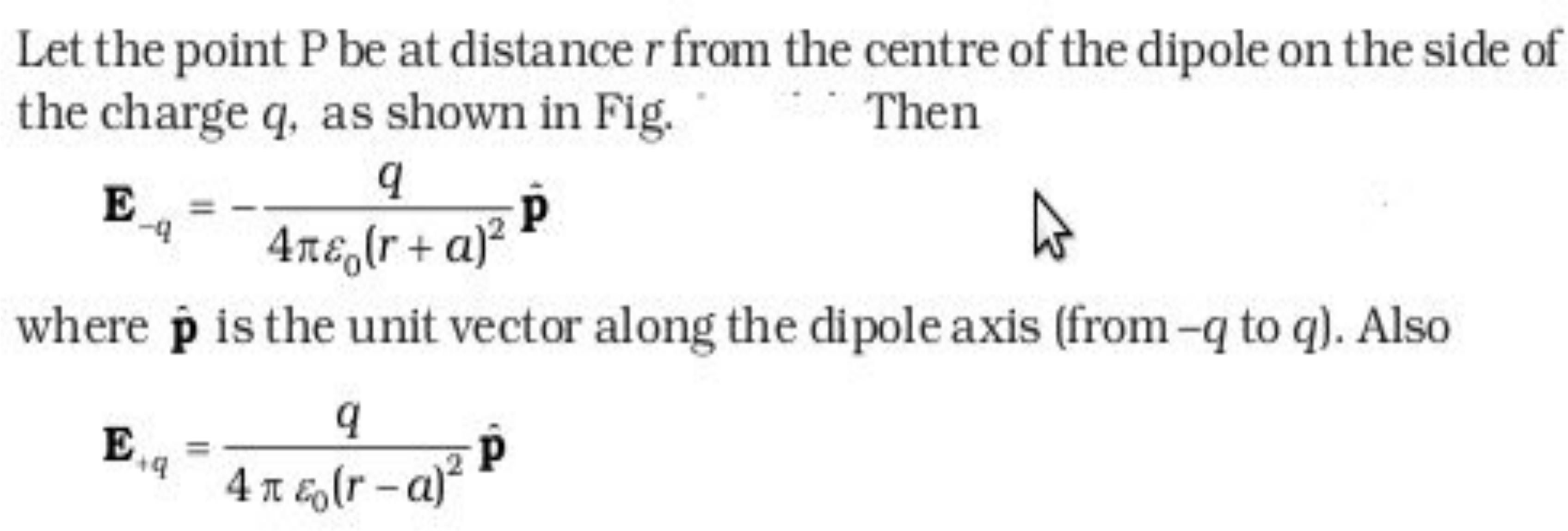
It is a **vector** quantity whose direction is along the axis of the dipole **from -ve** charge to **+ve** charge. It is the fundamental property of molecules.

The field of an electric dipole (i) For points on the axis

The electric field of the pair of charges at any point in space can be found out from Coulomb's law and the superposition principle.



The electric field at any general point P is obtained by adding the electric fields E_{-q} due to the charge –q and E_{+q} due to the charge q



Let the point P be at distance *r* from the centre of the dipole on the side of the charge *q*, as shown in Fig. Then

$$\mathbf{E}_{-q} = -\frac{q}{4\pi\varepsilon_0 (r+a)^2}\hat{\mathbf{p}}$$

where $\hat{\mathbf{p}}$ is the unit vector along the dipole axis (from $-q$ to q). Also

$$\mathbf{E}_{+q} = \frac{q}{4\pi\varepsilon_0 (r-a)^2}\hat{\mathbf{p}}$$

where $\hat{p}$ is the unit vector along the dipole axis (from –q to q)

The total field at P is

$$\mathbf{E} = \mathbf{E}_{+q} + \mathbf{E}_{-q} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]\hat{\mathbf{p}}$$

$$= \frac{q}{4\pi\varepsilon_o}\,\frac{4ar}{(r^2-a^2)^2}\,\hat{\mathbf{p}}$$

For $r >> a$

$$\mathbf{E} = \frac{4qa}{4\pi\varepsilon_0 r^3}\hat{\mathbf{p}} \qquad (r >> a)$$

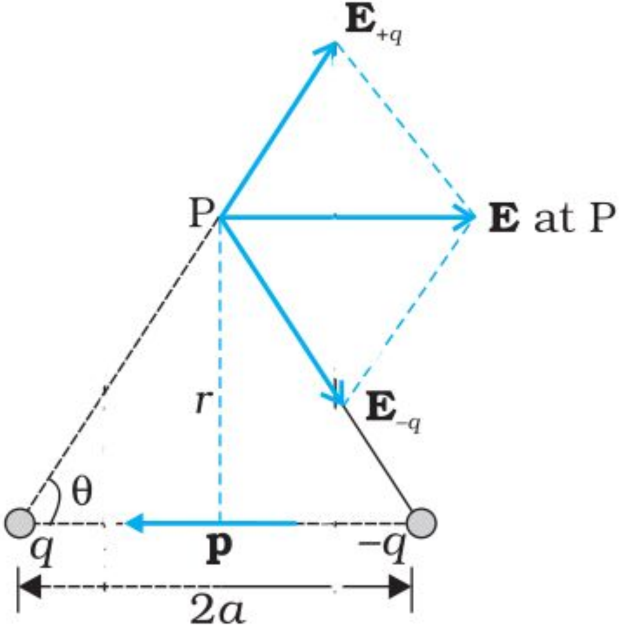
The dipole moment vector p of an electric dipole is defined by

$$\mathbf{p} = q \times 2a\ \hat{\mathbf{p}}$$

At a point on the dipole axis

$$\mathbf{E} = \frac{2\,\mathbf{p}}{4\pi\varepsilon_o r^3} \qquad (r >> a)$$

(ii) For points on the equatorial plane



The magnitudes of the electric fields due to the two charges +q and –q are given by

$$E_{+q} = \frac{q}{4\pi\varepsilon_0} \frac{1}{r^2 + a^2} \qquad E_{-q} = \frac{q}{4\pi\varepsilon_0} \frac{1}{r^2 + a^2}$$

Clearly, the components normal to the dipole axis cancel away. The components along the dipole axis add up.

$$\mathbf{E} = -\left(E_{+q} + E_{-q}\right)\cos\theta\ \hat{\mathbf{p}}$$

$$= -\frac{2qa}{4\pi\varepsilon_o\left(r^2 + a^2\right)^{3/2}}\hat{\mathbf{p}}$$

At large distances ($r >> a$), this reduces to

$$\mathbf{E} = -\frac{2qa}{4\pi\varepsilon_o r^3}\hat{\mathbf{p}} \qquad (r >> a)$$

But

$$\mathbf{p} = q \times 2a\,\hat{\mathbf{p}}$$

At a point on the equatorial plane

$$\mathbf{E} = -\frac{\mathbf{p}}{4\pi\varepsilon_o r^3} \qquad (r >> a)$$

We can think of the limit when the dipole size 2a approaches **zero**,the charge q approaches infinity in such a way that the product

$p = q \times 2a$ is finite.

Such a dipole is referred to as a **point dipole**

Physical significance of dipoles

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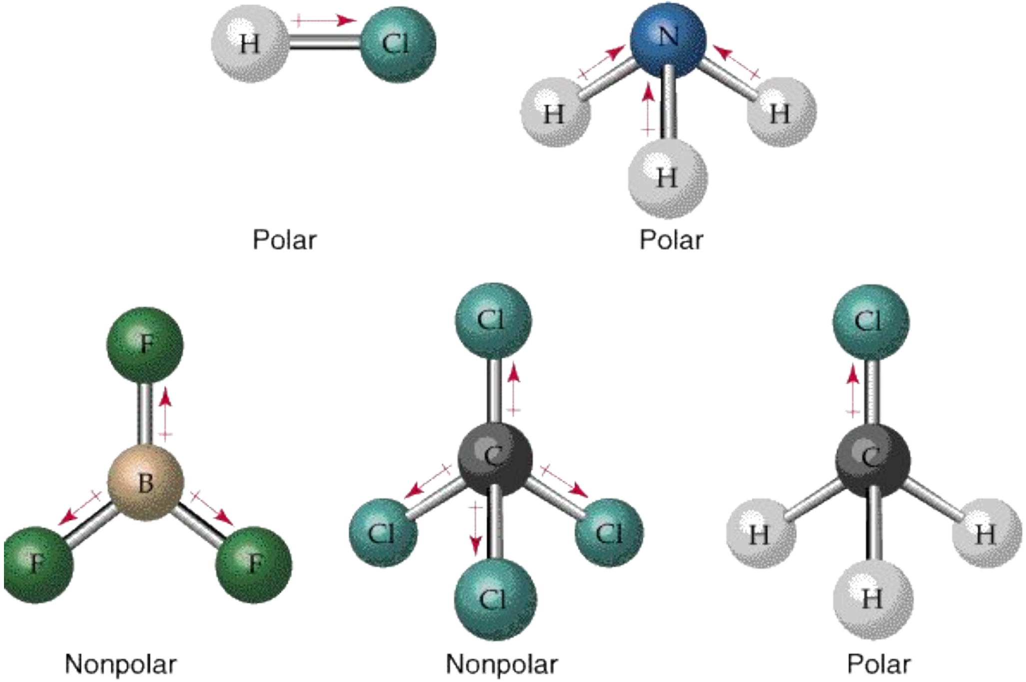
Polar and non-polar Molecules



In most molecules, the centres of positive charges and of negative charges lie at the **same place**. Therefore, their dipole moment is zero. CO_2 and CH_4 are of this type of molecules. However, they develop a dipole moment when an **electric field is applied**.

But in some molecules, the centres of negative charges and of positive charges **do not coincide**. Therefore they have a **permanent** electric **dipole moment**, even in the **absence** of an **electric field**. Such molecules are called **polar** molecules. Water molecules, H_2O, is an example of this type.

DIPOLE IN A UNIFORM EXTERNAL FIELD

Consider a permanent dipole of dipole moment p in a uniform external field E,

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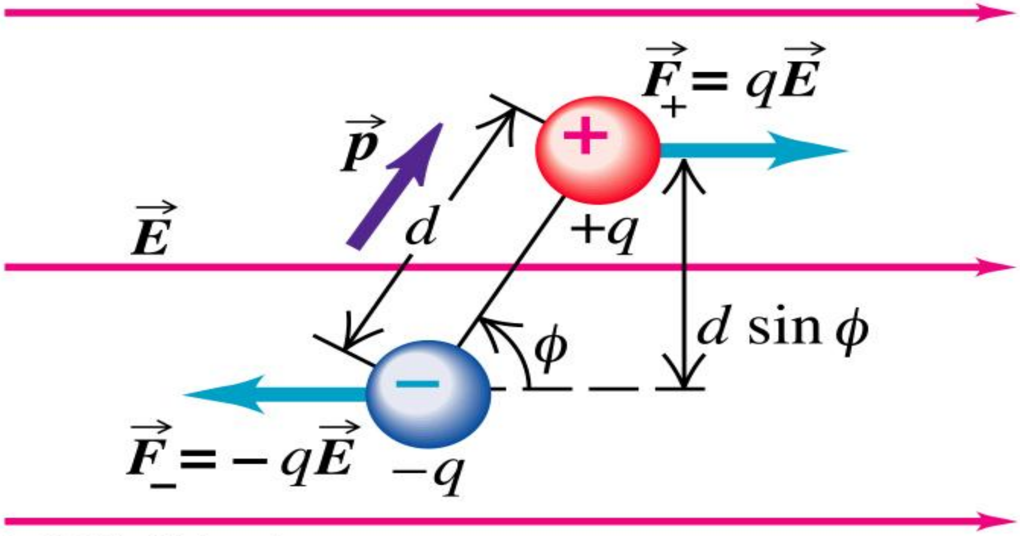

There is a force **qE** on q and

a force **–qE** on –q.

The **net force** on the dipole is **zero**, since **E** is uniform. However, the charges are separated, so the forces act at different points, resulting in a **torque** on the dipole.

Torque = One of the force x perpendicular distance between the charges

Magnitude of torque $= q\,E \times 2\,a\,\sin\theta$

$= 2\,q\,a\,E\,\sin\theta$

$\tau \quad = pE\sin\theta = p \times E$

What happens if the field is not uniform?

In that case, the net force will evidently be non-zero. In addition there will, in general, be a torque on the system as before.

In **addition** to the **torque**, the dipole experiences an **unbalanced force** and so, it executes **translatory** motion also