Electric Field due to Dipole

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Electric Dipole

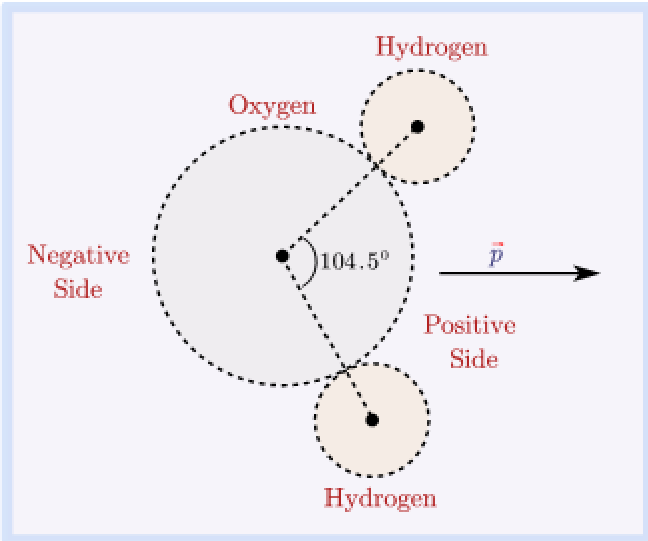
- Electric dipole is a pair of equal and opposite charges, $+q$ and $-q$, separated by a very small distance..

- Total charge of the dipole is zero but electric field of the dipole is not zero as charges q and -q are separated by some distance and electric field due to them when added is not zero.

- **Examples of electric dipole:-** Dipoles are common in nature. Molecules like

- H_2O,HCl,CH_3COOH

- are electric dipoles and have permanent dipole moments. They have permanent dipole moments because the center of their positive charges does not fall exactly over the center of their negative charges.Figure given below shows molecule of water.



Center of mass of negative and positive charges does not coincide in a water molecule

In this figure the electric dipole moment $\vec{p}$ points from negative or oxygen side to the positive or hydrogen side of the molecule.

Electric Dipole as a couple

Electric Dipole is defined as a couple of opposite charges q and –q, which are at 2a distance apart from each other. When we connect these two charges by a line, the line becomes responsible for the direction of the electric dipole in space. By default, the direction of the dipole is from negative charge –q to positive charge q. Also, the mid-point of q and –q is called **Center of the Dipole**.

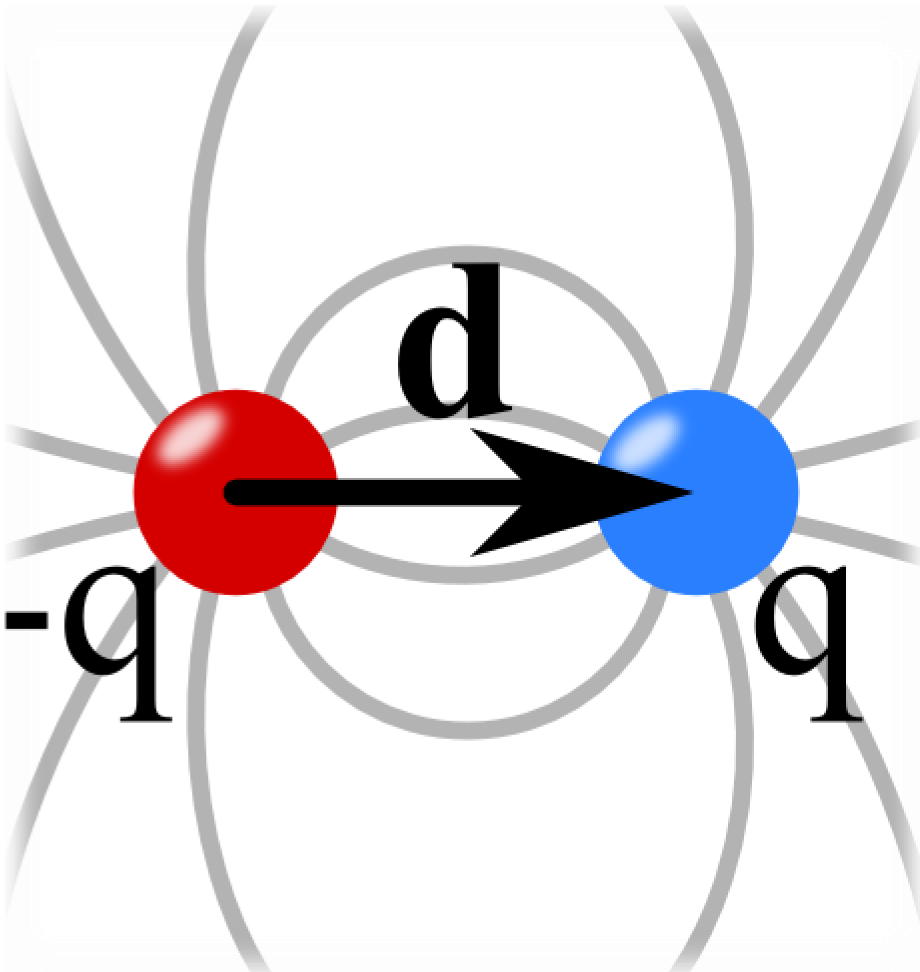


Image 1: Electric Dipole

Mathematically, electric dipole is denoted by symbol $\vec{p}$ and equals to product of charge (only magnitude) and distance $\vec{d}$ between them. The magnitude of $\vec{d}$ is 2a.

$$\vec{p} = q\vec{d}$$

The magnitude of dipole will be

p = 2aq

What will be the total charge of the dipole? Will it generate an electric field or not? As in a dipole both charges are of opposite sign, they will eventually cancel out, that is, net charge on the electric dipole is zero. But since there is the distance between them, the electric field will not be zero and yield some electric field.

Electric Field Due to Electric Dipole

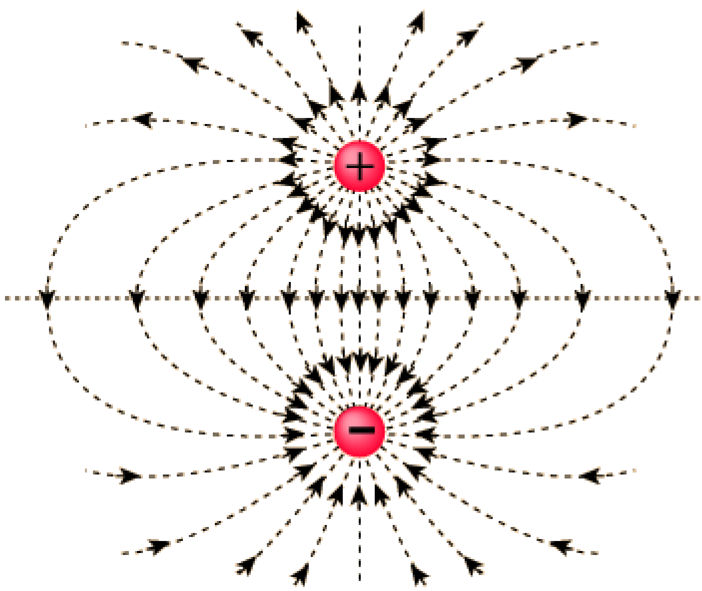


Image 2: Electric Field due to electric dipole

The electric field due to a dipole that is, a pair of charges q and –q, can be evaluated easily from Coulomb’s Law and Superposition Principle. The field due to electric dipole is also called dipole field. The electric field due to a dipole at a point can be found in two cases:

- When the point is axis of the dipole
- When the point is in the equatorial plane of the electric dipole that is, perpendicular to the axis of the dipole, passing through the center

The net electric field due to dipole will be the vector sum of the electric field due to charge q and –q. Let the electric field due to positive charge q be E_B and due to negative charge – q be

E_{-q}.

On the axis

When the point is on the axis of dipole

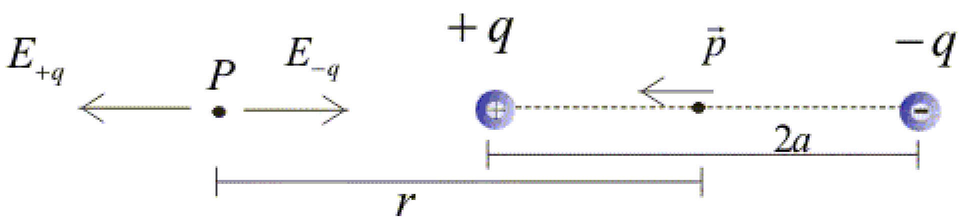


Image 3: Electric Field along the axis of the dipole

Let there be a point P at a distance ‘r’ from the center of the dipole. Then electric field E_{-q} ,due to negative charge –q will be

$$E_q = \frac{-kq}{(r+a)^2}\ \hat{p}\ \ (\text{as point P is } (r+a) \text{ distance from } -q)$$

The electric field E_q due to positive charge q will be

$$E_q = \frac{kq}{(r-a)^2}\ \ (\text{as point P is } (r-a) \text{ distance away from q})$$

The net electric field at point P will be the vector sum of both the electric fields.

Note: Since the electric fields are antiparallel, the vector sum will be:

$$E_{net} = E_q + E_{-q}$$

$$E_{net} = kq\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right]\hat{p}$$

$$E_{net} = kq\frac{4\ ar}{(r^2 - a^2)^2}\ \hat{p}$$

Since r >>> a, we can neglect a with respect to r, then ($r^2 - a^2)^2$ becomes r^4, then the net electric field becomes

$$E_{net} = \frac{4\ ka}{r^3}\ \hat{p}$$

Physical significance of Electric Dipole and dipole moment

- Atoms as a whole are electrically neutral in their ground state. We know that atoms have equal amount of positive and negative charge. Similar to atoms molecules are also neutral but they also have equal amount of positive and negative charges.

- Now when in a system, algebraic sum of all the charges is zero it does not necessarily mean that electric field produced by the system is zero everywhere. This makes study of electric dipoles important for electrical phenomenon in matter.

- Matter which is made up of atoms and molecules is electrically neutral. If the center of mass of positive charges coincides with that of negative charges then molecule behaves as *non-polar molecule*. On the other hand, if center of mass of positive charges does not coincides with that of negative charges then molecule behaves as *polar molecule*. These polar molecules have permanent dipole moments. These dipole moments are randomly oriented in the absence of external electric field. If we place a material with polar molecules in external electric field then these molecules align themselves in the direction of the field. This results in the development of a net dipole moment. This particular piece of material is said to be *polarized*.

- So study of dipole and dipole moments gives a measure of the polarization of a net neutral system. The study of dipole moments measures the tendency of a dipole to align with an external electric field.

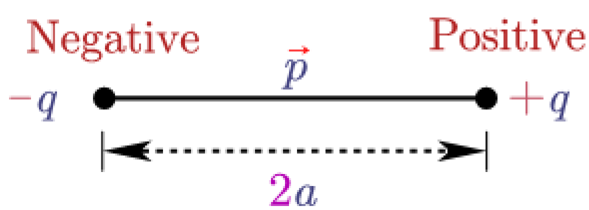
Electric dipole moment occurs when there is a separation of charge. It can occur in electrically neutral molecules with ionic bonds or molecules with covalent bonds. Dipole moments measures the electric polarity of system of charges.

Electric dipole moment measures the strength of an electric dipole. It is a vector quantity.

Electric dipole moment definition :- The dipole moment of an electric field is a vector whose magnitude is charge times the separation between two opposite charges.

- Direction of dipole moment is along the dipole axis from negative charge to positive charge.

- Consider the figure given below which shows an electric dipole consisting of charges $(\pm q)$ separated by a small distance $2a$.



Electric Dipole

Mathematically,

Dipole Moment=either one of charges×separation vector from +ive to -ive

$pp=q(2\vec{a})$C.m

Above equation gives *Electric dipole moment formula*

- Magnitude of dipole moment is
- $|\vec{p}| = q \times 2a|$
- The *Electric dipole moment direction* is from negative charge to positive charge.
- The SI unit of dipole moment is Coulomb-meter(C−m)