

# Electric dipole

An **electric dipole** is a system of two charges of the same size  $Q$  and opposite sign at a fixed distance determined by the mutual position of a vector  $\mathbf{d}$  oriented from the negative charge  $Q^-$ , to the positive charge  $Q^+$ .

## Dipole moment

The vector quantity dipole moment  $\mathbf{p}$  is used to mathematically express an electric dipole. For a pair of equal-sized charges of opposite sign  $Q^-$  and  $Q^+$  with mutual position vector  $\mathbf{d}$ , the dipole moment is determined as follows:

$$\mathbf{p} = Q\mathbf{d}$$

If the distance between the dipole charges can be considered small, the electric field intensity  $\mathbf{E}$  at a distance  $r$  from the center of a dipole with a dipole moment  $\mathbf{p}$  will have the following relation:

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\epsilon_0} \left( \frac{3(\mathbf{p} \cdot \mathbf{r})\mathbf{r}}{r^5} - \frac{\mathbf{p}}{r^3} \right)$$

The intensity of the electric field of a dipole decreases with distance from the dipole roughly with the third power of the distance, while in the case of charge only with the square power. This fact is of a great importance in the study of interactions between atoms and molecules.

## Multipolar development

When studying the electric field of a system of charges or a charged body, it can sometimes be advantageous to convert the general description of the field into another expression. The field is studied as the contribution of the point charge, the electric dipole, the electric quadrupole and possibly other terms. It should be emphasized that these are mathematical operations that can simplify the calculation, since the higher the element, the faster its contribution decreases with distance.

To illustrate, an ion in a solution can usually be considered a point-charge, i.e. the dipole moment and higher moments can be neglected when describing its field. But if we study non-bonding chemical interactions, the dipole moment of atoms and molecules must be taken into account.

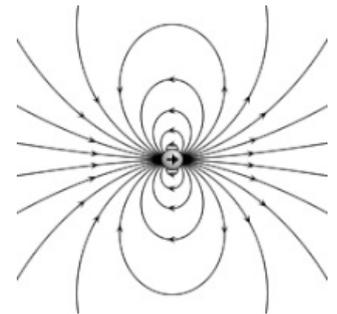
## Electric dipole of cells

The cell as a complex system with unevenly distributed electric charges in electrically **charged macromolecules**, in some compartments and especially on the cell membrane has its own electric field, which also has a significant dipole moment. During processes associated with electric charge movements, i.e. during an action potential, the dipole moment of the cell changes. There is a **time-varying** electric field in the vicinity of such an active cell.

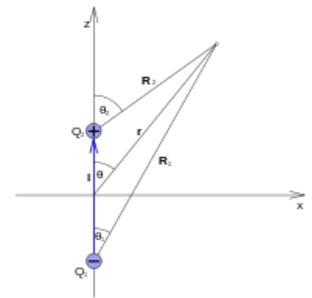
Although the electric field of a single cell is relatively **weak**, in the case of synchronized activity in tissues and organs, the electric field can be measured by macroscopic methods. In particular, temporal changes in distribution of the electric field around the relevant organ may contain diagnostically valuable information.

The electric field of the heart can be imagined as the result of the summation of the electric field of individual cardiomyocytes. Because cardiomyocyte activity is synchronized, the electrical field of the entire heart is also time-varying. Rather conceptually than actually solving such a task, a multipole development of the heart's electric field can be performed. **The dipole moment** of the heart is of a great importance. This vector changes its size and especially its direction during the cardiac cycle. The measurement of the development of the dipole moment, so-called vectorcardiography, has not been widely adopted in practice. On the other hand, measuring the projection of this vector into clearly defined points is, like electrocardiography, one of the basic diagnostic methods.

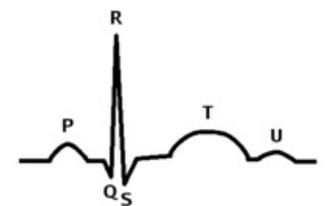
A time-varying electric field around the brain, muscle, or nerves appears in a similar way. Here too, it is measured for diagnostic purposes, usually rather specialized methods.



electric field around a dipole



distance from the dipole



an EKG curve as an example of the temporal change of the difference in electric potentials at two defined points around the heart

## Resources

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