6: The Electric Dipole

To make concrete all the ideas of electric phenomenon, we now work through the problem of an electric dipole. Note that this is one specific example of many available. It is more important to know the main ideas of this unit and how the ideas relate to one another (i.e. what is an electric field and how does it relate to electric potential?), than it is to know the specifics of the material presented in this section. The electric dipole was chosen because of its importance to magnetism.

The electric dipole consists of two charges of opposite signs separated by a small distance. Though this setup sounds fairly contrived, many molecules (water among them) act like dipoles, because within the molecule the charges separate leaving a net positive side and a net negative side. Much of the biology and chemistry you have studied has depended on dipole interactions. Note that there is no gravitational equivalent to a dipole, since there is no “negative” mass.

Let’s start off simply. Imagine two charges, each of the same magnitude but opposite sign. In previous sections, we discussed the interaction between these charges; now we will discuss interactions between this charge pair and other charges. We are then interested in the field and potential created by both charges, not simply the field created by one charge at the location of the other charge.

We will start by considering the electric field. Field lines must begin on a positive charge and end on a negative charge (or continue forever into space). The density of field lines represents the strength of the field. In this case, the charges have equal magnitude, so the density near each charge is the same. First consider the field lines from each charge in isolation, as shown below.
Next we need to connect the lines in a sensible fashion. This is shown below.

We can check our work by calculating a few sample electric field vectors. Suppose the charges are oriented horizontally and separated by a distance \(L\). Consider a point equidistant from both charges, such as the point labelled ‘A’ in this picture.

We first draw the individual field vectors from the positive charge and the negative charge. For the positive charge, the vector points away from the charge. For the negative charge, the vector points toward the charge, at the same angle from horizontal.
Point A is equidistant from each charge, so the magnitudes of the vectors are identical.

Using head-to-tail vector addition, add the vectors. The up and down components of the vectors cancel, leaving the sum pointing directly to the right. The sum, shown with a double arrow, points in the direction of the electric field at this point. Superimposing the field vector on top of the field lines, we see that the electric field vector is tangent to the electric field line at point A. This is reassuring, as field vectors are supposed to be tangent to field lines at every point.

Exercise 6.1.1

Check that the field vector is tangent to the field line at another point.

Next, we consider the electric potential. We wish to consider points very far from the dipole to have an electric potential of zero. Nearing the negative charge, the potential will get increasingly negative, and nearing the positive charge, the potential will get increasingly positive.

To directly calculate the potential at a given point, we will use the equation:

$$V = \frac{kQ}{r}$$

but we need to consider the contributions from each charge. At a point equidistant between the charges, the distance \( r \) is the same for both contributions, though the signs differ.

$$V = \frac{kQ}{r} + \frac{k(-Q)}{r} = 0$$

Any point equidistant to each charge has a potential of 0.

We will now draw the equipotentials using the information determined above and what we know about equipotentials from earlier sections:

- The potential far from the charges is 0.
- The potential equidistant from the charges is 0.
- The potential near either charge is increasingly positive (or negative).
- Equipotentials are perpendicular to field lines.
- In places where the field is strong, the potentials are closer together.
Exercise 6.1.2

In 9.1.6, we summarized the field map, field lines, and equipotential representations in tabular form. Using the table, and the image above, make certain you understand each representation.

You may wonder why so much of this chapter has been dedicated to the electric dipole. There are several reasons for this attention. For one, it has given us a chance to put together electric fields and potentials in a more complicated example. Additionally, dipoles are ubiquitous in chemistry, as you may recall from dipole-dipole bonding, for instance. Finally, as you will see in section 9.3, the dipole field is of critical importance to magnetism.

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