Potential energy of charge clusters

6.2.3.P6

Although the electric potential energy between a pair of charge has a quite simply form

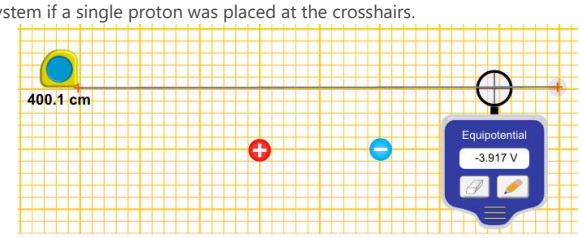
$$U_{qQ} = k_C qQ/r$$

we rarely have a situation in which we only have two charges. Often we want to find the energy that results from adding a charge to a system of existing charges. In this problem we will consider two of the simplest systems that are more complex than a simple pair of charges: (1) a test charge probing the field of a dipole, and (2) a test charge probing the field of a quadrupole. The first is important in understanding how charges behave within a polar liquid (like water). The second is important in understanding how charges move when an action potential travels down an axon.

To do this, we'll use the simulation Charges and Fields from the PhET group at the University of Colorado. (I recommend clicking on the triple-bar menu icon in the lower corner, choosing "Options" and clicking of the "Projector mode" box so the screen is displayed on a light rather than a dark background.)

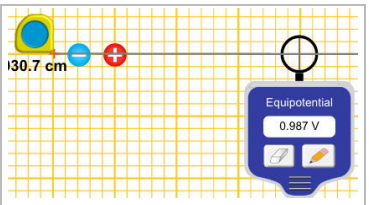
In the controls box at the upper right unclick the "Electric field" box and click the "Grid" box.

1. Put a pair of charges at the center of the screen separated by two large grid boxes. Stretch the measuring tape for 400 cm along the grid line above the charges and centered on them as shown below. The potential energy meter measures the extra energy (in electron Volts -- eV) that would be added to the system if a single proton was placed at the crosshairs.



1.1 Pick a coordinate system along the measuring tape. Create a table and measure the PE at various points along the measuring tape and graph the extra PE added as a function of position along that line. (Either use graph paper or a spreadsheet. Include the graph in your HW.)

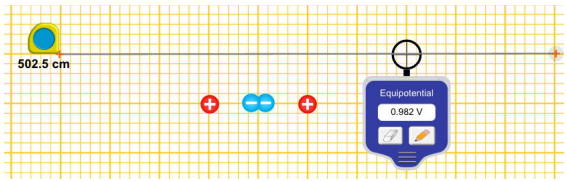
1.2. Explain physically why the graph looks like it does.

1.3. Now put the tape measure all the way on the left and put the dipole on the tape measure line as shown in the figure at the right. Measure the PE of an added charge along the tape measure's line beginning 3 boxes to the right of the dipole and extending as far out to the right as you can go. Make a log-log plot of your results. If the field far from the dipole went like 1/r, the slope of your log-log plot would be -1. What is the slope you find? (Include your graph in your report.)	

1.4. Can you explain physically why the slope is NOT -1?

1.5 If the charges each have magnitude e and the separation of the dipole charges is a distance d, write an equation for the PE of the extra proton (charge +e) a distance x along the tape measure in 1.3 taking the origin as the center of the dipole.

2. Now create a quadrupole by taking two dipoles and putting them back to back as shown.



2.1 Measure the PE of the added proton along the line of the measuring tape and include a table of your data and a graph of the result in your report.

2.2 If the charges each have magnitude e and the separation of the quadrupole + and - charges are a distance d, write an equation for the PE of the extra proton (charge +e) a distance x along the tape measure in 1.3 taking the origin as the place where the vertical line through the center of the dipole crosses the measuring tape.

2.3 Can you explain physically why it looks the way it does?

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