

# Motion in a Dipole Field

## Objectives

Dipoles, whether permanent or induced, play a key role in many electric interactions. In chapter 13 we found an analytical expression for the approximate electric field of a dipole at a restricted set of locations—along its axis and perpendicular axis—but not at other locations. Here you will first calculate the exact electric field of a dipole numerically at many locations, and predict the motion of a proton in a region near a dipole.

After completing this activity you should be able to:

- Calculate and display the net electric field of several source charges, at many observation locations
- Animate the motion of one or more charges under the influence of an electric field due to several source charges
- Monitor the sum of kinetic and potential energy for the system to check the accuracy of model predictions

## 1 A Dipole

Study the code below. Identify the orientation of the dipole axis, charge and dipole separation.

```
from __future__ import division, print_function
from visual import *
scene.width = scene.height = 800

## constants
oofpez = 9e9 # stands for One Over Four Pi Epsilon-Zero
qe = 1.6e-19
s = 4e-11
scalefactor = 1.0 # you may need to change this

p1 = sphere(pos=vector(0,s/2,0), radius=1e-11, color=color.red)
q1 = qe
p2 = sphere(pos=vector(0,-s/2,0), radius=1e-11, color=color.blue)
q2 = -qe

## for plotting

egraphs=gdisplay(x=600, width=600) ## move graph so it's not on top of scene
scene.width = scene.height = 600
Ug = gcurve(color=color.yellow)
Kg = gcurve(color=color.cyan)
KUg = gcurve(color=color.magenta)
```

## 2 Calculating $\vec{E}$ at Many Observation Locations

To display the pattern of electric field surrounding a dipole, we will create many arrows whose tails lie on a circle surrounding the dipole.

- Calculate and display the electric field of the dipole at 12 evenly spaced locations on a circle of radius  $3 \times 10^{-10}$  m, lying in the  $xy$  plane and centered on the dipole.
- Add a second circle of observation locations in the  $yz$  plane.

### 3 Motion of a Proton

- Add a proton, at rest, at location  $\langle -3s, 0, 0 \rangle$ . Make it leave a trail by setting `make_trail=True` in the constructor.
- Animate the motion of the proton under the influence of the dipole's electric field.
- Use a value of about  $1 \times 10^{-17}$  s for  $\Delta t$ , and `rate(300)`.

### 4 Using Energy as a Check

You may wonder if the trajectories you observe are reasonable. Recall that significant errors can occur if the proton gets into a region where the field is very large. Under that circumstance, the approximation that  $\vec{E}$  is approximately constant during one time step may no longer be valid, and predictions of motion may be very inaccurate. As discussed in Section 6.15, to check the accuracy of our predictions we can monitor the sum of  $(K + U)$ . In a closed system with no external energy inputs, we should expect that  $(K + U) \approx \text{constant}$ .

- For each step inside your motion loop, calculate the kinetic energy of the proton and the electric potential energy of the system of (proton + dipole charges). You need not include the potential energy associated with the interaction of the charges making up the dipole—this can be considered part of the internal energy of the dipole, and will not change because the dipole separation will not change.
- Plot  $K$  of the proton,  $U$  of the (proton + dipole) system, and the sum of  $(K + U)$  as a function of  $t$ :

```
Kg.plot(pos=(t,K))
Ug.plot(pos=(t,U))
KUg.plot(pos=(t,K+U))
```

- Terminate the loop at a value of  $t$  sufficiently small that you can examine the details of your graphs (for example, after 3 periods if the motion is periodic).

### 5 To-do list

1. Display the electric field pattern of a dipole. (Finish in class)
2. Animate the motion of a proton under the influence of a dipole.
3. Plot  $K$ ,  $U$ , and  $K + U$ .