13

Work and Energy

Potential Wells

Purpose

To apply the principle of conservation of energy to map a potential energy curve of a system and to investigate the forces exerted during the impulse.

Required Equipment and Supplies

air track system (1.5 to 2 meter)
strong, small magnets that can be attached to an air track glider
strong, large Alnico magnet (such as those from a magnetron or cow magnet)
Apple II Series computer
Super Sonic Plus ultrasonic ranging system
sonic reflector sail (rectangular piece of cardboard works well)
graph paper or *Data Plotter* graphing program

Note: The mathematics of this experiment involves elementary calculus.

Discussion

If the friction in a system can be eliminated, the total mechanical energy, E is simply the sum of the kinetic energy and potential energy, $K + U$. As U increases or decreases, K correspondingly decreases or increases, such that E remains constant. We say a system wherein mechanical energy is conserved is a *conservative system*—no heat is generated in a conservative system.

In a conservative system the *potential energy* as a function of position can be determined by measuring the *kinetic energy* as a function of position. The potential energy is given by

$$U(x) = E - K(x)$$

For a conservative system, the potential energy is related to the force involved by

$$U(x) = W = \int_{x_0}^{x} F_{\text{ext}}\,dx = -\int_{x_0}^{x} F\,dx$$

where F_{ext} is the external force. We choose x_0 to be the reference position where $U(x)$ is arbitrarily taken to be zero and F to be the *internal* force that the *external* force is working against. The external force, F_{ext}, equals the opposite of the internal force, F.

$$F_{\text{ext}} = -F$$

Taking the derivative of both sides yields

$$F = -\frac{dU}{dx}$$

$$= -(\text{slope of the potential energy curve})$$

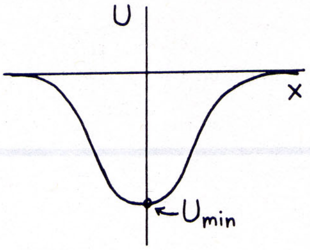


Figure 13.1

Two cases common in atomic physics are of special interest in illustrating of the potential energy curves.

Figure 13.1 is an example of a *potential well*, such as the scattering of an electron from a proton via the electrical attraction. Figure 13.2 illustrates an *alpha potential*, and is characteristic of the potential energy curve of an alpha particle scattering off the nucleus of a massive atom.

In this experiment, you will simulate a proton or the nucleus of a massive atom with a strong magnet along an air track and an electron or an alpha-particle with a ceramic magnet mounted on one side of an air track glider. Although the general relationship between force and total kinetic energy is described above, since we will actually measure the kinetic energy, *K*, it is more convenient to note that since the total energy is constant,

$$F = -\frac{dU}{dx}$$

$$= \frac{dK}{dx}$$

$$= (\text{slope of the graph of kinetic energy vs. distance})$$

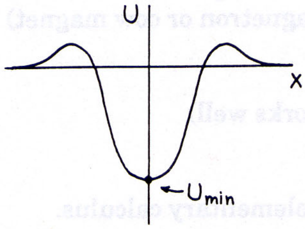
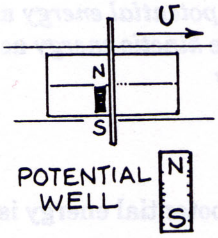


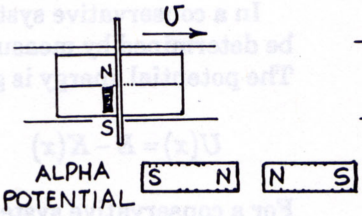
Figure 13.2

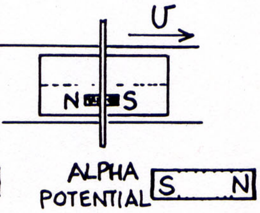
The map of its potential energy curve will be used to investigate the force being exerted on the system.

Procedure

Step 1. Level the air track so the glider remains stationary when the blower is turned on. Mount strong a magnet on the glider and a massive magnet in the middle along the side of the air track. Possible configurations are shown below.



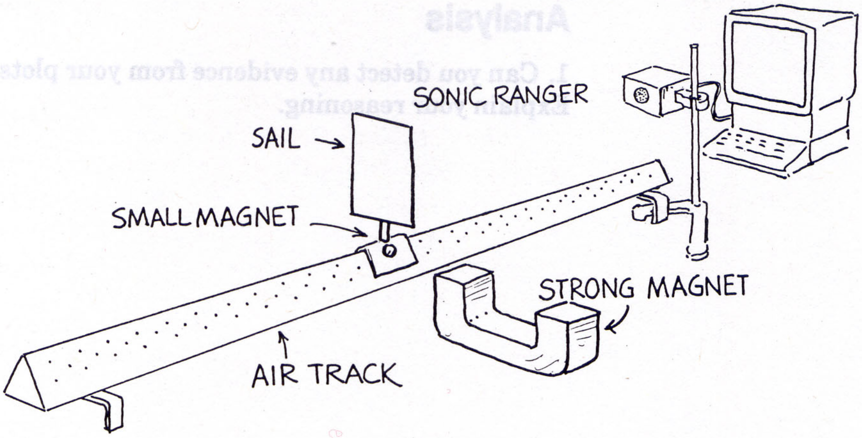




Mount a sonic reflector on top of the glider. Adjust the alignment of the sonic ranger so that it tracks the glider over the entire length of the air track. Point the ranger slightly off to one side of the track to prevent the sonic ranger from detecting the track as the target. Another technique that "collimates" the beam of the sonic ranger is to cut out the bottom of a 6–oz Styrofoam cup and tape it over the detector to form a "horn."

Proceed to the "Collect Data" screen and adjust the maximum range of the sonic ranger to approximately 1–2 meters. The "Samples per Point" option on the same screen can be used to track targets of different speeds. Faster moving objects require a faster rate (1 or 2); slower moving objects a slower rate (4 or 5). Turn on the "Continuous Graphing" mode and make a few trial runs to get the knack of operating the system.

Step 2. Release the air track glider from rest at a point near the end of the track. To simulate a potential well, the glider should be attracted to the massive magnet positioned along the side of the air track, accelerate past



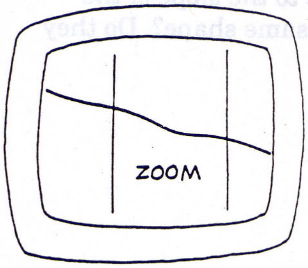
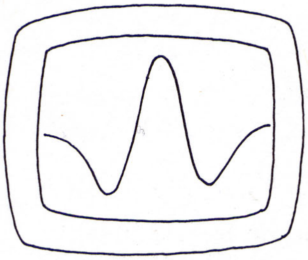


Figure 13.3

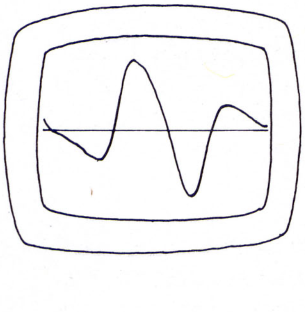
the massive magnet and come to rest on the other side. Have your partner activate the sonic ranger by pressing any key as you release the glider. Press any key to stop the sonic ranger. Use the "Zoom" feature to omit the extraneous data. Your plot should look something like Figure 13.3.

Step 3. After successfully acquiring and zooming the data, go to the "Regraph" screen and select "Data Options." Plot the velocity of the glider as a function of *distance*. Describe the resulting graph and make a printout. If you don't have a printer, make a sketch of the graph below.



Step 4. Return to the "Regraph" screen, and use the "Data Manipulation" option to change the power of the velocity data to make a graph of velocity^2 as a function of distance. Since the kinetic energy is proportional to the *square* of the velocity, a plot of v^2 vs. d is proportional to KE as a function of distance.

Step 5. Since $F = ma$, a graph of force vs. distance is proportional to a plot of acceleration vs. distance. Select "Data Options" and plot *acceleration* as a function of distance. Make a printout of your graph.



Step 6. Configure the magnets along the side of the air track and on the glider so that they simulate an alpha potential. This time the glider should be repelled by the massive magnet. Repeat the entire procedure above but launch the glider with sufficient speed to barely cross the alpha potential without stopping. One way to accomplish this is to select the "Continuous Graphing" mode and let the glider bounce back from the massive magnet until you launch the glider with sufficient speed that it just makes it by the magnet along the air track. When you get a good run displayed on the screen, press any key to halt the graphing *before* the graph reaches the end of the screen. Proceed and manipulate the data as in Steps 3–5.

What happens if the glider is released near the center of the well such that the total energy, E, is less than the maximum potential energy, $U_{\max}$? Try it and see!

Analysis

1. Can you detect any evidence from your plots of non-conservative forces? Explain your reasoning.

2. Qualitatively compare the force vs. distance curve to the slope of the kinetic energy vs. distance graph. Do they have the same shape? Do they agree with the forces the magnets actually produce?