PHYX 106 Lab

Experiment 6 — Measuring Potential Energy

Objective: To measure the potential energy of two repelling magnets as a function of the distance between them, r.

Equipment: Two repelling magnets, an air table, a strobe camera, a magnifying glass, and measuring calipers.

Theory:

When two magnets of the same polarity are placed in close proximity, there will be a force of repulsion between them. Another way to think about the system is that there is potential energy stored in the system when two magnets are brought together. That potential energy will be translated into kinetic energy when one of the magnets is released from rest.

Your job will be to measure the kinetic energy of a magnet released from rest on a nearly frictionless air table after it has been repelled by another magnet.

The Principle of **Conservation of Energy** states that the energy initially in the system will be equal to the energy in the system at all times, so long as no external work is done on the system. If we assume that the potential energy U of the system depends only on the distance r between the magnets, this principle gives:

$$E_0 = E_f \tag{1}$$

$$K_0 + U_0 = K_f + U_f \tag{2}$$

$$\frac{1}{2}mv_i^2 + U(r) = \frac{1}{2}mv_\infty^2 + U(\infty), \tag{3}$$

where $U(r)$ is the potential energy of magnets separated by r, $v_i = 0$ is the initial velocity of the magnet, v_∞ is the final velocity after the magnets are separated by a large distance, and $U(\infty)$ is the potential energy at large separations. When the force becomes zero at large distances, it is conventional to set the potential energy at infinity equal to zero: $U(\infty) = 0$. For this experiment, $r_f = 50$ cm is a good enough approximation of infinity. (In other words, the total force is so small at separations $r \geq 50$ cm that it is negligible compared to the forces at smaller r.) Substituting $U(\infty) = 0$ and $v_i = 0$ into equation (3) gives:

$$U(r) = \frac{1}{2}mv_\infty^2. \tag{4}$$

You will therefore measure $U(r)$ by observing the final velocity of the magnetic puck after being released from a distance of r from a stationary puck.

Preparation:

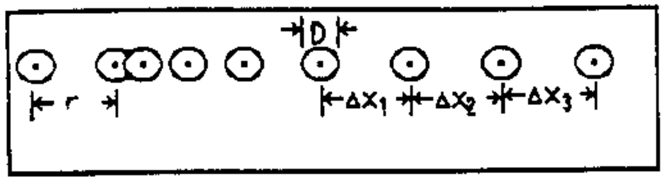

Figure 1: Typical strobe photograph

One magnet is to be bolted to the table. The second is attached to a sheet of glass which is supported by the air table. When released from the vicinity of the first magnet, the second moves across the air table. The motion is observed with a camera/strobe light system. A typical photograph will resemble Figure 1.

Question 1. Record the strobe rate of your camera in your lab book.

Question 2. Use the digital scale to record the mass m of your puck.

Procedure:

In the photo, you will be asked to measure the initial distance r between the two magnets, and three distances Δx_1, Δx_2, and Δx_3 that the magnet travels during a strobe interval Δt_{strobe} when the moving puck is more than 50 cm from the fixed puck. These Δx values should all be equal to within your uncertainties.

Measure the initial separation r and the Δx_i using the optical magnifiers with a centimeter scale. Tape your photo to the table. Due to distortion by the camera and mirror, caution is necessary in measuring Δx. First measure D, the diameter of the puck carefully with the vernier caliper. Then measure the diameter D with the magnifier, along the direction of Δx. Then measure Δx with the magnifyer and convert to "true" separation. You must be careful to measure D and Δx at the same point on the film, and along the direction defined by Δx, as the photo optics can distort shapes.

Once you have at least three good measured values of Δx, find the average of your measurements and its uncertainty. Use this average value and the strobe light time interval to calculate v_∞.

Enter your values of r, v_∞, $\log r$ and $\log v_\infty$ (three significant figures, please) into the table on the blackboard.

Analysis:

We would like to obtain a *model* for the potential energy between these two magnets. A model is an empirical mathematical description of the behavior of a system. Since many potential energy functions in nature have the form $U = Kr^n$, where K is a constant and represents the strength of the force, and n is also a constant relating to how quickly the force decreases (or increases) with distance, we will use this as our model. Substituting $U(r) = Kr^n$ into Equation (4) gives:

$$Kr^n = \frac{1}{2}mv_\infty^2. \tag{5}$$

We can get n out of the exponent by taking the log of both sides:

$$\begin{aligned}
\log\left(Kr^n\right) &= \log\left(\frac{1}{2}mv_\infty^2\right) &(6)\\
\log K + n\log r &= \log\left(\frac{m}{2}\right) + 2\log v_\infty &(7)\\
\log v_\infty &= \frac{1}{2}\log\left(\frac{2K}{m}\right) + \frac{n}{2}\log r &(8)
\end{aligned}$$

Equation (8) is the equation of a straight line of $\log v_\infty$ versus $\log r$, with slope $n/2$ and y–intercept $\frac{1}{2}\log\left(\frac{2K}{m}\right)$. If one plots all of the values from the table on the board of $\log v_\infty$ versus $\log r$, the graph "should" be a straight line of slope $n/2$.

Question 3. Plot the graph of $\log v_\infty$ vs. $\log r$ and determine values for n and $\frac{1}{2}\log\left(\frac{2K}{m}\right)$.

Question 4. From the y–intercept and your measurement of m, determine K. Write down the form of $U(r)$ with your values of n and K.

Question 5. Plot your potential function $U(r)$ on a graph from $r = 1$ cm to 5 cm and discuss the behavior of $U(r)$. Was $U(r) = Kr^n$ a good model for the potential?