Energy Conservation - MBL

In this experiment you will use a cart on an inclined track to investigate energy conservation.

THEORY

Objects moving under the influence of conservative forces only suffer no losses of energy by mechanisms such as friction. In this case the object's total energy $E = K + U$ is conserved, where $K = mv^2/2$ is the kinetic energy and U is the potential energy. An example is a mass m near the Earth's surface, moving under the influence of the Earth's gravitational force only. $E = K + mgh$ is a constant where h is the height of the particle with respect to some convenient zero level.

In many cases there are non-conservative forces (like friction) acting, but the work W done by any non-conservative forces is built into the Law of Conservation of Energy:

Law of Conservation of Energy: $K_i + U_i + W = K_f + U_f$ (1)

Where the subscripts i and f represent initial and final values.

A conservative force and the potential energy associated with that force are related by:

$$\Delta U = - \int \mathbf{F} \cdot \mathbf{dx} \qquad (2)$$

For our purposes we can interpret the equation as stating that the magnitude of change in potential energy is the area under the graph of force versus position. We'll use this idea to determine the potential energy associated with two sets of repelling magnets, one set embedded in a cart and the other attached to a force sensor.

In this experiment the object is to study force and potential energy for a system consisting of two sets of magnets, one fixed in position, oriented so they repel one another. You will then use equation (3) to predict the equation for the potential energy associated with two interacting magnets. Part III of the experiment, where you verify your prediction, involves rolling the cart down the inclined track. If no energy is lost to friction, which may not be entirely true, the total mechanical energy is conserved. The cart is released from rest, so the total energy E is equal to the initial gravitational potential energy and also equal to the sum of the kinetic energy K, gravitational potential energy U_g, and magnetic potential energy U_m at any point along the track. U_m is therefore:

$$U_m = E - U_g - K \qquad (3)$$

APPARATUS

❏ Computer and interface
❏ Cart with magnetic bumpers
❏ Motion sensor

❏ 2.2-meter track
❏ Force sensor with magnetic bumpers
❏ Ruler, and bar to tilt the track

PROCEDURE

NOTE: The magnets inside the cart and mounted on the force sensor have strong enough fields to destroy the magnetic memory of computer disks; **please keep the magnets away from any disks!**

Part I – Preparing to take measurements.

1. Initially, the track should be level. Check this by setting the cart on the track. If it rolls one way or the other, level the track using the adjustable feet on the track supports.

2. Make sure the switch on the force sensor is set to 10 N, and not 50 N.

3. You can use the ruler on the track to measure position. Choose a point 80 – 100 cm from the motion sensor as the zero position. This will be where the front of the magnets on the force sensor will be located, but first move the force sensor along the track away from the motion sensor and well beyond your zero point. Now position the cart so that the end furthest from the motion sensor is even with the zero point. Move it an additional 1 mm past the zero point away from the motion sensor. This accounts for the fact that the magnets in the cart are about 1 mm away from the front of the cart. From the Experiment menu, select Zero, and choose "Zero Distance". You should hear a series of clicks from the motion sensor as it measures the cart's position. Make sure the cart is stationary, and nothing is between the cart and the motion sensor, when the zeroing is going on.

4. Now move the cart well away from the zero point, and slide the force sensor back up the track. Position it carefully so the front of the magnets are even with the zero point. Make sure it does not move from this position for the rest of the experiment.

5. With the cart well away from the force sensor. From the Experiment menu, select Zero, and choose "Zero Force". After doing this make sure the fluctuations of the force readings are centered on zero.

Part II – Measuring force as a function of distance.

1. Place the cart on the track between the motion sensor and the force sensor, and position it so there is about a 25-cm gap between the cart and the force sensor. Hit the ▶Collect button to begin collecting data, and then smoothly move the cart toward the force sensor. Hit the ● Stop button when the cart is **about 2 cm** from the sensor (the computer is set to record for 10 seconds, so it may not be necessary to stop it recording). Repeat this until you get a reasonably smooth curve showing force as a function of distance.

2. Check the data carefully. When the cart is far from the force sensor the force readings may be small positive or negative values. Because you zeroed the force sensor previously, this should surprise you – the readings should fluctuate around zero. The reason they don't is that there is often some interference when both the motion sensor and force sensor are recording simultaneously.

The small offset you observe is a good example of a systematic error – all the force readings are consistently high or low. You should correct this by creating a new "Corrected force" column. From the Data menu select "New Column" and then "Formula". Enter the name of the new column, an abbreviated version of the name, the units, and then select the Definition tab. Set up the equation by choosing "Force" from the Variable pull-down menu, and then subtracting off the average value of the force readings you obtained when the cart was far from the force sensor. For example, if your force data fluctuated from -0.011 N to -0.017 N, your formula for Corrected force should read "Force" + 0.014

Question 1: Another thing you should notice about the force readings is that they are quantized, meaning that they can take on particular values, all separated by a small increment. What is the smallest increment separating the readings? The uncertainty in each measurement is half of this increment. What is the uncertainty in the force readings?

We'll come back to the force versus distance graph later, but now let's look at energy conservation.

Part III – Energy conservation.

For this part of the experiment you will incline the track and allow the cart to roll down the track toward the force sensor.

1. Place the bar under one set of legs of the track, and hold the cart at rest 20 – 40 cm from the force sensor. The exact distance doesn't matter, but you should release it from the same point every time. Hit the ⏸️ Collect button to start recording data and then release the cart. The track should be tilted so the cart rolls toward the force sensor! Stop the cart when it changes direction (if you don't do this the graphs you display later could be rather confusing). If you're really clever you can even time it so the computer stops recording data at just the right instant so the graph shows only the data up until the moment the cart is brought instantaneously to rest by the force sensor.

2. The software should already have a column for "Kinetic Energy". To see this instead of the force graph, click on the y-axis label which should bring up a box showing the different columns. Check what you want to display and un-check what you don't want. You may need to scroll down to see the full list of columns. The kinetic energy graph will probably fluctuate quite a bit. This is because the speed is obtained by differentiating the position, and that introduces some error. Squaring the speed then amplifies these errors.

3. Create a new column for the gravitational potential energy of the cart. The expression should be in terms of the distance measured along the track, with zero corresponding to the zero point, where the magnets on the force sensor are located. The simplest way to do this is to use $h=X\sin(\theta)$, where X is the distance measured by the force sensor, and $\sin(\theta)$ is stated as the ratio of two lengths you measure from your apparatus.

4. Create a column showing the sum of the cart's kinetic energy and its gravitational potential energy. Look carefully at the result.

Question 3 –When you look at the sum of the kinetic energy and the gravitational potential energy, what is the general behavior when the cart is far from the force sensor? What happens as the cart gets very close to the force sensor? Where is the energy going?

5. Create a new column showing the total initial energy minus the sum of the kinetic and gravitational potential energies (see equation 3). Note that the total initial energy is the gravitational potential energy at the point where you release the cart – you should read that off the graph and put it in the equation as a number. Record the peak value of this new graph.

Question 4 – What does this new graph represent?

6. Now view the graph of "Corrected force" versus distance. Click-and-drag with your mouse to select the entire graph, and then click the Integrate button, ☑, to determine the area under the force vs. distance graph.

Question 5 – Compare the area under the curve to the peak value you recorded from the graph in step 5. Are they similar? Why should you expect them to be similar?

Question 6 – Your two values may not agree exactly. One possible reason is that some of the cart's energy will be lost to friction, which we have not accounted for. If you do account for friction, will the agreement between your two values be better, worse, or unaffected?

7. Try to set up a new column estimating the energy lost to friction to see if you are correct. This takes some thought, but is definitely worth the effort. You'll need to estimate a value for the coefficient of friction, but you can use the energy graphs to guide you.

Question 7: Comment on the applicability of the Law of Conservation of Energy in this experiment.