Physics 6L, Summer 2008
Lab #5: Conservation Laws

Introduction:
So far in Physics 6A, you have learned about two major conservation laws: Conservation of Energy, and Conservation of Momentum. You will be running two experiments tonight, both of which explore these conservation laws in different combinations.

Materials -- Please read before starting lab, to avoid destroying materials.
The main materials you'll be using for this lab are a long strip of foam board and a blackboard eraser, set up to act as a sort of "sled" that slides along the foam board. The foam board has lines marked on it every ten centimeters, for easier distance measurements.

You will also have a photogate to measure the sled's velocity -- it is fitted with a paper flag to trip the photogate, much like the gliders that you used in the Dynamics lab in week #2. Finally, you will have the same set of ramps and steel marble that you used in last week's Forms of Energy lab. A plastic cup is attached to the eraser/sled thingy, and serves to catch the marble when it collides with the sled in Experiment #2.

The coefficient of kinetic friction $\mu_k$ between the foam board and the eraser sled will play a major role in both parts of today's experiment. Because $\mu_k$ is so important, please read and remember the...

Two important things to know about the materials:

Thing #1:
Never put any sticky tape on the front surface of the foam board, where the sled is meant to slide across it. The rough area left behind when you remove the tape will cause a major change in the coefficient of kinetic friction, and make it impossible to get sensible results. Even pen or pencil marks can dent the board and change $\mu_k$...so if you need to mark the board for any reason, use a felt tip pen or a very light touch.

Thing #2:
This one used to drive me crazy, until a Phys 6L student from an earlier quarter figured out what was going on. The coefficient of friction between the eraser and the foam board depends strongly on which way the fibers of eraser felt are "combed".
To make sure your eraser doesn't mysteriously change values of $\mu_k$ halfway through the experiment, please take your eraser and run it along the foam board a dozen or so times, in the same direction it will travel during your experiments. It might be wise to repeat this procedure a couple of times during the day's experiments.
Experiment #1: Energy Conservation and Nonconservative Forces

In this experiment, you will investigate the role that nonconservative forces such as kinetic friction play in energy conservation. You will slide your eraser down an inclined plane made of foam board, and deduce the amount of mechanical energy converted to heat (thermal energy) due to kinetic friction. From this result, in turn, you can deduce the coefficient of kinetic friction $u_k$ between the foam board and the eraser.

Step 1:
Make sure you are familiar with the quirks of the materials you will be using, as described above in the "Materials" section. The foam board is easy to damage, and if you fail to "comb" the eraser felt along the foam board, you will get crazily inconsistent results throughout this lab.

Step 2:
Use your piece of foam board to build an inclined plane. You want the board tilted at an angle of at least 25° to the horizontal. (At a smaller angle, static friction might prevent the eraser from beginning to slide.) Anchor the foam board so that it makes a straight line (i.e., does not curve or sag in the middle) and so that the board does not flex or vibrate when you slide the eraser down it.

The exact engineering details are left to your ingenuity -- you will have plenty of materials to work with. Again, though, remember not to put any tape or heavy pen marks on the top surface of the foam board.

Fig #1: Design & build an inclined plane.
Step 3:
Measure the foam board's angle $\theta$ to the horizontal. You can do this to reasonable accuracy with a protractor, but you should be able to do a much more accurate job with meter sticks and a little trig -- see if you can figure out how!

Also measure the eraser's mass $M$, and the width $w$ of the eraser's flag.

Step 4:
Choose a release point on the foam board; you will release the eraser from rest at this point. Somewhere further downhill from there, set up a photogate to measure the eraser's speed after it has slid downhill a distance $L$. Measure $L$.

Advice: Do a slow-motion trial run or two, moving the eraser by hand from the release point through the photogate. Make sure of three things:

#1) Be sure that the eraser can slide freely through the photogate without touching any wires or other obstacles.
#2) Make sure that the photogate timer starts running when the eraser's flag first enters the photogate beam, and stops running when the flag exits the beam.
#3) Make sure that the distance $L$ that you have measured is the distance that the sled moves, from the release point until its flag is centered in the photogate. This is probably not the same as measuring the distance from the release point to the photogate itself.

Fig. 2: how to measure $L$. 
Step 5:
Release the sled from rest at your chosen release point, and let it slide down through the photogate. If the sled doesn't move when you release it, then static friction is probably the culprit. You may need to tilt the track at a greater angle, although giving the sled a very small nudge to get it started may be quicker, and will not throw off your results too badly.

The photogate will record the time it takes for the sled's flag to pass through the beam. Using the same logic you used in the Dynamics Lab (Lab #2) and the Forms of Energy lab (Lab #4), calculate the eraser's speed as it passed the gate.

Step 6:
Using your result from step 5, calculate the amount of kinetic energy the sled gained while moving from its release point (Point A in Fig. 2) to the measurement point (Point B).

Also calculate the potential energy that the eraser lost while moving from point A to point B. (You will need to find the sled's vertical drop, which will require some simple trig, but no measurements that you haven't already taken.)

These two results did not come out equal to one another. Why not?

Step 7:
Using your results from step 6, calculate the work done by kinetic friction as the eraser moved from point A to point B. This, in turn, should allow you to calculate the force of kinetic friction acting on the eraser.

Step 8:
Calculate the coefficient of kinetic friction between the eraser and the foam board.

(Hint: you can take as given a result you have derived several times before for inclined plane problems such as this: The normal force acting on the sled is equal to \(mg \cos(\theta)\), where \(\theta\) is the angle between the track and the horizontal.)

Step 9:
The coefficient of kinetic friction should depend only on the nature of the two materials in contact -- not on their speed or on the forces between them. Repeat your measurements, using different sliding distances \(L\) and/or different track angles \(\theta\).
Did $\mu_k$ remain reasonably close to the same value? Identify and explain any sources random or systematic uncertainty that could explain any discrepancies you see.

**Step 10:**
Record your average value for $\mu_k$ on the blackboard. (You lab instructor might set up a chart for different groups' values.) How does your value for $\mu_k$ compare to those measured by other groups?

**Experiment #2: Momentum Conservation**

In this experiment, you'll be investigating a one-dimensional, (nearly) inelastic collision between your eraser and a steel marble. To propel the marble into the eraser, you'll use the same ramps you used in last week's lab (Forms of Energy):

Frame A: Before Collision

![Frame A](image)

Frame B: After Collision

![Frame B](image)

To find the ball's velocity $v_0$ just before the collision, you will re-use some data from last week's lab. Recall that three of the four ramps all launched the marble horizontally, with more or less identical launch speeds.

You may have directly calculated this launch speed last week; at the very least, you took data (the horizontal range and vertical drop of the ball's projectile motion) which can be used to quickly calculate the launch speed.

This week, you will assume that the marble's launch speed $v_0$ is still the same as you measured last week.

**Note:** do NOT use the expected speed which you calculated last week using energy conservation. The punch line of last week's lab was that your expected launch speed was significantly different from the actual launch speed.
**Step 1:**
Measure the mass $m$ of the marble.

You already measured the eraser's mass $M$ in Experiment #1. Using these two masses, and the marble's initial speed $v_C$ derived from last week's data, predict the velocity $v_B$ of the sled and marble in frame B, just after the collision.

*Assume that the collision is inelastic; the marble and the sled move together as one object after the collision. This may or may not be an accurate assumption; you can decide how close to accurate it was after running the experiment.*

**Step 2:**
Place the ramps on your desktop, and secure the foam board strip to the table at the base of the ramp, so that the eraser can slide across the foam board, but the foam board does not budge at all.

*As always, be careful not to put any tape on the front surface of the foam board where the eraser might slide.*

**Step 3:**
Do a trial run. Release the ball from the top of the ramp, let it roll off the base of the ramp and slam into the cup on the eraser. The eraser should recoil and be propelled some distance across the foam board, eventually coming to a stop.

Things to pay attention to:

1. Did the foam board move or vibrate at all when the marble hit the cup? If so, this will distort your results, try to anchor the foam board firmly to the desk.

2. Did the marble and the eraser seem to make a reasonably inelastic collision? If the marble rolled slowly back out of the cup, that's all right, but if it ricocheted back at high speed relative to the cup, then treating the collision as inelastic will be a significant source of systematic error.

**Step #4:**
The last remaining problem is how to measure the eraser's speed just after the collision, to compare it to our prediction from Step #2.

We could try to use the photogate, but let's try something different: we already know the coefficient of kinetic friction between the eraser and the foam board (from Experiment #1), so we should be able to deduce the eraser's speed at point B from the distance it slides before coming to rest at point C (shown in Fig. 4 below.)
So do a real run, and measure the distance $x$ that the eraser slides after the collision. In fact, it is probably a good idea to make several runs and average the results. How great is the variation from run to run?

**Frame B: Just after collision**

![Diagram of Fig 4B]

**Frame C: After Sled Stops**

![Diagram of Fig 4C]

**Step #5:**
Recall that you know the coefficient of kinetic friction between the eraser and the foam board -- you measured it in Experiment #1. Use this to calculate the force of kinetic friction acting on the sled as it moved across the level foam board in this experiment. *(Hint: What is the normal force, now that the foam board is level?)*

Now, using the force of friction you just calculated, find the work done by kinetic friction as the sled moves from point B to point C.

**Step #6:**
Using the usual relationship between work and energy, you can now deduce the kinetic energy of the eraser at point B, and in turn can find the sled's measured velocity $v_B$ at point B.

How does this measured velocity compare to the prediction you made using momentum conservation in Step #1?

Record your predicted and measured values of $v_B$ on the blackboard; again, your lab instructor might have a chart set up on the board to help compare different groups' results.

Identify and explain the main sources of systematic and/or random uncertainty affecting this experiment. Do these sources of uncertainty explain any discrepancy between your predicted and observed values of $v_B$?
**Pre-Lab Questions:**

#1) Suppose you are doing Experiment #1 from this lab -- the inclined-plane experiment. You have just finished Step #5, and have made the following measurements (which may or may not be realistic for the actual lab):

- Angle of Inclined Plane: $\theta = 30^\circ$
- Eraser sled's mass: $M = 100$ kg
- Sled's flag width: $w = 5.00$ cm
- Distance traveled from start to photogate $L = 40.0$ cm
- Time read from photogate: $t = 0.0400$ s

Using these measurements, run through the calculations described in Steps 6 - 8 of Experiment #1, culminating in a calculation of the coefficient of kinetic friction $\mu_k$.

#2) Now you are doing experiment #2, Step 1. Still using the same sled and foam board from Pre-Lab Question #1, you make the following measurements:

- Mass of steel marble: $m = 0.200$ kg
- Speed of marble before collision (from last week's data): $v_0 = 1.20$ m/s

Assume the marble and sled collide, and move together as one object after the collision. Predict the velocity $v_B$ of the marble and sled after the collision.

#3) You now make an actual run of Experiment #2 (Step 4). After the collision, the eraser slides a distance $x = 10.0$ cm across the foam board. Run through the calculations described in Steps 5 and 6, and find the eraser's measured post-collision velocity $v_B$.

How does this measured value of $v_B$ compare to the predicted value from Pre-Lab Question #2?