Experiment 10  
Conservation of Energy

In this experiment you investigate and verify energy conservation in the absence of friction. A rolling cart with low friction wheels and bearings is used.

Preliminaries.

The work-energy theorem can be used to simplify the analysis of many dynamic systems. Consider the system consisting of a cart of mass $M$ on an inclined track connected to a small hanging mass $m$ by a light string over a pulley, as shown in Figure 1. Note the “flag” (small rectangle) on top of the cart.

![Figure 1. Experimental setup](image)

When the small mass is allowed to drop, the cart is pulled up the incline. If there are no significant frictional losses in the system then the motion can be completely analyzed in terms of the changes in gravitational potential energy and kinetic energy. The hanging mass $m$, which falls a distance $\Delta y$, loses potential energy $\Delta U_{grav}$ according to

$$\Delta U_{grav} = mg\Delta y,$$

where $g$ is the acceleration due to gravity and the minus sign indicates energy loss.

This lost energy reappears as an increase of kinetic energy of both masses and increased potential energy of the cart. The change in kinetic energy $\Delta K_{tot}$ of the masses, originally at rest, moving at speed $v$ is given by

$$\Delta K_{tot} = \frac{1}{2}mv^2 + \frac{1}{2}Mv^2,$$

where the first term is for the hanging mass and the second for the cart. The cart, which rises a distance $\Delta Y$ as it moves up the track, gains potential energy $\Delta U_{GRAV}$ given by

$$\Delta U_{GRAV} = mg\Delta Y.$$

The measurement of cart velocity is performed at a photogate placed near the top of the track. As a cart rolls past a photocell the flag it carries interrupts an infrared beam, and this in turn starts an electronic timer displayed on the computer. The timer stops once the beam is again uninterrupted. The timer reading, $\Delta t$, is the time the cart needs to roll a distance equal to the width of its flag, $\Delta w$. The cart's average velocity while blocking the photocell is thus $v = \Delta w/\Delta t$.

Be careful! A common mistake is to set $v=(x-x_0)/\Delta t$. This is wrong! This quantity has no physical meaning since $\Delta t$ is not the time it takes the cart to travel distance $(x-x_0)$.

The smaller the width of the flag the closer the computed value of $v = \Delta w/\Delta t$ approaches the instantaneous final velocity of the cart.

Procedure.

- Prepare the timer. Turn on the computer and double-click on the icon on the desktop called photogate. A display appears and the timer is ready to be activated.

- Level the track using a long carpenter's level. Place a spacer under one set of the track's legs. Use trigonometry to determine the track's slope angle, $\theta$.

- Place a photogate near the upper end of the track, leaving enough room beyond the gate to stop the cart. Be sure that the cart’s flag passes completely through the gate before the small mass hits the floor.
• Determine and record the hanging and cart masses.

• Determine the location of the gate by moving the cart by hand very slowly past the photocell and record the position of the cart when the timer just starts and also when the timer just stops. Any point on the cart (such as the rear edge) can be used as a marker to read the position on the scale mounted on the track's side. The difference between timer start and stop points is the width \( \Delta w \) of the flag. The midpoint between these points is the location of the photocell. Determine and record the gate position and flag width.

• Choose a starting position for the cart, measured using the same part of the cart that was used previously. Do several trial runs from the same \( x_0 \) to make certain that the photogate timer readings \( \Delta t \) give consistent results. Take the average of the trials as the best value. Take the spread in the timer readings as the uncertainty in \( \Delta t \).

• Determine \( v \), the average speed of the cart as it passes the photocell: \( v = \Delta w/\Delta t \) as it is the motion of the flag that is being timed. Since the flag width is small, the average speed approaches the instantaneous speed of the cart through the gate.

• Determine and record the vertical rise \( \Delta Y \) of the cart from the distance traveled along the track and the track angle.

• Calculate the total change in potential energy \( \Delta U_{\text{tot}} = \Delta U_{\text{GRAV}} + \Delta U_{\text{grav}} \) and the total change in kinetic energy \( \Delta K_{\text{tot}} \) for the system.

• Calculate the change in the total energy of the system \( \Delta E_{\text{tot}} = \Delta U_{\text{tot}} + \Delta K_{\text{tot}} \).

Questions (Answer clearly and completely).
1. Is your result consistent with conservation of energy? If not, why not?

2. The rolling friction of the cart on the track is not accounted for in your calculation. If friction is accounted for, is total kinetic energy gain bigger than / same as / smaller than the total potential energy loss?

3. Suppose you repeat the experiment so that the cart moves twice the distance before it passes through the photogate. Compared with your experiment, is the final speed of the cart less / same / greater? If it is changed, is it different by a factor of two? Answer this question also for the following physical quantities: total change in kinetic energy, total change in potential energy, total change in mechanical energy, energy lost due to friction.

4. Suppose that you place the spacers under the wrong track legs so that the cart is pulled down the hill instead of going up the hill. Write down the algebraic equations in terms of measured quantities depicting conservation of energy for this case.