Atwood’s Machine & Energy

Goal: To measure kinetic, potential, and total mechanical energy in an Atwood’s machine and to test the law of conservation of mechanical energy.

Lab Preparation

A simple Atwood’s machine consists of a couple of masses hanging over a pulley as shown in Figure 1.

![Figure 1](image)

If $m_1 > m_2$, then, when $m_2$ is released the masses will move. This movement will change the kinetic and gravitational potential energy of the masses. Even though the individual energies change, the total mechanical energy of the system should stay the same if there are no non-conservative forces (i.e. friction).

Recall the following relationships for energy:

- Kinetic energy: $K = \frac{1}{2}mv^2$
- Gravitational potential energy: $U = mgy$
- Total mechanical energy: $E = K + U$
- Work done by non-conservative forces: $W_{nc} = E_f - E_i$

Once again consider Figure 1. You should be able to answer the following conceptual questions with increase, decrease, or remains the same. The reference level will be the ground as indicated by $y=0$.

- As $m_2$ rises, what happens to its gravitational potential energy?
- As $m_1$ falls, what happens to its gravitational potential energy?
- As the masses move what happens to the total gravitational potential energy of the system?
- As $m_1$ falls, what happens to its kinetic energy?
- As $m_2$ rises, what happens to its kinetic energy?
- As the masses move what happens to the total kinetic energy of the system?
- Assuming no friction, as $m_2$ rises and $m_1$ falls, what happens to the total mechanical energy of the system?
**Equipment**

Once again an ultra sonic motion detector will be used to measure the speeds and positions of the masses. The pulleys used in this lab have a low friction and very small mass.

**Procedure**

*Please be careful with the hanging weights and make sure they do not fall on the motion detector. Make sure you use the cage to protect the detector.*

I. Determining energy relationships

The system you will study is shown below in Figure 2. It is comprised of two masses and a string passing over a pair of pulleys.

![Diagram of the system](image-url)

**Figure 2**

Before proceeding with data collection, you need to develop energy relationships for the following questions. Use Figure 2 to help. All of your answers should be in terms of the variables $m_1$, $m_2$, $y_1$, $y_2$, $v_1$, and $v_2$.

A. What is the total gravitational potential energy of the system?
B. What is the total kinetic energy of the system?
C. What is the total mechanical energy of the system?

You should be able to predict how the total kinetic energy and total potential energy change as time goes by. Sketch a graph of your prediction of how total kinetic energy changes with time and how total potential energy changes with time for this system.
II. Entering equations

You will want to enter the relationships you developed into the computer. Before entering these in you need to think about how \( v_1 \) and \( v_2 \) are related and how \( y_1 \) and \( y_2 \) are related. Since the motion detector will only measure \( m_2 \), you need to be able to enter your relationships in terms of the variables \( y_2 \) and \( v_2 \) only. Answer the questions on your worksheet and rewrite your total mechanical energy relationship in terms of \( m_1, m_2, y_2, \) and \( v_2 \).

Open the “atwoodenergy” file. Create new columns to calculate the total gravitational energy \((U)\), the total kinetic energy \((K)\), and the total mechanical energy \((E)\). The masses that we will use are \( m_1 = 250 \text{ g} \) and \( m_2 = 200 \text{ g} \). Note: use the “parameters” to define and enter in your constants.

III. Set-up

Careful alignment of pulleys in a single plane is necessary for helping eliminate friction and collecting reliable data. **Do not** assume they are already properly aligned.

Use masses \( m_1 = 250 \text{ g} \) and \( m_2 = 200 \text{ g} \) (note: the hanger is 50g). Practice letting the masses run without the motion detector present. **You must step in and ensure that \( m_2 \) does not collide with the pulley and catch any masses that may fall off the hanger.**

Once you have the rhythm down, put the motion detector and protective basket in place. Remember the motion detector can sense false echoes from nearby objects so be sure it is aligned directly beneath \( m_2 \).

In Figure 2, the reference level is chosen to be when the masses are at equal heights relative to the ground. By default, when using motion detector, the origin for distance measurements is at the motion detector. To set the zero level to be as shown in Figure 2 you can set the masses at equal heights and use the zeroing function on logger pro to set the new reference level.
IV. Data collection
Set \( m \), about 50 cm above the ground. You should track the motion of \( m \) as it travels about 1 meter from its starting point. Make several trials to achieve consistent and high quality results. Once you are satisfied with your results print a copy of one trial of the graph to include with your report. Record the approximate distance traveled by the mass.

V. Analysis – Investigating energy changes
Examine your energy vs. time graph and answer the following questions.

1. How does your graph compare to your predicted graph from part I? Comment on any major differences.
2. Does your mechanical energy \( (E) \) stay the same? If it does then your data supports the conservation of mechanical energy. If it does not stay constant where did the energy disappear too?

Change your graph’s horizontal axis from time \( (t) \) to position \( (y) \). You may need to adjust the scales. Your graph should now show you how your energies change with position. Print a copy of this graph to attach to your lab report.

Use this graph to help determine \( \Delta E \), the total change in mechanical energy \( (E_f - E_i) \). Recall that \( E_f = K_f + U_f \) and \( E_i = K_i + U_i \). Use the coordinate readout tool to determine these values from your graph, record them in a table (also record \( y_i \) and \( y_f \)), and then find \( \Delta E \).

Answer the following questions.

3. How should the change in the total gravitational potential energy \( (\Delta U) \) compare to the total change in kinetic energy \( (\Delta K) \)? Compare and comment on these two values.

4. Do you expect the total mechanical energy \( E \) to increase or decrease as a consequence of friction as the system moves? Is the sign on \( \Delta E \) consistent with non-conservative work done by friction?

5. Assuming that any energy lost, \( \Delta E \), is due to friction we can estimate the average magnitude of the frictional force. Recall that \( W = Fd \cos \theta \). For our case \( W_{nc} = \Delta E = fd \cos \theta \) (where \( d \) is how far the masses move). Use this relationship to determine the frictional force \( f \).

*When finished with your lab clean up your lab station and make sure you pick up all the equipment off the floor.
Homework

Rotating pulleys have mass and also move, thus they have kinetic energy. This contribution of kinetic energy was neglected during your lab. If this were included, would the total mechanical energy more nearly remain constant? Explain.

To find the kinetic energy of the pulleys you need to know a little bit about rotational kinetic energy (you can reference that in your textbook). The kinetic energy for a rotating object is \( K = \frac{1}{2} I \omega^2 \) where \( I \) is called the moment of inertia and \( \omega \) is the angular speed. The moment of inertia in this case is \( I = \frac{1}{2}mr^2 \) where \( m \) is the mass of the pulley (about 5.5 g) and \( r \) is the radius of the pulley. The angular speed is related to linear speed by \( \omega = v/r \), where \( v \) would be the final speed of the masses and \( r \) is the radius. Combine these relationships to find the kinetic energy of one pulley and then compare the kinetic energy changes of the pulleys to \( \Delta E \) (note: if you combine the equations correctly you should not have to find the radius of the pulley). Also, you should be able to determine your final speed from your final kinetic energy.

What do your numbers suggest contributes more to \( \Delta E \), the rotational kinetic energy of the pulley or the friction in the pulley? Explain.