Introduction

A pulley is a considered a simple machine – something without a motor that is capable of redirecting and/or amplifying a force. In addition to pulleys, other simple machines include inclined planes, screws (a continuous curving inclined plane), levers, wedges, and wheels on axles. Pulleys are often used singly – to redirect a force - and in combinations to amplify a force.

In the simplest forms of simple machines, friction is assumed to be absent; if energy is conserved using a machine, then the work put into the machine must be equal to the work done by the machine (on a load):

\[ \text{Work in} = \text{Work out} \]

For example using a pulley, the work put into the machine by you pulling on a rope (the applied force) would be equal to the work by the pulley on a load (lifting a heavy box of physics books by ropes attached to the pulley). If the applied force is constant, the work that you put into the machine equals the Force that you exert on the rope, \( F \), times the distance that you pull it, \( d \):

\[ \text{Work in} = F \cdot d \]

The work done by a pulley equals the weight it lifts, \( W_{\text{load}} \cdot g = W_{\text{load}} \) times the height it lifts it, \( h \). (Note that \( h \) might not be equal to \( d \), as you’ll soon find out!) So, for an ideal pulley:

\[ \text{Work out} = W_{\text{load}} \cdot h \]

There usually is some friction present in any real pulley, so we would expect that some of the work that we put into the machine would be dissipated by friction (as heat energy, mostly). So for a real pulley,

\[ (F \cdot d) - \text{Work done against friction} = W_{\text{load}} \cdot h \]

And, in general for real pulleys, \( F \cdot d \geq W_{\text{load}} \cdot h \)

The efficiency of a pulley (or any simple machine) is the ratio of useful work done by the pulley (\( m_{\text{load}} g h \)) to the work you put in (\( F d \)), and efficiency is usually expressed as a percentage:

\[ \text{Efficiency of a Pulley System} = 100\% \cdot \left( \frac{W_{\text{load}} \cdot h}{F \cdot d} \right) \]

The mechanical advantage of a machine is the ratio of the output force to the input force, or:

\[ \text{Mechanical Advantage} = \frac{W_{\text{load}}}{F} \]
Lab Goal:
- Explore conservation of energy applied to pulleys, and calculate mechanical advantage

Materials
- Assorted single, double, and triple pulleys
- Table rod stands, support rods, clamps
- Cord
- Weight Sets and Balance Scale
- Rulers
- Force gauges, Spring Scales, and/or Vernier Force Sensors and LabPro’s connected to computers

Lab Procedure
1. Set up the first system as shown; make sure the support rod is clamped tightly to the table rod. Suspend a single pulley from the support rod with a short piece of string.

2. Tie a loop in another piece of string to hold the suspended mass (the load), and thread the string through the pulley. Start with a mass of at least 100 grams including the mass hanger.

3. Tie the other end of the string to the spring scale or force sensor.

4. Lift the mass. Record in a data table you create, using an appropriate number of significant digits and also noting your measurement uncertainties, the following values:
   a. The mass lifted, \( m \) (in kilograms)
   b. The vertical height the mass was lifted by the pulley, \( h \)
   c. The force required, \( F \), you read off the spring scale as you lift the mass (or from the computer display of the Force Sensor)
   d. The distance you pulled the spring scale as you lifted the mass, \( d \).

5. Calculate:
   a. The weight of the mass you lifted, \( W = mg \)
   b. The work done in lifting the mass, \( W \cdot h \)
   c. The work done by the pulley, \( F \cdot d \)
   d. The efficiency of the system
   e. The mechanical advantage

6. Repeat this for two additional masses, adding at least 200g, and then 300g, for a total of three trials.
7. Repeat this process for the second system shown; note here how many ropes are holding up the mass!

Again, record the same values listed above in steps 4-5 in a similar data table you create.

Do three trials with this experiment as well, with similar loads.

8. Repeat again for the combination of two single pulleys, as shown; note again how many ropes are holding up the mass (including the one you are pulling!)

Again, record the same values listed above in steps 4-5 in a similar data table you create.

Do three trials with this experiment as well, with similar loads.

9. Create your own version of the experiment using at least one double or triple pulley, or even two double or triple pulleys. Look at images b, c, and d in the diagrams to the right to see how they must be threaded.

Make a sketch (or take a picture!) of the system you used.

Again, record the same values listed above in steps 4-5 in a similar data table you create.

Do three trials with this experiment as well, with similar loads, and try using an even larger load for a fourth trial.
10. Answer in your lab report the following questions:

a. What is the uncertainty in your results for mechanical advantage and efficiency?

b. What is the relationship between the number of supporting ropes and the mechanical advantage?

c. Why would someone want to use a single fixed pulley if there is no mechanical advantage?

d. As the number of pulleys increase and the interconnection becomes more complex, how does the applied force change? What about the length over which that force is applied?

e. How much friction was present in the pulley systems? Is there a trend in that value as the load increased? Would you expect there to be?

Sample Data Table (you should make your own!)

Description of the Pulley System: Single fixed pulley (attached to the support bar)

<table>
<thead>
<tr>
<th>Mass (±/- kg)</th>
<th>Height raised h (±/- cm)</th>
<th>Force required F (±/- N)</th>
<th>Distance pulled d (±/- cm)</th>
<th>Load Weight Lifted W (N)</th>
<th>Work done by the pulley to lift load W · h</th>
<th>Work done on the pulley F · d</th>
<th>Efficiency</th>
<th>Mechanical Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.150 ±/- 0.002</td>
<td>20 +/- 0.5</td>
<td>1.6 +/- 0.1</td>
<td>20 +/- 0.5</td>
<td>1.47 +/-</td>
<td>0.29 J</td>
<td>0.32 J</td>
<td>91%</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Additional References:


