PhyzLab: An Uphill Climb
an investigation of force, distance, and work

• Pre-Lab Questions •
1. As an introduction to concepts in energy, we are going to consider the energy needed for a car to go from a lower elevation to a higher elevation. In other words, the car is to go up a hill to a specific height. But we can arrange the slope of the hill however we like. How should the hill be arranged so that the car burns as little fuel as possible? Should that angle of incline be small, medium, or large? Or—if it were possible—should the car go straight up (90°)? Or is the amount of fuel burned independent of the angle of incline? Explain. Since this is a pre-lab, you are not expected to have a perfectly reasoned correct answer. You are expected to respond based on what you believe right now.

2. Once you have recorded an answer for question 1, consider two cars that travel up a shallow incline:
   • Car A travels 1km at a certain speed
   • Car B travels 5km at the same speed
   a. Why does a car need to burn fuel to climb the hill at constant velocity? (Why can’t it coast indefinitely?)
   b. Which car required the greater force to maintain constant speed while it was moving?
   c. Which car traveled the greater distance?
   d. Which car burned more fuel (used more energy)? Explain.

3. Consider two cars:
   • Car A travels 1 mile along a 10° slope
   • Car B travels 1 mile along a 20° slope
   a. Why do cars burn more fuel going uphill than they do traveling on level ground? (What are they working against?)
   b. Which car required the greater force to maintain constant speed while it was moving?
   c. Which car traveled the greater distance?
   d. Which car burned more fuel (used more energy)? Explain.

4. After answering questions 2 and 3, do you still believe your answer for question 1 or do you wish to change it?
   ___AGREE (No change)   ___CHANGE (Record what you think now in the space below.)
• Purpose •
When going from a lower elevation to a higher elevation, one could choose a steep path or a more gradual path. In this activity you will determine whether or not one of these paths holds any advantage over the other in terms of energy consumption. You have already made a prediction (in the prelab); please keep that prediction in mind as you work through the lab.

• Apparatus •
___ wooden board
___ support rod
___ table clamp
___ three-finger clamp
___ brick (or equivalent)
___ dynamics cart
___ spring scale
___ meterstick
___ plumb line (weight attached to string) or equivalent
___ protractor
___ access to masking tape

• Procedure •
To determine the answer to our question, we might use an arrangement such as the one shown in the Post-Lab Question of this lab. (See diagram.) We would measure the length of each incline and the force required to move the cart up each incline. A simple calculation would then give us our answer. Sadly, we do not have such an arrangement. We do have a board, a brick, a rod, some clamps, etc. What we will do is to arrange inclines with varying steepness. For a given incline, we will mark the place along the board that represents the end of our journey (20cm above the table). We will then measure the length of the incline and the force required to move the cart on it. And then a simple calculation will lead us to our answer.

1. THE LOW ROAD
a. Arrange the apparatus as shown in the diagram above. For the shallow incline, the board should rise above the table at an angle somewhere between 20° and 30°. Measure the angle with a protractor as shown on the diagram below and record it.

θ = ________________

b. Place a strip of masking tape on the top surface of the board along one inclined edge. Using the meterstick and the plumb line, determine the point where the top of the board is 20cm above the table top as shown in the diagram below. (Use the plumb line to ensure that the meterstick is vertical.) Place a mark on the masking tape at that point.
c. Measure and record the distance from the table top to the 20cm high point along the incline as shown in the diagram below.

\[ d = \ldots \]

d. Attach the spring scale to the dynamics cart. The PASCO spring scales attach to the PASCO dynamics carts as shown. (Attaching requires patience and good fine motor skills.) A magnified 3-D view is shown to the right.

e. Pull the cart along the incline. Make sure you are pulling so that the spring scale is parallel to the incline.

\[ F = \ldots \]
2. MEDIUM ROAD
Repeat the procedure described above for an incline between 40° and 50°. Record your data on the table below.

3. HIGH ROAD
Repeat the procedure described above for an incline between 60° and 70°. Record your data on the table below.

4. STRAIGHT UP
Repeat the procedure described above for an incline of 90°. This means pulling straight up (no board needed for this one). Record your data on the table below.

• Calculations •
To answer our original question, we will use the data we gathered and a simple calculation. A quantity called work (abbreviated W) is equal to the product of the force applied and the distance through which the force was applied. In symbols,

\[ W = F \cdot d \]

Work is a measure of the energy used to move the cart up the incline. The incline that required the most work is the one on which we would use the most energy.

• Sample Calculations •
1. If an incline were 47.3cm long and the cart needed a force of 2.38N to keep it moving at constant speed, how much work would be needed? Show the equation, substitute values, and box answer.

2. Use the data you collected for the LOW ROAD incline and show a calculation of the work.

Complete the data table below with your data and calculated work values. Notice that distance is to be recorded in meters, not centimeters.

<table>
<thead>
<tr>
<th>Data</th>
<th>θ (°)</th>
<th>d (m)</th>
<th>F (N)</th>
<th>W ( )*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Low Road</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Med. Road</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. High Road</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Straight Up</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*What are the units for work?
• Analysis and Questions •
Graph your data on the axes on the following page. Make graphs of distance versus angle, force versus angle, and work versus angle. Leave these graphs as scatter-graphs: do not "connect the dots."

A. TRENDS
1. Based on the distance vs. angle graph, what trend—if any—exists between the distance (useful length of the ramp) and angle of incline?

2. Based on the force vs. angle graph, what trend—if any—exists between the required force and angle of incline?

3. Based on the work vs. angle graph, what trend—if any—exists between the required work and angle of incline?

B. DIFFERENCES
1. DISTANCE CONSIDERATIONS
   a. Which path required the cart to move the shortest distance? __Low __Medium __High __Straight Up __Same
   b. Which path required the cart to move the longest distance? __Low __Medium __High __Straight Up __Same
   c. What is the percent difference in distance traveled along these paths?*
   d. Is the difference significant? Why or why not? ___________________________________________________________

2. FORCE CONSIDERATIONS
   a. Which path required the smallest force? __Low __Medium __High __Straight Up __Same
   b. Which path required the greatest force? __Low __Medium __High __Straight Up __Same
   c. What is the percent difference in force required for these paths?*
   d. Is the difference significant? Why or why not? ___________________________________________________________

3. WORK CONSIDERATIONS
   a. Which path required the least work? __Low __Medium __High __Straight Up __Same
   b. Which path required the most work? __Low __Medium __High __Straight Up __Same
   c. What is the percent difference in work required for these paths?*
   d. Is the difference significant? Compare the difference between the most work and the least work. How does this compare to other differences listed above?

• Conclusions •
The question posed in the PURPOSE section of the lab concerned the energy consumption required to go from a low point to a high point. The question was which path required the least amount of work. Work is a measure of energy, so the answer to our question lies in the results calculated for work.

Based on your findings, what is your conclusion?

How does this compare with your prediction (Pre-Lab question 1)?

*The percent difference between two numbers, A and B, is \(|A-B|/(A+B)\) x 200
**Post-Lab Questions**

1. Based on the data you graphed, what would be the distance, force, and work involved in pulling a cart up a 10° incline.

2. Under high-precision laboratory conditions, the following data was collected by noted lab technician, "Thing." (Notice the height—0.200m—to which the cart is to be elevated.)

<table>
<thead>
<tr>
<th>DISTANCE (m)</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
<th>40°</th>
</tr>
</thead>
<tbody>
<tr>
<td>FORCE (N)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WORK (       )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Complete the data table above by writing the correct values in the empty spaces.

3a. If a 60° incline were used, what would the work be? (You won’t need a calculator for this one.)

3b. If a 60° incline were used, what would the distance and force be? This can be calculated. Hint: SOH CAH TOA.

4. Write a general statement that summarizes the relationship—if one exists—between the slope of an incline and the work required to ascend it.

5a. You cannot pick up a piano and put it on a moving truck because you cannot (choose one)
   __ EXERT ENOUGH FORCE TO LIFT THE PIANO
   __ PERFORM ENOUGH WORK TO RAISE THE PIANO

5b. Rolling the piano up a ramp to get it on the moving truck would require you to (choose one)
   __ EXERT LESS FORCE AND PERFORM LESS WORK
   __ EXERT LESS FORCE BUT PERFORM MORE WORK
   __ EXERT LESS FORCE AND PERFORM EQUAL WORK
   __ EXERT EQUAL FORCE BUT PERFORM MORE WORK
   __ EXERT MORE FORCE BUT PERFORM LESS WORK
   __ EXERT MORE FORCE AND PERFORM MORE WORK
   __ EXERT MORE FORCE AND PERFORM EQUAL WORK
   __ EXERT EQUAL FORCE BUT PERFORM LESS WORK

6. In general, what is the advantage of using an inclined plane?