

Name(s) and Alpha(s)

Date

SP211 Lab 5

Work and Energy

Equipment You will need the following equipment to complete this lab. Quantities needed are listed inside of the parentheses.

LabQuest Mini (1)

Screwdriver (1)

Track (1)

Motion Sensor (1)

Cart (1)

Force Sensor (1)

String (1 roll per room)

Table Clamp (1)

Big and Small Rod Holder (1)

Large and Small Rod (1)

500 g Mass (1)

Meter Stick (1)

Racquetball Set (1 per classroom)

2 m stick (1)

You will also need the Vernier Graphical Analysis software, which can be [downloaded here](#) or from the Software Center, and Google Gemini to complete this lab.

Experiment 1: Work and the Inclined Plane

1) Every time you plug a force sensor in or restart Vernier Graphical Analysis, you'll need to calibrate the force sensor. To do this, plug the force sensor into the LabQuest Mini and the LabQuest Mini into your computer. Open Vernier Graphical Analysis and click on the Force button in the bottom right corner of the window, then calibrate. Hang the force sensor on a rod and make sure it is set on ± 10 N. In the "Enter first known value" box, type 0, and click keep. Next hang a 500 g mass from the hook of the force sensor, type 4.9 in the "Enter second known value" box, and click keep.

2) Set up the metal track at an angle approximately 10 to 15 degrees above horizontal. Using trigonometry, calculate the angle the track is at and record it in Table 1 below. Lay the force sensor on the track with the hook facing down the slope. Zero the force sensor. You can do this by clicking on the same Force button in the bottom right corner where you calibrated the force sensor.

Quantity	symbol	Measured Value
Angle of Incline	θ	
Mass of Cart	m	

Table 1: Record the measurements of your experimental setup here. Show your work for inclination angle calculation below!

Work:

3) Measure the mass of the cart and record it in Table 1. Plug a motion sensor into the LabQuest Mini and place it at the bottom of the track.

4) Attach a short string to the front of the cart and make a loop on the other end to go around the force sensor hook. Place and hold the cart about 20 cm from the motion sensor on the track. The force sensor should be lying down on the track or held just above the track so that if you were to pull it upward, the cart would follow the force sensor up the ramp. You want the string between the force sensor and cart to be parallel with the track (see Figure 1).

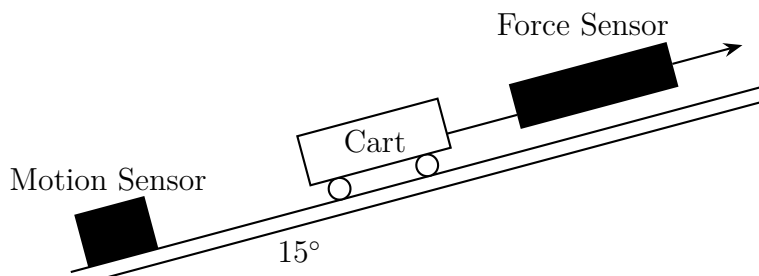


Figure 1: Set up for Experiment 1.

5) Collect data while pulling the force sensor up the ramp at a constant speed (the cart should follow behind at a constant speed). The force sensor should be parallel to the track—it's ok to place the force sensor on the track and drag it up. It may take a couple of tries to get good data.

6) From your force vs. time data, determine the average tension force in the string and record it in Table 2 below. One way to do this is to copy and paste the data taken while you were pulling the force sensor up the track into Google Gemini and ask it to find the average force.

Force	symbol	Measured Value
Tension	F_T	
Gravity	F_G	

Table 2: Record the forces on the cart. Show your work for the force of gravity calculation. Draw a free body diagram for the cart.

Work and Free Body Diagram:

7) Calculate the force of gravity on the cart and record it in Table 2. Draw a free body diagram for the cart below Table 2.

8) Identify the equation that is the mathematical definition of work and use it to answer the following Questions 1 through 3. Then answer the remaining questions.

Question 1: Using the mathematical definition of work, calculate the work done on the cart due to the force of tension (W_T) assuming the cart were pulled 1 m along the track. What angle did you use in this calculation? Show your work.

Question 2: Using the mathematical definition of work, calculate the work done on the cart due to the force of gravity (W_g) assuming the cart were pulled 1 m along the track. What angle did you use in this calculation? Show your work.

Question 3: Using the mathematical definition of work, calculate the work done on the cart due to the normal force (W_N) assuming the cart were pulled 1 m along the track. What angle did you use in this calculation? Show your work.

Question 4: Based on your answers to Questions 1 through 3, what is the net work on the cart ($W_T + W_g + W_N$)? Show your work.

Question 5: Based on the work-kinetic energy theorem, what is the net work on the cart? Show your work. (Hint: You pulled the cart at a *constant* speed.)

Question 6: How do your answers to question 4 and 5 compare to each other? If they do not agree with each other, why not?

CHECK POINT:

Experiment 2: Measuring the Height of the Chauvenet Catwalk

For safety only the racquetball may touch or go on the raised wall. Midshipmen feet shall remain on the walkway!

1) Take the racquetball and a stopwatch (you can use your phone) outside. *Reminder: Take your covers.* One lab partner should take the ball up to the catwalk outside Chauvenet, while the other partner should take the stopwatch to the ground below. Drop the ball from either the height of the catwalk's walking surface or the railing on the catwalk three times, using the same height for all three drops. Record the time it takes the ball to fall for each trial in Table 3.

2) Find the average time it took for the ball to fall and record it in Table 3. For uncertainty on this number (Δt), we will use the average human reaction time.

Time Trials	t_1 :		t_2 :		t_3 :	
t_{avg} :			Δt :		0.25 s	

Table 3: Record the measurements of the ball falling here. Show your work for any calculations below.

Work:

3) Derive an equation that relates how high the catwalk is to the time it took the ball to fall: Using conservation of energy, solve for the height of the catwalk in terms of the

final velocity of the ball. (Don't plug in numbers yet.) Record your work for this below in Question 7. Next, use your knowledge of kinematics to come up with an equation for the final velocity of the ball in terms of the time it took for it to fall. (Hint: The ball should have had no initial velocity.) Record this below and plug it in for the final velocity in the conservation of energy equation you just manipulated. Now, plug in numbers to find the height of the catwalk using the average time the ball fell in Table 3.

Question 7: What is the height of the catwalk?

4) Next we will calculate the uncertainty on the height of the catwalk. The basic error propagation formula is

$$\Delta f = \sqrt{\left(\frac{\partial f}{\partial x} \Delta x\right)^2 + \left(\frac{\partial f}{\partial y} \Delta y\right)^2 + \dots}$$

where Δx , Δy , etc. are the uncertainties on the x and y measurements, and the $\frac{\partial f}{\partial x}$, $\frac{\partial f}{\partial y}$, etc. are the derivatives of the equation that calculates f with respect to the quantities that have uncertainty measurements.

In our case, we have one uncertainty (on the time measurement). So our equation to calculate the uncertainty on the height of the catwalk will only have one term:

$$\Delta h = \sqrt{\left(\frac{\partial h}{\partial t} \Delta t\right)^2} = \frac{\partial h}{\partial t} \Delta t.$$

Take the derivative of the height equation you derived in Question 7 with respect to time ($\frac{\partial h}{\partial t}$). Plug it into the above equation and calculate the uncertainty on the catwalk height.

Question 8: Calculate the uncertainty on the height of the catwalk. Show your work.

Question 9: The actual height of the catwalk is 4.4343 ± 0.0254 m to the walking surface of the catwalk and 5.3086 ± 0.0254 m to the top of the railing. Does your measurement of the height of where you dropped the ball from on the catwalk agree *within uncertainties* to the actual height of the catwalk? If they do not, what are some possible sources of error that may account for the difference?

CHECK POINT:

Experiment 3: Bouncing Ball Energy Audit

In this portion of the lab we will be calculating the energies of a racquetball by observing it bounce several times. We will use your cell phone to record a video that we will later analyze of the ball dropping from a known height and bouncing at least twice.

1) Find a location to conduct this experiment that has plenty of room (e.g. a stairwell, the hallway, etc). Once you have determined where you will conduct the experiment, set up a 2 m stick to establish your drop height. Use a drop height of at least 1.5 m. Set up your phone camera so that it will record the entire 2 m stick while remaining stationary. Record the drop height you are using in Table 4 below.

Bounce	Height
Initial Height	
1	
2	

Table 4: Record the measurements of the ball heights here.

2) Once everything is in position, have one person record the video while the other person drops the ball from the top of the 2 m stick. Past experience suggests red balls are the easiest to pick out and analyze later on the video, but at minimum you want a ball whose color does not blend in with the background of the video. You want the ball to bounce at least twice. So the ball should drop from the initial height, hit the floor, travel up to a new height, hit the floor a second time, and reach a new height before you stop recording.

3) Return to your lab room, measure the mass of your ball, and record it below. Watch your video carefully and record the maximum height the ball reaches after the first and second time it touched the floor in Table 4.

m_{ball}	
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4) Calculate the initial gravitational potential energy of the ball at each of the three heights you recorded in Table 4. Record these potential energies in Table 5. Think about what happens when the ball is at its maximum height and record the kinetic energy it has at those times in Table 5 as well.

Bounce	Potential Energy	Kinetic Energy
Initial Height		
1		
2		

Table 5: Record the potential energy of the ball. Show your work.

Question 10: Using the work-energy theorem, calculate the work done on the ball by external forces during the first and second bounces. This represents energy lost by the ball. Show your work. What are some sources of this energy loss?

CHECK POINT:

Clean Up

Please return your lab station and the drawer of equipment to a clean and organized form. Follow any directions your instructor gives you about where to return equipment to when you are finished with the lab.