


# KPU

## Phys 1100 Online Labs

### Pilot Project

### Spring Semester 2017


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July 2017



### Uniform Circular Motion

mass of IOLab device,  $m = \underline{\hspace{2cm}}$  measured in a previous IOLab activity

time for 30 rotations,  $\Delta t = \underline{\hspace{2cm}}$  measured with IOLab - Force sensor




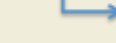
radius of rotation,  $r = \underline{\hspace{2cm}}$  measured with a tape measure

period of rotation,  $T = \underline{\hspace{2cm}}$  calculated from  $T = \Delta t/30$


speed of rotation,  $v = \underline{\hspace{2cm}}$  calculated from  $v = 2\pi r/T$

net force,  $F_{\text{theoretical}} = \underline{\hspace{2cm}}$  calculated from  $F = mv^2/r$

**Compare**

net force,  $F_{\text{measured}} = \underline{\hspace{2cm}}$  measured with IOLab - Force sensor

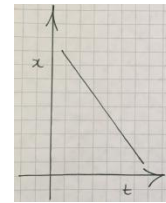
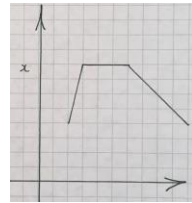
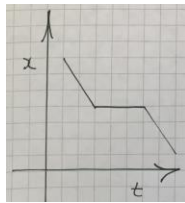
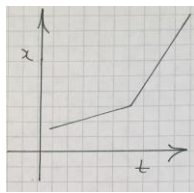


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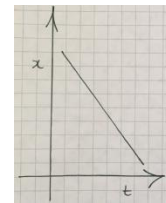
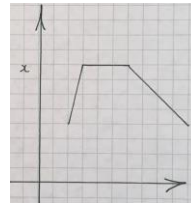
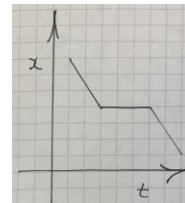
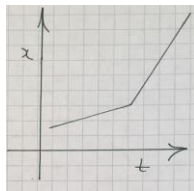
Date:

### Pre-lab 1: Uniform Motion

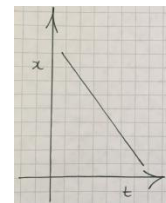
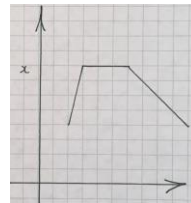
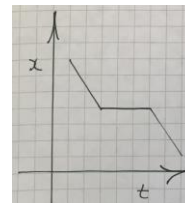
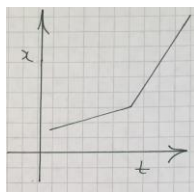
- 1) How can you tell if velocity is constant from a *position-time* graph?
- 2) How is the velocity determined from a linear *position-time* graph?
- 3) Assume the direction to the right is positive. What is the difference between the *position-time* graphs of a cart moving to the left at constant speed and a cart moving to the right at an equal constant speed?
- 4) Assume the direction to the right is positive. **Choose the best *position-time* graph** for the following descriptions of motion (delete the ones that don't belong):
  - a) A constant slow speed to the right and then (immediately) a constant fast speed to the right:



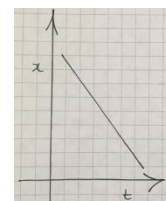
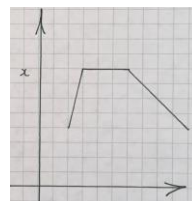
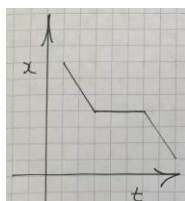
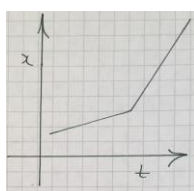
- b) A constant speed to the left:



- c) A constant speed to the right, stationary for a few seconds and then a constant slower speed to the left:

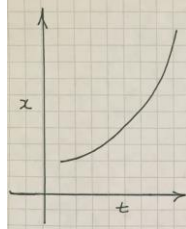


- d) A constant velocity to the left, stationary for a few seconds, constant velocity further to the left:



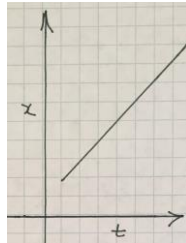
5) **Describe the motion** shown in the following *position-time* graphs (assume the direction to the right is positive). Describe the motion in terms of speed, velocity, acceleration, direction of the cart's motion, etc. **Whenever you are answering pre-lab questions, give as much detail as possible, but avoid redundancy.**

a) Sample graph:



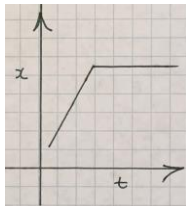
Sample Description: Acceleration to the right

b) Graph:



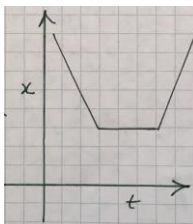
Description:

c) Graph:



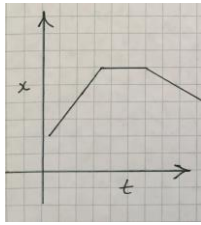
Description:

d) Graph:



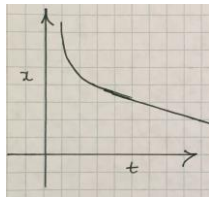
Description:

e) Graph:



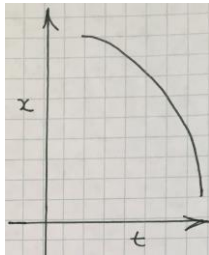
Description:

f) Graph:



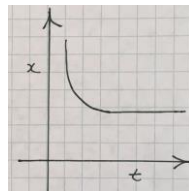
Description:

g) Graph:



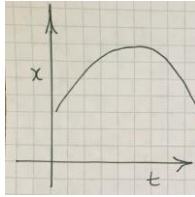
Description:

h) Graph:



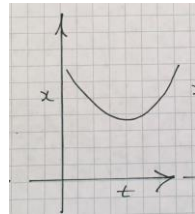
Description:

i) Graph:



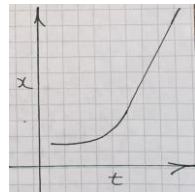
Description:

j) Graph:



Description:

k) Graph:



Description:

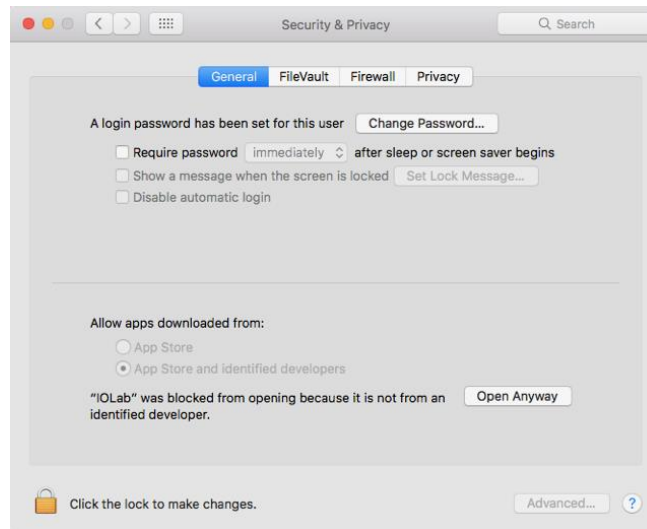
6) **Download the IOLab software** to your computer using these [instructions](#). For the PC, you must also download a driver: see this [page](#) for instructions. For extra help, you may want to use these YouTube videos for [Windows](#) or [Mac](#).

**Open the IOLab software.** Because each computer can be set up slightly differently, you might run into some problems at this stage. If you are unable to solve them, then you can always email your lab instructor or even come into the lab for help. Before you do that, try the following:

If you run into a problem with opening the Mac version of the software due to it being from a “non-trusted developer,” you can change the security settings on your computer to allow you to open it: Open System Preferences under the Apple menu and click on “Security & Privacy”:



Then click “Open Anyway” for the blocked IOLab.



7) Take the IOLab device out of its box and **remove the “dongle”** from the back of the device (the dongle is the smaller red plastic part with a USB connector) by **gently** prying it out from the back of the device with a screwdriver or knife (see picture below). The dongle is used by the IOLab device to communicate wirelessly with the computer. **Plug in the dongle** to a USB port on your computer.



**Turn on the IOLab device** (see picture below). If it's on, you'll see flashing green lights.



Important: The IOLab device has an auto-off feature to preserve the battery when not in use. If the IOLab device goes off, you must turn it on again to enable you to select sensors in the software.

8) **Calibrate the IOLab device** using these [instructions](#).

9) **Test the IOLab device:**

Attach the eyehook (from the plastic bag of accessories supplied in the IOLab box) to the IOLab device as shown in the picture below.



Measure the weight of the IOLab device using the **Force** sensor as seen [here](#).

Note: In the IOLab software, you may have to hit reset repeatedly before it allows you to select sensors.

Do not forget to “rezero the sensor” as shown. Note: The version of the software shown in the video is not the latest version, so some of the buttons are in different places, but the names of the buttons are the same, and you should have no trouble figuring everything out. Note:  $\mu$  is the average, not  $a$  ( $a$  is *area* under the graph). Insert a [screenshot](#) of your results here:

What is the **weight of the IOLab device** (in N)?

**Precision:** Always record data to as many decimal places as possible given the instrument, but no more than these. For **digital instruments** and software, that means **all** of the visible digits. For **analogue instruments** (like rulers, protractors, triple-beam balances, non-digital thermometers, etc.), record **all of the digits you are certain of plus one estimated digit**. Include zeros, whenever that is the case. In general, if you can tell the difference between a zero and a 1 or a 9, then that zero is significant. Zeros are no less significant than any other digit.


10) Calculate the **mass of the IOLab device** from its weight (in kg)?

A note about **significant figures**: Always record calculated results with approximately the same number of significant figures as in the values used to do the calculation. The correct way to determine significant figures involves a more rigorous treatment of uncertainties than we will require in this course, so just pick a reasonable number based on the data. In other words, don't give all of the digits you see on your calculator or round off to less precision than indicated by your data. This will involve a judgment call on your part and anything reasonable with respect to the above will be acceptable for this course.


11) Get rid of the Force sensor/graph and select the **Thermometer** sensor:

Hitting **reset once** clears the data for **another run with the same sensors**. Hit **reset again** (twice or more in total) to **pick new sensors** (this gets rid of the graphs/sensors so that you can pick new graphs/sensors).

Hit **Record**. After a few seconds hit **Stop**.

Click on the **Histogram Tool** . Drag/select a large flat area of your graph. Look at the statistics (the blue numbers that appear) and determine the average temperature from the  $\mu$  value given.

**Temperature of the room** =       °C. (Note: Always use **metric** units for this course.)

Hit the toolbar button , and select a smoothing of 5, then 25. How do the graphs change?

Insert a [screenshot](#) (showing the most smoothed out Temperature-time graph with statistics showing) here:

12) Get rid of the **Thermometer** sensor/graph and select the **Light** sensor (see box above). Hit **Record** and then cover up the light sensor (indicated by a light bulb on the IOLab device) 3 times, for about 1 to 2 seconds each time. Hit **Stop**.

Now use the Histogram tool as above (Remember:  $\mu$  is the **average** of the selected region) to determine an average value when the sensor is covered (use any one of the three relevant areas). Note: there are no units “n.a.” for this reading:

Insert a [screenshot](#) of your results here:


13) Finally, we are almost where we need to be for the lab. Get rid of the **Light** sensor/graph, select the **Wheel** sensor (see box above) and de-select the “Velocity” and “Acceleration” under Wheel, so that only “Position” is selected. Turn the cart upside-down (i.e., wheels down).


Important: The **positive** direction of motion is indicated by the **y** arrow on the back of the IOLab device (Note: Position is denoted by  $r_y$  on the IOLab *position-time* graphs):




As well, we will use the following convention for these labs: the positive direction is to the right and the negative direction is to the left.

Hit **Record**, move the car across the desk/table, back and forth, many times at many different constant speeds and accelerations, making sure to include at least one fairly constant velocity to the right. Hit **Stop**.

Now, select/zoom-in on any one fairly constant positive velocity using the Magnifying Tool . Start at the top-left of the region you want to zoom-in on, and drag to the bottom right of the region and release. **To undo a zoom, double-click anywhere on the graph.** You may have to play around with this tool a bit to get the hang of it. You may also need to reset and re-do the graph a number of times to get your data.

When you have a nice constant positive slope on your *position-time* graph, use the Histogram Tool  to select a portion of the graph to determine the velocity of the cart from the slope  $s$ .

Always show your graphs in the most clear/exaggerated way possible. You may have to change the Y-axis settings to do this. Use the  button to change the Y-axis settings.



What is the constant velocity of your cart?      m/s.

Insert a [screenshot](#) of your results here:

14) Turn off your IOLab device. **You should always turn off the IOLab when you are not using it** to prevent the batteries from wearing down. To turn it off, hold the on/off switch until the LED turns **red**, and then release the button.



## Lab 1: Uniform Motion

### Objective

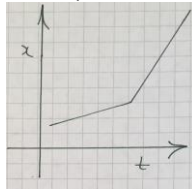
To use the IOLab device to produce position-time,  $x$ - $t$  graphs for the following examples of motion:

- a constant slow velocity to the right and then (immediately) a constant fast velocity to the right,
- a constant velocity to the left,
- a constant velocity to the right, stationary for a few seconds and then a constant slower velocity to the left, and
- a constant velocity to the left, stationary for a few seconds, constant velocity further to the left.

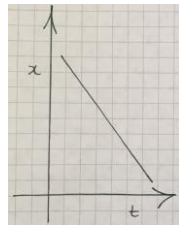
### Theory

The slope of a position-time,  $x$ - $t$  graph for the motion of a cart gives its velocity. Assuming the direction to the right is positive, we expect the graphs for the following descriptions of motions to be as follows:

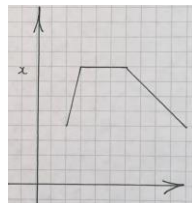
- A constant slow velocity to the right and then (immediately) a constant fast velocity to the right:



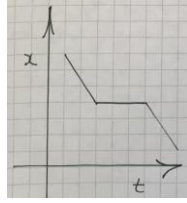
- A constant velocity to the left:



- A constant velocity to the right, stationary for a few seconds and then a constant slower velocity to the left:



- A constant velocity to the left, stationary for a few seconds, constant velocity further to the left:



### Apparatus

IOLab device and a computer with the IOLab software installed

With the **Wheel** sensor selected in the IOLab software, and only the Position selected (i.e., de-select Velocity and Acceleration),  $x$ - $t$  graphs of the IOLab cart's motion (i.e., as it rolls on its wheels) can be produced. Using the Magnifying Tool, the graph can be restricted to the area of interest.

### Data and Calculations

The IOLab cart was moved in various ways and the following screenshots of the graphs were collected with the IOLab software. These graphs show **only the motion described** and the **axes are re-scaled to expand the graph so that it fills the area as much as possible**:

- a) a constant slow velocity to the right and then (immediately) a constant fast velocity to the right:
  
- b) a constant velocity to the left:
  
- c) a constant velocity to the right, stationary for a few seconds and then a constant slower velocity to the left:
  
- d) a constant velocity to the left, stationary for a few seconds, constant velocity further to the left.

### Analysis

The graph for a constant slow velocity to the right and then (immediately) a constant fast velocity to the right showed roughly two distinct slopes on the graph, with the second one steeper than the first. For the graph of a constant velocity to the left, my graph showed . For the graph of a constant velocity to the right, stationary for a few seconds and then a constant slower velocity to the left, my graph showed

. For the graph of a constant velocity to the left, stationary for a few seconds, constant velocity further to the left, my graph showed .

The expected results are given in the Theory section above.

The experimental graphs were similar to the expected graphs with respect to , but different with respect to .

The differences are most likely due to .

Therefore, best way to improve the agreement of experimental and theoretical results would be to .

Name:

Date:

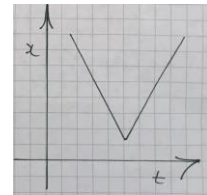
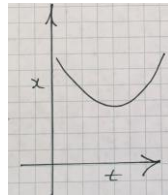
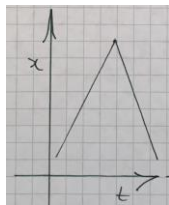
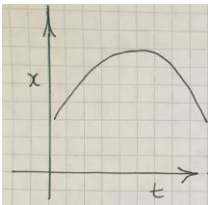
### Pre-Lab 2: Acceleration

- 1) How can you tell if acceleration is constant from a *velocity-time* graph?
- 2) How is the acceleration determined from a linear *velocity-time* graph?
- 3) As always, we will use the following convention for these labs: the positive direction is to the right and the negative direction is to the left.

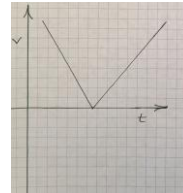
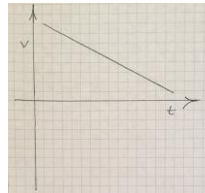
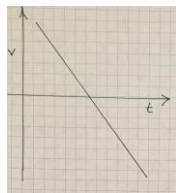
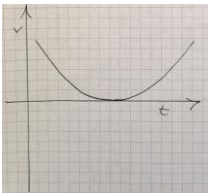
**True or false:** If an object is slowing down (i.e., speed is decreasing), then the acceleration is negative and if an object is speeding up (i.e., speed is increasing), then the acceleration is positive.

- 4) If a cart moves up a ramp to the right (after an initial push) with only the force of gravity acting on it, it will slow down, turn around and come back down.

Choose the best *position-time* graph for this description of motion (delete the ones that don't belong):



Choose the best *velocity-time* graph for this description of motion (delete the ones that don't belong):



5) Fully label/describe every measurement you take. Also, include its units, estimate an uncertainty and justify your uncertainty estimate.

Example of a correctly recorded measurement with its uncertainty and the justification of its uncertainty:

Written description	Symbol	Measurement	Estimated uncertainty
Length of wooden block,	$L$	$= 12.20 \pm 0.15$	cm
$(2 \times \frac{1}{4} \text{ mm}) = 0.05$ cm reading uncertainty due to reading both ends of ruler.			
0.10 cm physical uncertainty due to roughness of block.			
Explanation of uncertainty estimate			

There are many types uncertainty, but the uncertainty that you estimate for any given measurement should be large enough to account for all of them. Here, we outline some common sources of uncertainty. You must add up the various uncertainties to get the total uncertainty for an individual measurement.

### Reading Uncertainty

The source of uncertainty you will come across most often in the lab is called **reading uncertainty**. It is determined by how precisely you can read a value off a scale. For this course, the reading uncertainty can be taken to be  **$\frac{1}{2}$  of the smallest scale division on the instrument** that the measurement in question is being taken on.

### Ruler and Protractor Measurements

When you take a measurement of length with a ruler (or an angle with a protractor), there are two reading uncertainties involved. One of them comes from reading the measurement off of the ruler (or protractor), and the other comes from lining up the starting position of the measurement with zero on your ruler (or protractor).

Because of this, when measuring a length with a ruler that has divisions every 0.1cm, it is appropriate to choose your uncertainty as follows:

$$2 \times (\frac{1}{2} \text{ the smallest division}) = 2 \times (0.05 \text{ cm}) = \pm 0.1 \text{ cm}$$

If you're very careful, you could argue that the value can be read to the nearest  $\frac{1}{4}$  of the smallest division and therefore, the uncertainty for a length could be given as:

$$2 \times (\frac{1}{4} \text{ the smallest division}) = 2 \times (0.025 \text{ cm}) = \pm 0.05 \text{ cm (as seen in the example above)}$$

It's probably safer to go with the  $\pm 0.1$  cm, but the choice is yours. The important thing is that you can reasonably justify your estimate.

### Physical Uncertainty

Sometimes the quantity you are measuring has an intrinsic uncertainty that is larger than the reading uncertainty of the device you are using to measure it.

For example, if you try to measure the length of a cotton ball, the "fuzziness" of the cotton ball is where most of your uncertainty comes from – not the precision of the ruler. Your ruler might be subdivided into

0.1 cm divisions, but because the cotton ball has a poorly defined edge (i.e., it's "fuzzy"), your **physical uncertainty** might be another  $\pm 0.1$  cm or even more.

Another example would be trying to measure how far a cart rolls up a hill before it reverses direction. The fact that the cart only pauses for an instant at the place where you need to take your measurement can make it difficult to see the exact location that the cart turns around at. This will increase your uncertainty for that measurement. Again, your ruler might have 0.1 cm divisions, but your physical uncertainty could be another  $\pm 0.5$  cm or even more (depending on the measurement/experiment).

### Instrument Uncertainty

The instrument you are taking a measurement with may contain a built-in uncertainty that has nothing to do with your ability to read the device. A device with a digital display has no (or little) reading uncertainty, but you don't know what the uncertainty of that device is until you read the manufacturer's specifications. The instrument uncertainty can be much larger *or* much smaller than the smallest digit on the display.

In Physics 1100, instrument uncertainties are given to you in the Apparatus section of each lab. For example, the statistics given by the IOLab software will be given to you in the Apparatus section of the lab whenever you will be using the IOLab software to measure things. The statistics given by the IOLab software have an uncertainty of  $\pm 3\%$ .

Choose an **uncertainty for the measurement of the length of a book using your tape measure?**  $\pm$  cm. This is the **absolute** uncertainty of the length of the book.

Provide a **justification** for your choice:

6) Sometimes the uncertainty is given in % form. If not, then you will be required to calculate a % uncertainty for each measurement.

### Percent Uncertainty

For  $A \pm \delta A$ ,

$A$  is the **value**

$\delta A$  is the **absolute** uncertainty of  $A$

$\frac{\delta A}{A} \times 100\%$  is the **percent** uncertainty of  $A$

It is standard to state % uncertainties to 1-2 significant figures.

If the book in Question 5) is measured to be 10.65 cm, what is the **% uncertainty of the book?** %

7) How tall are you (measure your height with a tape measure)? cm

Estimate an **uncertainty for the measurement of your height?** cm

**Justify** why this uncertainty is higher than the uncertainty of the length of the book:

Your height,  $h$  = cm  $\pm$  cm

$$= \quad \text{cm} \pm \quad \%$$

8) For PHYS 1100 labs, you will be required to calculate the % uncertainty for all of your calculated results.

**To calculate uncertainties for your calculated results, use the following rules:**

- If 2 or more quantities are **multiplied or divided**, then the % uncertainty of the result is the **sum of the % uncertainties** of the values you are multiplying or dividing.
- It follows that **squaring a value doubles its % uncertainty** and taking the **square root halves the % uncertainty**.
- **Multiplying or dividing a value by a constant does not change the % uncertainty** of the result.
- **Applying trig (or inverse trig) functions does not change the % uncertainty** of the result.

If  $v = 2.36 \text{ m/s} \pm 3.1 \%$  and  $t = 0.4567 \pm 1.1 \%$ , then  $a = v/t = \quad \text{m/s}^2 \pm \quad \%$

If the *height of a ramp*,  $h$  is  $3.55 \pm 0.3 \text{ cm}$  and *length of the ramp*,  $l$  is  $25.60 \pm 0.2 \text{ cm}$ , calculate the *angle of incline*,  $\theta$ :

$$\sin \theta = h/l = \quad \pm \quad \%$$

$$\theta = \arcsin(\sin \theta) = \quad ^\circ \pm \quad \%$$

9) Open the IOLab software, and turn on the IOLab device. With the **Wheel** sensor selected in the IOLab software, and only the Position and Velocity selected (i.e., **de-select Acceleration**). Turn the cart upside-down (i.e., wheels down).


Important: The **positive** direction of motion is indicated by the **y** arrow on the back of the IOLab device:




As always, we will use the following convention for these labs: the positive direction is to the right and the negative direction is to the left.

Hit Record, **push the cart in the positive y-direction, to the right, and let it roll to a stop**. Hit Stop.

Now, select/zoom-in on the part of the  $v$ - $t$  graph showing constant acceleration (i.e., deceleration) using


the Magnifying Tool .



When you have a nice constant negative slope on your v-t graph, use the Histogram Tool  to select a portion of the graph to **determine the acceleration** of the cart from the slope  $s$ . The uncertainty of IOLab statistics is  $\pm 3\%$ .

What is the **acceleration** of the cart?      m/s  $\pm$       %.

Always show your graphs in the most clear/exaggerated way possible (e.g., so that the graph is not squished into a narrow section of the area shown). You may have to change the Y-axis settings to do this.

Use the  button to change the Y-axis settings.

Attach a screenshot of your results here:

Don't forget to turn off your IOLab device.

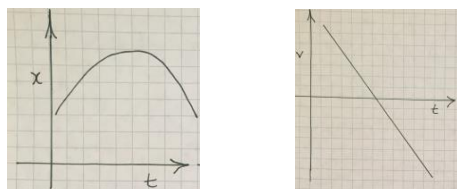
## Lab 2: Acceleration

### Objective

To a) use the IOLab device to produce *position-time* and *velocity-time* graphs for a cart moving up a ramp and then back down the ramp, after an initial force is applied, b) determine the acceleration of the cart, and c) determine the angle of the ramp.

### Theory

If a cart moves up a ramp to the right (after an initial push) with only the force of gravity acting on it, it will slow down, turn around and come back down. Assuming the direction to the right is positive, we expect the *position-time* and *velocity-time* graphs for a cart to appear as follows:



The slope of a  $v$ - $t$  graph for the motion of a cart gives its acceleration.

To find the angle of a ramp  $\theta$ , the following equation may be used

$$\theta = \sin^{-1}\left(\frac{h}{l}\right)$$

where  $h$  is the height of the ramp and  $l$  is the length of the ramp.

### Apparatus

IOLab device and a computer with the IOLab software installed

With the **Wheel** sensor selected in the IOLab software, and only the Position and Velocity selected (i.e., de-select Acceleration), the *position-time* and *velocity-time* graphs of the IOLab cart's motion can be produced. Using the Histogram Tool to select the relevant region of the graph, the acceleration of the cart can be found from the slope  $s$ . The uncertainty of the slope  $s$  of an IOLab  $v$ - $t$  graph is  $\pm 3\%$ .

A ramp created by elevating a board or book, etc. at one end (something smooth will reduce the effect of friction)

Ruler and/or tape measure to measure the dimensions of the ramp

### Data and Calculations

After an IOLab cart was given an initial push to the right in its positive  $y$ -direction, the cart moved up a ramp, turned around and came back down. The following *position-time* and *velocity-time* graphs were found with the IOLab software. These graphs (screenshots) have the relevant part of the cart's motion zoomed-in on (using the Magnifying Tool), and the statistics for the relevant parts showing (using the Histogram Tool):

The acceleration  $a$  of the cart was found to be:           $\text{m/s}^2 \pm$           %.

The *height of the ramp*,  $h$  was measured to be           $\text{cm} \pm 0.2 \text{ cm}$ .

Justification of uncertainty: The total uncertainty of the height of the ramp  $h$  was estimated to be  $\pm 0.2 \text{ cm}$  by adding the  $\pm 0.1 \text{ cm}$  reading uncertainty (double the uncertainty of  $\pm 0.05 \text{ cm}$  for reading each end of the ruler) and another  $\pm 0.1 \text{ cm}$  for the difficulty in locating the top of the ramp exactly.

The % uncertainty of the height of the ramp is          /           $\times 100\% =$           %.

The *length of the ramp*,  $l$  was measured to be           $\text{cm} \pm$            $\text{cm}$ .

The total uncertainty of the length of the ramp  $l$  was estimated to be           $\text{cm}$  for the same reasons as given above for the height uncertainty estimate.

The % uncertainty of the length of the ramp is          /           $\times 100\% =$           %.

The *angle of the ramp*,  $\theta$  is found using trig:

$$\theta = \sin^{-1} \left( \frac{\quad}{\quad} \right) = \quad^\circ$$

The % uncertainty of  $\theta$  is the sum of the % uncertainties of the height and length since those values are divided (applying the inverse trig function does not change the % uncertainty). Therefore, the uncertainty of  $\theta$  is          %.

### Analysis

The *position-time* graph for a cart moving up and down a ramp, after an initial force was applied, can be described as          . The *velocity-time* graph for a cart moving up and down a ramp, after an initial force is applied, can be described as          . The acceleration of the cart was found to be:           $\text{m/s}^2 \pm$           %.

The angle of the ramp was found to be:           $^\circ \pm$           %.

The *position-time* graph was expected to be a concave downward facing curve and the *velocity-time* graph was expected to have a constant negative slope (as seen in the Theory section). There was no expected value for the acceleration of the cart, as this was not considered in this lab. There was also no expected value for the angle of the ramp.

My *position-time* and *velocity-time* graphs were similar to the expected graphs with respect to          , but different with respect to          .

This differences between my graphs and the expected graphs were most likely due to          .

Therefore, the best way to improve the agreement of experimental and theoretical results would be to          .

Name:

Date:

### Pre-lab 3: Freefall

1) When similar measurements are repeated, a table is usually the best way to record the data. For PHYS 1100 labs, you are expected to follow standard conventions for making tables. Example of a table showing standard conventions:

Table 1: Extension of a Spring, demonstrating Hooke's Law.	
Total Mass Applied to Spring $m$ ( $\pm 0.05$ g)	Extension of Spring $x$ ( $\pm 0.05$ cm)
22.50	0.84
42.50	1.59
62.50	2.43

0.05 g instrument uncertainty due to balance.  
 $(2 \times \frac{1}{4} \text{ mm}) = 0.05$  cm reading uncertainty due to reading both ends of mirrored scale.

Explanation of uncertainty estimates

Include as much information as possible in the column headings only rather than repeating the units, uncertainty, etc. on every line. However, if the uncertainty is not the same for the entire column, then the values will need to be recorded on each line.

According to the criteria for lab report tables given above, **which of the following is the best table?**  
 (Indicate your choice in some way, e.g., put a background colour on it.)

Table #1: Measurements to Determine the Speed of Sound in a Resonance Tube

f (Hz) ( $\pm 5\%$ )	d (cm) ( $\pm 0.5$ cm)
250	42.4
500	38.9
1000	25.6
1500	18.0
2000	14.6
4000	10.9

Tuning Fork Frequency f (Hz) ( $\pm 5\%$ )	Internodal Distance d (cm) ( $\pm 0.5$ cm)
250	42.4
500	38.9
1000	25.6
1500	18.0
2000	14.6
4000	10.9

Table #1: Measurements to Determine the Speed of Sound in a Resonance Tube

Tuning Fork Frequency f (Hz) ( $\pm 5\%$ )	Internodal Distance d (cm) ( $\pm 0.5$ cm)
250 Hz $\pm 5\%$	42.4 $\pm 0.5$ cm
500 Hz $\pm 5\%$	38.9 $\pm 0.5$ cm
1000 Hz $\pm 5\%$	25.6 $\pm 0.5$ cm
1500 Hz $\pm 5\%$	18.0 $\pm 0.5$ cm
2000 Hz $\pm 5\%$	14.6 $\pm 0.5$ cm
4000 Hz $\pm 5\%$	10.9 $\pm 0.5$ cm

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1000 Hz $\pm 5\%$	25.6 $\pm 0.5$ cm
1500 Hz $\pm 5\%$	18.0 $\pm 0.5$ cm
2000 Hz $\pm 5\%$	14.6 $\pm 0.5$ cm
4000 Hz $\pm 5\%$	10.9 $\pm 0.5$ cm

2) For PHYS 1100 labs, you are expected to follow standard conventions for graphing as described below:

When measuring values to be plotted on a graph, always choose your measurements to cover the **largest possible range** given your experimental apparatus/setup and try to measure 6-8 values that have **approximately equal increments** for the controlled variable.

When choosing values to graph, the theory you are working with will usually suggest what should be plotted on the x- and y-axes. If the theory doesn't suggest something different, then plot the controlled variable on the x-axis. If *time* is one of the variables, then plot *time* on the x-axis (unless there is a reason to do otherwise). When done correctly, a hand-drawn graph can be just as accurate as one done by computer, but using a graphing program (e.g., Linegraph) saves you time and may be used instead if you prefer.

### Drawing Graphs by Hand

Finely scaled graph paper (1mm) is required to get adequate precision from your graphs.

- Your graph must **always occupy at least half** of the graph paper in each direction. If your graph is confined to a smaller region, then the precision of any results taken from the graph will be limited. Stretch out the scaling and/or start the axes from values other than zero if that helps spread your graphed relationship over a larger portion of the graph area.
- **Scale the axes by values that are easy to work with** whenever possible (e.g., multiples of 1's, 2's, 5's, etc. rather than 3's, 7's, etc.). Draw in the axes as solid lines. Not every division needs to be numbered, but make tick marks along the axes for the ones that you do number.
- **Label the axes** clearly with quantity **name**, **symbol**, **units** and **uncertainty** value (if the uncertainty is constant for all of the data along that axis).
- Plot the data points as small sharp dots using a sharp **pencil**.
- To account for the estimated experimental uncertainty of the data, draw in **uncertainty bars (more often called "error bars")** for each data point. These must be drawn to scale, showing how large the uncertainties on the x- and y-axes are for each data point (see diagram below).

Note that the two uncertainty bars form an **uncertainty box**. According to the measurement uncertainties chosen, the data point lies anywhere inside that box.

- Draw in the **"best fit" line (or curve)**. Use **pencil** for best-fit lines or curves. If the data suggests a **linear** relationship, then use a **ruler** to draw in your best estimate of the linear regression line (e.g., the line which has the minimum sum of the distances from the points to the line). If the data suggests a **curve**, then use a **flexible ruler** or **French curve** to help draw in a smooth (if your hand is steady, then sketching in the curve by hand is also acceptable). **Never join point-to-point and do not "force the graph through the origin."**
- Give the graph a **descriptive title** related to the experiment. Do not simply name the variables being graphed. The title should add information, not just duplicate what is already clear.

### Drawing Graphs by Computer

All of the above requirements apply to graphs drawn by computer, except using pencil. **Add in, by hand, anything your computer program does not provide, e.g., error bars.**

Note: If you have **MS Excel®**, you may use “**Linegraph**,” a KPU-made Excel macro that has the ability to draw in error bars. You may download it from the PHYS 1100 labs course webpage at <http://courses.kpu.ca>.

If you were to draw error bars on the data point indicated on the following graph as indicated, **how many of the graph divisions would the error bars be in length (total)?**

Vertical (up and down):

Horizontal (left and right):

3) According to the criteria for graphing given above, **which of the following is the best graph?** Note: you may have to zoom in to see all the details of the graphs.

4) If the **best-fit line** drawn goes through all of the **boxes** defined by the error bars (see 2 above), then the graph is **linear within uncertainty**.

Is the following graph linear within uncertainty?

5) The equation relating *position*  $x$  and *time*  $t$  for an object with constant acceleration  $a$  starting from an *initial position*  $x_0$  of 0 and *initial velocity* of  $v_0$  of 0 is

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$
$$0 + 0 + \frac{1}{2} a t^2$$

$$\frac{1}{2}at^2$$

Is the **x-t graph** for an object falling from rest for various *heights*  $x$  in *times*  $t$  **linear or curved**?

If we want to produce a linear graph of  $x$  and  $t$  measurements, then we can plot distance  $x$  on the y-axis and the **square of the time**  $t^2$  on the x-axis.

In other words, if  $t^2$  is plotted on the x-axis and  $x$  is plotted on the y-axis, then the relationship is in the form of a linear relationship with the slope  $m = \frac{1}{2}a$  and  $b = 0$  (Note: we expect  $b = 0$  if the object is falling from rest since  $v_o = 0$ ;  $x_o = 0$  as well since the distance fallen is measured from this position).

From this, **how can you calculate acceleration  $a$**  from the slope  $m$  of the  $x$ - $t^2$  graph?

6) Sometimes there is a previously determined value for a quantity being experimentally determined. There are many good ways to find these values, but using a reliable source is required. If you're unsure of the credibility of a source, don't use it. **Always give the source of values you cite.** One credible source for the purposes of this course is an online database/software called [Wolfram Alpha](#).

Look up a value for the **acceleration due to gravity  $g$**  for your location using [Wolfram Alpha](#). Example for Kelowna:  $g = 9.81307 \text{ m/s}^2$

Although  $g$  values are measured and therefore do have uncertainty, the % uncertainty is so small that it can be safely considered to be  $\pm 0\%$  for our purposes.

Acceleration due to gravity,  $g =$              $\pm$             % for the geographical location of            .  
The source of this value is            .

7) Often you will want to compare two values. One way to do this is to calculate **% discrepancy**.

$$\% \text{ discrepancy} = \left| \frac{\text{value}_1 - \text{value}_2}{\text{best value}} \right| \times 100\%$$

where the **best value** is whichever value you think is **more reliable**: e.g., a **theoretical/literature value**, **your result**, the **average** of two values (if your numbers are close and you have no reason to believe one is more reliable), the **initial** value (if you are comparing an initial and final value), etc.

% discrepancies are generally given to 1-2 significant figures.

What is the **% discrepancy between the following two values**?

$$a_{\text{experimental}} = 5.6 \text{ m/s}^2 \pm 2.1\% \quad \text{and} \quad a_{\text{theoretical}} = 5.4 \text{ m/s}^2 \pm 1\%$$

Show the calculation here:

8) Two values agree if the % discrepancy between them is less than or equal to the sum of the % uncertainties of the values you're comparing.

State whether the following 2 values agree and show your work:

$$a_{\text{experimental}} = 5.6 \text{ m/s}^2 \pm 2.1\% \quad \text{and} \quad a_{\text{theoretical}} = 5.4 \text{ m/s}^2 \pm 1\%$$

9) Open the IOLab software and turn on the IOLab device. With the **Accelerometer** sensor selected in the IOLab software, and  $A_x$  and  $A_y$  de-selected (i.e., **only  $A_z$  selected**), the time the IOLab is in the air falling can be determined from the  $a$ - $t$  graph. Because the accelerometer measures  $\sim 9.8 \text{ m/s}^2$  in the  $z$ -direction when it is on a surface (or being held), the **time  $\Delta t$  that the acceleration drops from  $9.8 \text{ m/s}^2$  to zero is the time the IOLab device took to fall**. The Histogram Tool will be used to measure this time  $\Delta t$  along the  $x$ -axis.

Using a **very soft surface** (e.g., a bed, a large pillow, blankets, coats, etc.), you will drop the IOLab device from above the surface onto the surface. Before you measure the time, measure the initial height. Note: This is very difficult to do with any kind of precision, so account for this fact by choosing an appropriately large uncertainty value.

Choose a starting point for this measurement (see the video posted to your PHYS 1100 online labs course webpage; somewhere between 10 and 50 cm should work for this). What is the **initial height  $h$  of the IOLab device?**

**height  $h$**  =        cm  $\pm$         cm

**Justification** for the estimated uncertainty:

**height  $h$**  =        cm  $\pm$         %

11) Now measure the time it takes the IOLab device to fall the **height  $h$** . Hit **Record**, wait a few seconds and then drop the IOLab device onto the soft surface and hit **Stop** a few seconds later. Select/zoom-in on the relevant part of the  $a$ - $t$  graph using the Magnifying Tool. Use the Histogram Tool to **select the time span  $\Delta t$  along the  $x$ -axis that the IOLab was falling (i.e., the time  $t$  that the acceleration is zero)**.

Note: Your graph may not look as clean as the sketch above for various reasons. You may have to make a judgment call. This is normal, but always be prepared to justify your choices. Remember that the time of fall is seen where acceleration is 0.

Recall that the uncertainty of IOLab statistics is  $\pm 3\%$ .

What is the **time of fall  $\Delta t$  of the cart?**        s  $\pm$         %.

Attach a screenshot of your results here:

Don't forget to turn off your IOLab device.



## Lab 3: Freefall

### Objective

To determine the *acceleration due to gravity*  $g$  of a falling object.

## Theory

By comparing the kinematics equation  $x = x_0 + v_0 t + \frac{1}{2} a t^2$  to the general form of the equation for a straight line  $y = mx + b$ , it can be seen that *position-time squared* ( $x-t^2$ ) graph for an object falling from rest (i.e.,  $v_0=0$ ) from an *initial position*  $x_0$  of 0 will be linear. From this, we can calculate the acceleration as twice the slope.

For free fall, the acceleration is expected to be equal to the acceleration due to gravity  $g =$  \_\_\_\_\_ m/s<sup>2</sup> ± \_\_\_\_\_ % for the geographical location of \_\_\_\_\_ according to \_\_\_\_\_.

### Apparatus

IOlab device and a computer with the IOlab software installed

Using the **Accelerometer** sensor with  $A_x$  and  $A_y$  de-selected (i.e., **only  $A_z$  selected**) in the IOLab software, the time the IOLab is in the air falling can be determined from the  $a$ - $t$  graph. Because the accelerometer measures  $\sim 9.8 \text{ m/s}^2$  in the  $z$ -direction when it is on a surface (or being held), the time  $\Delta t$  that the acceleration drops from  $9.8 \text{ m/s}^2$  to zero is the time the IOLab took to fall. The Histogram Tool can be used to measure this time along the  $x$ -axis  $\Delta t$ .  $\Delta t$  is  $\pm 3\%$ .

A tape measure to measure the initial heights of the object

A very large soft landing surface (e.g., a bed, large pillow, cushion, coats or blankets)

## Data and Calculations

Using the Accelerometer sensor with  $A_x$  and  $A_y$  de-selected (i.e., only  $A_z$  selected) in the IOLab software, the time of fall of the IOLab device was measured for various measured heights up to 100.0 cm.

Table #1: Measured Distances and Times for a Falling IOLab device

[illegible]

The uncertainty in height  $h$  was chosen to be  $\pm$       cm because      .

The uncertainty in time  $t$  was chosen to be  $\pm$       % because      .

Sample calculation of  $t^2$ :

Calculation of the % uncertainty of  $t^2$ :

Table #2: Distances and Squares of Times for a Falling IOLab device

Initial Height of IOLab Device $x$ (cm) ( $\pm$ cm)	Square of Time the IOLab fell distance $x$ $t^2$ (s <sup>2</sup> ) ( $\pm$ %)

Graph #1: Determination of Acceleration of a Falling IOLab Device

The slope  $m$  of this graph is      cm/s<sup>2</sup>.

The slope will have a % uncertainty of the sum of the % uncertainties of  $x$  and  $t^2$  since the slope is found from dividing the “rise”  $x$  by the “run”  $t^2$ . But since the % uncertainty of  $x$  is insignificant compared to the % uncertainty of  $t^2$ , the uncertainty of  $x$  can safely be ignored. The % uncertainty of the slope is therefore the % uncertainty of  $t^2$ .

Therefore, the slope  $m$  of this graph is       $\pm$       %.

Calculation of the acceleration  $g$  from Graph #1: Determination of Acceleration of a Falling IOLab Device:

The acceleration of the falling IOLab  $g$  was found to be:  $\text{cm/s}^2 \pm \quad \%$ .

The % uncertainty of  $2 \times m$  is the same as the % uncertainty of the slope  $m$ , since multiplication or division by a constant does not affect the % uncertainty.

The units of  $g$  were converted so that a comparison with the expected value could be made using a % discrepancy.  $\text{m/s}^2 \pm \quad \%$ .

% discrepancy between the experimental value and the expected value of  $g$ :

Analysis

The acceleration  $g$  of a falling object from the  $x-t^2$  graph was found to be  $\pm \quad \%$ .

The acceleration  $g$  was expected to be  $\pm \quad \%$  for the geographical location  $\quad$  according to  $\quad$ .

The % discrepancy between the experimental value and the expected value of  $g$  is  $\quad \%$ . The combined % uncertainty of the experimental value and the expected value is  $\pm \quad \%$ . These values agree since the % discrepancy is  $\quad$  the combined % uncertainty.

This % discrepancy is most likely due to  $\quad$ .

Therefore, the best way to improve the agreement would be to  $\quad$ .

Name:

Date:

#### Pre-lab 4: Projectile Motion

1) What is the only **force** that acts on a projectile (by definition)?

In what **direction** does this force act?

2) We will use a simulation to model the behaviour of projectiles in order to become familiar with the concepts involved. Later, we will measure an actual projectile.

Open the **Physics Classroom Projectile Simulator** [Interactive](#), read the instructions given, expand the simulator and enter the following settings:

Speed: 10 m/s

Angle: 0 °

Height: 120 m

Select "Show Velocity Vectors"

Hit **start** and observe the motion of the projectile. Hit **reset** and **start** as many times as necessary to answer the following questions:

Does the horizontal velocity (indicated by the red horizontal arrow) change during the flight of the projectile?

If so, how?

Why or why not (use the concept of force to answer)?

Does the vertical velocity (indicated by red vertical arrow) change during the flight of the projectile?

If so, how?

Why or why not (use the concept of force to answer)?

What is the initial velocity of the projectile in the vertical direction?

3) Based on the simulation and using the appropriate kinematics equation from your class notes, write an **equation for the position  $y$  of a projectile in the vertical direction** only (in terms of its *initial position  $y_0$* , *initial velocity  $v_0$*  in the vertical direction, *time of flight  $t$*  and *acceleration  $a$* ):

If *initial position  $y_0$* , *initial velocity  $v_0$*  are both = 0, simplify and solve this equation for  $t$ :  
 $t =$

4) Based on the simulation and using the appropriate kinematics equation from your class notes, write an **equation for the position  $x$  of a projectile in the horizontal direction** only (in terms of its *horizontal velocity  $v$*  and *time of flight  $t$* ):

$x =$

5) Now try the simulation with speeds of **20 m/s, 30 m/s and 60 m/s**.

What changes?

What stays the same?

6) In Lab 4, you will measure the height of the surface that you will launch a projectile from, and calculate the time of flight using the equation you derived above. How you will calculate the **% uncertainty of the time  $t$**  of flight? Hint: Look back at the rules for calculating uncertainties in Pre-lab 3 and/or the info at the top of your Phys 1100 labs course webpage.

7) In Lab 4, you will measure the initial horizontal launch velocity of the projectile from an IOLab  $v$ - $t$  graph and then calculate the range  $x$  (i.e., the horizontal distance measured from directly under the edge of the table from which it is launched to where the projectile lands) using the equation you derived above. How will calculate the **% uncertainty of the range  $x$** :

8) Open the IOLab software and turn on the IOLab device. With the **Wheel** sensor selected in the IOLab software, the horizontal velocity of the IOLab being projected horizontally off of the edge of a table (or other horizontal surface) can be determined. Before launching the IOLab, please look at the video posted to your Phys 1100 labs course webpage. With the wheels down and the cart moving in the direction of the  $y$ -arrow towards the edge of the surface, practice launching the IOLab device along the surface so that it projects horizontally from the edge of the surface onto a pillow or other **very soft surface below**. When you have a good technique, hit **Record**, wait a few seconds and then launch the IOLab device horizontally off the edge of a table onto a soft surface and hit **Stop** a few seconds later. Repeat until you have a graph that you feel accurately represents the projectile motion described.

Select/zoom-in on the relevant part of the  $v$ - $t$  graph using the Magnifying Tool.

Hover the cursor over the  $v$ - $t$  graph at the point representing the beginning of projectile launch. Recall that the uncertainty of IOLab statistics is  $\pm 3\%$ .

What is the **horizontal launch velocity** of the cart?      m/s  $\pm$       %.

Attach a **screenshot** of your results here:

Don't forget to turn off your IOLab device.

## Lab 4: Projectile Motion

### Objective

To predict and measure the range of a projectile.

### Theory

In terms of the initial launch height  $y$  above the ground, the time of flight  $t$  of a projectile is:

$$t = \sqrt{\frac{2y}{g}}$$

where  $g$  is the acceleration due to gravity.

If the initial horizontal launch velocity  $v$  off of the edge of a surface is measured, then the predicted range  $R_{\text{predicted}}$  of the projectile can be determined from  $v$  and the predicted time of flight  $t$  according to:

$$R_{\text{predicted}} = vt$$

The actual measured range  $R_{\text{measured}}$  of the projectile is expected to agree with the predicted range  $R_{\text{predicted}}$ .

### Apparatus

IOLab device and a computer with the IOLab software installed

With the **Wheel** sensor selected in the IOLab software, and only the Velocity selected (i.e., de-select Position and Acceleration), the horizontal velocity of the IOLab being projected horizontally off of the edge of a surface can be determined from the software. IOLab statistics have an uncertainty of  $\pm 3\%$ .

A horizontal surface from which the IOLab device can be launched from (e.g., a table, desk, large block)

A very large soft landing surface (e.g., a bed, large pillow, cushion, coats or blankets)

tape measure

### Data and Calculations

The IOLab was launched with horizontal velocity only off of the edge of a horizontal surface of *height*,  $y =$  \_\_\_\_\_ cm.

The uncertainty of  $y$  is  $\pm$  \_\_\_\_\_ cm which can be justified as the sum of \_\_\_\_\_ cm due to reading both ends of the tape measure and \_\_\_\_\_ cm due to the uncertainty of where the cart lands on the soft surface and \_\_\_\_\_ due to the possibility that the tape measure was not held perfectly vertical when height was measured.

The % uncertainty of  $y$  is  $\pm$  \_\_\_\_\_ %

Therefore, the height  $y =$  \_\_\_\_\_ cm  $\pm$  \_\_\_\_\_ %

Since I will need to use consistent units in later calculations, I converted my height  $y$  into metres (Note: % uncertainty does not change when unit conversions are done):

Therefore, the height  $y =$             m  $\pm$             %

The initial *horizontal velocity*  $v$  was found using the IOLab software. Screenshot of this  $v$ - $t$  graph:

From this graph, the *horizontal velocity*  $v =$              $\pm$             %

The predicted time of flight  $t$  is calculated as follows:

The % uncertainty of  $t$  is calculated as follows:

Therefore,  $t =$              $\pm$             %

The predicted range  $R_{\text{predicted}}$  is calculated from the measured horizontal velocity  $v$  and the predicted time of flight  $t$  as follows:

The % uncertainty of  $R_{\text{predicted}}$  is calculated as follows:

Therefore,  $R_{\text{predicted}} =$              $\pm$             %

The range of the projectile measured with the tape measure  $R_{\text{measured}} =$             cm

The uncertainty of  $R_{\text{measured}}$  is  $\pm$             cm due to            .

Therefore,  $R_{\text{measured}} =$             cm  $\pm$             %

Since I will need to use consistent units in later calculations, I converted my  $R_{\text{measured}}$  into metres (Note: % uncertainty does not change when unit conversions are done):

Therefore,  $R_{\text{measured}} =$             m  $\pm$             %

The % discrepancy between  $R_{\text{predicted}}$  and  $R_{\text{measured}}$  is calculated as follows:

### Analysis

The predicted range of the projectile  $R_{\text{predicted}}$  was             $\pm$             %. The actual measured range  $R_{\text{measured}}$  was             $\pm$             %.

The theory indicates that when comparing these values, they should .

The % discrepancy between  $R_{predicted}$  and  $R_{measured}$  is . The values agree since the % discrepancy is than the combined uncertainty of  $R_{predicted}$  and  $R_{measured}$  which is .

The % discrepancy between  $R_{predicted}$  and  $R_{measured}$  is most likely due to .

Therefore, the most likely way to improve the results would be to .



Name:

Date:

### Pre-lab 5: Acceleration on an Incline

3) We will use a simulation to practice drawing free-body diagrams.

Open the **Physics Classroom Free-Body Diagrams Interactive**, read the instructions given, expand the simulator and complete all 12 Situations. All instructions are given within the Interactive. Note: You can change the length of the arrows — see the instruction in the top right hand corner of the interactive. Each time you successfully draw a free-body diagram, that situation will be marked with a star. When you've collected all of the stars (or as many as you can get), take a screenshot showing the stars and paste it here.

4) Consider a cart on a **frictionless** incline at an angle  $\theta$ . Use free-body diagrams and Newton's laws to **derive an equation for the acceleration  $a$**  of the cart on the incline in terms of the angle of the incline  $\theta$ . Refer to class notes to do this if necessary. You can draw it out on paper and insert a picture/scan of it, or if you can do it using software, feel free to do it that way.

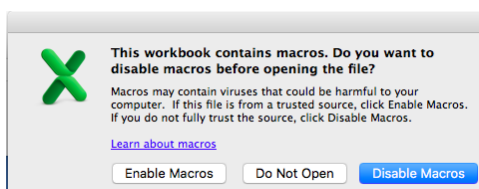
5) Hopefully you found that  $a = g \sin \theta$  in question 2). If not, go back and correct your mistake(s). **How will you determine the % uncertainty of the acceleration  $a$**  in terms of the % uncertainty of the angle of the incline  $\theta$ . Remember that taking the sine of an angle doesn't affect the % uncertainty, and multiplying by a constant (e.g.,  $g$ ) also doesn't affect the % uncertainty.

6) In the lab, you will **use a remotely located apparatus to experimentally measure the acceleration  $a$  of a cart on an incline and the angle of the incline  $\theta$** . The remote physics lab facility called **RWSL** (which stands for **Remote Web-based Science Lab**) is at North Island College in Courtney, BC. You will control the apparatus from your own computer at home. Watch this short (2min:36sec) [video](#) to become familiar with the RWSL technology. Note: In the video, you see the e/m apparatus that we will be using in Lab 10.

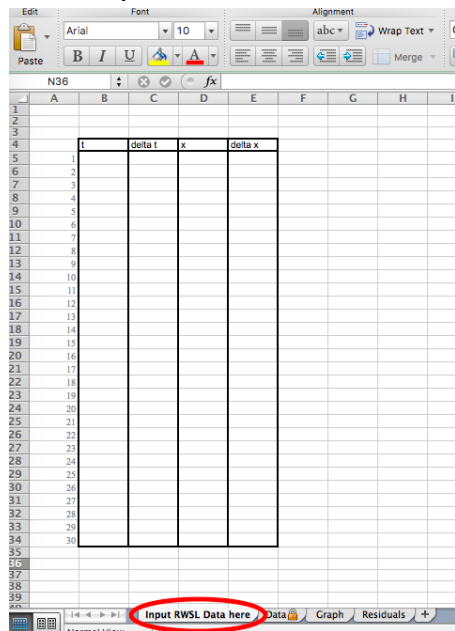
5) **Sign up** for a time to conduct your lab on the RWSL. The sign-up tool is posted on your Phys 1100 labs course webpage. What is your sign-up time?

6) If you have Excel® on your computer, then download **Lab 5 v-t Graph Generator** from your Phys 1100 labs course webpage. If you do not have Excel®, email your lab instructor and ask for a v-t graph of the data.

If you have Excel®, then open **Lab 5 v-t Graph Generator**. If you see the following, select **Enable Macros**:



Click on **Input RWSL Data** as shown here:

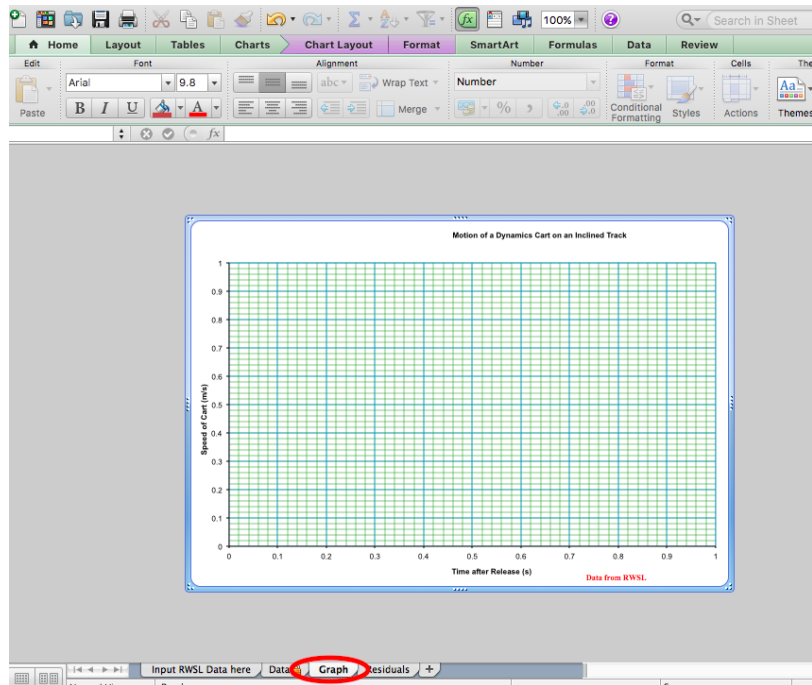


**Input the data below** (copy and paste the **numerical values only** into the appropriate x and y-columns: **t values in the x-column** and **x values in the y-column**). It might take some practice using this file, and that's why we are practicing using it here in the pre-lab. Normally, you would fill in the uncertainties (i.e., delta t and delta x) too, but they are already entered for you:

Table #1: Distance and Time Data Collected for a Cart Rolling Down an Incline Plane

Time t ( $\pm 0.005s$ )	Distance x ( $\pm 0.001m$ )
00.00	0.011
00.10	0.011
00.20	0.036
00.30	0.088
00.40	0.160
00.50	0.273
00.60	0.438
00.70	0.692
00.80	0.888

Display the v-t graph by clicking on the **Graph** tab as shown here:



Is this graph **linear within uncertainty**?

How can you tell (see previous lab work if you forget)?

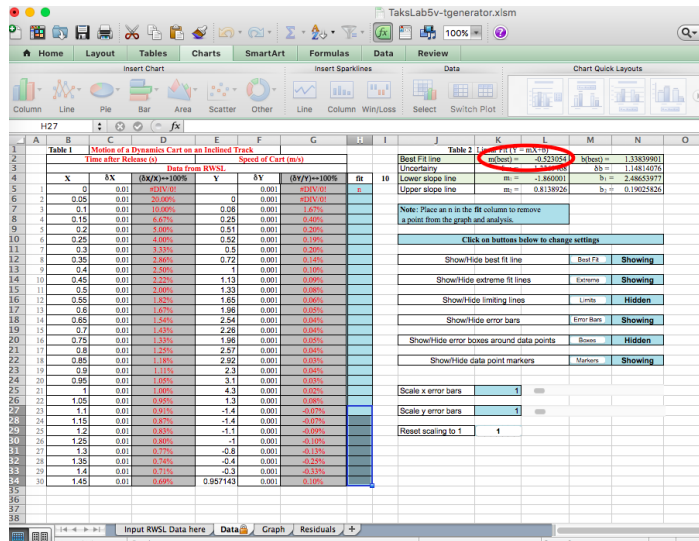
In general, to show that a relationship is linear, then the graph must be linear within uncertainty. If it is not, then the next step is to **fix any mistakes** in calculations or graphing, adjust the apparatus and/or parameters of your run and **re-run the experiment** to see if the graph is not linear due to some mistake made, etc. If you've done everything you can and your graph is still not linear within uncertainty, then **give the most plausible reason** the graph is not linear as expected in your report analysis:

- Sometimes the relationship is not actually a linear one and this is the correct explanation!
- You should never mention mistakes as your reason, as you are expected to have fixed them.
- "Human error" is not a sufficient reason; be more specific.
- It could be something to do with the equipment or procedure itself. In this case, explain what you think is specifically the issue.

In this pre-lab example, if you find the graph is not linear within uncertainty, then you cannot give the reason because you did not do the experiment yourself. In general lab work, however, you will be required to do this analysis.

Next, click on the **Data** tab (beside the Graph tab).

The **slope  $m$**  of the graph is found as follows (the slope value given is  $\pm 3\%$ ):



What is the **slope  $m$**  of this  $v$ - $t$  graph?  $\text{m/s}^2 \pm \%$

Therefore, the **acceleration  $a$**  is  $\text{m/s}^2 \pm \%$

7) **Read the following instructions** for using the RWSL for your computer, i.e., the computer you will be using for Lab 5 (PC pp. 5-11 or Mac pp. 12-19). **Set up your computer** for your RWSL session as indicated in Before your sign up time; and have these instructions handy (printing them out may be helpful) at your sign up time to complete the data collection by following the instructions given in At your sign-in time.

PC

Before your sign up time (PC)

If using a PC, you will need **Microsoft's Internet Explorer** browser. If you don't have this browser, either download it and install it on your computer or when it comes time to do Lab 5, use another computer that has this browser (e.g., KPU library). **Make sure you can get to this point before your sign-up time.**

At your sign-in time (PC)

**If you run into problems during your sign-up time**, you can email Albert Balbon at [balbon@nic.bc.ca](mailto:balbon@nic.bc.ca) or call him at: 250-334-5222.

Open the **Microsoft's Internet Explorer** browser and go to <https://nanslo-labs.nic.bc.ca>

You should see this:

The image shows a web browser window displaying the North Island College RemoteApp Connection sign-in page. The page has a light blue header with the college's logo and name. Below the header, there is a white box containing two input fields: 'User name:' and 'Password:'. A 'Sign in' button is located at the bottom right of the white box.

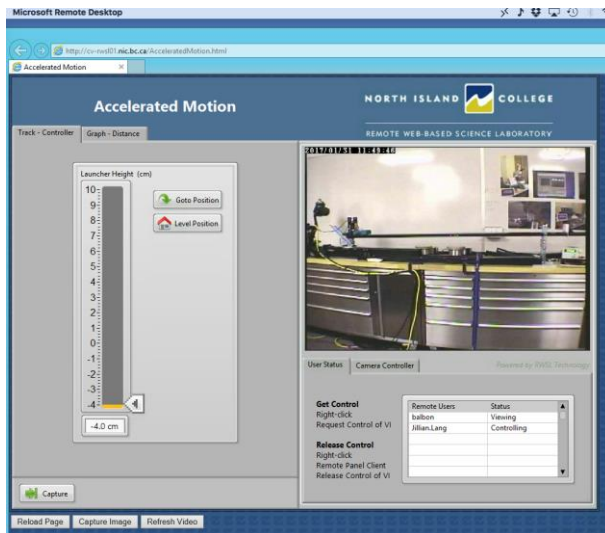
Enter your **User name:** RWSL\Kwantlen.Student and **Password:** Kwantlen and hit **Sign in**.

You should see this:

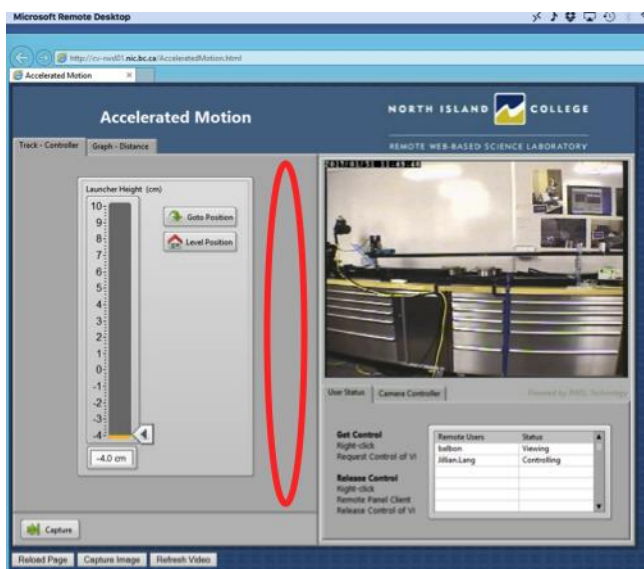


Click on the icon labeled **Accelerated Motion**.

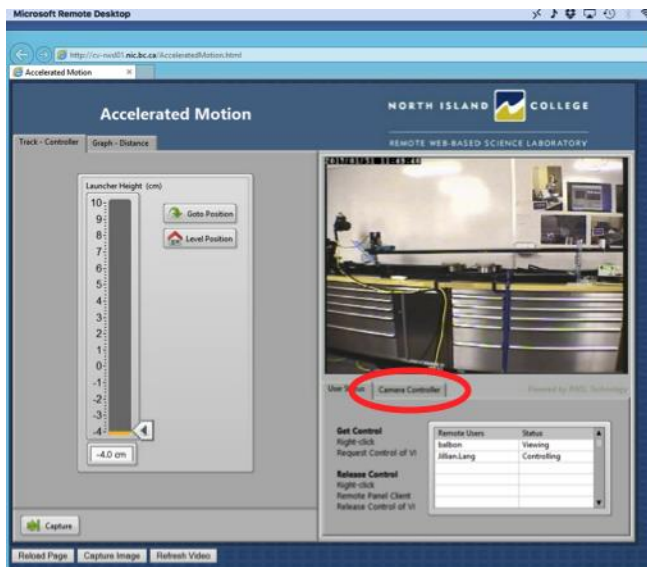
You should see this:



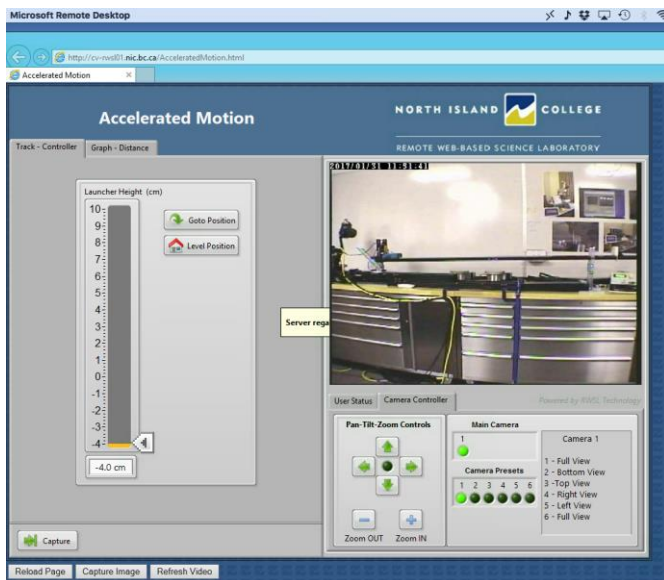
**Request control** by **right-clicking on any grey area** (e.g., shown below in the red circle) and selecting **Request control** from the options that appear.



Once you have control, click on **Camera Controller** tab (shown below):

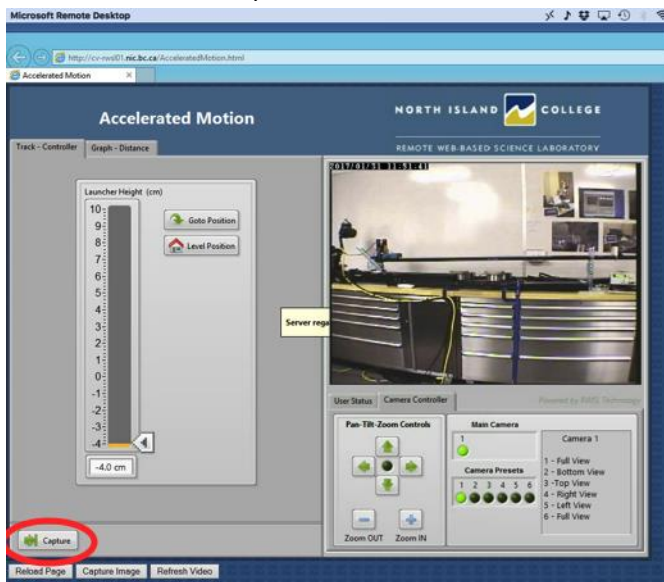


You should then see this:



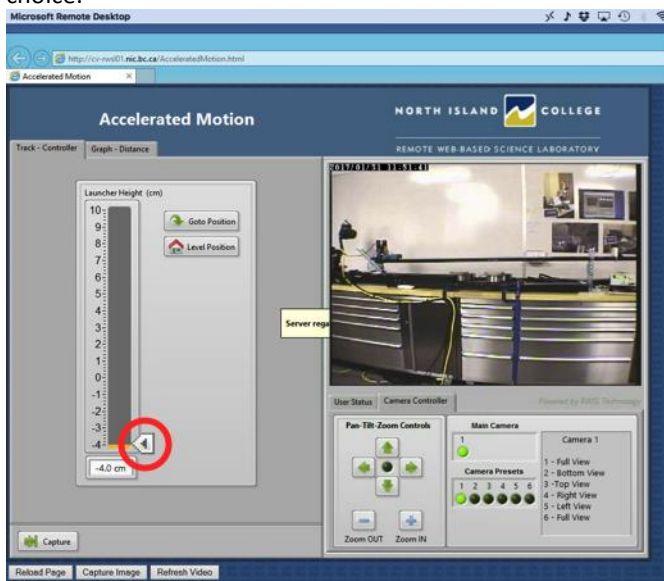
If you like, you can play around with the camera controls to get a better view of different parts of the apparatus.

If the cart is not already at the far left end of the track, then click the **Capture** button (shown below):



Wait until the cart is completely captured and stationary at the left end of the track. Be patient!

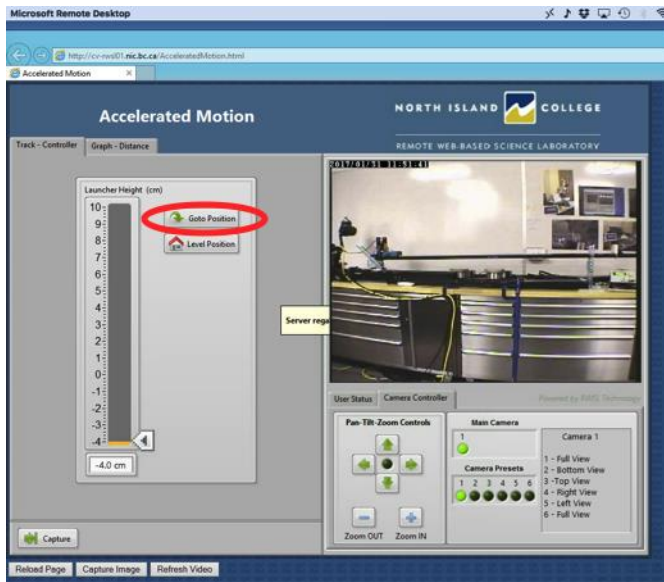
Once cart is captured, **adjust the Launcher Height** slider (shown below) to **anything above 2.5cm**, your choice:



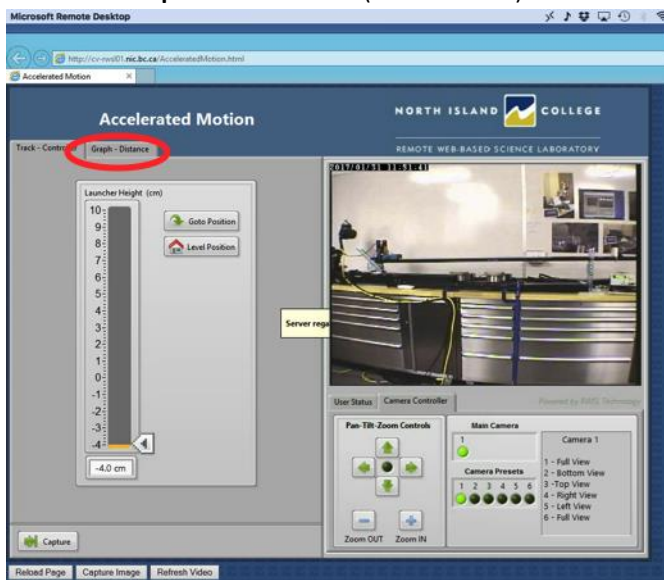
**Record the Launcher Height** value that you selected (found below the slider, in *cm*):



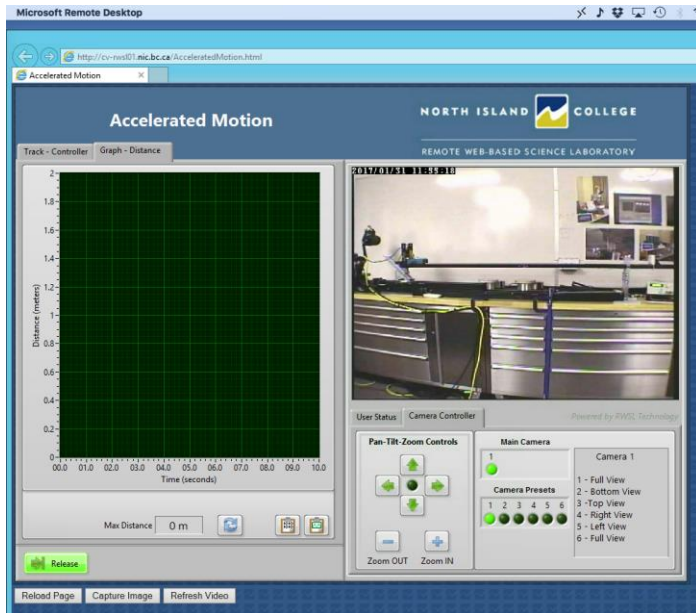
Hit **Goto Position** (shown below) and wait for the incline to move up to your selected height:



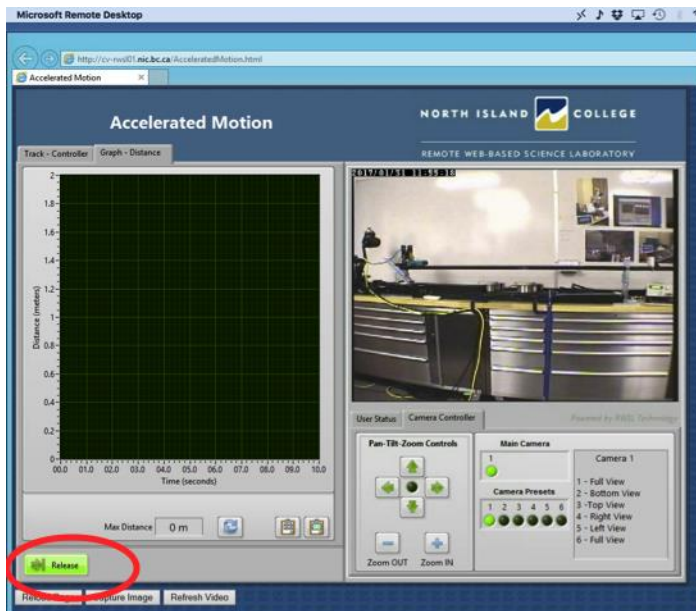
Select the **Graph - Distance** Tab (shown below):



You should see this:

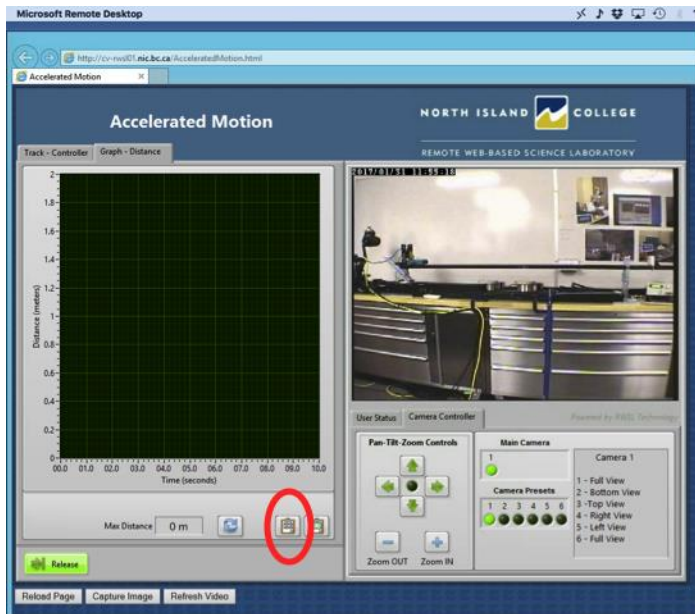


Finally, hit the **Release** button (shown below) and watch the graph form as the cart rolls down the track:



Record the **Max Distance** (shown at the bottom of the graph, in  $m$ ).

Copy the data by clicking on the 1's and 0's button (shown below):



Paste the data into the **Data And Calculations** section of your **Lab 5** lab report.

If you want to re-run the experiment, feel free to do so.

When you are done, **release control** by **right-clicking on any grey area** (as you did earlier to request control) and selecting **Release control** from the dialogue box that appears. **You MUST release control so that the next student is able to take their data.** Close the windows to automatically log off of the system.

If you have Excel®, then produce a  $v$ - $t$  graph of your data using **Lab 5  $v$ - $t$  Graph Generator**. **Important: Include data up to the highest distance only** (beyond that, the cart was bouncing off the bottom of the track and we don't want to include this data). If you don't have Excel, **email your data** to your lab instructor and you will be sent back a  $v$ - $t$  graph of your data.

## Mac

### Before your sign up time (Mac):

If you have a two-button mouse, then you can right-click in the RWSL interface when indicated. **If you do not have a two-button mouse**, then follow these instructions to enable a two-finger tap on your trackpad:

- Go to **System Preferences** on your Mac
- Select **Trackpad**
- Select **Secondary click** and **Click with two fingers** and then close that dialogue box

Download the Microsoft Remote Desktop app from:

<https://itunes.apple.com/ca/app/microsoft-remote-desktop/id715768417?mt=12>

Click on **View in Mac App Store**:

View in Mac App Store

Then click on **Get**:



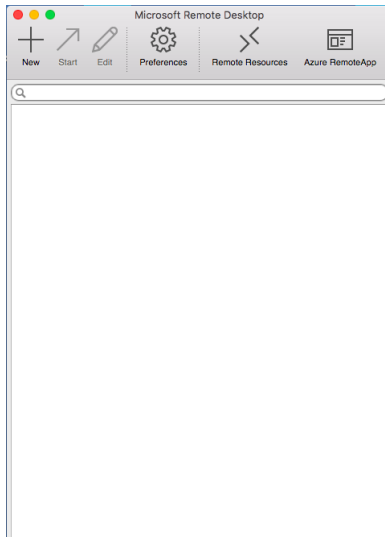
Get

Then click on **Install App**:

Install App

Find and **open the app** on your computer.

You should see this:



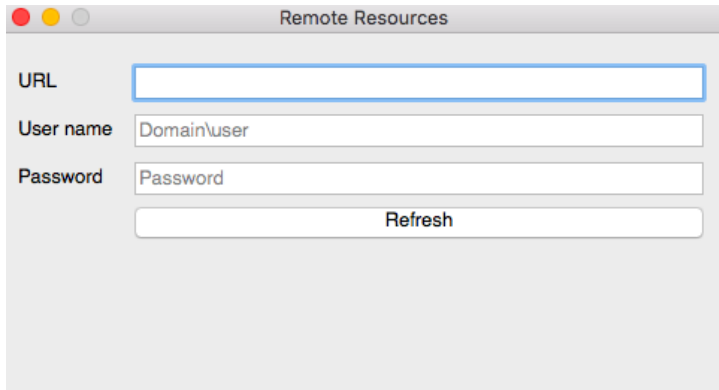
**Make sure you can get to this point before your sign-up time.**

At your sign-in time (Mac):

**Make sure you have followed the instructions above before your sign-up time.** If you run into problems during your sign-up time, you can email Albert Balbon at [balbon@nic.bc.ca](mailto:balbon@nic.bc.ca) or call him at: 250-334-5222.

Click on **Remote Resources**.

You should see this:



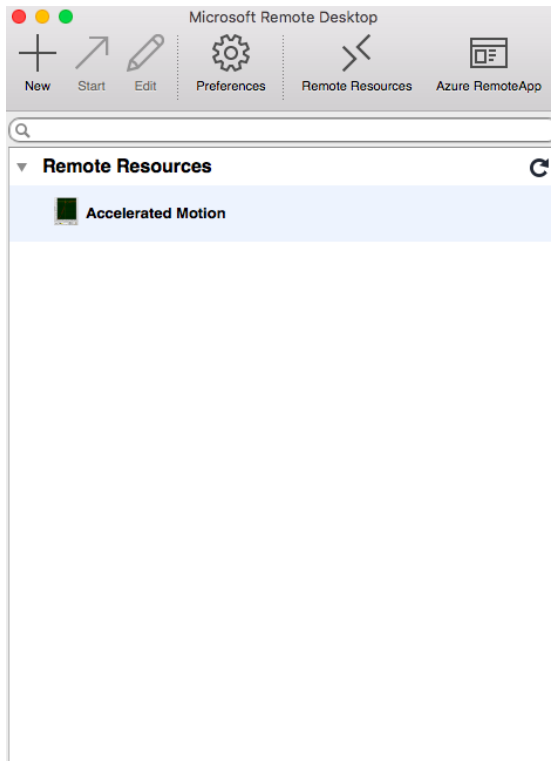
The screenshot shows a window titled "Remote Resources". It contains three input fields: "URL" (empty), "User name" (containing "Domain\user"), and "Password" (containing "Password"). Below these fields is a "Refresh" button.

Enter <https://nanslo-labs.nic.bc.ca/RDWeb/Feed/webfeed.aspx> into the URL field.

Enter the **Username**: RWSL\Kwantlen.Student and **Password**: Kwantlen

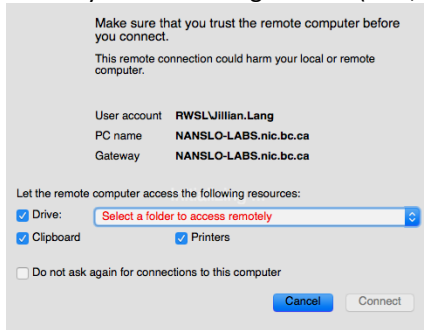
Hit **Refresh**.

You should see this:

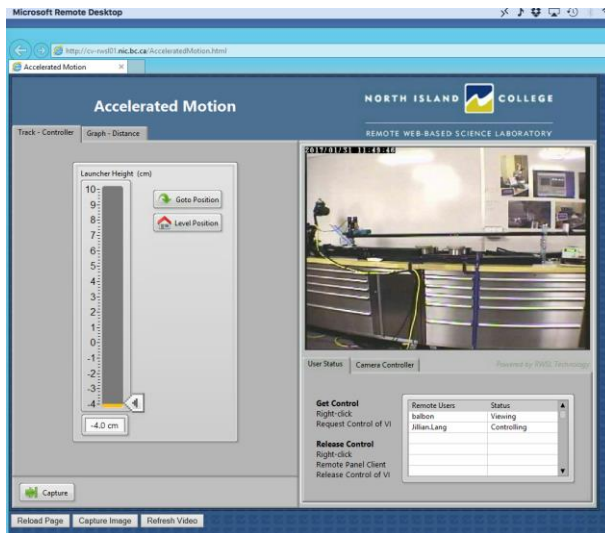


Click on **Accelerated Motion**

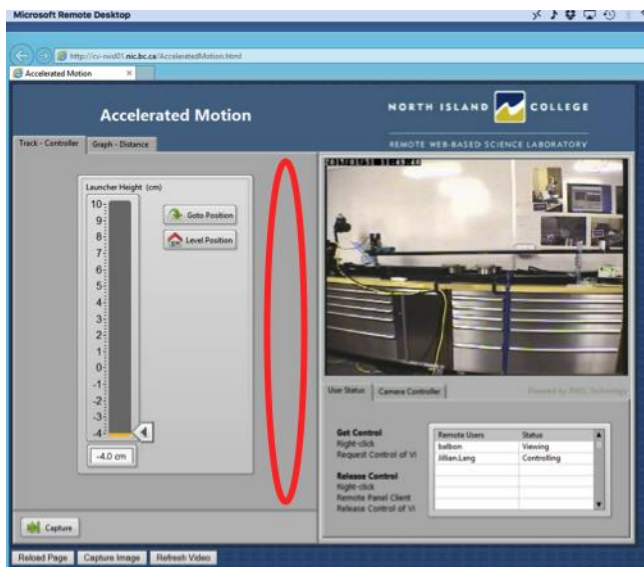
You may see something like this (If so, browse to any folder on your computer and hit **Connect**):



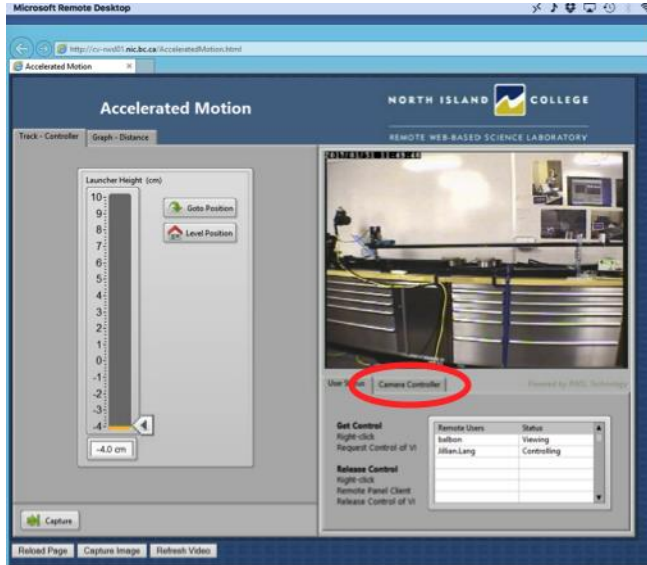
You should see this:



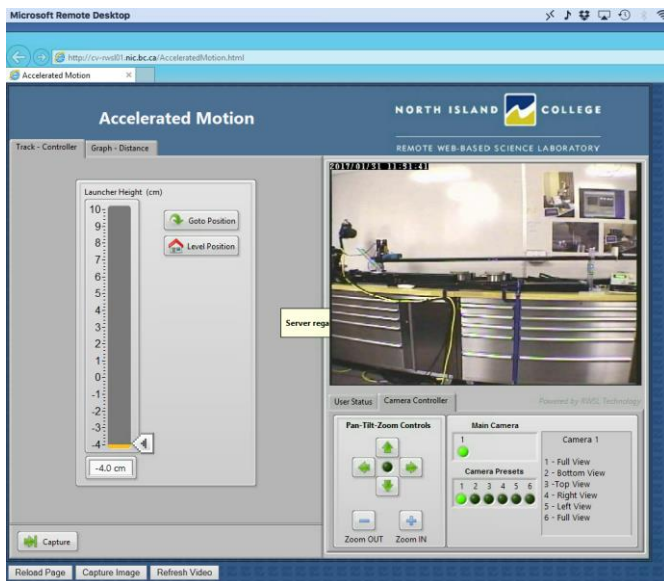
**Request control** by **secondary-clicking** (right-clicking if you have a 2-button mouse or double finger clicking on the trackpad if that is the way you set it up earlier) **on any grey area** (e.g., shown below in the red circle) and selecting **Request control** from the options that appear.



Once you have control, click on **Camera Controller** tab (shown below):



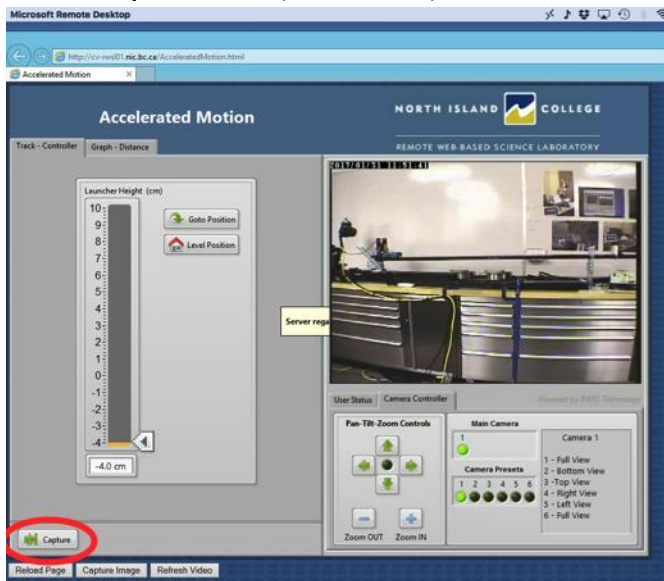
You should then see this:



If you like, you can play around with the camera controls to get a better view of different parts of the apparatus.

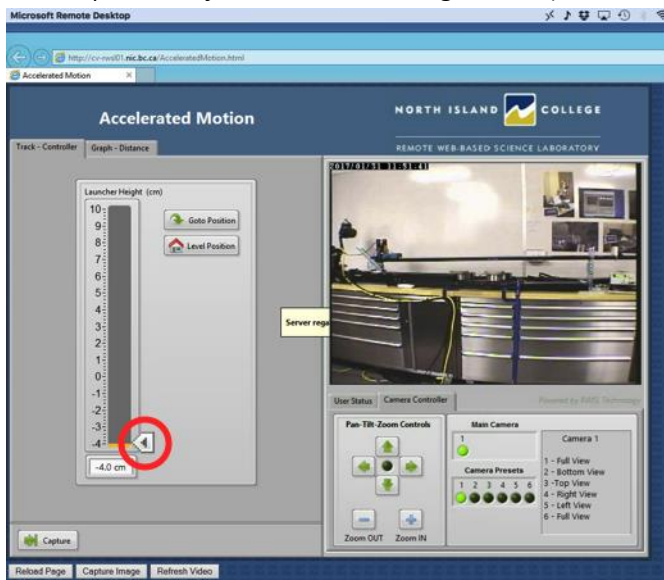


Click the **Capture** button (shown below):



Wait until the cart is completely captured and stationary at the left end of the track. Be patient!

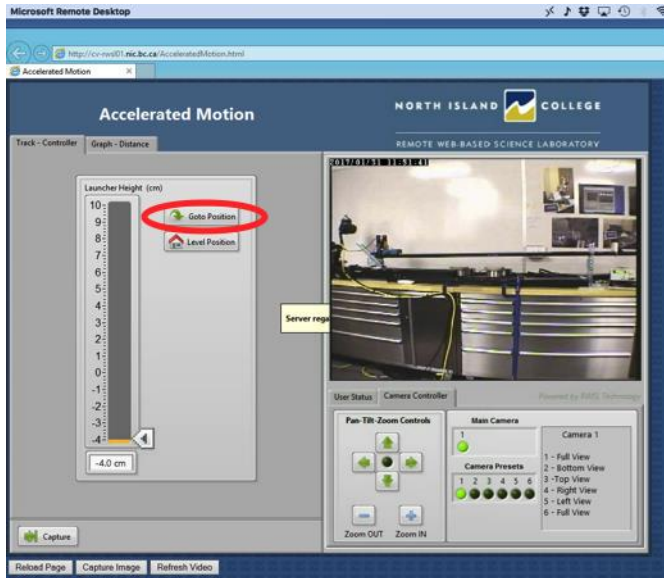
Once captured, **adjust the Launcher Height** slider (shown below) to **anything above 2.5cm**, your choice:



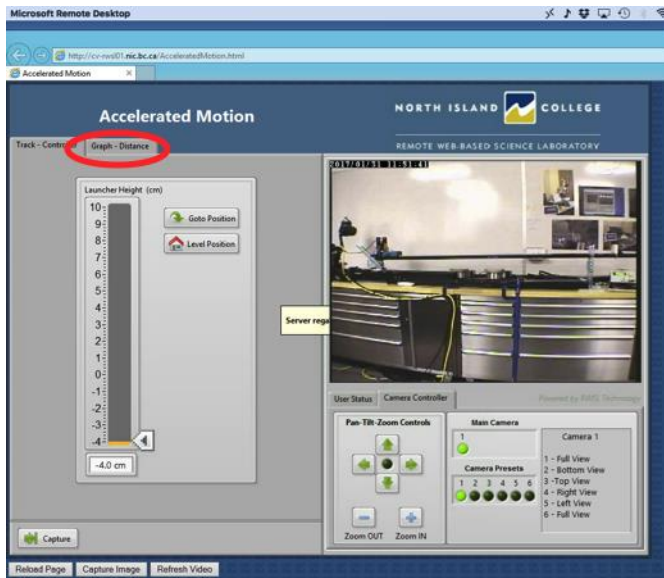
**Record the Launcher Height** value that you selected (found below the slider, in *cm*):



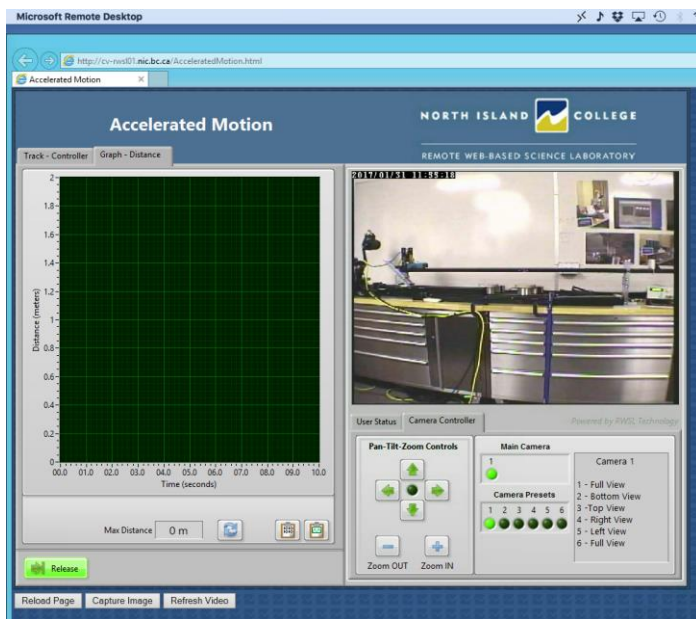
Hit **Goto Position** (shown below) and wait for the incline to move up to your selected height:



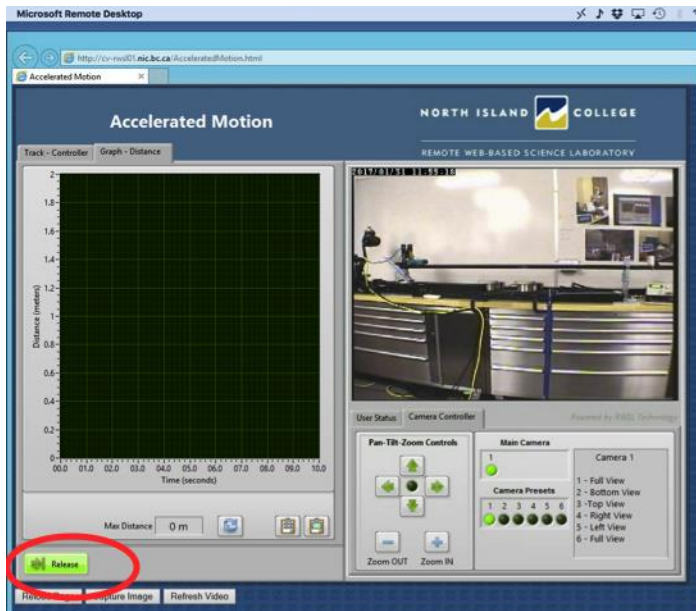
Select the **Graph – Distance** Tab (shown below):



You should see this:

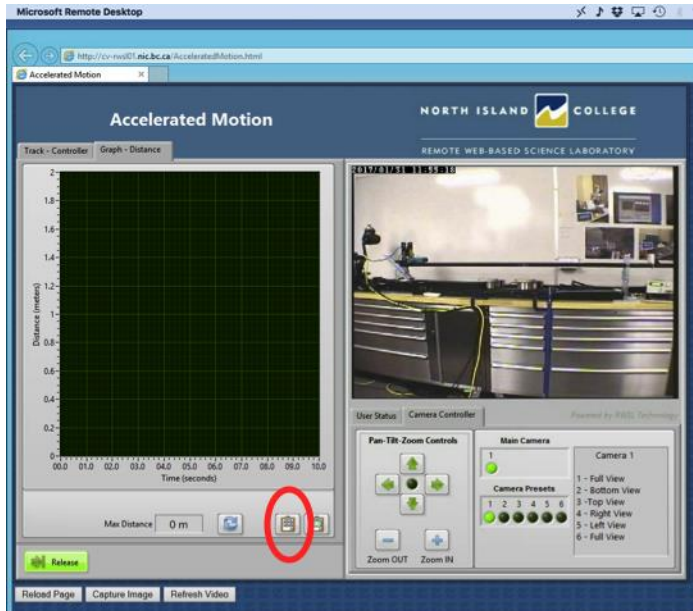


Finally, hit the **Release** button (shown below) and watch the graph form as the cart rolls down the track:



Record the **Max Distance** (shown at the bottom of the graph, in *m*).

Copy the data by clicking on the 1's and 0's button (shown below):



Paste the data into the Data And Calculations section of your Lab 5 lab report.

If you want to re-run the experiment, feel free to do so.

When you are done, **release control** by **secondary clicking on any grey area** (as you did earlier to request control) and selecting **Release control** from the options that appear. **You MUST release control so that the next student is able to take their data.** Close the windows to automatically log off of the system.

If you have Excel®, then produce a v-t graph of your data using **Lab 5 v-t Graph Generator**. **Important: Include data up to the highest distance only** (beyond that, the cart was bouncing off the bottom of the track and we don't want to include this data). If you don't have Excel, **email your data** to your lab instructor and you will be sent back a v-t graph of your data.

## Lab 5: Acceleration on an Incline

### Objective

To predict and measure the acceleration  $a$  of a cart on a frictionless incline.

### Theory

For an object on a frictionless incline at angle  $\theta$ , the *predicted acceleration*  $a$  of the object is

$$a = g \sin \theta$$

where  $g$  is the acceleration due to gravity.

To find the angle of a ramp  $\theta$ , the following equation may be used

$$\theta = \sin^{-1} \left( \frac{h}{l} \right)$$

where  $h$  is the height of the ramp and  $l$  is the length of the ramp.

### Apparatus

[RWSL](#), [a remote web-based science lab in which an experiment can be done remotely to measure the acceleration of a cart on an incline and the height and length of the incline. The uncertainty of the slope of the v-t graph is  \$\pm 3\%\$ .](#)

### Data and Calculations

At my pre-chosen sign-up time and using the given instructions, I gained access to the RWSL Accelerated Motion lab apparatus. I found the following to be very straightforward:      . I had difficulty with      . Summing up my experience during the session,      . The total session time was about      minutes.

Using the RWSL, the height  $h$  of the incline was:      cm  $\pm$  0.05 cm.

The length  $l$  of the incline was:      cm  $\pm$  0.05 cm.

The angle of the incline  $\theta$  was calculated to be:       $^\circ \pm$        $^\circ$ .

Therefore, angle of the incline  $\theta$  is       $^\circ \pm$       %.

Using the RWSL, the following distance and time data was collected:

This data was put into Excel© to generate a  $v$ - $t$  graph and this is a screenshot of that graph:

The *acceleration*  $a$  of the cart on the inclined plane was found to be:  $\text{cm/s}^2 \pm \quad \%$ .

Using the equation derived from using free-body diagrams and Newton's laws and the measured incline angle  $\theta$ , the predicted acceleration  $a$  of the cart =  $\text{m/s}^2$ .

The uncertainty of the predicted acceleration  $a$  of the cart =  $\text{m/s}^2$ .

Therefore, *the predicted acceleration*  $a$  of the cart was  $\text{m/s}^2 \pm \quad \%$ .

### Analysis

Name:

Date:

### Pre-lab 6: Uniform Circular Motion

7) We will use a simulation to model the behaviour of an object in uniform circular motion in order to become familiar with the concepts involved. Later, we will actually measure an object in uniform circular motion.

Open the Physics Classroom Rotational Motion [Interactive](#), read the instructions given, and **expand** the simulator. Hit **go**. Adjust the **Angular Velocity of Disk slider to 126 deg/sec**. Hit the **graph** button.

The red curve is the position-time  $x$ - $t$  graph for the ladybug. Each tick mark on the time axis of the graph marks off 0.5 s. Note: you can hit **reset graph** and **graph** to watch the graph form again and again.

Based on the graph, what is the **period of rotation  $T$**  of the ladybug (i.e., the time it takes for the ladybug to make one full revolution)? (no uncertainties, since this is a simulation)

Move/**drag the ruler** so that one end of the ruler is at the centre of rotation (i.e., at the centre of the record). If the tick marks on the ruler mark off 5 cm each, what is the **radius of revolution  $r$**  of the ladybug (from the centre of the record to the centre of the ladybug; assume the centre of mass of the ladybug is at the centre of the ladybug)?

Write an **equation** for the linear speed  $v$  of the ladybug using only  $r$  (radius of rotation) and  $T$  (the period of rotation). Hint: think of distance around the circle over time?  $v =$

Calculate the **ladybug's linear speed  $v$**  in cm/s:

What is the **Ladybug's linear velocity given in the simulator?**

Calculate a **% discrepancy** between these two  $v$  values (they should be close!):

Subtracting any two velocity vectors results in a velocity vector pointing towards the center of rotation. It follows that this is also the direction of  $\Delta v/t$ . Therefore, the **direction of the acceleration  $a$  is also towards the center of rotation**. This type of acceleration is often called **centripetal acceleration** and denoted as  $a_c$ .

Using the relationship  $a_c = \frac{v^2}{r}$ , what is the **ladybug's acceleration  $a$**  in  $\text{cm/s}^2$  (give the **direction** of  $a$  as well)?

Assume the mass of the ladybug is 1g. Using **Newton's second law**, what is the **net force  $F_{net}$**  acting on the ladybug in Newtons (give the **direction** of the force as well)?

N (Note: to  $F_{net}$  in Newtons, you must convert the mass  $m$  to kg and the acceleration  $a$  to  $\text{m/s}^2$ )

The net force acting on an object in uniform circular motion is often called **centripetal force** and denoted as  $F_c$ .

What is the **centripetal force  $F_c$**  on the ladybug in Newtons (give the **direction** of the force as well)?

N

Repeat the above for the **ant** (assume the **ant also has a mass of 1g**). To show the green  $x$ - $t$  graph for the ant, hit **show ant graph**.

period of rotation  $T =$

radius of rotation  $r =$

calculated linear speed  $v =$

given linear speed  $v =$

% discrepancy between calculated and given  $v$ 's =

centripetal acceleration  $a_c =$

centripetal force  $F_c =$

8) In Lab 6, you will estimate uncertainties for  $r$ ,  $T$  and  $m$  (and then calculate their % uncertainties). Using these % uncertainties and the rules for calculating uncertainties used in previous lab work (and given at the top of your Phys 1100 labs course webpage), **you will have to calculate the % uncertainties of  $v$ ,  $a_c$  and  $F_c$ .**

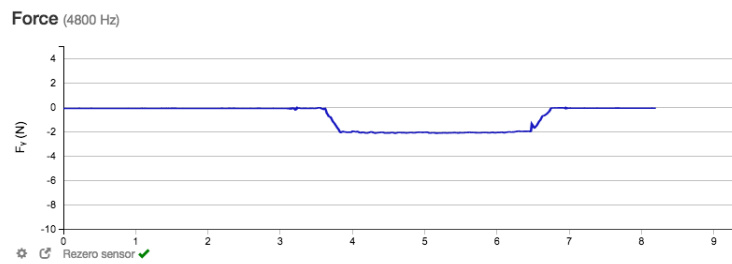
Recall  $v = \frac{2\pi r}{T}$  How will you calculate the % uncertainty of  $v$ ?

Recall  $a_c = \frac{v^2}{r}$  How will you calculate the % uncertainty of  $a_c$ ?

Recall  $F_c = ma_c$  How will you calculate the % uncertainty of  $F_c$ ?

9) **Attach the eye hook accessory** to the IOLab device as you did in Pre-lab 1. Thread the string that was supplied in your kit through the eye hook and through the loop at the other end of the string as seen in **Sample Lab 6 Set-up Video** found on your Phys 1100 labs course webpage (Note: **Please do not tie a knot!**). Wrap the other end of the string around your hand a few times as shown in the video, so that you won't be able to accidentally let it go.

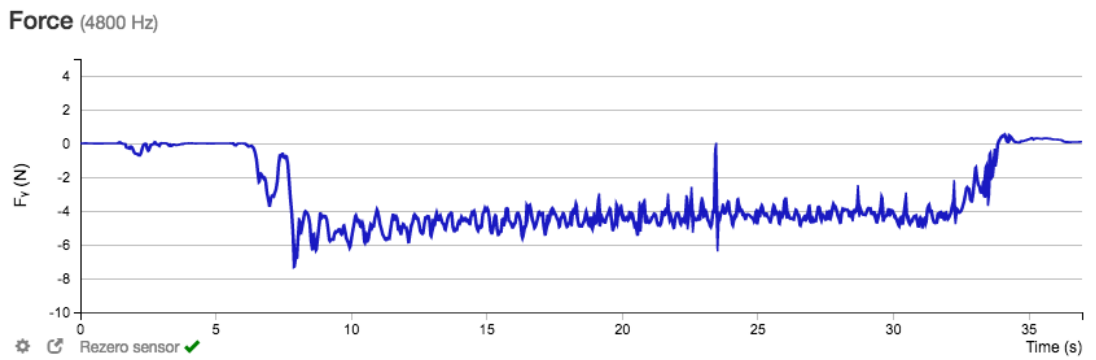
Open the IOLab software and turn on the IOLab device. With the **Force** sensor selected in the IOLab software, click **Rezero sensor** and choose a **smoothing of 25**. Place the IOLab on the surface in front of you, hit **Record**, then **pick up the IOLab device by the force eye hook attachment** for a couple of seconds, **put it down** and then hit **Stop**. You should have a graph that looks something like:



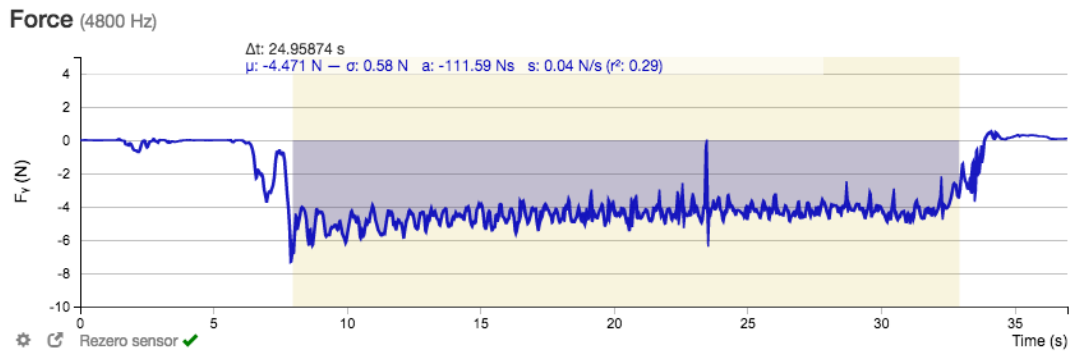
If not, you need to re-calibrate your IOLab device (see Pre-lab 1 or the top of your Phys 1100 labs course webpage).

Hit **Reset**, **Rezero sensor** and again choose a **smoothing of 25**. Hit **Record**, then pick up the IOLab device from a resting position and **swing the IOLab device in a circle at a fairly constant speed** as seen in the sample set-up video **for 30 revolutions being extremely careful that the IOLab device doesn't hit anything**, then carefully stop the device and set it down to rest again, and finally hit **Stop**.

You should obtain a graph that somewhat resembles this one (depending on your chosen radius and speed):



Since it takes a while to get the IOLab swinging the way you want it, and then some time to wind down before you hit Stop, only some of the graph is relevant for determining the average force acting on the IOLab during uniform circular motion. Selecting the relevant part of the  $F$ - $t$  graph using the Histogram Tool (i.e., the area where the IOLab was moving in uniform circular motion) the above example appears something like this:



What is the **average force  $F_c$**  on the IOLab device while it was moving in uniform circular motion in this example (include uncertainty)? (ignore the sign/take the absolute value)

The time selected in this example is  $\Delta t = 24.95874$  s. From this, **how long did it take the IOLab to make one revolution** (include uncertainty)? Period  $T =$

From previous work, the mass  $m$  of your IOLab device was found to be:  $m =$     $\pm$   

Now, use the Histogram Tool to **select a range of your own graph representing when the IOLab was moving in uniform circular motion for the 30 revolutions.**

Attach a **screenshot** of your results here:

From your graph, **what is the average force  $F_c$**  acting on the IOLab device while it was moving in uniform circular motion (include uncertainty)?



**Calculate the period  $T$**  of the IOLab device while it was moving in uniform circular motion (include uncertainty)?

10) In some ways, the hardest part of Lab 6 will be to measure the radius of rotation  $r$ , since you will not be able to measure it while the IOLab is being swung in a circle! **Suggest a way you could determine the radius.** Hint: you could pick a radius before you start, mark it somehow, and then swing the IOLab device with that marked radius. Or you might come up with something even better than this. You don't need to measure it for the pre-lab; just describe how you will do it when you do Lab 6:

Don't forget to turn off your IOLab device.

## Lab 6: Uniform Circular Motion

### Objective

To predict and measure the centripetal force acting on an object being swung in a circle at constant speed.

### Theory

If an object is moving at a constant speed  $v$  in a circle of radius  $r$  and a period of rotation  $T$ , then the linear velocity  $v$  is

$$v = \frac{2\pi r}{T}$$

and the centripetal acceleration  $a_c$  is

$$a_c = \frac{v^2}{r}$$

Therefore, the centripetal force  $F_c$  acting on the object is

$$F_c = ma_c = \frac{mv^2}{r}$$

where  $m$  is the mass of the object moving in uniform circular motion.

### Apparatus

IOLab device and a computer with the IOLab software installed

With the **Force** sensor selected in the IOLab software, and the eyehook attachment attached to the IOLab device, the force of pull on the IOLab can be measured as the eyehook is pulled. IOLab statistics have an uncertainty of  $\pm 3\%$ .

A string inserted through the eyehook (the other end of which is used to swing the IOLab in a circle at constant speed)

Tape measure

### Data and Calculations

From previous work, the mass  $m$  of the IOLab device was found to be  $\text{_____} \pm \text{_____}$

The IOLab device was swung (by a string attached to the eyehook of the IOLab device) in a horizontal circle at roughly constant speed for 30 revolutions. With the **Force** sensor selected in the IOLab software, the average force acting on the IOLab device in uniform circular motion was found from the average force on the  $F-t$  graph using the Histogram tool:  $F_c = \text{_____} \pm \text{_____}$

as seen in this screenshot:

The period  $T$  of the IOLab device was also determined from the  $F$ - $t$  graph. The period  $T$  is the amount of time for **one** complete revolution. The period  $T$  is calculated as follows:

Therefore, the period  $T =$              $\pm$

The radius of rotation  $r$  was measured to be:             $\pm$

Justification of the chosen uncertainty value for  $r$ :

The % uncertainty of the radius  $r$  is            %

Therefore, radius of rotation  $r$  was measured to be:             $\pm$             %

The constant speed  $v$  is calculated as follows:

The % uncertainty of constant speed  $v$  is calculated as follows:

Therefore, the constant speed  $v =$              $\pm$             %

The centripetal acceleration  $a_c$  is calculated as follows:

The % uncertainty of centripetal acceleration  $a_c$  is calculated as follows:

Therefore, the centripetal acceleration  $a_c =$              $\pm$             %

The predicted centripetal force  $F_c$  on the IOLab device was calculated as follows:

The % uncertainty of the predicted centripetal force  $F_c$  is calculated as follows:

Therefore, the predicted centripetal force  $F_c$  is             $\pm$             %.

Table #1: Summary of Results for Centripetal Force on the IOLab Device in Uniform Circular Motion

Predicted centripetal force $F_c$ using mass, radius and period measurements	$\pm$
Measured centripetal force $F_c$ measured directly by IOLab software	$\pm$

% discrepancy calculation between predicted and measured centripetal force:

### Analysis

Name:

Date:

### Pre-lab 7: Momentum and Impulse

- 1) From previous lab work, what is the **mass  $m$  of the IOLab device** (include its % uncertainty)?
- 2) The change in momentum  $\Delta p$  of an object of mass  $m$  before and after an interaction is given by

$$\Delta p = m\Delta v$$

where  $\Delta v$  is the its change in velocity during the interaction (Important: the **sign of the velocity must be taken into account**).

The **impulse on an object is defined as  $F\Delta t$**  where  $F$  is the force acting on an object and  $t$  is the time that the force is applied to the object during the interaction.

**The change in an object's momentum is equal to the impulse on the object.**

The product  $F\Delta t$  can be found from the **area  $a$**  under the force-time  $F$ - $t$  graph during an interaction.

Therefore, in an interaction, how do you expect  $m\Delta v$  to compare to the **area  $a$**  under the force-time  $F$ - $t$  graph during the interaction?

- 3) We will use the IOLab device (with the **spring accessory attached**) and the IOLab software with the **Force** and **Wheel** sensors selected to measure the force and velocity on the IOLab device during an interaction, i.e., as it hits and bounces off of a solid object. The force on the IOLab cart is measured as the spring is pushed in and released. This force on the cart will be seen on a force-time  $F$ - $t$  graph. The velocity of the cart will be seen on the  $v$ - $t$  graph.

We will measure  $F\Delta t$  as the **area  $a$**  under the  $F$ - $t$  graph during the interaction using the Histogram tool.

We will measure the **initial and final velocities** on the  $v$ - $t$  graph by hovering the cursor over the  $v$ - $t$  graph.

Recall that the IOLab statistics have an uncertainty of  $\pm 3\%$ .

Attach the **spring** to the IOLab device as it appears in this [video](#). Open the IOLab software and select the **Force** and **Wheel** sensors (also, de-select Position and Acceleration under the Wheel sensor). Select a **smoothing of 3** and **Rezero sensor**.

Hit **Record** and give the IOLab device a push to get it going and then let it go so that it hits and bounces off a solid object e.g., a book, wall or your hand (as shown in the video). Hit **Stop**.

Use the Magnifying tool to **zoom-in on the area of graph showing the interaction** of the cart with the object. You may have to repeat this measurement many times to get a good result.

Use the Histogram tool to **select the area of the interaction**. This is also shown in the video. Note: Unlike in the video, you will see only the green line on the  $v$ - $t$  graph. Include a screenshot of both graphs with the selected area shown here:

What is  **$F \cdot t$**  or the **area  $a$**  under the  $F$ - $t$  graph during the interaction (include its % uncertainty)?

Hover the cursor over the  $v$ - $t$  graph at the beginning of the selected area, i.e., **immediately before the interaction**. What is the velocity  $v_i$  (include its % uncertainty)?

Now determine the velocity **immediately after the interaction**  $v_f$ . What is the velocity  $v_f$  (include its % uncertainty)?

Calculate the change in velocity  $\Delta v = |v_f - v_i|$ :

Important: the **sign of the velocity must be taken into account**

Note:  $\Delta v$  is the **absolute value** of  $v_f - v_i$  (this is only because the IOLab is moving in its negative direction when the spring is facing forward; opposite the direction of the positive  $y$ -arrow on the device)

Assume the % uncertainty of the difference between the initial and final velocities is the same as the % uncertainty of the individual velocities. What is the % uncertainty of  $\Delta v$ ?

Calculate  **$m\Delta v$** :

Calculate the **% uncertainty of  $m\Delta v$** :

How do  **$F \cdot t$**  and  **$m\Delta v$**  compare?

Don't forget to turn off your IOLab device.

## Lab 7: Momentum and Impulse

### Objective

To determine the change in momentum and the impulse on a cart bouncing off of a solid object.

### Theory

The change in momentum  $\Delta p$  of an object of mass  $m$  and change in velocity  $\Delta v$  is given by the following equation:

The impulse on an object is defined as  $\int F dt$ , where  $F$  is the force acting on an object during an interaction and the  $t$  is the time it takes for the interaction to occur. This is also equal to the area under the  $F$ - $t$  graph for the interaction.

The change in momentum of an object is equal to the impulse acting on the object (or the area under the  $F$ - $t$  graph) during an interaction.

### Apparatus

IOLab device and a computer with the IOLab software installed

With the **Force** and **Wheel** sensors selected in the IOLab software (also de-select Position and Acceleration under the Wheel sensor, and select a **smoothing of 3**, and select **Rezero sensor**), and the **spring accessory** attached to the IOLab device, the force on the IOLab device can be measured as the spring is pushed in or released, and the velocity of the IOLab device at any point can be determined from the  $v$ - $t$  graph. IOLab statistics have an uncertainty of  $\pm 3\%$ .

### Data and Calculations

The mass  $m$  of the IOLab device is \_\_\_\_\_.

The interaction of the cart bouncing off of a solid object was measured and the following  $F$ - $t$  and  $v$ - $t$  graphs resulted. This screenshot shows the area of the interaction zoomed in on and selected:

The *area*  $a$  under the  $F$ - $t$  curve is \_\_\_\_\_.

The impulse during the interaction is \_\_\_\_\_.

The velocity  $v_i$  immediately before the interaction is \_\_\_\_\_.

The velocity  $v_f$  immediately after the interaction is \_\_\_\_\_.

Calculation of change in velocity  $\Delta v = |v_f - v_i|$ :

Calculation of change in momentum  $\Delta p$ :

Table #1: Summary of Results for Change in Momentum and Impulse for an Interaction

Change in momentum $\Delta p$	
Impulse	

% discrepancy calculation between  $\Delta p$  and the impulse:

Analysis

Name:

Date:

### Pre-lab 8: Conservation of Mechanical Energy

11) We will use a simulation to model mechanical energy of a roller coaster in order to become familiar with the concepts involved. **Open the Physics Classroom Roller Coaster Model [Interactive](#)**, read the instructions given, and **expand** the simulator.

Select **Ramp** and **Show Velocity Vector**. Select **start**.

What happens to potential energy  $PE$ ?

What happens to kinetic energy  $KE$ ?

What happens to the total mechanical energy  $ME$ ?

Does the cart go back up to its initial position after it bounces off the bottom each time?

What can you say about friction in this model?

Now **add friction** to the model by selecting **Track Drag**.

Does the cart go back up to its initial position after it bounces off the bottom now?

What happens to potential energy  $PE$ ?

What happens to kinetic energy  $KE$ ?

What happens to the total mechanical energy  $ME$ ?

Now select **Loop** and **start** (no friction).

What happens to potential energy  $PE$ ?

What happens to kinetic energy  $KE$ ?

What happens to the total mechanical energy  $ME$ ?

Now **add friction** to the model by selecting **Track Drag**.

What happens to potential energy  $PE$ ?

What happens to kinetic energy  $KE$ ?

What happens to the total mechanical energy  $ME$ ?

12) From previous lab work, what is the **mass  $m$  of the IOLab device?**  $\pm$

13) **Set up a ramp** or roller coaster-like track using a board, book, bristle board, etc. There are some videos on your Phys 1100 labs course webpage to give you some ideas, but feel free to be creative!

Place the IOLab device at the top and **measure the height  $h$  of the IOLab device at the top of the ramp** from the level of the bottom of your ramp/track straight up to the centre of the IOLab device when it's at the top.

$h =$   $\pm$

**Justification** for the uncertainty of  $h$ :



Open the IOLab software and turn on the IOLab device. With the **Wheel** sensor selected in the IOLab software (and Position and Acceleration de-selected), the velocity of the IOLab device at the bottom of the ramp can be determined.

With the wheels down and the cart moving in the direction of the y-arrow down the ramp or track, practice releasing the IOLab device from the top and catching after it reaches the bottom. When you have good technique, then hit **Record**, wait a few seconds and then release the IOLab device from the top of the ramp, let it roll down the ramp, catch it after it reaches the bottom and then hit **Stop** a few seconds later. Repeat until you have a graph that you feel accurately represents the motion of the cart down the ramp/track.

**Select/zoom-in** on the part of the  $v$ - $t$  graph showing the entire run from top to bottom using the Magnifying Tool.

Use the Histogram Tool to **determine velocity at the bottom** on the  $v$ - $t$  graph (as you measured velocity in Pre-lab 7 and Lab 7). Hint: this should be the highest velocity reached.

$v =$         m/s  $\pm$         %.

Attach a **screenshot** here:

14) In Lab 8, you will be calculating  $mgh$  and  $\frac{1}{2}mv^2$ . You will determine % uncertainties for  $m$ ,  $h$  and  $v$ . Using these and the rules for calculating uncertainties given previously (and at the top of your Phys 1100 labs course webpage), you will have to calculate % uncertainties of  $mgh$  and  $\frac{1}{2}mv^2$ .

How will you calculate the % uncertainty of  $mgh$ ?

How will you calculate the % uncertainty of  $\frac{1}{2}mv^2$ ?

Don't forget to turn off your IOLab device.

## Lab 8: Conservation of Mechanical Energy

### Objective

To measure the mechanical energy at two different points of a “roller coaster.”

### Theory

The potential energy  $PE$  of an object of mass  $m$  at a height  $h$  is defined as

$$PE = mgh$$

The kinetic energy  $KE$  of an object of mass  $m$  moving at a velocity  $v$  is defined as

$$KE = \frac{1}{2}mv^2$$

If the mechanical energy of an object is conserved between an initial and final point, then

total mechanical energy at the initial point = total mechanical energy at the final point

or

$$PE_i + KE_i = PE_f + KE_f$$

Consider the situation of a cart of mass  $m$  on a roller coaster. If we consider two points, one at the very top where the cart is at rest and one at the bottom where the height is 0.

Then the total mechanical energy at the top is:

$$PE = mgh \text{ since } KE \text{ is zero at the top where it is at rest (i.e., } v = 0)$$

and the total mechanical energy at the bottom is:

$$KE = \frac{1}{2}mv^2 \text{ since } PE \text{ is zero at the bottom where } h = 0$$

### Apparatus

### Data and Calculations

The mass of the IOLab device is  $\pm$

The initial height  $h$  of the cart at the top of the “roller coaster” is  $\pm$

The justification for the uncertainty of the initial height is

The total mechanical energy (in Joules) at the top is calculated as:

The velocity  $v$  of the IOLab device at the bottom of the “roller coaster” was found from the IOLab software using the Wheel sensor as seen in selected area in the following screenshot:

The velocity  $v$  at the bottom is  $\pm$

The total mechanical energy (in Joules) at the bottom is calculated as:

The % discrepancy between the total mechanical energy at the top and the total mechanical energy at the bottom is calculated as:

### Analysis

Name:

Date:

### Pre-lab 9: Electrostatics

\*This lab is adapted from *Electric and Magnetic Interactions*, Chabay and Sherwood, 1995 (and borrowed with thanks from Langara College)

1) Electrostatic interactions have the following basic properties:

- There are two kinds of charge, called “+” and “-”,
- Like charges repel, unlike charges attract,
- The electrostatic force:
  - is proportional to the amounts of both charges,
  - acts along a line between the charges, and
  - decreases rapidly as the distance between the charges increases.

You will investigate these basic aspects of electrostatics using “invisible” tape to make electrostatically charged objects in a reproducible manner. You will attempt to explain these basic interactions using three fundamental physical principles:

- **conservation of charge:** The net charge of a closed system does not change,
- **Coulomb's law**,  $\vec{F} = k \frac{q_1 q_2}{r^2} \hat{r}$ , and
- **the superposition principle:** The net electrostatic force on a charged object is the vector sum of the individual forces on the object due to all other charged objects.

Preparing a base-tape:

- Use a strip of tape about 20 cm (about as long as this paper is wide). Shorter pieces are not flexible enough and longer pieces are difficult to handle.
- Fold over one end of the strip to make a non-sticky “handle”:



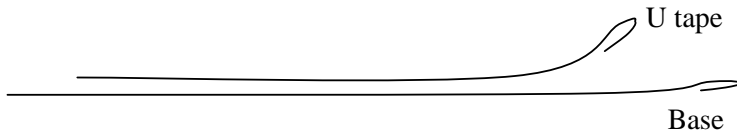
Handle

- Stick the strip of tape with the handle down onto a smooth flat surface like a desk.
- Smooth this base tape down with your thumb or fingertips.

This base tape provides a standard surface to work from. Without this base tape, you may get different effects on different kinds of surfaces.

Preparing a U-tape:

- Run your finger slowly across the base-tape.
- Stick another tape with a handle down *on top of* the base tape.
- Smooth the upper tape down well with your thumb or fingertips.
- Write “U” (for Upper) on the handle of the upper tape
- Quickly pull the “U tape” up and off the base tape, leaving the base tape stuck to the desk.



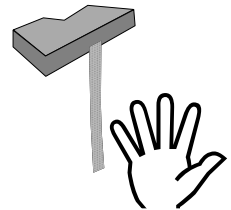
Note: U-tapes can be re-used by following the above procedures to recharge them.

Here we will see if invisible tape exhibits the properties of electrostatic interactions mentioned earlier. If so, we can conclude that the tape becomes electrically charged when we pull it off another piece of tape, and we can study the behaviour of pieces of tape as a concrete example of electrostatic interactions.

Hang the U tape vertically from the edge of the desk, and bring your hand near the hanging tape.

Write a brief description of what happens:

Bring your hand towards the other side of the tape and observe what happens. Does it matter which side of the tape you approach?



2) If U-tapes are electrically charged, how would you predict two U-tapes to interact with each other?

Why? (Yes, like charges repel, but why do they have like charges?)

Prepare a second U tape in exactly the same way (remember to write “U” on the handle). Bring it near the hanging U tape. Since the hanging tape is attracted to your hands, try to keep your hands out of the way. For example, you might approach the vertically hanging tape with the other tape oriented horizontally, held by two hands at its ends. Describe what happens:

You should find that the two U tapes repel each other rather strongly. If the air is very humid, you may have to do the experiment very fast.

We continue our investigation to decide whether the interaction between two U-tapes is electrostatic by checking the direction and the strength of the interaction. We will next investigate whether the force acts along a line connecting the objects (not all forces act along a line joining the two objects, e.g. magnetism).

Suspend a U-tape from a thread. Hold the thread in your hand or use a short piece of tape to stick the upper end of the thread to the desk. Approach the suspended thread from various directions with another U-tape. Does the force act along a line drawn from one tape to the other?

Describe the direction of the force on the hanging tape:

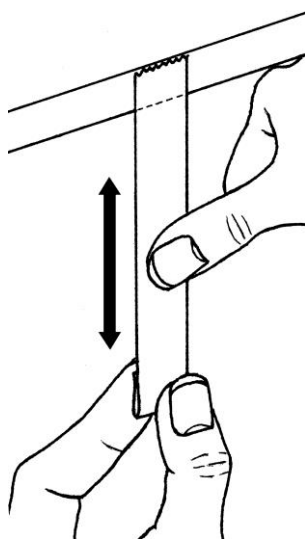
Next we will investigate whether the force decreases rapidly as the distance between the two tapes increases.

Move a U-tape very slowly toward a hanging U-tape. Observe, at several distances, the deflection of the hanging tape from its original position (for example, from the distance at which you first see repulsion, then half that distance, etc.) The deflection of the hanging tape away from its *original* vertical position is a measure of the strength of the interaction. Does the strength of the interaction depend on distance?

How can you tell?

Does the force decrease rapidly as the distance between the two tapes increases?  
Next we will investigate whether the force depends on the amounts of both charges.

Making a U-tape NOT interact: Make a fresh U-tape and stick it to the desk's edge. Hold its bottom end with one hand and slowly rub the thumb of your other hand along its non-sticky side. This action decreases the charge and creates a weaker U-tape. Now make observations and answer the following questions (delete the wrong answers):



Interaction between a weaker U-tape with your hand compared to a fresh U-tape with your hand	Interaction between a weaker U-tape with a fresh U-tape compared to a fresh U-tape with a fresh U-tape	Interaction between a weaker U-tape with a weaker U-tape compared to fresh U-tape with a weaker U-tape
stronger	stronger	stronger
weaker	weaker	weaker
same as before	same as before	same as before
no interaction	no interaction	no interaction

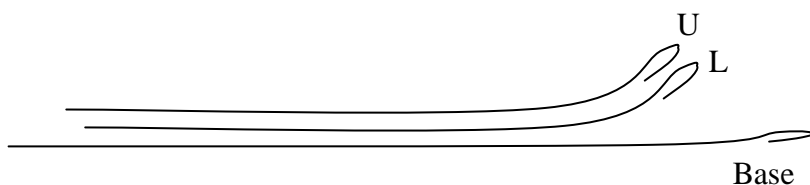
Does the force depend on the amounts of both charges?

3) How could you prepare a tape that has an electric charge unlike the charge of a U-tape (Try to think of a way before you continue.)?

**Preparing an L-tape:** (a reproducible way of making a tape with a charge that is unlike the U-tape).

- Run your finger slowly across the base-tape.
- Stick another tape, with a handle down, on top of the base tape and smooth it down well.
- Write "L" (for Lower) on the handle of this tape.
- Stick another tape, with handle down, on top of the L-tape and smooth it down well.
- Write "U" (for Upper) on the handle of this tape.

You now have three layers of tape on the desk: a base-tape, an L-tape, and a U-tape:



- *Slowly* lift the L-tape off the base tape, bringing the U-tape along with it (and leaving the base-tape stuck to the desk).
- Check to see whether there is attraction between the double layer of tape and your hand. If there is, get rid of the interaction by slowly rubbing the slick side with your fingers or thumb. *Check that the double layer of tape is no longer attracted to your hand.*
- Quickly separate the L and U-tape.

Make two L-tapes and two U-tapes. Make sure that all tapes are active.

- (a) If an L-tape is indeed electrically charged, and its charge is unlike the charge on a U-tape, what interaction would you predict between an L-tape and a U-tape?
- (b) What interaction do you ACTUALLY observe between an L-tape and a U-tape?
- (c) What interaction do you predict between two L-tapes?
- (d) What interaction do you ACTUALLY observe between two L-tapes?
- (e) Summarize the interactions that you have observed between U-tapes and L-tapes:

	U-tape	L-tape
U-tape		
L-tape		

4) Move a U-tape very slowly toward a hanging L-tape. Observe, at several distances, the deflection of the L-tape from vertical, as measured from L-tape's original position. (For example, from the distance at which you first see a deflection, then at half that distance, etc.) Note that you can't really go all the way to 0 distance!

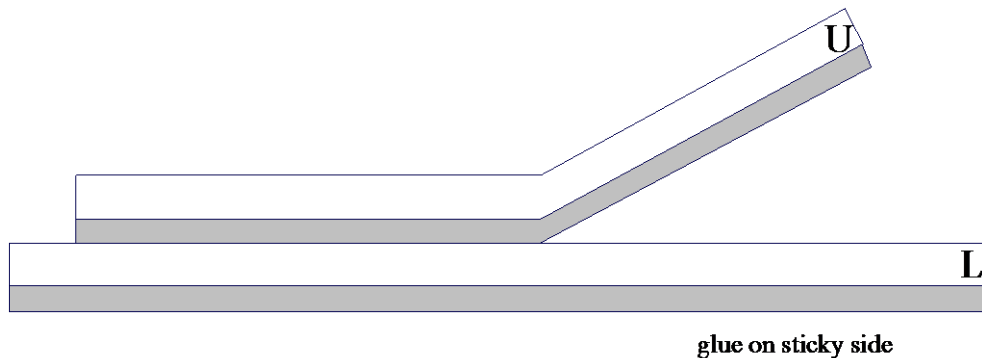
- (a) Describe how the strength of interaction changes with distance between the two tapes. The deflections of the tapes from the vertical are a measure of the strength of the interactions.
- (b) Does the force decrease rapidly as the distance between the tapes increases?
- (c) Why is the measurement more difficult with a U- and an L-tape than with two U-tapes?

5) Which other objects (hand, paper, metal, plastic, etc.) interact with a hanging U- or L-tape? Record the objects you try in the table below, and the interactions observed (try lots of different objects).

	U-tape	L-tape
Repulsion	<b>1.1</b>	
No interaction		
Attraction		

6) Charged objects, such as invisible tape, are negatively charged if they have more electrons than protons, and positively charged if they have fewer electrons than protons. To determine if U-tapes are positively or negatively charged, we can use the fact that if you run a plastic comb or pen repeatedly through your hair, or rub it with cotton or wool, **the plastic ends up having a negative charge** and therefore repels electrons.

- (a) Prepare a U-tape and an L-tape and hang them from your desk. Test them with your hand to make sure that they are both charged. Charge a plastic pen or comb and bring it close to each tape. Record your observations.
- (b) What can you conclude about the sign of the electric charge on (positive or negative)?  
the U-tape?  
the L-tape?
- (c) On this side-view of a U-tape being pulled up off an L-tape, draw minus signs (–) where a surface has become negatively charged (either by gaining negatively-charged particles, such as electrons or negative ions, or by losing positive ions). Draw positive signs (+) where a surface has become positively charged (either by gaining positive ions or losing negatively-charged particles). Be careful! Place the –'s and +'s only on the appropriate surfaces where they actually **are**! (The shading represents the glue on the sticky side of the tape.)

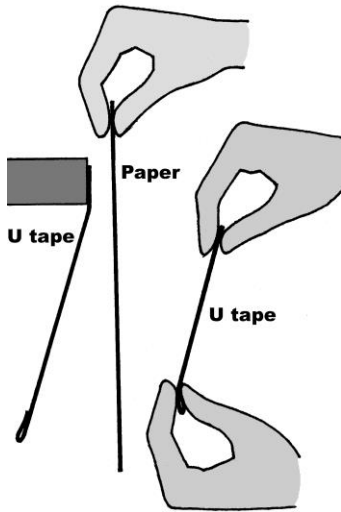


7) The presence of matter between two charged objects does not affect their electrostatic interactions. Intervening matter does not “screen” or “shield” charged objects from each other, just as your desk does not “screen” or “shield” your book from gravitational interactions with the earth.

Under good conditions of low humidity, when tapes remain strongly charged and interactions are observable with the tapes quite far apart from each other, it is possible to see interactions with paper between them, which shows that electrostatic interactions do go right through intervening matter. (You have already observed the case of electrostatic interactions through intervening matter. When approaching either side of a hanging U-tape, you saw the same interaction despite the charges presumably only being on the sticky side of the tape.)

- (a) Have another person hold a piece of paper close to (but not touching) a hanging U-tape. Bring another U-tape toward the hanging tape from the other side of the paper, holding both ends of this tape so that it can't swing.





Can you observe an interaction occurring right through the intervening paper?

This can be difficult, because the paper interacts with the hanging tape, which masks the interaction due to the other tape. This is an example of the superposition principle: the net electrostatic force is the vector sum of the force due to the tape plus the force due to the paper. Each individual interaction is unaffected by the presence of other charges.

To increase the sensitivity of the experiment, move the tape rhythmically toward and away from the hanging tape, as though you were pushing a swing. This should allow you to build up a sizable swing in the hanging tape even though the force is quite small, because you are adding up lots of small interactions.

(b) Using rhythmic movements, are you able to observe an interaction through the intervening paper?

8) We will use a simulation to model the behaviour of electric fields in order to become familiar with the concepts involved.

Open the Physics Classroom [Interactive](#).

Drag a negative charge into the middle of the screen. The arrows are pointing in the direction of the electric field. What is the direction of the electric field around the negative charge?

Put the negative charge back into the box and drag a positive charge into the middle of the screen. What is the direction of the electric field around the positive charge?

De-select "Electric Field" at the top right hand side of the screen.

Bring a sensor from the box near the positive charge. Move the sensor around. Try to generalize what you see:

Put the positive charge back in the box and bring out a negative charge. Move the sensor around. Try to generalize what you see:

## Lab 9: Electrostatics

### Objective

To demonstrate basic properties of electrostatic interactions.

### Theory

Electrostatic interactions have the following basic properties:

- There are two kinds of charge, called “+” and “-”,
- Like charges repel, unlike charges attract, and
- The electrostatic force:
  - is proportional to the amounts of both charges,
  - acts along a line between the charges, and
  - decreases rapidly as the distance between the charges increases.

### Apparatus

clear tape  
ruler

### Data and Calculations

### Analysis

Name:

Date:

### Pre-lab 10: Charge-to-mass Ratio of the Electron $e/m$

15) You will need to understand **direct and inverse relationships** in order to do Lab 10. If you need to review this, watch this Khan Academy [video](#) and practice identifying direct and inverse relationships by working through these [exercises](#).

According to the relationship  $V = kIr^2$  (where  $k$  is a constant), identify whether the following pairs of variables are related **directly** or **inversely**.

$V$  and  $r$  (if  $I$  is constant)?

$I$  and  $r$  (if  $V$  is constant)?

$V$  and  $I$  (if  $r$  is constant)?

16) Watch the following [video](#). Set up your IOLab device as shown in the video. Use the piece of wire, tape and an AA battery from your kit to **observe the magnetic field produced inside a wire coil**. You should expect the magnetic field to be directed into the device, or in other words, the negative  $z$ -direction. For this reason, let's focus on the  $z$ -direction only (de-select  $B_x$  and  $B_y$  after you select the Magnetometer sensor).

Attach a **screenshot** of your IOLab magnetic field measurement here:

**In what way(s) does this graph confirm (or contradict) what is expected from the theory** of magnetic fields created by passing current through a coil of wire?

Turn off your IOLab device.

3) Around 1900, a dramatic experiment established the existence of the **electron**, a charged particle very much smaller than an atom in size and in mass. In 1897, J. J. Thomson analyzed the motion of cathode rays (i.e., beams of moving electrons) as they passed through electric and magnetic fields.

Thomson's investigations gave the following results:

- 1) The **rays consist of particles that have a negative electric charge and a definite mass**.
- 2) The **charge-to-mass ratio of the electron  $e/m$  is constant** (and very large, about 2000 times that of a hydrogen ion, the lightest known ion).

To do this, an apparatus similar to the one shown in Figure 1 below was used.

In this apparatus, a small piece of metal called a cathode is heated up with a power supply so that electrons are "boiled off" of the heated cathode inside a specially designed glass bulb filled with low-pressure helium called a "discharge bulb" in Figure 1 below.

Then the electrons are accelerated towards another nearby piece of metal, called an anode, by a high voltage applied across the cathode and anode. Think of this as an **electron gun**, in which electrons are shot out with high energy in a continuous beam. The path of the narrow **beam of electrons** produced by

the electron gun is **visible** due to the glow discharge caused by ionizing collisions between electrons and the helium gas inside the bulb. Note: It is easier to see the beam if the apparatus is in a darkened room or some kind of covering or box is used to shield surrounding light.

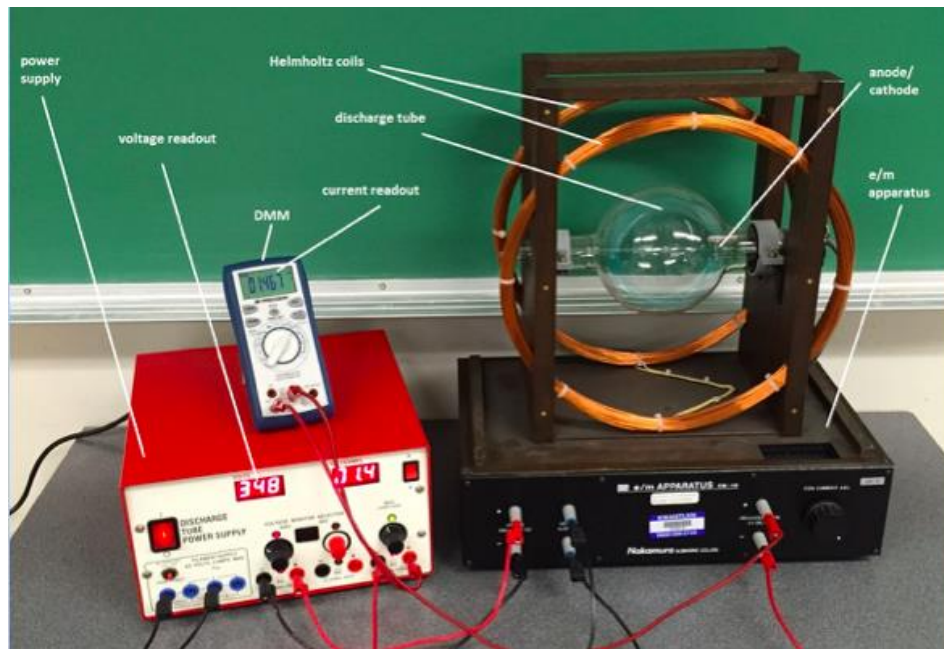


Figure 1 e/m apparatus

The **electron beam** emerges from a small hole in the anode and **enters a uniform magnetic field produced by passing current through a pair of Helmholtz coils** (as shown in Figure 1). The Helmholtz coils produce a magnetic field similar to what you saw in step 2) above. The electron beam is directed perpendicular to the magnetic field of the coils, so the magnetic force will be perpendicular to the direction of the beam. Once current is directed through the coils (like the battery did in your wire coil in step 2), the magnetic force changes the beam's direction of motion, but not its speed. Therefore, the electrons will be moving in uniform circular motion, and **the electron beam will appear as a circle**.

There is a **scale inside the glass bulb for measuring the diameter of the path** traced by the circular electron beam. From the diameter, you can calculate the radius  $r$ . How will you calculate the radius  $r$  of the beam from the measured diameter of the beam?

4) Although the derivation of this equation is beyond the scope of Phys 1100, in Lab 10, we will simply **explore and use this relationship**:

$$V = (3.0365 \times 10^{-7} \cdot e/m) r^2 I^2 \quad (1)$$

where  $r$  is the **radius of the circular path of the electron beam** in meters (m),  $I$  is **current through the Helmholtz coils** in Amperes (A) and  $V$  is the **voltage applied to the electrons in the electron beam** in volts (V).

As explained above, the quantity  $e/m$  is a **constant** (and so is  $3.0365 \times 10^{-7}$ , of course) so this equation can be rewritten as

$$V = kr^2I^2 \quad (2)$$

which you have already looked at in step 1) above. That is:

**V and r are related directly** (if I is held constant): As V goes up, r goes (up or down)

**I and r are related inversely** (if V is held constant): As I goes up, r goes (up or down)

**V and I are related directly** (if r is held constant): As V goes up, I goes (up or down)

5) Go to the following webpage to explore a simulation of this experiment:

<http://www.didaktik.physik.uni-muenchen.de/elektronenbahnen/en/b-feld/B-Feld/experiment.php>

Using the simulator, **use the sliders to change V and I and record your observations:**

As V goes up, r goes (up or down)

As I goes up, r goes (up or down)

If r is held constant: As V goes up, I must go (up or down)

6) Rearranging the equation (1) above gives an equation that can be used to calculate the value of  $e/m$  if you know V, I and r:

$$e/m = \frac{V}{(3.0365 \times 10^{-7})r^2I^2} \quad (3)$$

Look up an **accepted value of  $e/m$**  in C/kg and **cite the source** you used (if you prefer, look up the charge of the electron  $e$  and the mass of the electron  $m$  and calculate your expected  $e/m$  value in C/kg).

$e/m =$  C/kg according to .

If you have the % uncertainties of V, I and r, how can you calculate the % **uncertainty of your  $e/m$  value?**

7) In Lab 10, we will be accessing a sophisticated RWSL  $e/m$  apparatus, which is essentially the apparatus in Figure 1 above, but adapted so it can be controlled remotely. The software interface you will be working with is shown in Figures 2.1 and 2.2.



Figure 2.1 The Software Interface for the  $e/m$  Lab when looking at the **User Status** Tab



Figure 2.2 The Software Interface for the  $e/m$  Lab when looking at the **Camera Controller** Tab

The measurement of the beam shown in the top right-hand area of Figure 2.2 is the beam **diameter (in cm)**. Therefore, the diameter  $d$  shown in Figure 2.2 is 9.5 cm and the radius  $r = 4.75$  cm. The uncertainty of the measured diameter is fairly large on this since the exact location of the beam is not very precise.

Give a reasonable uncertainty value for the diameter  $d$ :  $\pm$       cm.

N.B. The uncertainty of both  $V$  and  $I$  are  $\pm 1\%$ .

Please watch the [e/m at RWSL](#) video to become familiar with the RWSL apparatus that you will be using.

The sign-up schedule is on your Phys 1100 labs course webpage. Sign-up for a time to collect your Lab 10 data. **What is your sign-up time?**

8) For Lab 10, you are given the following objective:

Objective: To use a remotely located  $e/m$  apparatus to

- a) determine how the voltage given to electrons  $V$ , the current in a set of Helmholtz coils used to create a magnetic field  $I$  and the resulting radius of the electron beam  $r$  are related to each other, and
- b) determine the ratio of the charge to the mass of an electron  $e/m$ .

At your sign-up time, use the **same instructions from the first RWSL lab you did (Lab 5: Acceleration on an Incline)** to gain access to the RWSL  $e/m$  apparatus at your sign-up time. Note: the lab will be called something like EM Apparatus instead of Accelerated Motion.

When you gain access to the apparatus, you will turn on the power supplies as shown in the video and then you will **vary the voltage  $V$  and the current  $I$**  as shown in the video and observe/record what happens in order to answer the objective given above.

In other words:

- when you turn the voltage  $V$  up, does the diameter (and therefore radius) get bigger or smaller?
- when you turn the current  $I$  up, does the diameter (and therefore radius) get bigger or smaller?
- the hardest one will be to record what you have to do to the voltage  $V$  when you turn up the current  $I$  to get the same radius back.
- finally, record the actual voltage, current and diameter readings so that you can later calculate  $e/m$  (Note: You can use any beam diameter you choose, but it's a good idea to avoid using the extreme ends of the range of any settings on any apparatus, if you have the choice.)

If you have any **questions** about how you will **access** or **use this RWSL apparatus to answer the objective** for this lab, please ask them here so that I can help you well before your sign-up time:

If you encounter problems with any of this **during your sign-up time**, remember that you can always call or email Albert Balbon as given in your instructions for the Acceleration on an Incline lab. Albert will be watching over the apparatus in Comox, BC and he is more than willing to help.

Good luck!

Lab 10 lab report is written by the students from scratch using previous lab reports as a guide

