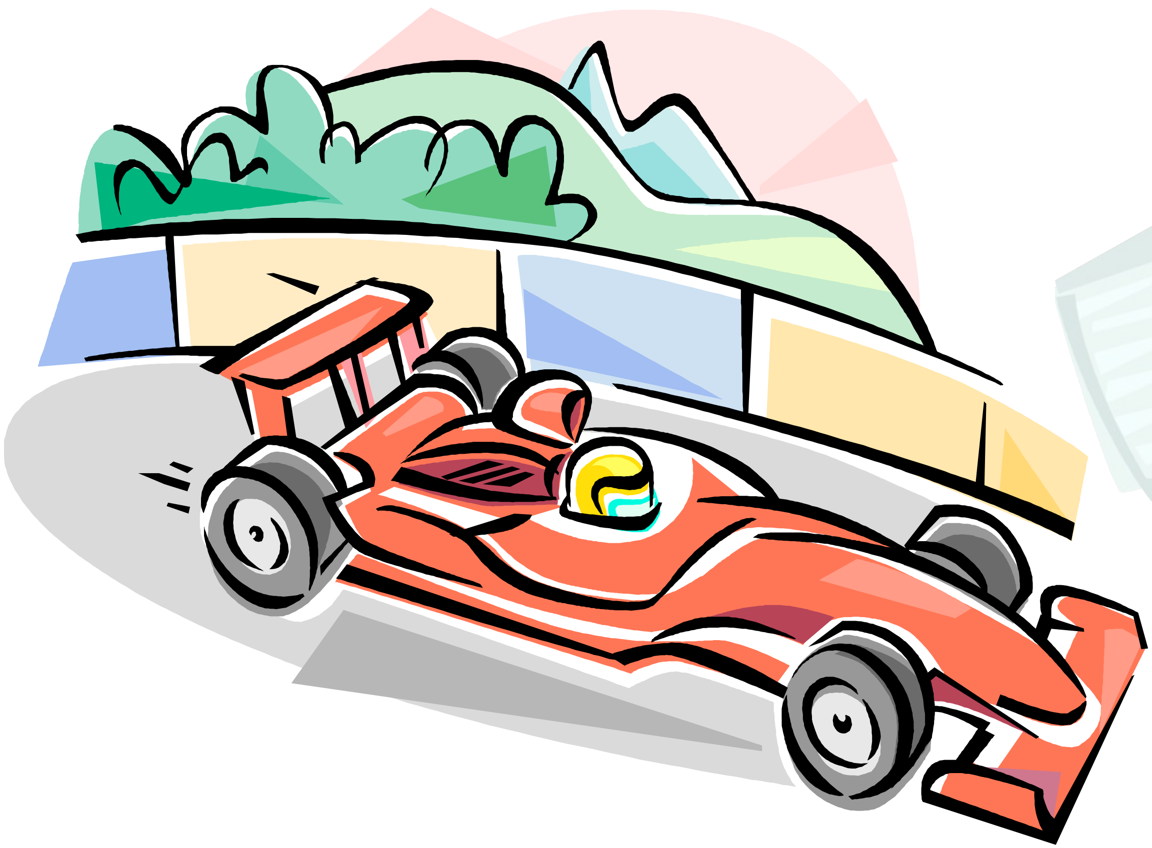
Physics 1050
Experiment 1

Introduction to Measurement and Uncertainty



Prelab Questions

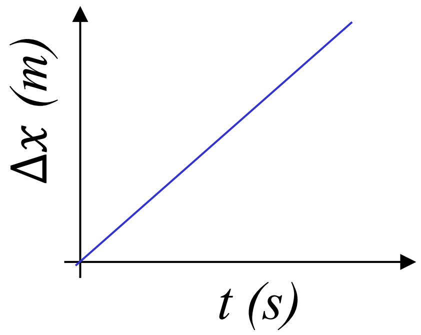
These questions need to be completed **before** entering the lab. Show all workings.

Prelab 1:

A car takes time $t = 2.5 \pm 0.2\ s$ to travel a distance $\Delta x = 0.955 \pm 0.005\ m$. Find the speed of the car with its absolute uncertainty.

Prelab 2:

For an object with zero acceleration, the position versus time graph is linear and looks as shown:



What does the slope of this graph represent? Explain.

Prelab 3:
Write, in a sentence or two, the **objective** of this experiment.

Introduction

In this experiment, you will study measurement and uncertainty by measuring the time and position of a travelling cart. You will do this with two methods and compare your results.

When a physical quantity is measured, a judgement of the reading is made based on a reading a scale. The precision of the reading can be limited by the measuring device itself, by complications due to the object to be measured, by the size of the smallest division on the scale, or some combination of these and other factors. The **uncertainty** is a reflection of the confidence in the measurement.

Looking at some examples on the following slides may help in understanding some of these complications.

Introduction

Example 1:
A new metre stick measuring a board with a **well defined edge**:
The position can reliably be measured to a fraction of a *mm*.
The uncertainty will be a fraction of a *mm* (between $0.2\ and\ 0.5\ mm)$.

The measurement to the edge in this image may be read as $60.46\ \pm\ 0.03\ cm$.

Introduction

Example 2:
Using a different metre stick measuring a board with a **rough** edge:
The position can only reliably be measured to a single *mm*, if not greater.
The uncertainty will certainly be larger than the previous measurement.

The measurement to the edge in this image could be read as $60.2 \pm 0.2\ cm$, as an example.

Definitions

Absolute and Relative Uncertainty

If δx represents the **absolute uncertainty** in a measured quantity, then **relative uncertainty** is given by $\delta x/x$. The uncertainty is usually rounded to 1 significant figure. A result is generally reported in the form $x \pm \delta x$.

For the example, if we make a reading of the length of an object with a metre stick of $(60.46 \pm 0.03)\, cm$, the **absolute uncertainty** δx is $\mathbf{0.03\ cm}$ and the **relative uncertainty** is $0.03/60.46 = \mathbf{0.0005}$.

Standard Error

The standard error in a measurement x indicates variation of an individual measurement from the mean $\bar{x}$ and is given by

$$\delta \bar{x} = \frac{\sigma_x}{\sqrt{N}} ,$$

Where σ_x is the standard deviation of x and N the number of samples. The method of calculation is given on pages $VII - X$ of your laboratory workbook.

Rules for the propagation of uncertainties

Rule 1:

When **adding or subtracting** measured quantities, the absolute uncertainty in the result is the sum of the absolute uncertainties in the measured quantities.

Example 1: $z = x - y,$

$$\delta z = \delta x + \delta y$$

Example 2: $z = x + y,$

$$\delta z = \delta x + \delta y$$

Rule 2:

When **multiplying or dividing** measured quantities, the relative uncertainty in the result is the sum of the relative uncertainties in the measured quantities.

Example 1: $z = x/y$

$$\frac{\delta z}{z} = \frac{\delta x}{x} + \frac{\delta y}{y}$$

Example 2: $z = xy$

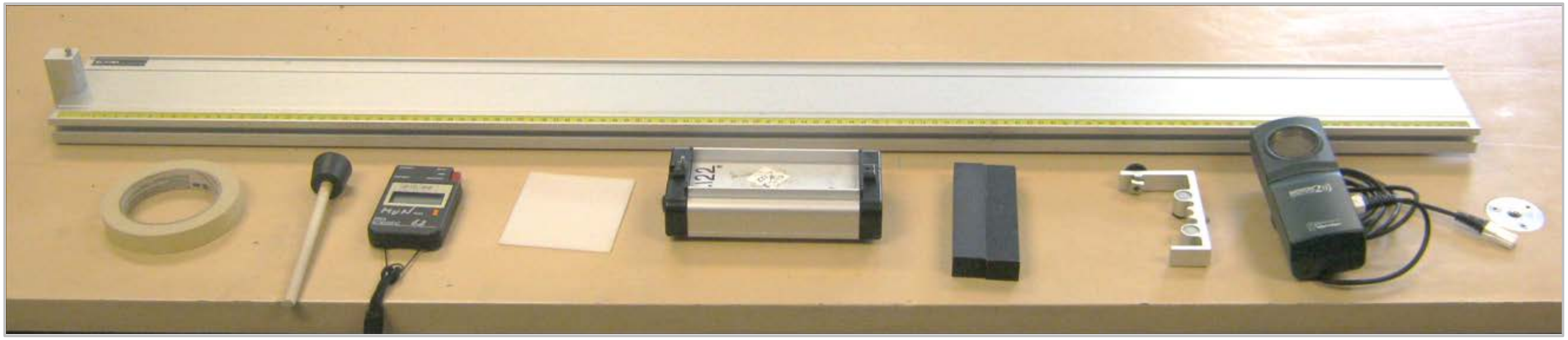
$$\frac{\delta z}{z} = \frac{\delta x}{x} + \frac{\delta y}{y},$$

These and the other rules are further discussed in the introductory material.

Part I: Apparatus

You have been provided with the following:

- Track
- Cart
- Blocks
- Card
- Bumper
- Motion sensor
- Stopwatch
- Mallet
- Masking tape



Part I: Using a triple beam balance

You will use a triple beam balance to find mass.

Click on the video and follow the instructions if you haven't used a triple beam balance before.

1. Lay the object on the plate.
2. Slide the middle slider in the notches until the arm drops. Slide it back $100\ g$.
3. Slide the rear slider in the notches until the arm drops. Slide it back $10\ g$.
4. Slide the front slider until the arm points to the zero mark.
5. Add the numbers corresponding to the positions of the sliders.
6. The object in the video has a mass of $381.12 \pm 0.03\ g$.

Click to play video

Insert video "balance.mp4" here

Part I: Speed of a Dynamics Cart

Using the triple beam balance, weigh your dynamics cart, the two black masses, and the white card.

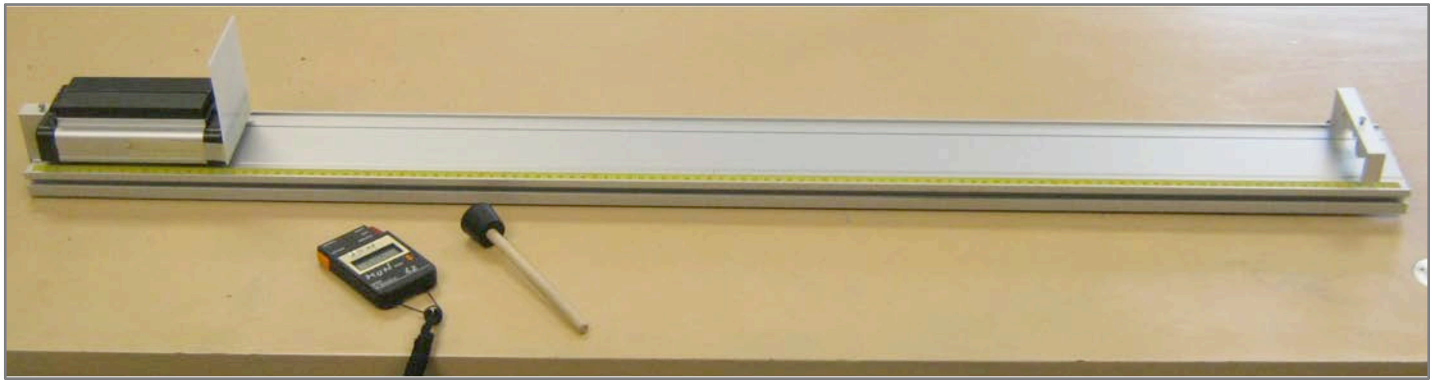
LW Record the masses and their estimated uncertainty in **Table 1**.

LW Calculate the total mass and its uncertainty and record in **Table 1**.

Assemble your apparatus as shown below.

Be sure to have the plunger pushed in and locked and placed firmly against the end of the track.

! The track must be level!



Part I: Speed of a Dynamics Cart

Place the cart on the track with the plunger against the bumper at the end of the track.

LW

In **Table 2**, record the (initial) position of the front of your cart. Include the estimated uncertainty.

Part I: Speed of a Dynamics Cart

Carefully slide your cart to the far end of the track.

LW

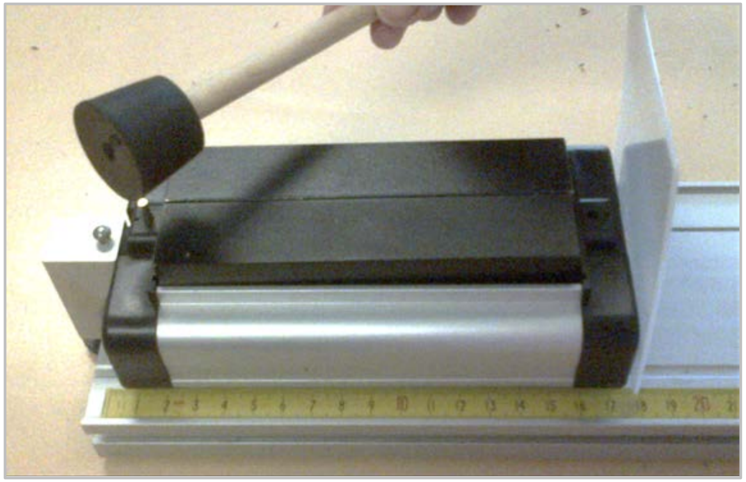
In **Table 2**, record the (final) position of the front of your cart. Include the estimated uncertainty.

LW

Calculate and record the **total displacement** of the cart and the associated uncertainty in **Table 2**.

Replace the cart to its initial position.

Part I: Speed of a Dynamics Cart



With the cart at its initial position:

Tap the plunger with the mallet to set the cart in motion.

Use the stopwatch to measure the time the cart is in motion.

Work with your partner and be as careful as possible!

LW

In **Table 3**, record the time your cart was in motion.

Repeat the procedure another 7 times and record your measurements.

Try to tap the plunger as uniformly as possible each time.

LW

For each run, calculate the speed of the cart.

Part I: Speed of a Dynamics Cart

A quick method to estimate the uncertainty is to calculate half the range of your data, e.g.

$$\delta t \approx \frac{t_{max} - t_{min}}{2}$$

LW

Write your estimate for an appropriate uncertainty for time and record it in **Table 3.**

The uncertainty in speed is not needed in the table.

Q

Question 1: From your data in the **Trial 1 only**, calculate:

a) The relative uncertainty in the distance.
b) The relative uncertainty in time.
c) The relative uncertainty in speed.
d) The absolute uncertainty in speed.

Part I: Speed of a Dynamics Cart

Click the icon to launch Graphical Analysis.

Enter your speed values in the speed column of the table.

Click **Analyze** then **Statistics**.

LW Record the mean, standard deviation, and number of samples in **Table 4**.

LW Calculate the standard error and record your result in **Table 4**. Check the Laboratory Introduction section at the beginning of your workbook for reference.

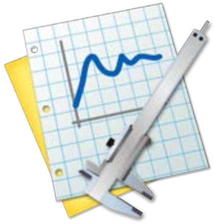
Q **QUESTION 2:** Write the average speed of the cart in the form $\bar{v} \pm \delta\bar{v}$.

Part II: Speed of a Dynamics Cart

We now use a motion sensor and software to calculate the velocity. Assemble your apparatus as shown.

Plug the motion sensor into DIG/SONIC 1.

Click the icon to launch Logger Pro.



Part II: Speed of a Dynamics Cart

In Logger Pro, click ▷ and wait until you hear the motion sensor begin to collect data.

Tap the plunger with the mallet, as before, but stop the cart before hitting the motion detector.

Examine your position vs time graph.

Q

QUESTION 3: Sketch your position vs. time graph. Circle the region of your graph that corresponds to constant, non-zero speed.

Q

QUESTION 4: What does the slope of a Δx vs. t graph represent? Explain.

CP

Have an instructor check your graph and above questions.

Part II: Speed of a Dynamics Cart

Highlight the region of constant non-zero speed on your graph.

Find the slope of your *position vs time* graph by clicking **Analyze** then **Linear Fit**.

Double click the pop up box and check **Show Uncertainty**.

LW

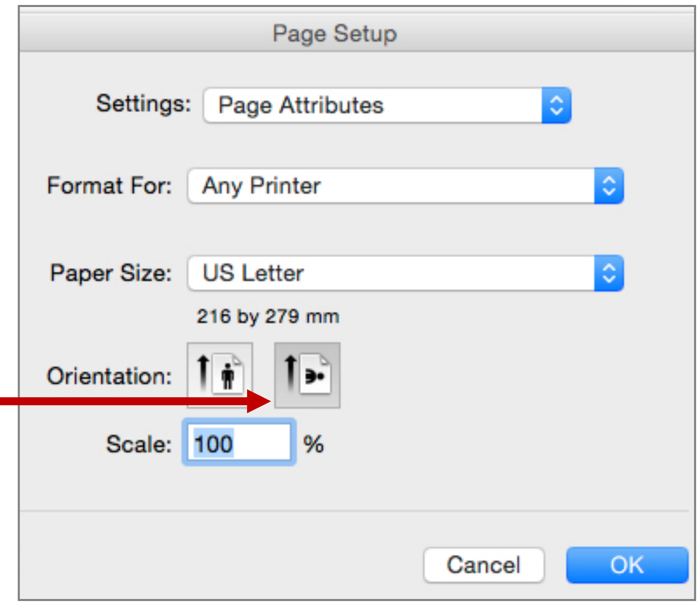
Record the slope and uncertainty in **Table 5**.

Double click the graph in the white space and add a **Title**.

Print your graph by following the directions on the following slide.

Printing Your Graph

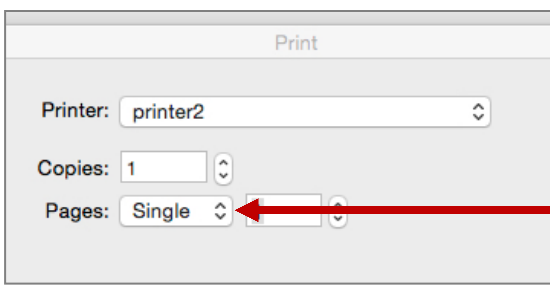
Click **File** then **Page Setup** and choose the landscape orientation.



Click **File** then **Print**.

To select the only necessary page:

Click Pages and choose Single.



P

Staple your graph in your workbook.

Part II: Speed of a Dynamics Cart

Q

QUESTION 5: Using the information in Table 5, write down the speed and its uncertainty for the cart.
Hint: Think about your answer to **Question 4**.

Q

QUESTION 6: Write the ranges of each of the two velocities you found. Do the values of velocity agree with each other? If not, explain why.

Q

QUESTION 7: Considering your experimental methods and results, which method of determining the velocity is more precise? Support your answer.

Part III: Summary

Q

QUESTION 8: List at least three sources of the experimental uncertainties. Classify them as random or systematic.

Q

QUESTION 9: Write a brief paragraph summarizing the experiment and your findings. Comment on how we use uncertainty to determine if values are in agreement.

Ensure that you have completed all **Tables** and answered all **Questions** completely.

Attach your *position* vs. *time* **graph** to the appropriate page.

Submit your workbook to the appropriate shelf/box as directed.