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 $d = 0.955 \pm 0.005$ 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.
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Objective

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.
Introduction

When a physical quantity is measured, a reading is made on a scale. The precision of the reading is limited by the device itself and by the size of the smallest division on the scale. The uncertainty is a reflection of the confidence in the measurement. Examples are given in the following two slides.
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 position of the edge may be read in this image as 60.46 ± 0.03 cm.
Example 2:
An old metre stick measuring a board with a rough edge:
The position can only reliably be measured to a single $mm$.
The uncertainty will be a single $mm$.

The position of the edge may be read in this image as $60.3 \pm 0.1 \text{ cm}$. 
Definitions

Absolute and Relative Uncertainty

If \( \delta x \) 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 32.45 cm \( \pm \) 0.05 cm, the **absolute uncertainty** \( \delta x \) is **0.05 cm** and the **relative uncertainty** is \( 0.05 / 32.45 = 0.002 \).

Standard Error

The standard error in a measurement \( x \) indicates variation of an individual measurement from the mean \( \bar{x} \).

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: \( z = \frac{x}{y} \) \[ \frac{\delta z}{z} = \frac{\delta x}{x} + \frac{\delta y}{y} \]
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: Speed of a Dynamics Cart
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 until the arm drops. Slide it back 100 g.
3. Slide the rear slider until the arm drops. Slide it back 10 g.
4. Slide the front slider until the zero mark lines up.
5. Add the numbers corresponding to the position of the sliders.
6. The object in the video has a mass of 381.1 ± 0.1 g.

Click to play video
Part I: Speed of a Dynamics Cart

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

Record the masses in the Table 1.

Estimate the uncertainty of the balance using the method discussed on slides 6 and 7.

Record the uncertainty in Table 1.

Calculate the total mass and its uncertainty.

Record these in Table 1.
Part I: Speed of a Dynamics Cart

Assemble your apparatus as shown.

Be sure to have the plunger pushed in.
The plunger should be firmly against the end of the track.
The track must be level!
Part I: Speed of a Dynamics Cart

Place the bumper at the far end of the track.

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.

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

Calculate and record the displacement of the cart and the associated uncertainty.

Replace the cart at 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!

In Table 3, record the time your cart was in motion.
Estimate the uncertainty in time and record it in Table 3.
The uncertainty of the stopwatch is reaction time.
If you do not know reaction time, you can find it in two ways:
   (i) do the measurement twice and find the difference or
   (ii) go online to do a reaction time test.
Part I: Speed of a Dynamics Cart

Repeat the procedure another 7 times and record your measurements. Try to tap the plunger as uniformly as possible each time. For each run, calculate the speed of the cart.

The uncertainty in speed is not needed in the table.

Question 1: For your data in the first trial only, calculate:

i. The relative uncertainty in the distance.
ii. The relative uncertainty in time.
iii. The relative uncertainty in speed.
iv. The absolute uncertainty in speed.
Part I: Speed of a Dynamics Cart

Use Graphical Analysis to determine the standard error in speed:

Click to open Graphical Analysis.

Enter your speed values in the table.
Click Analyze then Statistics.

Record the mean, standard deviation, and number of samples in Table 4.
Calculate the standard error and record your result in Table 4.

QUESTION 2: Write the average speed of the cart in the form $v \pm \delta v$.
For the uncertainty of the speed, use either the uncertainty from Question 1 or Table 4, whichever is larger.
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.
- Launch Logger Pro by clicking on the icon below.
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.
Examine your position vs time ($d$ vs $t$) graph.

**QUESTION 3:** Sketch your $d$ vs $t$ graph. Circle the region of your graph that corresponds to constant, non-zero speed.

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

**CHECKPOINT:** 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 $d$ vs $t$ graph by clicking Analyze then Linear Fit.

Double click the pop up box and check Show Uncertainty.

Record the slope and uncertainty in Table 5.

Print your graph. Be sure to include a title and axes labels.
Part II: Speed of a Dynamics Cart

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.

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.

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

QUESTION 8: List at least three sources of the experimental uncertainties involved in Parts I and II of this experiment. Classify them as random or systematic.

QUESTION 9: As an example of the propagation of errors, consider the combined masses of the cart with the blocks and cards: Was the absolute uncertainty of the total mass larger or smaller than the absolute uncertainties of the individual masses? Is this an expected result? Explain.
Wrap it up!

- Check that you have completed all Tables.
- Make sure that you have answered all Questions completely.
- Attach your graph of position versus time.