Welcome to the Physics Lab!

Welcome to the Introductory Physics Lab series at Washington University in St. Louis! The labs you'll be performing have been designed to teach critical thinking through experimentation: **how do we know what to trust and what to do?** In addition, the labs will teach you good lab techniques while giving you direct experience with the phenomena you're studying in the physics course.

What are the course objectives?

By the end of this course, you should be able to:

1. Engage in experiences with experimental process and design.
2. Gain experimental and analytical skills.
3. Understand how to calculate and interpret measurement uncertainty.
4. Enhance understanding of basic physics concepts.
5. Understand the role of direct observation in physics.
6. Instill interest in how the physical world works.
7. Communicate the process and outcomes of an experiment.
8. Conduct an experiment collaboratively and collaboratively and with scientific integrity.

The specific learning goals for each lab are available at the beginning of each manual. Each experiment will focus on developing and applying tools of experimental physics to extend our understanding of physics principles. Experiments will often critically assess the conceptual and experimental basis for physical models discussed in lecture and their applicability or limitations in specific physical situations.

The goal is to understand *how* we know, not *what* we know,
not *how* to think, not *what* to think.

Lab Canvas Page

1. Make yourself familiar with the Lab Canvas page, its organization, the location of the reference documents and the labs. Each lab has its own module. It includes the manual, the lab worksheet template, Station Cleanup, and other necessary resources.

2. Every lab has its own lab worksheet. The worksheet must be prepared *individually*, using Google doc. After answering all questions and completing the worksheet, it should be downloaded and saved in pdf format. Name the worksheet using the lab name and upload into Gradescope.

In addition to knowing how to navigate Canvas, you will need to learn how to use the main software we use in the lab to collect data and analyze them, Logger Pro. This software is ready to be used in the lab computers. If you wish to use your own device, download the software to your computer and use it when in the lab. Find the link in Canvas, as mentioned in one of the announcements. Logger Pro is a program that allows you to collect data and perform analysis such as graphing, best curve fitting, statistical analysis, etc. Refer to *Everything About Plotting with Logger Pro* tutorial document or videos to learn how to use its features.

In order to perform a successful experiment, everyone will need to learn about how to design and run it, so that the data are useful and clear. Secondly, everyone will need to learn what to do with the data: we call this Analysis or Evaluation of Data. It includes graphing, any additional calculations, and interpreting. And finally, if the experimenter is going to convince anyone else of the conclusions, it is necessary to learn how to communicate the work clearly and concisely in writing.

This first lab will teach you the basics of some of these skills, and you'll practice and perfect them throughout your time in the lab. Let's get started!

Graphing with Logger Pro & Video Analysis

Learning Goals

By the end of this lab, you should be able to...

- use Graphical Analysis process by utilizing Logger Pro and its features to analyze data and communicate the analysis to others.
- graph data and determine the relationship between the two variables being tested.
- Utilize Video Analysis to analyze the motion of an object.

Part 1: – Using Logger Pro to Plot Data

You get an email from your friend who is studying at Saint Louis University. They had their first physics lab last week and your friend is lost. Some numbers have been provided, but she doesn't know what to do with them. She asks you if you can help her figure out how to analyze her data and write a good report. Since helping her will help you prepare for your own lab, you agree. Very appreciative and relieved, your friend sends you the information from her lab.

Q1 **Question 1**: Help your friend analyze the data sets she sent and determine the mathematical relationship between the physical quantities.

Include in the Lab Work/Lab Participation document for each data set:

a. Independent variable (IV), Dependent variable (DV), Constant or Controlled variables (CV)
b. Logger Pro graph with a curve fit and accompanied by the data table.
c. Analysis of each graph: (see table below)
    i. relationship found
    ii. plausibility of the outcome - Do the data follow the general trend you might expect, based on your understanding of the physics involved?

Below are the data sets your friend sent to you. When doing measurements and reporting data, several trials must be performed and uncertainties must accompany each measurement. The uncertainties will be ignored for this lab. You will start considering trials and/or uncertainties in the upcoming labs.

Data Set 1: Consider an experiment where adding various masses (m) in grams (g) to a spring affects the length that the spring is stretched (Δl) in centimeters (cm).

Mass (m) (g)	Stretch (Δl) (cm)
10	6.2
20	9.3
30	12.1
40	15.4
50	18.3
60	21.2
70	24.3

Data Set 2: The second set represents some data about the Volume (V) of a gas in meters cubed (m^3) and the pressure (P) of the gas in Pascal (Pa).

Volume (V) (m^3)	Pressure (P) (Pa)
0.1	40.0
0.5	8.0
1.0	4.0
2.0	2.0
4.0	1.0
5.0	0.8
8.0	0.5
10.0	0.4

Data Set 3: The third set represents some data about the time (t) in seconds (s) and the position (x) of a cart rolling on a track in meters (m).

Time (t) (s)	Position (x) (m)
0.1	0.06
0.2	0.24
0.5	1.50
1.0	6.00
2.0	24.00
3.0	54.00
4.0	96.00
5.0	150.00

How to Analyze Data and the Respective Graph

The independent variable (IV) is represented with data in the first column, dependent variable (DV) is represented with data in the second column. Constant variables (CV) are recorded during the experiment, but not reported here. Think about some of them. Your friend is expected to report them in the final lab report.

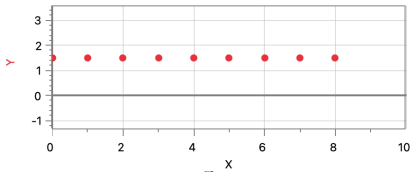
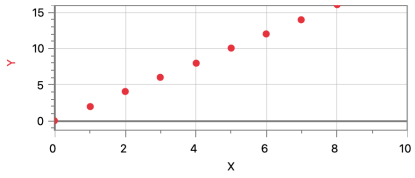
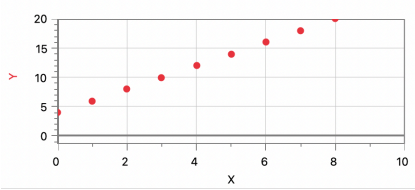
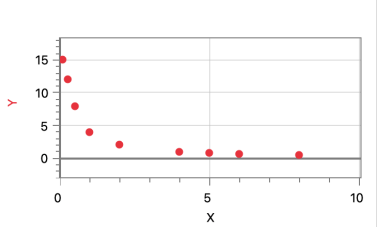
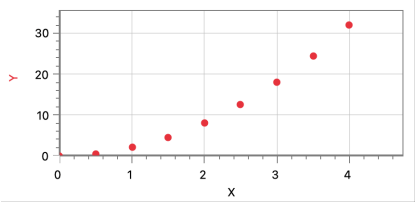
1. Use Logger Pro to plot your data, Δl vs. m, P vs. V, and x vs. t. Follow the instructions in the *Everything About Plotting with Logger Pro* document on Canvas.

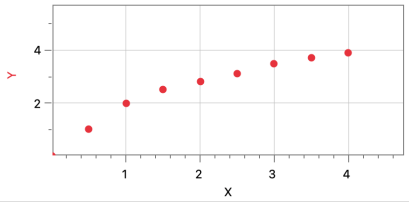
   Tips:

   a. *A graph should have enough information to stand on its own. It should be titled, and the axes should be labeled. Please avoid titles like y vs. x. Be descriptive!*
   b. *Always submit a graph accompanied by a data table. This table must include columns of **data plotted** and error columns when applicable. If the data collected during an experiment include more information than the ones you plot, such as trials, then the raw data table must be included in your worksheet.*

2. Include the best fit - Apply a curve fit to your data using the *curve fit* button (). Try different options of the curve fit by selecting an equation on the left side of the window and use "Apply Fit". Continue until you find one that fits the best. Then click Ok.
3. Take some time to play with Logger Pro by following the document, so you can be more familiar with it. This will be the main software we will use in most of the labs.

The table below gives the most common graph shapes:

Trend of the Data (Shape Characteristics)	**Modification to Linearize Graph**	**Mathematical Model**	**Written Relationship**
 Trend that looks like a horizontal straight line.	N/A	Constant: $y = b$	As x increases, y remains the same. There is **no relationship** between the variables.
 A trend that resembles a diagonal straight line that goes through origin (0,0)	N/A	Proportional: $y = mx$	As x increases, y increases **directly proportional** to x. $(b = 0)$
 A trend that seems like a straight line that doesn't cross the origin.	N/A	Linear: $y = mx + b$	As x increases, y increases **linearly.** $(b \neq 0)$
 A curve that resembles an inverse rectangular hyperbola trend.	Plot y vs $\frac{1}{x}$	Inversely Proportional: $y = \frac{a}{x} + b$	As x increases, y decreases **inversely proportional** to x.
 A curve that resembles a parabolic trend.	Plot y vs x^2	Square Law: $y = ax^2 + b$	- Y is **directly proportional** to the square of x $(b = 0)$. - Y is **linearly** proportional to the square of x $(b \neq 0)$. OR - quadratic - parabolic - power (specify that the exponent is equal 2).

 A curve that resembles a logarithmic trend.	Plot y^2 vs x	Square-Root Law $y^2 = mx + b$	The square of y is **directly proportional** to x ($b = 0$). OR The square of y is **linearly** proportional to x ($b \neq 0$).

Part II – Video Analysis

Another powerful tool used to collect data and analyze physical phenomena is Video Analysis. It consists of using a short video clip and Logger Pro instead of measuring tools, sensors, or probe wares. Everyone can use a mobile device in the laboratory, at home, or in the field to record the motion of one object or many of them, insert it into Logger Pro, track the object(s), and analyze by using Graphical Analysis. So, this is what you will be doing in the next question.

Q2 **Synthesis Question 2**: Use *Video Analysis* method to collect data and analyze the motion of a rolling ball on a smooth surface. Report your findings clearly and concisely.

Your Analysis Should Include:

a. *Position* and *velocity* graphs with data tables and best fits.
b. Analysis of the graphs: (see table above)
    1. Describe the shape of graphs obtained and their acceptability.
    2. Explain the relationship between variables in each graph.
    3. Identify the type of motion represented (constant/changing motion).
    4. Use the position vs. time graph to find the speed of the ball, detailing your method and any calculations performed.
    5. Use the velocity vs. time graph to find the speed of the ball, detailing your method and any calculations performed.
    6. Compare these two values quantitatively - calculate the % difference and reflect on that.

Helpful Notes:

1. You will be using a pre-recorded video to complete the work. Below are the steps you need to follow to access the video.
    - Click the *Galileo's Projectile Video* link from the lab module.
    - Above the video, click "Download Galileo's Projectile Video.mp4".
    - Open Logger Pro software.
    - Go to *Insert* and then *Movie.*
    - Find the video in your Downloads folder and upload.
2. Refer to the *Video Analysis Tutorial* document and follow the steps provided in it to prepare the video and analyze the motion of the object.

End of In-Lab