Bitz and Pieces
of
Physics Labs

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Contents

Chapter 1

Lab Skills

1.1 Measuring

Every science course involves measuring of some type. The important thing about measuring in a lab is to BE CAREFUL. Simple mistakes in measuring will lead to the propagation of errors, which you will read about later. The instruments we use at Hannan High include the meter stick, the triple beam balance, and stopwatches. Please see the instructor immediately if you can not correctly measure with these devices.

When making measurements, there are uncertainties. However, you must be careful about the uncertainties. The distance from New Orleans to Los Angeles is about 1500 miles. What is the uncertainty in this measurement? Certainly, you can not say the distance is off by a fraction of an inch.

Question 1 *What is a realistic uncertainty in the distance from New Orleans to Los Angeles?*

1.2 Graphing

To represent data that is gathered in lab, we use graphs. There are several graphs that you should recognize, but first we must discuss how to set a graph up.

1.2.1 Setup

In every experiment, there is an independent variable and a dependent variable. The independent variable is the variable which you control, physically change. The dependent variable is the variable which you measure. With few exceptions, the independent variable goes along the horizontal axis, while the dependent variable goes along the vertical axis.[1]

All axis should have labels and units The axis should occupy at least 3/4 of the available space

1.2.2 Relationships

There are three basic relationships which you will graph in this class: linear, square, and inverse.

1.2.2.1 Linear or Direct

A linear (or direct) relationship is graphed by a straight line. It is often said that two variables which have a linear relationship are said to be proportional. Two variables have a linear relationship if both variables are raised to the first power and both are "on top."[2] The math equation for a linear relationship is:

$$y = mx + b \tag{1.1}$$

where m is the slope and b is the y-intercept.

1.2.2.2 Square

A square relationship is graphed by a parabola (or half of a parabola). Two variables have a square relationship if one the variables is raised to the second power and both variables are "on top." The math equation for a square relationship is:

$$y = kx^2 \tag{1.2}$$

where k is a proportionality constant[3].

[1] Notice that the reference is to the horizontal and vertical axis, not the x and y axis. In this class, x and y are variables representing displacements; x and y do not represent the same thing as in math class. Therefore, we do not reference the "x axis;" say instead the horizontal axis.

[2] What is meant by on top is that if there is a fraction, both variables are on top the fraction and on either side of the equal sign. This is also true if both variables are on bottom of the fraction.

[3] This is just some constant in front of the squared variable

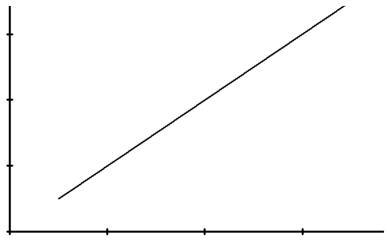

Figure 1.1: Graph between two variables that have a linear relationship

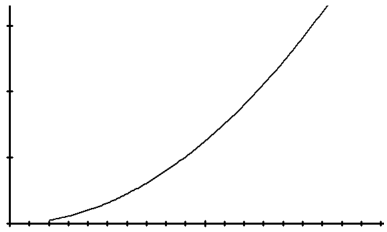

Figure 1.2: Graph between two variables that have a square relationship

1.2.2.3 Inverse

An inverse relationship is graphed by a hyperbole. Two variables have an inverse relationship both variables are raised to the first power but one variable is "on top" while one is "on bottom." The math equation for a square relationship is:

$$y = \frac{k}{x} \tag{1.3}$$

1.2.2.4 Other Graphs

There are other graphs you may come across: inverse square, square root, and a no relation graph. These graphs are not used often, and, with the skills we have attained, we can not ascertain much information from them. We will discuss each graph at length when we come across it in lab.

1.2.3 Best Fit Line

When graphing a linear relationship (See Equation 1.1), it is helpful to draw a best fit line. This is a straight line that best fits the data. It is considered blatantly wrong (and sophomoric) for you to "connect the dots." Do NOT connect the dots of ANY graph you create. Connecting the dots will not help you decipher anything from the data. However, a best fit line will. A best fit line approximates the data by going through the "middle" of the dots. It does not go through any dot in particular; it simply goes through the points so that there are an equal number of dots above and below the line.

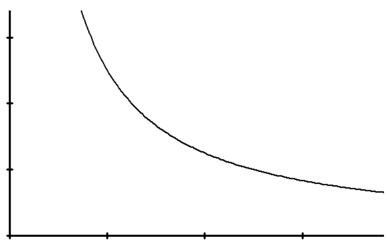

Figure 1.3: Graph between two variables that have a inverse relationship

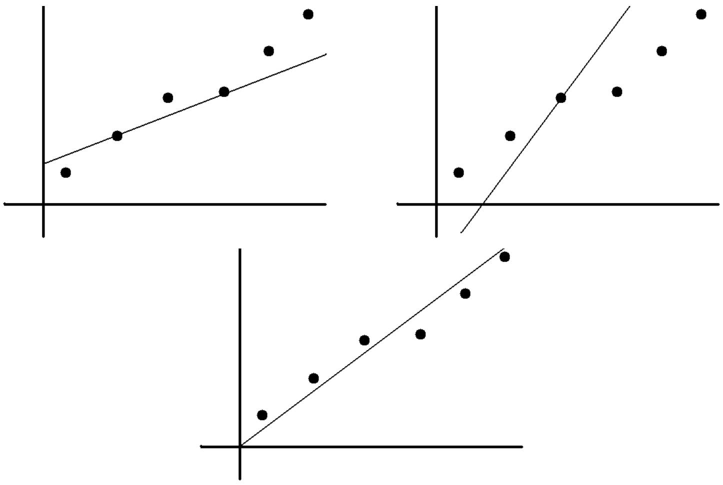

Figure 1.4: Examples of Best Fit Lines

Question 2 *Hand drawn best fit lines are not perfect, but can* be good *with practice. Look at the three graphs in Figure 1.2.3. Which one has a best fit line that best approximates the data?*

Note that is wrong (and unnecessary) to draw a best fit for a graph of square or inverse data.

1.2.4 Slope

The slope of a best fit line often yields very important physical characteristics. Therefore, it is vital that a lab techician[4] be able to find the slope. The higher a slope for a graph, the steeper the line on the graph is. An algebra formula tells how to find the slope, m:

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\text{rise}}{\text{run}} \tag{1.4}$$

To find the slope of the best fit line, simply pick two points on the line. The points should not be close together; pick one end of your best fit line and the other at the other end. Label one of the points "Point 1" and the other "Point 2." It does not matter which point is which. Use "X"'s to signify what points you are using.

Find the x and y values of each point. Subtract the y's. Divide by the difference of the x's. That's the slope

IMPORTANT! Notice that the points you choose are points on the line. Do NOT pick data points! This will give a wrong slope.

1.2.5 Area Under Graph

Sometimes the area under a graph can yield important information, much like the slope.

1.2.5.1 Shapes Method

When dealing with a linear relationship, the area under the graph is often a recognizable shape, usually a triangle. Since you know the formula for the area of a triangle[5], you can find the area under the graph my measuring the base and height.

Occasionally, the graph will comprised of a triangle and a rectangle. In this case, find the area of each and then add.

[4] You!

[5] $\frac{1}{2}$base*height

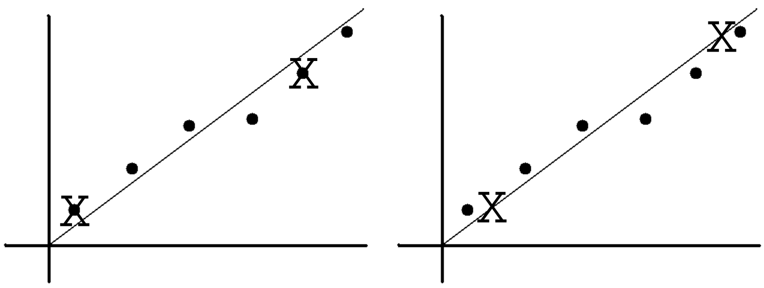

Figure 1.5: Right and Wrong Way of Finding Slope

1.2.5.2 Counting the Squares

When dealing with a nonlinear relationship, the graphs do not make recognizable shapes. In this case, it is easier to "count the squares." Find the area of one square on the graph paper. Then count the number of squares that are below the graph. Multiply the area of one square by the number of squares. This gives you the area under the graph.

1.3 Statistics

In every physical science course, statistics are used to analyze an experiment or a set of data. From psychology to physics, mean, standard deviation, and other terms are used to relate the results of an experiment and how trustworthy it is.

All terms in this section can be found using the Statistics Worksheet, located in the back of the book in Appendix ??.

1.3.1 Notation

There are many different strange looking notations that people use for statistics. Don't worry, they're fairly simple, and we will keep their use to a minimum.

The first, and maybe most important is the sigma notation. The Greek capital letter Σ means "the sum of." For instance if I wanted the sum of the first five positive integers, I would write it as

$$\sum n; n = 1; 5 \tag{1.5}$$

The number on bottom is where you start summing, while the number on top is where you would stop. $\sum n; n = 1; 5$ is a shorthand way of writing $1 + 2 + 3 + 4 + 5$.

We also have what I call "bar" notation. Anytime you see a straight bar over a variable, we assume it is the average value. For instance, if we use v to symbolize velocity, then

$$\bar{v}$$

is the notation for the average velocity. Important note: do NOT confuse this with the arrow notation for a vector! $\bar{v}$ is very different from $\vec{v}$. The former reads "average velocity", while the latter reads "the velocity vector."

1.3.2 Mean

After we have measured our object, now what? Usually, we repeat our measurement several times. Now that we have a bunch of measurements, we want find the mean of these measurements. The mean of a set of measurements is the average of the measurements.

To find the mean, simply add each measurement together. Take this and divide it by the total number of measurements.

The mean of a set of values has units - whatever the units of the measurements, the mean will have the same units.

Question 3 *Find the mean of these times (t): 1 sec, 2 sec, 3 sec, 4 sec, 5 sec*

1.3.2.1 Finding the Mean - Technical

Let n be the number of measurements made. x_i will symbolize each measurement. The mean, $\bar{x}$, is then given by:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{1.6}$$

1.3.3 Percent Error

Percent error is the primary indicator of how successful (and accurate) your lab was. It indicates how close a lab is to an accepted value.

To find the percent error, you must first find the mean. The mean is the experimental value. The theoretical value is what is supposed to be (accepted value). You can usually look this up in a book. The percent error is given by:

$$\text{percent error} = \frac{|\text{experimental value - theoretical value}|}{\text{theoretical value}} * 100 \tag{1.7}$$

Notice the absolute value bars on top the fraction. The percent error is always positive.

1.3.4 Standard Deviation

The standard deviation tells an experimenter how trustworthy a lab is. If the measurements are far apart from each other, then the experiment will have a high standard deviation.

Think of a gallup poll.[6] At the bottom of the poll, it usually tells the viewer this poll has an error of $\pm$ 3 percent, or something like that. This is the standard deviation. If the viewer learned the poll had an error of $\pm$ 30 percent, it is not trustworthy. The smaller the standard deviation, the more trustworthy the experiment.

Standard deviation is symbolized by the lowercase Greek letter sigma, σ. It relates the spread of the values in the experiment. It is easiest to use the Statistics Worksheet to find the standard deviation.

The standard deviation of a set of values has units - whatever the units of the measurements, the standard deviation will have the same units.

Question 4 *Find the standard deviation of these numbers: 1 sec, 2 sec, 3 sec, 4 sec, 5 sec*

1.3.4.1 Finding the Standard Deviation - Technical

To find the standard deviation, you must first find each deviation, d_i. The deviation is how far from the mean each value is. Take each value from the experiment and subtract it from the mean. Mathematically:

$$d_i = \bar{x} - x_i \tag{1.8}$$

Keep in mind this can be positive or negative, so we now square each deviation. Once we square each deviation, they are added together. Mathematically:

$$\sum d_i^2 = \sum (\bar{x} - x_i)^2 \tag{1.9}$$

[6] A gallup poll is a poll used in politics. It tells what percentage of votes a candidate received.

Take this and then divide by the total number of measurements, $\bar{x}$ (see Equation 1.6). Take the square root of the entire result. This is the standard deviation, σ.

$$\sigma = \sqrt{\frac{\sum d_i^2}{n}} = \sqrt{\frac{\sum(\bar{x} - x_i)^2}{n}} \qquad (1.10)$$

For this reason, the standard deviation is sometimes known as the root mean square. It is the square root of the mean of the deviations squared.

1.3.5 Percent Standard Deviation

The percent standard deviation, or fractional standard deviation[7], is to standard deviation as percent error is to mean. This gives a rule for determining the precision of an experiment.

To find the percent standard deviation (P.S.D.):

$$P.S.D. = \frac{\sigma}{\text{mean}} * 100 \qquad (1.11)$$

The percent standard deviation is expressed as a percentage. For labs at Hannan High, the percent standard deviation is typically 10 percent. Any lab with a percent standard deviation greater than 10 percent is considered to be not precise.

1.4 Problems

.250 cm, .0013 cm, .5%

1. Find the mean and standard deviation of these numbers. Also find the percent standard deviation.

Trial Number	Measurement (cm)
1	.251
2	.248
3	.250
4	.249
5	.250
6	.252

.04%, 8.6 x 10^{-6}%

2. The number pi (π) is given by 3.14159265 (approximate). Find the percent error in each of the following values: A) 22/7 B) 355/113

.250 cm, .002 cm, .4%, 1%

3. Ten measurements of the diameter of a hard steel rod yielded the following data (in cm):

.250	.246
.252	.250
.255	.248
.249	.250
.248	.252

Find the mean, standard deviation, and percent standard deviation. If the theoretical value was .251 cm, what is the percent error?

4. In book: pg 38 # 16
5. In book: pg 38 # 17 Also, find the density at each point. Find the mean, standard deviation, and percent standard deviation of these densities.
6. In book: pg 38 # 18

[7] The percent standard deviation is the fractional standard deviation expressed as a percentage.

7. In book: pg 38 # 19
8. In book: pg 688 # 9
9. In book: pg 688 # 10
10. In book: pg 689 # 8

1.5 Errors

Unfortunately, in every experiment there will be errors. This is an imperfect world; therefore, we will get imperfect experiments. What you can do in the lab is to help minimize those errors.

1.5.1 Systematic Errors

Systematic errors are errors due to experimentation or instrumentation. These are due to the way the experiment is done or the instruments used.

Systematic errors are related to the accuracy of an experiment.

1.5.2 Random or Chance Errors

Random errors are related to the precision of an experiment. error due to fluctuations in other variables (temperature, wind, etc).

line voltage, mechanical vibration.

Random errors can result from fluctuations in estimating. Notice this is not a human error, which will be discussed later. This is not reading the instrument wrong, but simply estimating the last decimal place.

Random errors are usually distributed in a way that makes for simple analysis. Most experiments follow a Gaussian distribution (think of a bell curve); in advanced statistics courses, there are a number of factors that can be figured out.

1.5.3 Human Errors

These are really should not be included in an error discussion. These are the worse kind - due to an experimenter's sloppy work. These may include reading the instruments wrong, recording the wrong number, or mistakes in arithmetic. These are NEVER included in a proper error analysis.

1.5.4 Propagation of Errors

If an experimenter makes a mistake while measuring, then that error will affect other calculations later. This is known as error propagation. A carefully done experiment will limit error propagation.

1.6 Accuracy and Precision

1.6.1 Accuracy

Accuracy describes how close the measurement comes to the accepted value.

Accuracy can be affected if the instrument used is not calibrated. For example, if a triple beam balanced is not properly calibrated before used, then a wrong mass will be measured. This is an example of a systematic error (Section 1.5.1); it affects the accuracy. An thermometer that shows 102°C is improperly calibrated; this produces an systematic error (something is wrong with the instrument) and affects the accuracy of the lab.

It is important to note that an accurate lab does not necessarily have to have the correct value every time; it simply has the average out to the correct value. Accuracy is related to the percent error, which

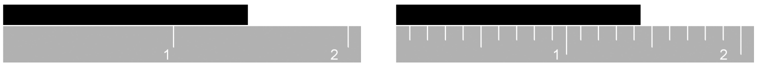

Figure 1.6: Two rulers With Different Precision

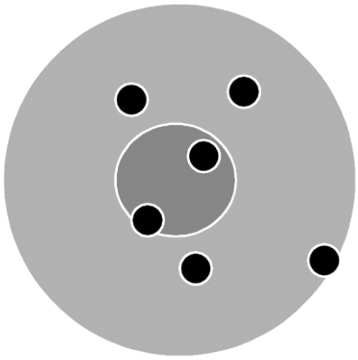

Figure 1.7: An Accurate Sharpshooter

is determined by the mean (or average). An accurate sharpshooter does not have to hit the bulls eye; the average of his shots should be around the bulls eye.[8]

1.6.2 Precision

Precision is related the repeat-ability of a lab. A precise lab measures values that are close together. Every time you do the experiment, you get close to the same value. As mentioned previously, a good indicator of precision is the percent standard deviation. For labs at Hannan High, the precision should 10% or less.

The precision of an experiment is limited by the precision of the instruments used. This can be misleading; notice this is concerned with the precision of an instrument, not the precision of the lab. An instrument that has poor precision usually leads to an inaccurate lab, not a lab with low precision. Keep this in mind while doing an error analysis.

Question 5 *How might the precise sharpshooter improve his accuracy?*

[8] This may be counterintuitive to what you may think now. In physics class we often use terms that have other meanings outside the class; it is important not to confuse them! We have specific words for specific things

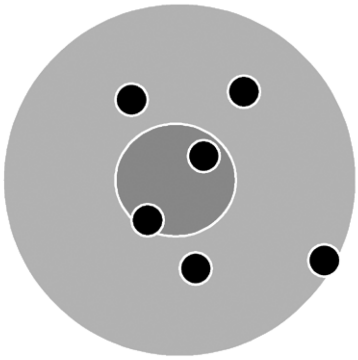

Figure 1.8: A Precise Sharpshooter

Question 6 *What would an accurate and precise sharpshooter's target look like?*

Chapter 2

Pythagoras, What a Guy

2.1 Ticket in the Door

1. State the Pythagorean Theorem.
2. Explain (in words) how to find the area of a triangle.
3. Explain how to find the area of a rectangle.

2.2 Theory

The sum of the squares of the sides of a right triangle is equal to the square of the hypotenuse.

2.3 Procedure

Assemble the shapes to form one large rectangle. This may take some patience. Also, measure each side of each shape to 2 significant digits.

2.4 Calculations

After you assemble the large rectangle, record the picture. The large rectangle looks like (careful with the triangles!):

The large rectangle can be broken into two squares of equal area. Using the area of each figure in the square, we can find the Pythagorean Theorem. We start by adding all the areas of each figure together and cancelling like terms.

The expression we derived when we added all the areas together:

The final expression above should look very familiar to you!

Plug in the numbers that you measured in the lab into the final expression you have above. Does this prove the theorem? Why?

2.5 Ticket out the Door

1. Sketch the large rectangle, fully assembled.
2. What are the measurements of each side?

2.6 Questions

1. What is the area of a right triangle that has sides a and b and a hypotenuse c?
2. What is the area of a rectangle sides a and b?
3. What is the area of a square that has a side a?
4. (CP only) What is the area of the "big" rectangle? When we divide this into two squares of equal area, what is the area of each square?

Chapter 3

Don't Be So Dense

Table 3.1: Table to record measurements

Volume of Water (mL)	Mass of Water and Cylinder	Mass of Water	Density of water
100			
150			
200			
250			
300			
350			
400			
450			

3.1 Ticket in the Door

1. Define density.
2. What are the MKS units for density?
3. What is the theoretical value for the density of water in gm/cm^3? in kg/m^3?
4. What is the unity conversion factor to go from milliliters and cubic centimeters?

3.2 Theory

Density is given by

$$\text{density} = \frac{\text{mass}}{\text{volume}} \tag{3.1}$$

Question 7 *Since density is a mass over volume, what are the MKS units for density?*

The more dense an object, the more likely it is to sink. A penny sinks in water because it has a higher density than water. On the other hand, ice floats in water because it has ice has a smaller density than water. Liquids behave the same way - oil floats on top of water because it has a lower density than water. It "floats" on top of the water; it doesn't mix.

3.3 Procedure

Find the mass of a dry graduated cylinder. Record this.

Fill the cylinder with 100 mL of water. Record the mass in Table 3.1. From this find the mass of just the water. Hint: you know the mass of the cylinder and the mass of water + cylinder. Record this in the appropriate column. Using the volume of water, calculate the density. Record this in the table as well. Repeat for each volume listed in Table 3.1.

3.4 Calculations

Using the density of water that you calculated, find the mean of these values. Also, find the standard deviation.

Produce a graph of the mass of the water versus the volume of water. Remember, the volume of water is what we controlled, while we measured the mass.

Find the slope of the best fit line for this data.

Question 8 *What does this slope give you? (Hint: The answer is not a number.)*

Using the slope as the experimental value, calculate the percent error in the experiment. Calculate the percent standard deviation.

Discuss the accuracy and precision of the experiment.

3.5 Ticket out the Door

1. Clean workspace.

3.6 Questions

1. If you wanted to make layers of four liquids so that they do not mix in a graduated cylinder, in what order would you pour the liquids?

2. How could you find the density of an irregular solid?

Chapter 4

Tank Lab

4.1 Ticket in the Door

1. Convert 9.8 m/sec^2 to cm/sec^2.

4.2 Theory

In this lab, we will be studying the motion of an object with a constant velocity and an object moving with a constant acceleration.

Displacement is just a change in position. The recording timer makes a mark every 1/60 of a second. This is called the period of the timer. The frequency of the time is the reciprocal of the period.

Question 9 *What is the frequency of the timer?*

Velocity is simply how the displacement of an object changes during a certain amount of time. Formally, velocity is the time rate of change of position. Velocity is a measure of how fast an object is moving.

Acceleration is how the velocity changes with time. Think of an accelerator in a car. When you push it, you speed up. Your velocity changes. Formally, acceleration is the time rate of change of velocity.

Question 10 *What is slope?*

When producing a plot of displacement vs. time, the slope of this graph yields the velocity. If it is a straight line, then the velocity is constant.

Question 11 *What is the general equation for a straight line?*

We can also produce a velocity vs. time graph. The slope of this yields acceleration.

Question 12 *A completely horizontal line has what slope?*

4.3 Procedure

The lab table should already be set up for you to measure the cart moving with a constant acceleration. There is a mass attached to a string, and the string should be thread through the pulley. The other end should be attached to the cart. Record the mass (in kilograms) of this mass.

While one student holds the cart still, another student will allow the mass to drape over the side of the table. The cart should be pulled back so that the mass is just hanging over the edge. Drop the mass. Make sure everything runs smoothly, i.e. no jerks in movement, the mass doesn't catch on the pulley, etc.

Repeating the steps from above, pull the cart back. While one person is still holding the mass, thread the paper through the timer, and attach it to the cart with tape.

After this, turn on the recording timer. Now drop the mass again. You should get a piece of paper approximately one meter in length that has many distinct and recognizable dots on it. Repeat so that every person in your group has their own piece of paper.

Once everyone has their own has their own piece of ticker tape, find the mass of the cart to 1 decimal place.

Now, we are going to repeat the experiment with the constant velocity cart. Load the timer with a new piece of paper. Tape the paper to the cart. Turn the timer on and then turn the cart on. Again, you should get a piece of paper approximately one meter long.

For each piece of paper, identify where the first distinguishable dot is. Mark this "0". Count off one dot. Mark this one "1". Continue until you have marked 20 points (including zero). We call each point is a tic. You should have every other dot marked.

Question 13 *One tic is how many seconds?*

Measure the distance in centimeters to one decimal place between each mark. Record in the attached table.

4.4 Calculations

To fill out the chart properly, take each displacement and divide it by the time elapsed. Similarly for acceleration, we will take the velocity and divide it by the time elapsed.

We will produce three graphs for each cart: displacement vs. time, velocity vs. time, and acceleration vs. time. Each one should be clearly labelled. For the accelerating cart, we will find the slope of the velocity time graph. This should give us experimental acceleration. The units will be cm/tics^2. This should be converted to m/sec^2.

The theoretical acceleration can be found with this formula:

$$a_{\text{theory}} = \frac{m_{\text{hang}} * 9.8}{m_{\text{hang}} + m_{\text{cart}}}$$

This answer is in m/sec^2

Question 14 *What is the percent error in the acceleration of the cart in this experiment?*

Question 15 *What is the velocity of the constant velocity cart?*

4.5 Ticket out the Door

1. A completed chart for displacement
2. Two separate pieces of paper
3. A clean workspace should be left exactly the way you found it

4.6 Questions

1. What type of relationship is shown by the accelerating cart's displacement vs. time graph? velocity vs. time graph?
2. What type of relationship is shown by the constant velocity cart's displacement vs. time graph? velocity vs. time graph?
3. If you used a heavier mass to drop and accelerate the cart, how would the spacing of the dots change?
4. If we used another constant velocity cart but with greater velocity, how would the spacing of the dots change?
5. What keeps us from getting a perfect answer, i.e. why doesn't our theoretical and experimental data match?

tics	dist b/t tics	total distance
0	0	0
1	4	4
2	6	10
3	9	19

Table 4.1: Table for displacement

tics	dist b/t tics	velocity	acceleration
0	0	0	0
1		4	4
2		6	3
3		9	3

Table 4.2: Table for Velocity and Acceleration

Chapter 5

Ding Ding Ding Goes the Trolley

5.1 Ticket in the Door

1. Tick

5.2 Theory

5.3 Procedure

5.4 Calculations

5.5 Ticket out the Door

1. Tick

5.6 Questions

Ticket in the Door:

1. Convert 9.8 m/sec^2 to cm/sec^2.

Part I

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We can also produce a velocity vs. time graph. The slope of this yields acceleration.

Question 19 *A completely horizontal line has what slope?*

Part II

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While one student holds the cart still, another student will allow the mass to drape over the side of the table. The cart should be pulled back so that the mass is just hanging over the edge. Drop the mass. Make sure everything runs smoothly, i.e. no jerks in movement, the mass doesn't catch on the pulley, etc.

Repeating the steps from above, pull the cart back. While one person is still holding the mass, thread the paper through the timer, and attach it to the cart with tape.

After this, turn on the recording timer. Now drop the mass again. You should get a piece of paper approximately one meter in length that has many distinct and recognizable dots on it. Repeat so that every person in your group has their own piece of paper.

Once everyone has their own has their own piece of ticker tape, find the mass of the cart to 1 decimal place.

Now, we are going to repeat the experiment with the constant velocity cart. Load the timer with a new piece of paper. Tape the paper to the cart. Turn the timer on and then turn the cart on. Again, you should get a piece of paper approximately one meter long.

For each piece of paper, identify where the first distinguishable dot is. Mark this "0". Count off one dot. Mark this one "1". Continue until you have marked 20 points (including zero). We call each point is a tic. You should have every other dot marked.

Question 20 *One tic is how many seconds?*

Measure the distance in centimeters to one decimal place between each mark. Record in the attached table.

Part III

To fill out the chart properly, we will do this together in class, but you take each displacement and divide it by the time elapsed. Similarly for acceleration, we will take the velocity and divide it by the time elapsed.

We will produce three graphs for each cart: displacement vs. time, velocity vs. time, and acceleration vs. time. Each one should be clearly labelled. For the accelerating cart, we will find the slope of the velocity time graph. This should give us experimental acceleration. The units will be cm/tics^2. This should be converted to m/sec^2.

The theoretical acceleration can be found with this formula:

$$a_{\text{theory}} = \frac{m_{\text{hang}} * 9.8}{m_{\text{hang}} + m_{\text{cart}}}$$

This answer is in m/sec^2

Question 21 *What is the percent error in the acceleration of the cart in this experiment?*

Question 22 *What is the velocity of the constant velocity cart?*

Ticket out the Door:

1. A completed chart for displacement
2. Two separate pieces of paper
3. A clean workspace should be left exactly the way you found it

Part IV

Questions to be answered at the end of your lab:

1. What type of relationship is shown by the accelerating cart's displacement vs. time graph? velocity vs. time graph?
2. What type of relationship is shown by the constant velocity cart's displacement vs. time graph? velocity vs. time graph?
3. If you used a heavier mass to drop and accelerate the cart, how would the spacing of the dots change?
4. If we used another constant velocity cart but with greater velocity, how would the spacing of the dots change?
5. What keeps us from getting a perfect answer, i.e. why doesn't our theoretical and experimental data match?

tics	dist b/t tics	total distance
0	0	0
1	4	4
2	6	10
3	9	19

Table 5.1: Table for displacement

tics	dist b/t tics	velocity	acceleration
0	0	0	0
1		4	4
2		6	3
3		9	3

Table 5.2: Table for Velocity and Acceleration

Chapter 6

Reaction Time

6.1 Ticket in the Door

1. Tick

6.2 Theory

6.3 Procedure

6.4 Calculations

6.5 Ticket out the Door

1. Tick

6.6 Questions

Ticket in the Door:

1. Convert 9.8 m/sec^2 to cm/sec^2.
2. Name the standard equation for an accelerating object.
3. You should have an understanding about units before starting. There are many numbers given in this lab in varying units; be prepared to handle these appropriately.
4. Part of your grade will include reading the instruction thoroughly. Therefore, if you ask a question that is answered in the write up, expect to be docked points.
5. Is distance a scalar or a vector? Can it be positive? negative? zero?
6. Is displacement a scalar or a vector? Can it be positive? negative? zero?

Part I

The time it takes to react in a given situation is known as your reaction time. It has many variables, including your stimulus and the body part doing the reacting. For instance, it takes longer for a nerve impulse to get to your foot than it does to your hand, increasing your reaction time.

We will be dropping a ruler and measuring the distance it falls before you catch it. By finding the distance the ruler drops, we should be able to relate this to the time the ruler drops. This time is your total reaction time.

Using the standard equation, everyone should be able to derive an equation for an object that is dropped that is solved for time. The equation you should get is

$$t_r = \sqrt{\frac{2x_f}{a}} \tag{6.1}$$

Here, the acceleration is just the acceleration due to gravity, which everyone should have.

Question 23 *An object falls and moves downward. Is its displacement positive, negative, or zero?*

Question 24 *If an object moves in a straight line, then what is its displacement if the distance travelled is 25 m downward?*

Your reaction time, given by t_r can actually broken down into three different times:

1. processing time (t_p) - the time it takes for your brain to realize what's going on

2. nerve time (t_n) - the time it takes for the nerve signal to travel from your brain to whatever body part is moving
3. dynamic time (t_d) - the time it takes for your body part to move

Therefore, we can say that your reaction time is simply the sum of the other three times, i.e.

$$t_r = t_p + t_n + t_d \tag{6.2}$$

Using the ruler, we will first find our total reaction time. From this, we can find our process time, t_p. Using this, the time your brain takes to react in any situation, we will find our total reaction time in a car t_{car}.

Part II

First, we need to drop the ruler and measure the distance it falls. Before you begin, you need to make sure that your hand is resting on the table. Take your index finger and your thumb and move them one inch apart. Then, have your partner drop the ruler. Your partner should NOT tell you when the ruler is dropped. You simply react and pinch; catch the ruler with your finger and thumb. Record each measurement to one decimal place.

It is imperative that the ruler is held even with your finger before you drop (not throw) it. Make sure the bottom of your thumb is at 0 cm. Drop the ruler and measure the distance it fell. Take the measurement from the bottom of your thumb. Record this information in the table provided. Your values should be between 10 and 30 cm. If you do not catch the ruler, record the value as 35 cm. Using the Statistics Worksheet, find the mean of these values.

Question 25 *How does the mean of the distance travelled relate to displacement of the ruler?*

Record the displacement as the x_{mean}. If the ruler started at the initial position of zero, then we can use x_{mean} as the final position, to find t_r. Use equation (6.1). Record your value as $t_{r_{ruler}}$. Find this time and ALL times in the lab to four decimal places.

Honors only: All measurements MUST be recorded. However, in figuring out the average reaction time, we can throw out and ignore measurements that are way off. If you do this you will get a better answer (more accurate) with a smaller error (more precise), but you must justify why you did this (sneeze, sudden loss of motor control, etc).

We can find the nerve time by measuring the distance from your brain to your fingers, using a flexible ruler. A nerve impulse travels at a constant 30,000 cm/sec. So since we know distance and speed, we can find the time. Record this as the nerve time for the ruler $t_{n_{ruler}}$. Find this time and ALL times to 4 decimal places.

In order to find the dynamic time, we find the time for 25 complete pinches. Do this three times, and find the average. Divide this by 50. Record this is as $t_{d_{ruler}}$.

Question 26 *Why do we divide by 50, not 25?*

This half of the lab. The other half involves reaction time in a car. In order to find this we also need to find nerve time and dynamic time for a car.

To find the nerve time for a car, measure the distance from your brain to your foot, using a flexible ruler. A nerve impulse travels at a constant 30,000 cm/sec. So since we know distance and speed, we can find the time. Record this as the nerve time for the ruler $t_{n_{car}}$.

Finally, find the time it takes for you to move your foot back and forth 15 times from the accelerator to the brake. Repeat three and find the average. Divide this by 30. Label this t_{dincar}.

$\Rightarrow$ IMPORTANT $\Leftarrow$ You should record all of YOUR values on a separate sheet of paper. You will be turning this in!

Part III

There are TWO parts to the lab. First we analyze the times we measure for the ruler. Using the nerve time, the dynamic time, and total reaction time for the ruler, we should be able to find the process time using equation (6.2). Remember, find all times to 4 decimal places.

Using this process time (this time is the same for almost any situation) and the other times for the car, find the total reaction time in a car. Hint: you will use equation (6.2) again!

Make a graph of distance vs. trial number. On this graph, draw a straight line for the mean. Notice the relationship of the mean value to each measurement.

Question 27 *What is the name for the distance between each measurement and the mean on the graph?*

You should also find the standard deviation for your distances the ruler fell. This is related to the error in the lab. See the associated presentation on how it is related. Be sure to include an error analysis in your conclusion.

While you are driving, your reaction time is the time before you actually start braking. For instance, if you see a dog crossing the street and hit the brakes, you will travel a certain distance during your reaction time before your car actually begins to decelerate. Then while you are braking, your car will travel an additional distance. The sum of these two distances is your total stopping distance. During your reaction time, your car travels at a constant velocity, but then starts to decelerate. If you decide to drink and then drive, your reaction time is greatly impacted, increasing the distance it takes for you to stop and increasing your chances in getting in a wreck (or possibly killing someone).

Ticket out the Door:

1. All charts completely filled out, including the Stats Worksheet.
2. A value for your total reaction time for the ruler.
3. A value for your process time.

Part IV

Questions to be answered at the end of your lab:

1. Remark generally about the relationship between this line and each measurement and your standard deviation.
2. How far do you travel during your reaction time if you are going 20 mph? 45 mph? 65 mph?
3. Assuming a car braking has a deceleration of $13.3\frac{ft}{sec^2}$, how long will it take you to stop from each of those speeds (do not include reaction time considerations in these values)?
4. Now consider the time it takes you to react AND the time it takes to stop. How far do you go, using each speed?
5. Using the data in Table 6.6 produce a graph of total stopping distance versus speed. What type of relationship is shown by this?
6. Just two beers in an hour can seriously impact your reaction time. This gives a blood alcohol content (BAC) of about .05, which increases your simple reaction time by about 10 percent(Stanford University study,2001). Another beer during that hour will increase your BAC another .2, which increases your simple reaction time by 20 percent.** Now how long will it take to stop from those speeds? How far do you go before you stop?

**Note: These values only say how it will affect only your simple reaction time. Driving a car is very complex; you have to make quick and complex decisions. Alcohol also affects the speed of these decisions, further increasing the distance you travel before you stop.

Trial Number	dist falls
1	
2	
3	
and so on	
14	
15	

Table 6.1: Table for Distance Ruler Drops

Trial Number	Time for 25 pinches
1	
2	
3	

Table 6.2: Table for Pinches

Trial Number	Time for 15 foot to brake
1	
2	
3	

Table 6.3: Table for Foot to Brake

Speed	RT	time for car stop	total time stop	dist during RT	dist car stop	total stop dist.
20 mph						
35						
45						
65						
100						

Table 6.4: Table for Questions 2 to 4

Chapter 7

Time is on My Side

7.1 Ticket in the Door

1. Tick

7.2 Theory

7.3 Procedure

7.4 Calculations

7.5 Ticket out the Door

1. Tick

7.6 Questions

Ticket in the Door:

1. How long does it take an object to free fall from a height of 7.60 m
2. Honors: Derive an expression for the time an object will fall when dropped from an initial height.
3. An object falls from a height of 7.60 m. Do a time iteration for every .1 sec for this problem. Find the position and velocity. Record you values in a chart. Produce a x-t graph and a v-t graph. Make sure you use the same time scale for both and each is on a separate sheet of graph paper.
4. Obtain and print the slides on "Lab Skills" from the web site, www.geocities.com/hannanphysics
5. Just a note: pay careful attention to significant digits in this lab!

Part I

In this lab, we are dropping a ball and finding the time it takes to reach the ground. In this lab, we are introducing terms such as mean, standard deviation, percent error, and fractional standard deviation.

To find the value you're supposed to get in the lab, we use our TID (Ticket in the Door). We will compare this to our what we actually get. Percent error is given by the following formula:

$$\text{percent error} = \frac{|\text{ experimental value - theoretical value }|}{\text{theoretical value}} * 100\% \tag{7.1}$$

Part II

We will drop the ball several times, and we will have several people find the times for the ball to drop. We will drop the ball approximately 30 times. Using the Statistics Worksheet, find the mean of these values. We will also find the standard deviation of the times. For the lab, we will want to know the percent error and fractional standard deviation. This is related to precision and accuracy. See our presentation for more in depth information.

Part III

Unlike other labs, there is very little to now figure out. Most values have been calculated before hand. However, we will do a more complete error analysis. How do you know if the lab went well? We need to compare the experimental value, what we got in lab, to the theoretical value, what we're supposed to get. In this case, the experimental value is the mean; the theoretical value is the answer from TID 1.

Using the formula for percent error, you should find the percent error. Also, find the fractional percent error.

Part IV

Questions to be answered at the end of the lab:

1. From your theoretical graphs, what time should the ball strike the ground?
2. From your theoretical graphs, when is the ball at a height of 3.8 meters?
3. From your theoretical graphs, where is the ball after .60 sec of free fall?
4. From your theoretical graphs, what is the velocity of the ball after .60 seconds of free fall?
5. From your theoretical graphs, what is the velocity of the ball as the ball hits the ground?
6. What if we did this in a vacuum? What error would this help minimize? Would that make this more precise or more accurate?
7. What if we had a stopwatch with 4 decimal places (instead of two)? What error would this help minimize? Would that make this more precise or more accurate?
8. If we dropped this object from a bigger height, what values would increase?

How to do a Write Up

We will break this lab into five parts:

- Problem
  - What are we trying to find?
- Theory (Hypothesis)
  - THIS IS NOT AN IF/THEN STATEMENT!
  - Which equation do you use in TID? Show the work that you did to find what the time is.
  - "For an object dropped from a height of ?m, then time to strike the ground should be _________ ."
- Data and Calculations
  - "Using the Statistics Worksheet, I found the mean of the time values to be _________ ."
  - "Using the Statistics Worksheet, I found the standard deviation of the time values to be _________ ."
  - Therefore, the experimental time for the object to drop is _________ .
- Conclusion and Error Analysis
  - My experimental value is _________ . My theoretical value is _________ .
  - What is the percent error of this experiment? Make sure you show your work.
  - My standard deviation is _________ .
  - What is the fractional standard deviation? Make sure you show your work.
  - Is this experiment precise? Is this experiment accurate? Be sure to explain why, using the percent error and fractional standard deviation as proof.
  - What systematic errors were present in the lab? How does this affect the experiment?
  - What chance errors were present in the lab? How does this affect the experiment?
- Charts and Graphs
  - Graph 1: Theory x-t
  - Graph 2: Theory v-t
  - Chart 1: Values of time
  - Chart 2: Your own stats worksheet