

Physics 102: Earth, Air, Fire, and Water
Laboratory

Laboratory Manual

Montana State University-Billings

Lab # 1

Measurement

Introduction:

The laboratory in the physical sciences involves the measurement, interpretation and prediction of physical phenomenon and the testing of the laws of physics, chemistry and geology developed by others. In order to do this, one has to know how to use the measuring devices and their basic principle of operation. The purpose of this lab is to let you become acquainted with some of these instruments and how to use and read them.

Procedures:

1. Distributed about the lab are the various measuring devices. Examine them; determine how they operate and the scale units used. Record the smallest division on the scale and the largest single measurement that can be made with each of the listed instruments.

	Smallest Division	Largest Single Measurement
Meter Stick		
Stop Watch		
Spring Balance		
Digital Balance		
Dial-o-Gram Balance		
Calipers		
50 ml graduated cylinder		
10 ml graduated cylinder		
Protractor		

2. Find the mass of the articles provided using each of the instruments below.

	Mass (rectangular solid)	Mass (cylinder)
Substance:		
Digital Balance:		
Dial-o-Gram Balance		

Which of the above values do you think is more accurate, and why do you think so?

3. Measure the dimensions of the articles provided in Procedure 2 and calculate its volume. Use the calipers to measure. (Show your calculations)

a. Rectangular Solid

$$L = \underline{\hspace{2cm}} \text{ cm}$$

$$W = \underline{\hspace{2cm}} \text{ cm}$$

$$H = \underline{\hspace{2cm}} \text{ cm}$$

$$V = L \times W \times H$$

$$r = \frac{d}{2}$$

b. Cylinder

$$\text{Diameter} = \underline{\hspace{2cm}} \text{ cm}$$

$$\text{Height} = \underline{\hspace{2cm}} \text{ cm}$$

$$V = \Pi r^2 h \quad \Pi = 3.14$$

4. Using the most accurate mass in Procedure 2, and the volume in Procedure 3, calculate the density of both items. (Show your calculations)

$$D = \frac{m}{V}$$

$$\% \text{ of Error} = \frac{|E - A|}{A} \times 100\%$$

Rectangular Solid

Experimental value of density

Cylindrical Solid

Experimental value of density

Identify the Element: _____

Accepted value of density _____

Calculations of % of error for rectangular solid: _____

Calculations of % of error for cylindrical solid: _____

5. Determine an experimental value for Π (pi).

A. Measure the distance around (circumference) and the distance across (diameter) of at least eight circles. Record your values in the data table below:

	C	D
1		
2		
3		
4		
5		
6		
7		
8		

B. Plot the points: Circumference, vertical axis; diameter, horizontal axis

C. Draw the line that best fits the majority of points.

D. Now determine the slope of this line by finding two points on this line and substituting in the slope formula:

$$m = \frac{y_2 - y_1}{x_2 - x_1} \quad \text{For this experiment:} \quad m = \frac{C_2 - C_1}{D_2 - D_1}$$

E. Determine the % of error if the accepted value for Π is 3.14

Lab # 2

The Simple Pendulum

Introduction and Objectives: The laboratory is a place for the investigation of physical phenomena and principles. Originally, scientists studied physical phenomena in the laboratory in the hope that they might discover relationships and principles involved in phenomena. This might be called the “trial and error” method. Today, investigations are carried out using the *Scientific Method*. This approach states that no theory, model, or description of nature is tenable unless the results it predicts are in accord with experimental observations. We will use the scientific method to determine the acceleration due to gravity g , using a simple pendulum.

Procedure: A pendulum consists of a “bob” (a mass) attached to a string that is fastened to a point in such a manner that it can swing freely, or oscillate, in a plane about that point. For a simple pendulum, it is assumed that all of the mass of the bob is concentrated at one point, i.e. the center of mass of the bob.

1. Set up a pendulum using the bob provided and a length of string of about 75 cm.
2. Measure the period of oscillation (the time required for the bob to complete one cycle of its swing) as a function of the angle through which the pendulum is displaced. A protractor is used to measure this angle. The period is determined by timing 10 oscillations with a stopwatch and then dividing by 10.

Angle	Time for 10 oscillations (sec)	Time for 1 oscillation (T) (sec)
10°		
20°		
30°		
40°		
50°		

In the space below, write a statement concerning the period T with the size of the angle. Is there a consistent relationship?

3. Now we want to experimentally investigate the relationship between the mass of the bob and the period of oscillation of the pendulum. Keep the length of the string constant at about 75 cm and use a constant displacement angle of about 20°. Vary the mass of the bob by adding the provided washers to the bob.

Mass of washers (grams)	Mass of washers plus bob (grams)	Time for 10 oscillations (sec)	Time for 1 oscillation (T) (sec)
1 washer			
2 washers			
3 washers			
4 washers			
5 washers			
6 washers			

In the space below, write a statement concerning the period T as a function of the total mass. Is there a consistent relationship?

4. Next we want to investigate the relationship between the length of the string and the period of the pendulum. Theoretically, this relationship is given by

$$T = 2\pi \sqrt{\frac{L}{g}}$$

where g is the acceleration due to gravity and L is the length of the string. Measure the period of oscillation of the pendulum as a function of the length of the string and record this value in the table below. Use a small displacement angle (it is not necessary to measure this angle). Also calculate and record the theoretical value of

the period, and the percent error between the experimental value and the theoretical value using

$$\%error = \frac{|Exp - Theory|}{Exp} \times 100.$$

Length (L)	Time for 10 osc. (sec)	Time for 1 osc. T (sec)	T² (sec²)	T_{theory} (sec)	Percent error
20 cm					
40 cm					
60 cm					
80 cm					
100 cm					
120 cm					

In the space below, write a statement concerning the period T you experimentally determined and the length L of the pendulum. Is there a consistent relationship?

5. Finally, to test the equation in part 4, plot a graph of L vs the experimental value of T². Let L be the y-axis and T² be the x-axis. Draw a straight line best fit of the data and determine the slope m of this line using

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{L_2 - L_1}{T_2^2 - T_1^2}.$$

Rearranging the equation for the pendulum gives

$$L = \frac{g}{4\pi^2} T^2.$$

Your value of the slope of the line is therefore $\frac{g}{4\pi^2}$. From your data for the slope of your line, calculate g . In other words, we have $g = m \times 4\pi^2$. Compare your calculated value of g with the accepted value of 980 cm/sec^2 , and calculate the percent error.

$g_{\text{exp}} =$

Percent error =

Lab #3 Torque and Center of Mass

Introduction

An object is in equilibrium when the forces acting on the object in one direction equal the forces acting on the object in the opposing direction, i.e. there are no net forces on the object. If there are no net forces acting on an object, we know from Newton's First Law that the object will stay at rest or maintain a constant straight-line velocity.

A concept that is analogous to force is that of torque. While force causes objects to translate, torque causes objects to rotate. Objects rotate about a pivot point, or fulcrum. Torque is defined as the force applied to the object times the distance between where the force is applied and the fulcrum. This distance is called the lever arm. In other words,

$$\text{Torque} = \text{force} \times \text{moment arm.}$$

Torque can cause clockwise or counterclockwise rotation. If an object doesn't rotate, or rotates with a constant angular velocity, then there is no net torque acting on the object. This means that the total torque that produces clockwise rotation equals the total torque that produces counterclockwise rotation.

Procedure

1. Balance a meter stick in the knife-edge clamp and record the reading of the position or location of the fulcrum. This should be close to the 50-cm mark. Record this position below.

$$\text{Fulcrum position} = \underline{\hspace{2cm}} \text{ cm.}$$

2. Next suspend a mass using mass hangers at the 30 cm mark. Use a mass M_1 of 100 to 400 g. Suspend a greater mass M_2 on the opposite side of the fulcrum at a point where the meter stick balances. Don't forget to include the mass of the mass hanger and clamp. Record these values below.

$$M_1 = \underline{\hspace{2cm}} \text{ g; lever arm } D_1 = \text{fulcrum position} - 30 \text{ cm} = \underline{\hspace{2cm}} \text{ cm}$$

$$M_2 = \underline{\hspace{2cm}} \text{ g; lever arm } D_2 = \underline{\hspace{2cm}} \text{ cm}$$

Determine the torques on both sides of the fulcrum. Are they equal? If not, what is the percent difference between the two?

$$\text{Torque 1} = \underline{\hspace{2cm}}$$

Torque 2 = _____

$$\% \text{ difference} = \frac{\text{difference}}{\text{average}} \times 100. = \underline{\hspace{2cm}}$$

3. Now suspend two masses M_1 and M_2 at different positions on one side of the fulcrum and one mass M_3 on the other side. Record these masses and the corresponding lever arms D_1 , D_2 , and D_3 below.

$M_1 = \underline{\hspace{2cm}}$ g; $D_1 = \underline{\hspace{2cm}}$ cm

$M_2 = \underline{\hspace{2cm}}$ g; $D_2 = \underline{\hspace{2cm}}$ cm

$M_3 = \underline{\hspace{2cm}}$ g; $D_3 = \underline{\hspace{2cm}}$ cm

In this case, the torque equation is

$$M_1D_1 + M_2D_2 = M_3D_3.$$

Assume that we don't know the value of M_3 . Solve the above equation for M_3 and record this value below.

Calculated value of $M_3 = \underline{\hspace{2cm}}$ g.

Calculate the percent difference between the measured or actual value of M_3 and the calculated value of M_3 using

$$\% \text{ difference} = \frac{\text{difference}}{\text{actual}} \times 100.$$

4. Finally, with only one mass M_1 suspended near one end of the meter stick, slide the stick through the knife edge clamp until you find the point where the stick's weight is counterbalanced by the weight of M_1 . Record your data below.

$M_1 = \underline{\hspace{2cm}}$ g; moment arm $D_1 = \underline{\hspace{2cm}}$ cm

moment arm $D_2 = \underline{\hspace{2cm}}$ cm

Using the torque equation $M_1D_1 = M_{\text{stick}}D_2$, calculate the mass of the meter stick. Compare this value to the value obtained from the balance and calculate the percent difference.

M_{stick} calculated = $\underline{\hspace{2cm}}$ g

M_{stick} determined using digital balance = $\underline{\hspace{2cm}}$ g

% difference = $\underline{\hspace{2cm}}$

Questions and Exercise

1. The product of force and lever arm that tends to produce rotation is called _____.
2. The fulcrum is the pivot point about which torque is calculated. However, the position of the single point associated with a body where all of its mass can be considered concentrated is called the _____.
3. A uniform meter stick supported at the 20 cm mark balances when a 200 g mass is suspended at the 0 cm end. What is the mass of the meter stick? Show your work.

Lab # 4

Projectile Motion

In this lab, we will use the equations for projectile motion to determine the initial velocity of a ball fired from a spring-loaded gun, which we will then use to predict the range of the ball when the gun is elevated. The gun is placed on a lab table so that it will fire a ball horizontally off of the table. From our knowledge of projectile motion, we know that it will follow a parabolic path to the floor. If we know the height of the table and the range of the ball, we can work the equations for projectile motion backwards to find the initial velocity of the ball as it leaves the gun. The equations we will use are

$$v = \frac{x}{t}$$
$$h = \frac{1}{2}at^2$$

where x is the range the ball traveled and h is the vertical distance the ball traveled (i.e. the height of the gun above the table).

Procedure:

Set the gun up on the edge of a lab table and fire the gun once to get an idea for the range of the ball. Next, tape a piece of paper to the floor in the approximate location of where the ball landed. Fire the gun again. If the ball lands on the paper, it will leave a mark. Do this five times without moving the gun or the paper. Measure the horizontal distance from the end of the gun to the marks on the paper and take the average of the five readings. Record this value and the largest deviation which your individual measurements make from the average:

$$x_{av} =$$

$$\Delta x =$$

Measure and record the height of the gun off of the floor:

$$h =$$

Knowing that the ball has no initial vertical component of velocity, we can calculate the time required for it to drop from the height h . Show this calculation and record your answer.

$$t =$$

Knowing the range of the ball and the time that it spends in the air, we can calculate the initial velocity. Show this calculation and record your answer:

$$v_o =$$

Lab #5 Specific Heat and Calorimetry

Theory:

The specific heat (c) of an object is defined by the equation that relates the heat energy (Q) absorbed by an object of mass m to its corresponding increase in temperature (ΔT):

$$Q = mc\Delta T.$$

If two different objects with different temperatures are brought into contact and isolated from the rest of the world, they exchange thermal energy until they reach a common equilibrium temperature. Mathematically, this can be written as $Q_{\text{lost}} = Q_{\text{gained}}$ or

$$m_1 c_1 (T_1 - T_e) = m_2 c_2 (T_e - T_2) \quad (1)$$

where m_1 and m_2 are the masses of objects 1 and 2, respectively, and object 1 is initially warmer than object 2. This statement is nothing more than conservation of energy applied to the notion of heat energy. We can exploit this property to find the specific heat of one substance in terms of the known specific heat of another. Since the specific heat of water is defined to be $1 \frac{\text{cal}}{\text{g}\cdot^\circ\text{C}}$, we can therefore measure the specific heat of any object by heating it up and immersing it in a bath of cool water. The specific heat of the object (1) is then related to the specific heat of water (object 2) by:

$$c_1 = c_2 \frac{m_2 (T_e - T_2)}{m_1 (T_1 - T_e)}. \quad (2)$$

Therefore, to measure c_1 we need to measure m_1 , m_2 , T_1 , T_2 , and T_e . We will follow this general procedure in this lab to measure the specific heat of an unknown substance and identify the substance by comparing the specific heat to a table of specific heats. A word of caution is appropriate here. We will use mercury-filled thermometers to measure temperatures. Mercury is a toxic heavy metal. *Please be careful not to break the thermometers!*

Procedure:

The device used to isolate the water and the unknown object from the rest of the universe is known as a calorimeter. Our calorimeters are constructed of aluminum and consist of two cans -- an inner can (which holds the water) and an outer can which keeps the universe at bay. Unfortunately, the inner can becomes part of the system and so it also absorbs heat from the unknown object. If the inner aluminum can and the water have the same initial temperature T_2 , equation (2) becomes with the inclusion of the unknown object

$$c_1 = \frac{m_{\text{water}} c_{\text{water}} (T_e - T_2) + m_{\text{Al}} c_{\text{Al}} (T_e - T_2)}{m_1 (T_1 - T_e)}. \quad (3)$$

where c_1 , m_1 , and T_1 are the specific heat, mass, and initial temperature, respectively, of the unknown object, and T_e is the final or equilibrium temperature of the system (the water, aluminum inner can, and unknown object). The first thing we must do is measure the specific heat of the inner can or c_{Al} . Once this is known, we can solve equation (3) for the specific heat of the unknown object.

First, measure the mass of the empty inner can. This is mass m_1 in Eq. 2.

$$m_{Al} = m_1 \text{ _____} .$$

Now immerse the inner can in the ice water bath provided and let it cool for a few minutes until it reaches the temperature of the ice water. Record this temperature with your thermometer. This is temperature T_1 in Eq. 2.

$$T_{\text{ice water}} = T_{Al} = T_1 = \text{_____} .$$

Pour about 100 ml of room temperature water into a beaker. Measure and record the temperature of this water. This is temperature T_2 in Eq. 2.

$$T_{\text{water}} = T_2 = \text{_____} .$$

Quickly remove the inner can from the ice water, dry off any excess water, pour the room temperature water from the beaker into the inner can, reassemble the calorimeter, and insert the thermometer into the calorimeter.. Again, this must be done quickly. Let the calorimeter come to an equilibrium temperature. This will take a few minutes. Record this temperature.

$$T_e = \text{_____} .$$

Remove the inner can without spilling any water and find the mass of this full can. The mass of the water in the can is the mass of the full can minus the mass of the empty can. This is mass m_{r2} in Eq. 2. Record these values.

$$m_{\text{water}} = m_{\text{full}} - m_{\text{empty}} = m_2 = \text{_____} .$$

Use this data to find $c_{Al} = c_1$ using equation (2). Show your calculations. In Eq. 2 $c_2 = c_{\text{water}}$

$$c_{Al} = c_1 = \text{_____} .$$

Next, place the inner can full of water back into the calorimeter. Find and record the mass of the unknown sample. Refer to Eq. 3 for this part of the lab.

$$m_1 = \text{_____} .$$

Tie the unknown substance to a string and hang it in the boiling water provided. Record the temperature of the boiling water (DO NOT USE THE THERMOMETER FROM

THE CALORIMETER). This is also the temperature T_1 of the unknown. Record this value.

$$T_1 = \text{_____}.$$

Record the temperature T_2 of the water in the calorimeter (DO NOT USE THE THERMOMETER FROM THE BOILING WATER). This is also the temperature of the inner can.

$$T_2 = \text{_____}.$$

Quickly remove the unknown sample from the boiling water and place it into the calorimeter. Allow the water and the unknown object to reach an equilibrium temperature. Record this temperature.

$$T_e = \text{_____}.$$

Using equation (3), calculate the specific heat of the unknown substance. Show your work.

$$c_1 = \text{_____}.$$

Identify the unknown substance.

Lab # 6

Simple Harmonic Motion

Theory:

Simple harmonic motion is one of the most common types of motion found in nature, and its study is therefore very important. Examples of this type of motion are found in all kinds of vibrating systems, such as water waves, sound waves, the rolling of ships, the vibrations produced by musical instruments and many others. The archetype for simple harmonic motion is a mass on the end of a spring.

One of the criteria for determining whether a system will produce simple harmonic motion is that the force exerted by the system on a mass is proportional to the displacement of the mass from its equilibrium position and that the force points back toward the equilibrium position. For a spring, this force is:

$$F = -k\Delta x$$

which obviously satisfies this requirement. This force then gives the following relationship between the acceleration and the position of the mass:

$$a = -\left(\frac{k}{m}\right)\Delta x .$$

Using calculus, this equation can be shown to require that "period of oscillation", T (which is the time required for the mass to go through one cycle and return to its original position) is given by:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

where m is the mass of the object and k is the spring constant of the spring. Note that the period is independent of the size of the oscillation. This is true as long as the oscillation is not so big that it starts to permanently deform the spring and the force is no longer described by $F = -k\Delta x$. We will test this result by measuring the spring constant of a spring, the mass of an object oscillating on the end of the spring, and the period of the mass' oscillation. The measured period should be equal to the value calculated using the above formula and the measured values of m and k .

Procedure:

We will first measure the spring constant, k , by hanging a mass from the end of the spring and allowing the mass to come to equilibrium. At equilibrium, the force of gravity pulling down on the mass will be canceled by the force of the spring pulling up on the mass. Therefore,

$$mg = k\Delta x$$

so

$$k = \frac{mg}{\Delta x}.$$

Since Δx is equal to the displacement from the equilibrium position of the spring when it has no mass attached to it, we need to first find the equilibrium position of the spring. Hang the spring from a support pole and measure the height of the bottom of the spring from the table. Record this position as the equilibrium position, x_0 .

$$x_0 =$$

Now, hang five different masses from the spring and record the mass (m) and the height of the bottom of the spring from the table (h). Calculate the displacement ($\Delta x = x_0 - h$) and record this for each mass.

m (kg)	mg (Newtons)	h (meter)	$\Delta x = x_0 - h$ (meter)

The spring constant k is the slope of the line found by plotting mg as a function of Δx . Find k by plotting the weight of the suspended mass, mg , along the y axis and Δx along the x axis. Draw a best fit line through these data points and then find the slope of the line. This is k or the spring constant. Record k and the units associated with it.

$$k = \underline{\hspace{10em}}$$

We will now investigate the relationship between the period of oscillation of the spring and the mass of an object attached to the spring. To do this, hang a known mass (m) on the end of the spring. The total mass suspended by the spring is this mass plus the mass of the spring m_s . Measure the time (t) required for 10 oscillations. Repeat this procedure three times, and record your results in the data table below.

m	t	$M = m + m_s$	$T_{\text{exp}} = t/10$	$T = 2\pi\sqrt{M/k}$

Using the data you have gathered, do the calculations required to fill out the rest of the data table. For each trial, calculate the percent discrepancy between $T_{\text{exp}} = t/10$ and $T = 2\pi\sqrt{M/k}$. Record these values below.

T_{exp}	T	% Difference

Lab #7

Resonance in Closed Tubes

The velocity with which a sound wave travels in a substance may be determined if the frequency of the vibration and the length of the wave are known. In this experiment the velocity of sound in air will be found by using a tuning fork of known frequency to produce a wavelength in air that can be measured by means of a resonating air column.

Theory:

If a vibrating tuning fork is held over a tube, open at the top and closed at the bottom, it will send air disturbances, made up of compressions and rarefactions, down the tube. These disturbances will be reflected at the closed end of the tube. If the length of the tube is such that the returning disturbances are in phase with those being sent out by the tuning fork, then resonance takes place. This means that the disturbances reinforce each other and produce a louder sound. Thus, when a tuning fork is held over a tube closed at one end, resonance will occur if standing waves are set up in the air column with a node at the closed end and a loop (or anti-node) near the open end of the tube. This can take place if the length of the tube is very nearly an odd number of quarter wavelengths of the sound waves produced by the fork. Hence resonance will occur when $L = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4},$ etc., where L is the length of the tube and λ is the wavelength of the sound waves in air. N.B.: The center of the loop is **not exactly at the open end of the tube**, but is outside of it by a small distance that depends on the wavelength and on the diameter of the tube. However, the distance between successive points at which resonance occurs, when the length of the tube is changed, gives the exact value of a half wavelength.

The relation between the velocity of sound, the frequency, and the wavelength is given by the equation:

$$v = f\lambda.$$

The velocity can be calculated from the above equation if the wavelength and the frequency are both known. The velocity of sound in air depends on the temperature of the air by:

$$v = (331.4 + 0.6T) \text{ m/s}$$

where T is temperature measured in °C.

Procedure:

Adjust the level of the water in the glass tube by raising the supply tank, until the tube is nearly full of water. Hold the tuning fork about 2 cm. above the tube in such a manner that the prongs will vibrate vertically. Start the tuning fork by striking it gently with a rubber mallet (or your knee) -- **do not smack it against the edge of the table**. Slowly lower the water level while listening for resonance to occur. At resonance, there is a sudden increase in the intensity of the sound at the instant the air column is adjusted to

the proper length. When the approximate length for resonance has been found, run the water level up and down near this point until the position for maximum sound is found. Measure and record the length of the resonating air column to the nearest millimeter. Make two additional determinations of this length by drastically changing the water level and relocating the position for maximum sound again. Record these two readings also. Lower the water level and repeat this procedure to find the second location at which resonance occurs. Again make three independent determinations of this length and record the readings to the nearest millimeter. Repeat this for a tuning fork with a different frequency. Record the temperature of the room and the frequency of each tuning fork. Use this information to fill out the appropriate positions in the data table. The wavelength of the sound waves can be calculated by finding the difference between the length of the tube at the first position of resonance (L_1) and the length at the second position of resonance (L_2). This gives one half of a wavelength. In other words,

$$L_2 - L_1 = \frac{\lambda}{2}.$$

Using the averages from the data table, calculate the wavelength and record these values in the data table. Finally, calculate the experimental value for the speed of sound in air ($v = f\lambda$) from the data for each tuning fork and enter these numbers in the data table.

f	L_1	L_2	λ	v

Using the measured room temperature, calculate the theoretical value of the speed of sound in air from the equation:

$$v = (331.4 + 0.6T) \text{ m/s}.$$

Record this value and compare it with the average of the two experimentally determined values. What is the percent discrepancy?

Lab #8 Lenses

The relationship between the focal length (f), object distance (o) and image location (i) for thin lenses is given by the equation:

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

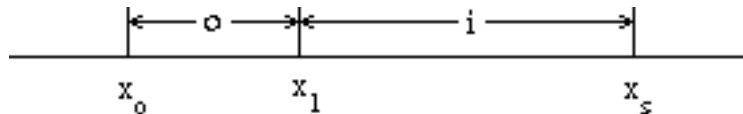
If the lens is a converging lens, f is a positive number, while f is a negative number for a diverging lens. In this lab, we will test this equation by determining the focal length of a lens and then using the experimentally determined focal length to predict the location of the image for an object placed a known distance away from the lens. To begin, place the object at a convenient point on the optical bench, and place the screen at the other end of the bench (also at some convenient point). Next, place the lens in between the object and screen. Slide the lens back and forth along the optical bench until a clear and focused image appears on the screen. Record the locations of the object, lens, and screen as x_o , x_l , and respectively:

$$x_o =$$

$$x_l =$$

$$x_s =$$

The configuration on the bench can be drawn as shown:



where

$$o = x_l - x_o \quad \text{and} \quad i = x_s - x_l$$

Use this information and the lens equation to determine the value of the focal length for the lens and record this value:

$$f =$$

Next, place the lens so that the object is two focal lengths away. Using the lens equation, calculate where the image should be located. Record this predicted number:

$$i_{\text{th}} =$$

Finally, move the screen along the optical bench until a sharp image of the object can be seen. Record this experimental number:

$$i_{\text{ex}} =$$

Calculate the percent deviation from your theoretical and experimental values of the image location:

$$\text{Percent deviation (\% error)} =$$

Is this reasonably small? (If not, do it again).