Physics 202 Lab 1
Simple Harmonic Motion

Apr 8, 2013

Equipment

- Meter sticks
- Graph paper
- Force sensors
- Photogates
- Height-finder protractors
- Thread
- Scissors
- Stopwatches
- Pendulum clamps
- Pendulum weight sets
- Small springs
- Large springs
- Lab stands
- Hanging weight sets

Simple Pendulum

Recall that the frequency for a pendulum is

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$$

Basic Simple Pendulum

Set up a pendulum the lab stand, clamp, thread, and a hanging mass. Orient the photogate so that the pendulum swings through the sensor.

Using the formula above, calculate the frequency of the pendulum you have constructed.

Using the Data Studio feature specifically designed for a photogate and pendulum, select to view the period, T, of your pendulum in table format. Verify the accuracy of this equation for the pendulum you have constructed by calculating the average measured frequency.

Calculate the percent difference between your calculated and measured values and list some possible sources of error.

Frequency Dependence on Mass

Now explore the effect on period of changing the mass. Double the mass on your pendulum and measure the average frequency. Is there a difference? If so, why?

Frequency Dependence on Initial Angle

Recall that our equation for frequency, f , was derived using the assumption that θ is less than $10°$. Measure and record the period for several larger amplitudes. Describe the effect that progressively increasing θ has on the validity of the equation for frequency.

How to Make a Clock

Suppose you were making a clock, and you wanted to create a pendulum with a period of exactly 1.00 second. What would the corresponding frequency be? Calculate the length of this pendulum. Set up a pendulum of this length, and verify your result.

Mass on a Spring

Suppose that instead you wanted to have a mass on a spring oscillate with a period of 1.00 second. Recall that the frequency for a mass on a spring is:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Determine Spring Constant

In order to construct our clock we need to determine our spring constant. Hang the small spring from the lab stand and clamp. Hang a small mass such that the spring just begins to stretch and measure the distance between the table and the bottom of the spring.

Now hang five difference masses from the spring and measure the distance between the table and the bottom of the spring. The incremental mass is what causes the extra stretch. You can now calculate a spring constant for each trial using $F = kx$ where F is the extra weight (remember, $W = mg$) and x is the extra stretch.

How to Make a Clock (Again)

Now that you have a good idea of the value of the spring constant for the small spring, calculate the mass that you would want to have oscillating on this particular spring in order to observe a period of 1.00 second.

Does it work? Test your calculation and describe your result including possible sources of error.

Physics 202 Lab 2
Archimedes' Principle

Apr 15, 2013

Equipment

- Force sensors
- Cork rafts
- Vernier calipers
- Thread
- Scissors
- 12" rulers
- Beakers (600 mL)
- Pennies
- Cork stoppers
- Rubber stoppers (#10-0)
- Raquetballs
- Superballs

Buoyant Force

Measure Buoyant Force Directly

Zero the force sensor by holding it vertically, and pressing the "tare" button with nothing suspended from the hook. This calibrates the internal voltage of the sensor to zero force.

Now tie a string around the rubber stopper, and suspend it from the force sensor to measure its weight. This works because the force sensor measures the force required to counter-balance the weight of the stopper. Record this weight reading. With the rubber stopper still suspended from the force sensor, submerge the stopper completely in a beaker of water (make sure that the force sensor doesn't get wet). Record the new reading of the force sensor.

Using a free body diagram in Figure 1, show all forces acting on the submerged stopper including the buoyant force present.

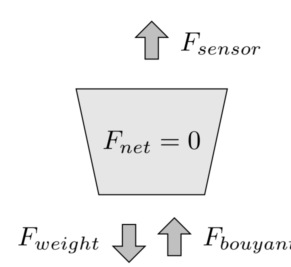

Figure 1: Forces on Floating Stopper

Calculate Buoyant Force

The formula for the volume of the stopper is:

$$V = \frac{1}{3}\pi(r_1^2 + r_1 r_2 + r_2^2)h$$

Now calculate the volume of the rubber stopper. Calculate the mass and weight of the displaced water (recall that the density of water is 1000 kg/m^3 and density = mass/volume).

Archimedes' Principle states that the buoyant force is equal to the weight of the displaced water. Verify this by calculating the percent difference between the two.

Floating

Calculate the volume of a racquetball. Calculate the mass of water that would be displaced by the entire racquetball. Compare the weight of the racquetball to the weight of the water it can displace. According to Archimedes, will it float? Test your result.

Using Archimedes' principle, determine the percentage of the racquetball that will be under water as it floats. Test your result visually.

Whatever Floats Your Boat

Initial Raft Measurements

Soak the cork raft until it is saturated with water. We want the raft to be wet for any measurements, since it will be wet when it is floating. Calculate the volume of the wet raft. Measure the mass of the wet raft. Calculate the weight of the wet raft.

Calculate Maximum Load

Similar to the previous calculation, calculate the buoyant force if it were entirely submerged. Use this value to determine the maximum number of pennies that you could stack on top of the raft without sinking it.

Determine the average mass of a penny by measuring the mass of 10 and dividing by 10. How much buoyant force is available to support the pennies? How many pennies can the raft support? Round your calculation down to the nearest penny.

Test Maximum Load

When you are certain of your calculation, place that number of pennies on the raft, verifying that it does not sink. Then verify that placing one more penny on the raft does indeed sink it. Describe your results.

Physics 202 Lab 3
Calorimetry

Apr 22, 2013

Equipment

- Styrofoam cups (large)
- Styrofoam square lid with no holes
- Digital thermometers (each with 2 leads)
- Beakers (400 mL)

Set Up

In this experiment we will be studying the transfer of heat. The timing can be fairly quick, so read through completely through this part before starting the measurements.

A calorimeter is a system designed to investigate the transfer of heat. The system is isolated so the total heat in the system is constant. That means that any heat lost in one part must be gained by another.

Measure the mass of the empty calorimeter. Be sure to include the thermometer also. Fill the calorimeter to roughly 2/3 full with hot tap water. Measure the mass of both.

Obtain several ice cubes directly from the freezer, noting the temperature of the freezer. Measure the temperature of the water just before adding the ice cubes and closing the calorimeter.

Mix and Measure

Add the ice cubes and gently swirl the mixture continuously, and record the final temperature of the mixture when all of the ice has just melted and calculate the change in temperature for the hot water and the ice cubes.

Measure the total mass of the calorimeter. Calculate the mass of the mixture and the mass of the original ice cubes.

Now we can calculate the heat lost by the hot water using the equation

$$Q = mc(\Delta T)$$

This heat lost must flow into the ice cubes. This heat both melts the ice and raises the temperature of the melted ice cubes up to the final temperature. Calculate the heat required for both of these changes.

Determine the percent difference between the heat lost and the heat gained and list possible sources of error in this experiment.

Physics 202 Lab 4
Waves on Strings

May 6, 2013

Equipment

- 2-meter stick
- Elastic string
- Mechanical vibrators
- Power amplifiers with cord
- Scissors
- Physics string
- Banana plug & clip
- Clamps with pulley
- Clamps with metal bar
- Hanging weight sets

For all waves, the wave speed, v, is equal to the product of the frequency, f, and the wavelength, λ:

$$v = f\lambda \tag{1}$$

For waves in a string, the wave speed, v, is determined by

$$v = \sqrt{T/\mu} \tag{2}$$

where T is the tension in the string, and μ is the mass per length, or linear density of the string ($\mu = m/L$).

Initial Set-Up

Set up a standing wave in the string by varying the tension and the frequency. Make sure that you don't hang so much weight from the end of the string that it stretches the string by a noticeable amount. You will be able to achieve the best result by fine-tuning the frequency until you clearly see a standing wave of maximum amplitude.

Calculate the wavelength of the standing wave by dividing the length of the string that is vibrating, by the number of full wavelengths it contains.

Calculate the wave speed using equation 1.

Find the Harmonics

Now, considering the total length of the vibrating string, calculate the wavelengths of the first 10 harmonics for your system.

For each wavelength, use the wave speed, v, for your system to determine the corresponding harmonic frequency.

Now adjust the mechanical vibrator to each of these frequencies, in turn, and verify that these are indeed the first ten harmonic frequencies of your system.

Verify Linear Density

Now using equation 2, with the value for v that you calculated, and the tension in the string ($T = mg$), solve for μ, the linear density of the string.

Now, remove the string from the setup, measure its mass and its entire length (undo any knots), and compare your value for μ obtained in this manner, to the value obtained in the previous step

Rinse and repeat

Repeat the previous steps for a different type of string.

Physics 202 Lab 5
Harmonics and Sound Waves

May 13, 2013

Equipment

- Meter sticks
- Elastic string
- Mechanical vibrators
- Power amplifiers with cord
- Scissors
- Physics string
- Banana plug & plug
- Clamps with pulley
- Clamps with metal bar
- Hanging weight sets

For all waves, the wave speed, v, is equal to the product of the frequency, f, and the wavelength, λ:

$$v = f\lambda \tag{1}$$

For waves in a string, the wave speed, v, is determined by

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where T is the tension in the string, and μ is the mass per length, or linear density of the string ($\mu = m/L$).

Initial Set-Up

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Verify Linear Density

Now using Equation 2, with the value for v that you calculated, and the tension in the string ($T = mg$), solve for μ, the linear density of the string.

Now, remove the string from the setup, measure its mass and its entire length (undo any knots), and compare your value for μ obtained in this manner, to the value obtained in the previous step

Rinse and repeat

Repeat the previous steps for a different type of string.

Physics 202 Lab 6
Mirrors and Lenses

May 20, 2013

Equipment

- Pins
- Pieces of cardboard
- Light box & optical set
- Power supplies
- 12” rulers
- Protractors

Reflection

Flat Plane Mirror

Place the ray box on top of a piece of paper so that you will have a surface upon which to trace the rays. Using the appropriate slit forming plate at the end of the ray box farthest from the bulb, project a single, narrow light ray upon the plane mirror at an angle.

Trace the incident ray, the reflected ray, and the mirror surface. Draw a line (the normal) perpendicular to the mirror at the point where the ray is reflected. Measure the angle of incidence and the angle of reflection, and verify the law of reflection.

Now verify the same law the old-fashioned way (without the ray box): Place the mirror on another piece of paper which has cardboard underneath it. Place a pin about 2 inches in front of the mirror, and use a straight edge to draw a sighting line aimed at the pin's image. The sighting line is the path of the reflected ray of light. The line from the pin to the mirror is the path of the incident ray. Draw the normal and verify the law of reflection. Keep this set up for the next part.

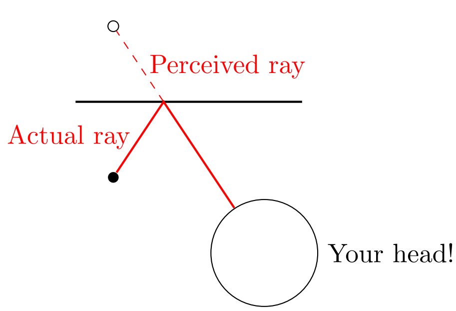

Figure 2: Ray Tracing

Using the same setup, draw another sighting line from a second position. Extend both sighting lines behind the mirror until they intersect (see Figure 3). This is the position of the image. How does the image position compare with the object position? Now, as a visual check on your results, place a second pin at the image position. Part of the second pin should now be visible above the mirror. If the second pin is at the correct image position, it will appear continuous with the image of the first pin, no matter what viewing position you choose. Verify that this is so.

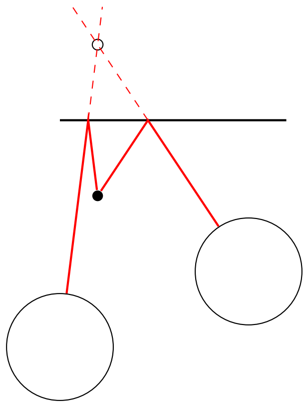

Figure 3: Finding the Image

Concave Spherical Mirror

Select the semi-circular concave mirror. Aim a set of four parallel rays into the center of the inside curve of the mirror so that the rays are parallel to the axis of symmetry of the mirror. Trace the incident and reflected rays, and note where the reflected rays meet. This point is called the focal point (or focus) of the mirror. Carefully measure the distance from the mirror to the focal point.

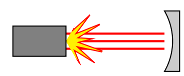

Figure 4: Concave Mirror Set Up

If the focal point appears blurred and broad, with too many rays overlapping through it, block the outer rays as they leave the light box and use only the central ones. The fact that the outer rays do not meet exactly at the focal point is referred to as spherical aberration, and can be corrected by using a parabolic mirror instead, as we will see below.

Now, set the semi-circular mirror on a piece of paper and trace the inside reflecting surface. Move the mirror around the curve and continue tracing until you have a complete circle. Measure the diameter of this circle in several directions and calculate an average diameter. How does the radius, R, compare with the focal length, f, above?

Convex Spherical Mirror

Project a number of parallel rays to strike the outside surface of the semi-circular mirror, parallel to its axis.

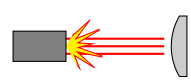

Figure 5: Convex Mirror Set Up

Trace the mirror position and ray paths and indicate the ray directions with arrow heads. Where do the diverging rays appear to come from? Locate this point by drawing the diverging rays backward through the mirror position. This is the focal point. Measure the focal length for the convex mirror. This focal length should be comparable with the concave side of the mirror. What possible sources of error might account for any difference in results?

Concave Parabolic Mirror

A parabolic mirror follows the curve produced by graphing the equation $y = x^2$.

Aim a set of four parallel rays into a parabolic reflector along paths parallel to the axis of symmetry of the mirror. Notice the sharpness of the focal point, in comparison to the spherical mirror.

Move the mirror perpedicualr to the beam (so the beam strikes off-center). Notice how the focal point is still sharp. Compare this with the spherical mirror.

This sharp focus is how such sharp images of stars that are very far away are formed. You'll notice that this parabolic shape is also used in radar antennae, radio-telescopes and car headlamp reflectors. In all of these examples, where would you put the receiving or transmitting device?

Refraction

Snell's Law

Place the ray box on top of a piece of paper so that you will have a surface upon which to trace the rays. Project a single light ray upon the clear plastic, rectangular object so that the ray makes a large angle with the normal. Trace the object, the incident ray, and the ray that emerges from the opposite side. Then remove the object and use the straight edge to complete drawing the path of the refracted ray. Also, draw the normals at each plastic/air interface.

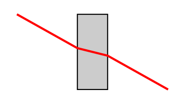

Figure 6: Refraction Through Slab

Upon entering the plastic, does the ray bend toward or away from the normal? Upon leaving the plastic, does the ray bend toward or away from the normal?

Snell' law states that for each plastic/air interface,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where n_1 and n_2 are the different indices of refraction for the two media 1 and 2 and are the respective angles each ray makes with the normal.

Consider first the point where the ray enters the plastic. Carefully measure the two angles with respect to the normal. Then, using $n_{\text{air}} = 1.00$, solve for n_{plastic}. Repeat the process for the point where the ray leaves the plastic. Your two values for n_{plastic} should compare favorably.

All lenses in your kit have the same index of refraction, so you can use this value throughout the lab.

Total Internal Reflection

When a light ray is emerging from a medium of higher index of refraction into one of lower index of refraction, if the angle it makes with the normal is large enough, it will be totally internally reflected. This critical angle is given by

$$\theta_c = \sin^{-1}(n_1/n_2)$$

where $n_1 > n_2$.

Use the value for n_{plastic} that you just calculated to determine the critical angle for the plastic/air interface.

Now we will determine this value experimentally. Aim a single beam of light at the shortest side of the 30-60-90 prism, so that the refracted beam inside the prism strikes the hypotenuse as shown.

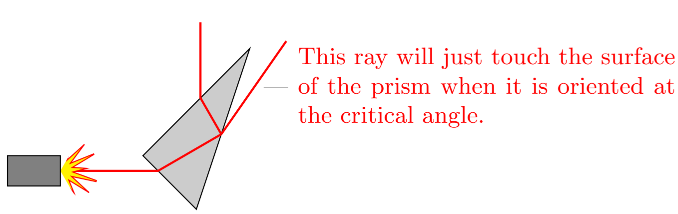

Figure 7: Measuring Critical Angle

Adjust the light box and prism positions until total internal reflection occurs and the ray emerges through the third side. Record the first position at which this occurs and measure the angle of incidence from the normal to the hypotenuse. This should be the same angle that you calculated a moment ago.

Dispersion

Have you noticed anything regarding the color of a light ray after it is refracted several times? Aim a single ray at the 60-60-60 prism in this manner:

Is the original beam white or colored? Is the emergent beam white or colored? For which color must the index of refraction in the plastic be the greatest? The least?

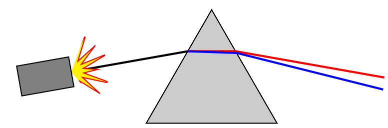

Figure 8: Making Rainbows

Physics 202 Lab 7
Interference of Light

May 27, 2013

Equipment

- Meter sticks
- Slit-film demonstrator plates (with white edges)
- Pen lasers
- Holographic diffraction gratings
- Vernier calipers
- 12" rulers

Young's Experiment

In 1801, Thomas Young demonstrated the interference of light waves in the same manner that you will today, thereby showing that light acts like a wave.

In the following diagram (Figure 9), light emerges from two slits that are separated by a distance d, and an interference pattern is observed on a screen that is a distance D from the slits, where $D \gg d$. An interference pattern appears on the screen, in which the bright fringes are points in which waves from the two slits are constructively interfering, and the dark fringes are points where they are destructively interfering. This is analogous to the interference of sound from two speakers.

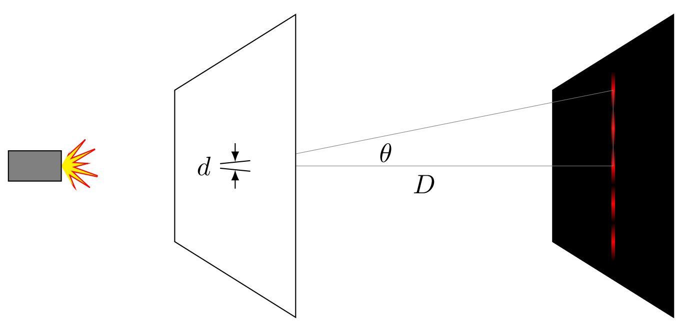

Figure 9: Double Slit Experiment

The angles at which constructive interference occurs (we call these points maxima), can be determined geometrically to be given by this equation:

$$\sin\theta = m(\lambda/d) \qquad m = 0, 1, 2, 3, \ldots$$

Hold the slit plate with the CAL monogram in the upper right hand corner. In the far right-hand column, except for the top element which is a single slit, there are several double slits of various spacings. Look through the various double slits at the clear light bulb on the counter. Comment on the spacing of the interference fringes that you see in relation to the spacing of the slits (d). Explain mathematically why this is so.

Until now, the "screen" we have been using is the retina of our eye. The same interference effects can also be observed on a screen outside of our eye. Using the pen laser (*don't ever look directly into it*), shine the laser light through the various double slits, and observe the interference patterns on a distant wall. Record your observations with drawings and comments.

The spreading out of light passing through a small aperture or around a sharp edge is called diffraction. This is the phenomenon that made Young's double slit interference possible. Diffraction can also be observed with a single slit. The far left column of the slit plate contains single slits of varying width. Look through each of them at the clear light bulb, and comment on the patterns you observe as the slits get narrower. Which gives a more noticeable diffraction pattern, a wide or narrow slit?

Diffraction Grating

A diffraction grating is an array of a large number of parallel, evenly spaced slits. The interference pattern observed through such a grating is similar to that from a double slit (see diagram from previous part), and the equation describing the positions of the maxima is identical:

$$\sin\theta = m(\lambda/d) \qquad m = 0, 1, 2, 3, \ldots$$

where d is the spacing between the centers of the slits in the grating.

The middle column of the slit plate contains diffraction gratings of various slit spacings. Look through the central diffraction grating at the bulb placed behind two different colored filters. Comment on the spacing of the interference fringes that you see in relation to the wavelength of the light (λ). Explain mathematically why this is so.

Using the holographic diffraction grating slide (please don't touch the surface) and the laser, observe the interference pattern on a wall several feet from the slide. This diffraction grating has 750 slits per mm. What would be its slit spacing, d?

Now, carefully measure the distance between two of the maxima on the wall and the distance from the slide to the wall. Use these two measurements to calculate θ (refer to Figure 9), and then using the above equation, solve for the wavelength, λ, of the laser light. Check with me when you have finished this calculation.

Now that you know the wavelength of the laser light, use this value and a method similar to what you just did, to solve for the slit spacings of two different diffraction gratings on the slit plate.

Poor Man's Single Slit

Use the Vernier calipers to make the smallest slit that you can measure on the calipers. Point the laser beam through the slit. Can you see a diffraction pattern on the wall?

Confirm that the pattern matches the diffraction equation for $m = 1$ (the first fringe from the center).

$$\sin\theta = m(\lambda/W) \qquad m = 1, 2, 3, \ldots$$

where W is the width of the slit.