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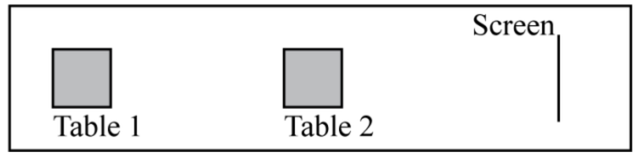
1. [4 pts] A physics instructor is setting up a single-slit interference demonstration. In the equipment room, they have access to a red laser ($\lambda_{red} = 640$ nm), a green laser ($\lambda_{green} = 550$ nm), a grating (grating A) with a single slit of width 0.20 mm and a grating (grating B) with a single slit of width 0.10 mm. The set-up of the room is shown. The instructor can place a laser and grating both on table 1 or both on table 2. Which set of conditions would produce the widest central maximum on the screen?



A. Green laser, grating B, table 1

B. Green laser, grating A, table 2

C. Red laser, grating A, table 2

D. Red laser, grating B and table 1

E. Information on table to screen distance is needed to answer.

The width of the central maximum for single-slit diffraction is given as:

$$w = \frac{2\lambda L}{d}$$

To maximize w, we want to maximize λ and L, and minimize D. We should therefore use table 1, the red laser ($\lambda_{red} > \lambda_{green}$) and grating B.

2. [4 pts] In a photoelectric-effect experiment, light of wavelength λ_0 is incident on a copper surface. As a result, electrons emerge from the copper surface ($E_{0,\text{copper}} = 4.65$ eV) with a maximum kinetic energy of 1.81 eV. What is the wavelength λ_0? ($hc = 1242$ eV · nm)

A. 192 nm

B. 293 nm

C. 350 nm

D. 410 nm

E. 437 nm

The relationship between the maximum kinetic energy of the ejected electron and the wavelength of the incoming photon is:

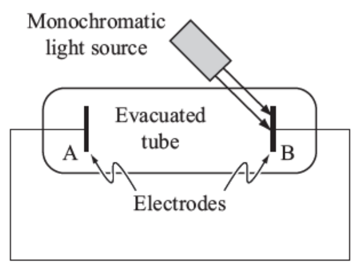
$$K_{max} = E_{photon} - E_0 = \frac{hc}{\lambda} - E_0$$

We can then rearrange the equation for λ_0:

$$\frac{hc}{\lambda_0} = K_{max} + E_0$$

$$\lambda_0 = \frac{hc}{K_{max} + E_0} = \frac{1242\ \text{eV} \cdot \text{nm}}{1.81\ \text{eV} + 4.65\ \text{eV}} = 192\ \text{nm}$$

3. [4 pts] Light source 1 with a wavelength λ and a power P_0 is incident on a metal surface. As a result, electrons are emitted from the metal surface. Suppose light source 1 is replaced with light source 2, of power P_0 and wavelength λ', where $\lambda' > \lambda$, but λ' is still less than the threshold wavelength. Which of the following statements are true after light source 1 is replaced with light source 2?



A. More electrons are emitted with greater kinetic energy than those ejected by Light #1

B. More electrons are emitted with the same kinetic energy as those ejected by Light #1.

C. More electrons are emitted with lower kinetic energy than those ejected by Light #1.

D. Less electrons are ejected with greater kinetic energy than those ejected by Light #1.

E. Less electrons are ejected with lower kinetic energy than those ejected by Light #1.

From question 2, we can write:

$$K_{max} = \frac{hc}{\lambda} - E_0$$

Increasing the wavelength, decreases the energy of the photon ($E_{photon} \propto \frac{1}{\lambda}$). As a result, this will decrease the maximum kinetic energy of the ejected electron.

The power of the light source is equal to I/a, where I is the intensity of the source. The intensity is directly related to the energy of the light. Since the light sources have equal powers (and considered identical except for their wavelength), the laser with the larger wavelength (lower energy photons) needs to emit more photons per second to have the same intensity as the light source with the shorter wavelength. With more photons emitted per second, this will lead to more electrons emitted per second.

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4. [4 pts] An electron moving with a speed v has a deBroglie wavelength of 495 nm. Determine the speed of the electron. $m_{electron} = 9.11 \times 10^{-31}$ kg

A. 1.47×10^3 m/s

B. 1.64×10^3 m/s

C. 1.90×10^3 m/s

D. 2.14×10^3 m/s

E. 2.59×10^3 m/s

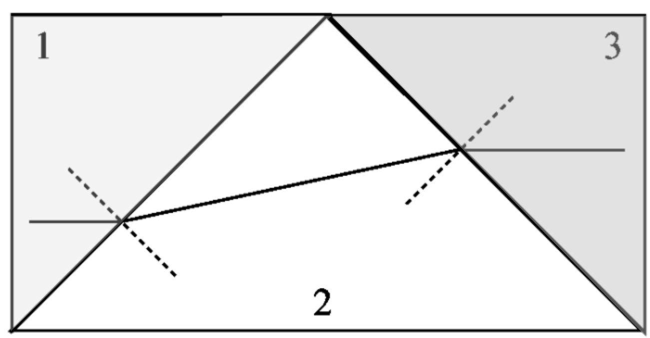
The deBroglie wavelength is given as:

$$\lambda = \frac{h}{mv}$$

Rearranging for v, we get:

$$v = \frac{h}{m\lambda} = \frac{6.63 \times 10^{-34}\ \text{Js}}{(9.11 \times 10^{-31}\ \text{kg})(495 \times 10^{-9}\ \text{m})} = 1.47 \times 10^3\ \text{m/s}$$

5. [4 pts] Three different transparent materials (1, 2, and 3) are stuck together. A laser beam that originates in material 1 passes through the three materials as shown. Rank the materials according to their index of refraction, from largest to smallest. The light rays in material 1 and material 3 are horizontal.



A. $n_2 > n_1 > n_3$

B. $n_1 = n_3 > n_2$

C. $n_2 > n_1 = n_3$

D. $n_3 > n_2 > n_1$

E. $n_1 > n_2 > n_3$

When the light ray moves from material 1 to material 2, the ray bends away from the normal (refraction angle is larger than incident angle). This means that $n_1 > n_2$. When the light ray moves from material 2 to material 3, the ray bends away from the normal (refraction angle is larger than incident angle). This means that $n_2 > n_3$.

6. [4 pts] A physics instructor is designing a classroom demonstration where they want to form an image of a light bulb on the wall of the classroom. They would like the image to be upright and enlarged. Which of the following set-ups could they use?

A. A diverging lens and place the object between the focal length and the lens.

B. A converging lens and place the object farther than $2f$ from the lens.

C. A converging lens and place the object between f and $2f$ from the lens

D. A converging mirror and place the object between the mirror and the focal point f.

E. None of the above choices will create the desired image.

To produce a real image, the instructor could use a converging lens or mirror and place the object farther than f from the lens or mirror. However, these real images would be inverted. It is not possible to create an upright real image with a single lens or mirror.

7. [4 pts] An 8.00-mm-tall object is placed 9.90 cm to the left of a converging mirror. An image of the object is formed 25.0 cm to the left of the mirror. What is the **radius of curvature** of the mirror?

A. 6.12 cm

B. 7.09 cm

C. 9.84 cm

D. 12.1 cm

E. 14.2 cm

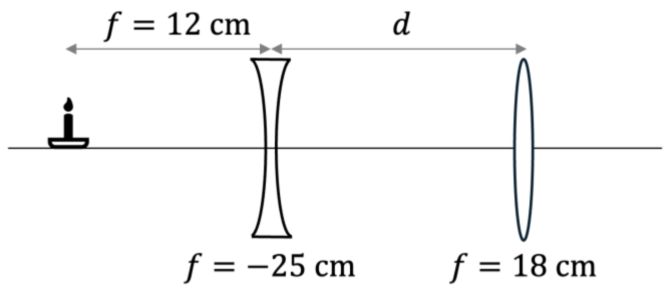
$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

$$f = \frac{R}{2}$$

$$\frac{2}{R} = \frac{1}{s} + \frac{1}{s'}$$

$$R = \frac{2}{\frac{1}{s} + \frac{1}{s'}} = \frac{2}{\frac{1}{9.9 \text{ cm}} + \frac{1}{25 \text{ cm}}} = 14.2 \text{ cm}$$

8. [5 pts] A candle is placed 12 cm to the left of a diverging lens with a focal length of -25 cm. The diverging lens is placed a distance d from a converging lens with a focal length of 18.0 cm. The final image produced by this two-lens system is formed 27 cm to the right of the converging lens. What is the distance, d, between the two lenses? *Diagram not drawn to scale.*



A. 32 cm

B. 46 cm

C. 54 cm

D. 62 cm

E. 70 cm

Let us call the diverging lens, lens 1 and the converging lens, lens 2. The image of the first lens becomes the object for the second lens. We can write the following equation for the lens 1:

$$\frac{1}{f_1} = \frac{1}{s_1} + \frac{1}{s_1'}$$

Since lens 1 is a diverging lens, the image formed is virtual and located left of lens 1. The object distance for lens 2 is therefore $s_1' + d$, which is equal to $-\left(\frac{1}{f_1} - \frac{1}{s_1}\right)^{-1} + d$ (negative sign is needed to account for the negative virtual image distance for lens 1). We can write the following equation for lens 2.

$$\frac{1}{f_2} = \frac{1}{s_2} + \frac{1}{s_2'} = \frac{1}{s_1' + d} + \frac{1}{s_2'} = \frac{1}{-\left(\frac{1}{f_1} - \frac{1}{s_1}\right)^{-1} + d} + \frac{1}{s_2'}$$

We can now rearrange for d.

$$\frac{1}{f_2} - \frac{1}{s_2'} = \frac{1}{-\left(\frac{1}{f_1} - \frac{1}{s_1}\right)^{-1} + d}$$

$$-\left(\frac{1}{f_1} - \frac{1}{s_1}\right)^{-1} + d = \frac{1}{\frac{1}{f_2} - \frac{1}{s_2'}}$$

$$d = \frac{1}{\frac{1}{f_2} - \frac{1}{s_2'}} + \left(\frac{1}{f_1} - \frac{1}{s_1}\right)^{-1} = \frac{1}{\frac{1}{18\text{ cm}} - \frac{1}{27\text{ cm}}} + \left(\frac{1}{-25\text{ cm}} - \frac{1}{12\text{ cm}}\right)^{-1} = 46\text{ cm}$$

9. [4 pts] You have noticed that one of your grandparents wears bi-focal glasses, which allows them to clearly see objects at 20.0 cm from their eyes and to also see objects at very large distances. The bi-focal lens has focal lengths of +2.8 D and -1.2 D.

What is the person's uncorrected near point?

A. 26.3 cm

B. 45.5 cm

C. 48.1 cm

D. 56.2 cm

E. 61.8 cm

The +2.8 D lens of the bi-focal is used to correct for the near point issue (hyperopia). We can set up the following equation:

$$P_{combined} = P_{lens} + P_{eye}$$

$$P_{combined} = 2.8\text{ D} + \frac{1}{f_{min}}$$

$$\frac{1}{s_{corrected}} + \frac{1}{i} = 2.8\text{ D} + \frac{1}{s_{uncorrected}} + \frac{1}{i}$$

$$\frac{1}{0.20\text{ m}} = 2.8\text{ D} + \frac{1}{s_{uncorrected}}$$

$$s_{uncorrected} = \frac{1}{\frac{1}{0.20\text{ m}} - 2.8\text{ D}} = 0.455\text{ m} = 45.5\text{ cm}$$

Conclusion: With their glasses, the person can see objects at 20.0 cm from their eye, which means they have 5.0 D of power plus 1/i. This power comes from the additive power of the lens and their eye, which means their eye alone has 2.2 D of power, which corresponds to a near point distance of 45.5 cm.

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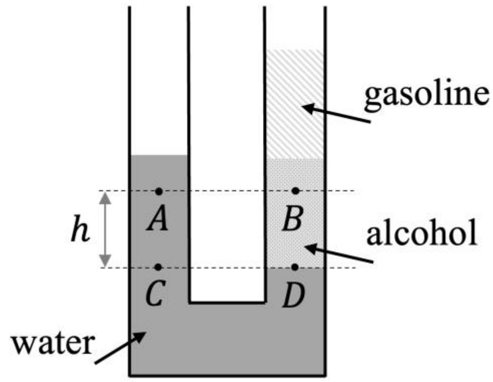
10. [4 pts] A U-tube is filled with water. Alcohol is then carefully poured into the right side of the U-tube, and a volume of gasoline is then poured onto the alcohol. Assume the liquids do not mix and all liquids are at rest. Points A and B are at the same horizontal level and both sides are open to the atmosphere. Is the pressure at point A *greater than, less than,* or *equal to* the pressure at point B? $\rho_{water} > \rho_{alcohol} > \rho_{gasoline}$.



A. Greater than

B. Less than

C. Equal to

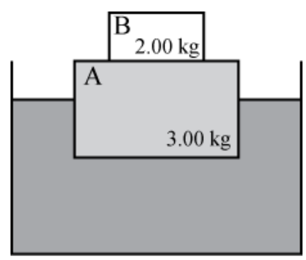
D. Not enough information

Consider points C and D. Since these points are at the same height, in the same fluid and in the same container, they have the same pressure. We can also write the following equations:

$$p_C = p_D$$
$$p_C = p_A + \rho_{water} gh$$
$$p_D = p_B + \rho_{alcohol} gh$$
$$p_A + \rho_{water} gh = p_B + \rho_{alcohol} gh$$
$$p_A = p_B + \rho_{alcohol} gh - \rho_{water} gh = p_B + gh(\rho_{alchol} gh - \rho_{water})$$

The quantity in parentheses is negative, so the pressure at point A is less than that at point B.

11. [4 pts] A wooden block, block A, with mass 3.00 kg and density 0.4 kg/L is placed in water ($\rho_{water} = 1$ kg/L). A concrete block, block B, with mass of 2.00 kg is then placed on top of block A. Determine the volume of block A that is *above the surface* of the water.



A. 1.5 liters

B. 2.5 liters

C. 3.0 liters

D. 5.0 liters

E. 7.5 liters

The combined mass of the two blocks is 5 kg. The two blocks will therefore need to displace 5 liters of water in order to float. The volume of block A is 7.5 liters ($V_A = m_A/\rho_A$).

So, 5 liters of block A will be below the surface, and 2.5 liters will be above the surface

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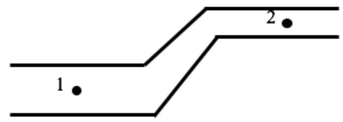
12. [4 pts] Water is traveling through the pipe shown at right. At point 1, the water pressure is 60.0 kPa and the water is moving at 0.400 m/s. The pipe has a diameter of 6.00 cm at point 1. Point 2 is a vertical height *y* above point 1. The diameter of the pipe at point 2 is 2.00 cm. The fluid pressure at point 2 is 45.0 kPa. Treat water as an ideal fluid with a density of 1000 kg/m^3. Find the height *y*.



A. 0.878 m

B. 1.39 m

C. 2.10 m

D. 2.33 m

E. 3.15 m

We can apply Bernoulli's equation to find the height y.

$$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$

Let's set $y_1 = 0$. At point 2, the diameter is 1/3 of the diameter at point 1. Due to continuity, the speed at point 2 is nine times larger than that at point 1.

$$Q_1 = Q_2$$

$$A_1 v_1 = A_2 v_2$$

$$v_2 = \frac{A_1 v_1}{A_2} = \frac{(\pi/4)d_1^2}{(\pi/4)d_2^2} v_1$$

$$v_2 = \frac{d_1^2}{d_2^2} v_1 = \frac{(3d_2)^2}{d_2^2} v_1 = 9v_1$$

Let's return now to Bernoulli's equation:

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$

$$y_2 = \frac{P_1 + \frac{1}{2}\rho v_1^2 - P_2 - \frac{1}{2}\rho v_2^2}{\rho g} = \frac{P_1 - P_2 + \frac{1}{2}\rho(v_1^2 - v_2^2)}{\rho g}$$

$$y_2 = \frac{P_1 - P_2 + \frac{1}{2}\rho(v_1^2 - (9v_1)^2)}{\rho g}$$

$$y_2 = \frac{60 \times 10^3 \text{ Pa} - 45 \times 10^3 \text{ P} + \frac{1}{2}(1000 \text{ kg/m}^3)((0.4 \text{ m/s})^2 - (3.6 \text{ m/s})^2)}{(1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)} = 0.878 \text{ m}$$

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13. [4 pts] A patient is diagnosed with a narrowing of a particular blood vessel of length L. The pressure across this blood vessel is higher than normal, and denoted P_{high}. The patient undergoes surgery which increases the diameter of this blood vessel by 3%. If the patient's blood flow rate and blood viscosity both remain the same, what is the new pressure (P_{new}) across this blood vessel?

A. $P_{new} = 0.71P_{high}$

B. $P_{new} = 0.81P_{high}$

C. $P_{new} = 0.89P_{high}$

D. $P_{new} = 0.94P_{high}$

E. $P_{new} = 0.97P_{high}$

We can apply Poiseuille's equation to solve for the new blood pressure.

$$\Delta P = \frac{8Q\eta L}{\pi r^4} = \frac{128Q\eta L}{\pi d^4}$$

From the equation above, we can see that the pressure difference is inversely proportional to the diameter raised to the power of four. The new pressure is thus:

$$\Delta P_{new} = \frac{1}{1.03^4} P_{high} = 0.89 P_{high}$$

Lab Multiple Choice Questions

14. [4 pts] In lab A3, a group of students explored how modifying the simulation affects wave propagation on a string. Originally, each non-end ball has a force due to the springs on the left and the right, but one modification you could make to the code was to add friction, which depended on the speed v_{ball} of the ball in the form $F_{fric} = -f\,v_{ball}$. Keeping the initial height above equilibrium, h_i, and the initial width w_i of the pulse the same, the group varies the values of f and measures the new height h_2 after a certain amount of time. Which of the following represents their dependent variable?

A. F_{fric}

B. w_i

C. h_2

D. f

E. h_i

The group controls for the initial height and the initial width. These are the control variables. They then vary the value of f, so this is the independent variable. They then measure the new height, h₂, which is the dependent variable

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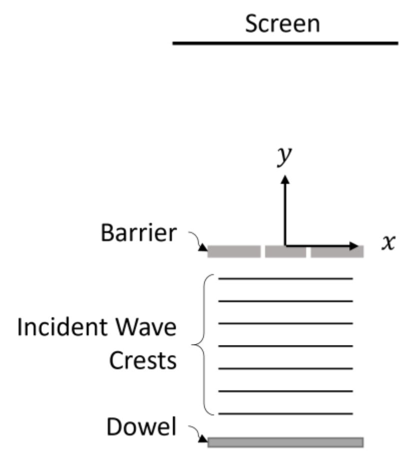
15. [4 pts] A pan of water contains a dowel that moves up and down at a constant rate producing straight wavefronts that propagate towards a barrier. The barrier contains two very narrow slits through which the waves can pass. Consider a coordinate system with the origin at the center of the barrier, as shown in the diagram at the right.



Consider water waves with a wavelength of 0.40 m, and a barrier with slit L at (-0.60 m, 0.00 m) and slit R at (0.60 m, 0.00 m).

Consider a point P on the screen with (x,y) coordinate of (1.475 m, 2.500 m). Will the interference of the two waves from the left and right slit at point be maximum constructive, complete destructive interference or something in between?

A. Maximum constructive interference

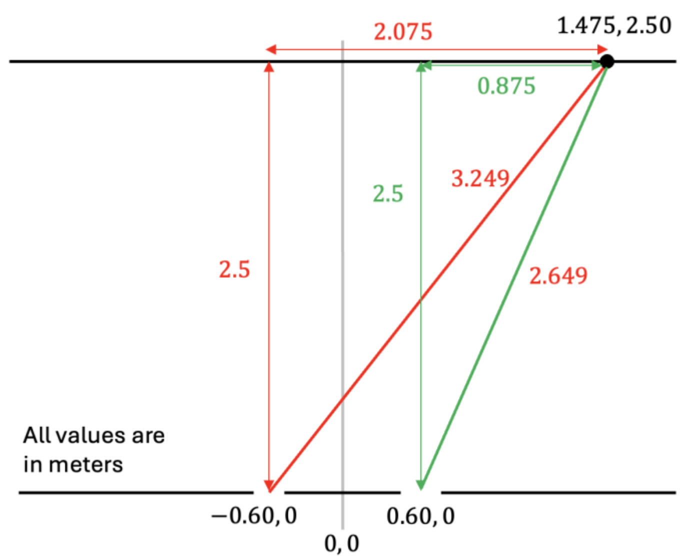
B. Complete destructive interference

C. Something in between

D. Not enough information

Consider the two wavefronts that are shown in the diagram at right. The path length to point P for the wavefront from the left slit is 3.249 m and the path length for the wavefront from the right slit is 2.649 m. The path length difference is therefore 0.60 m.

We are told that the wavelength is 0.40 m. This means that the path length difference is equal to 1.5λ. *The waves will thus have complete destructive interference at point P.*



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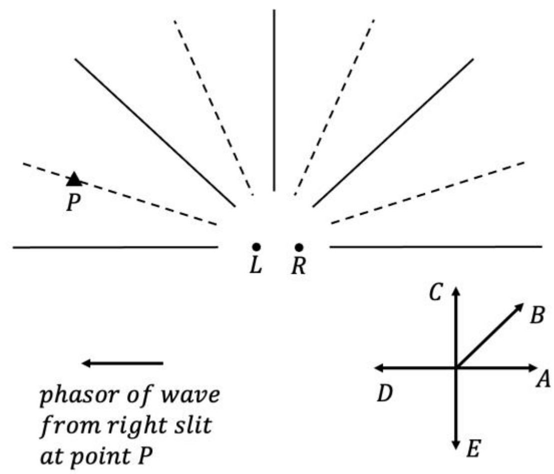
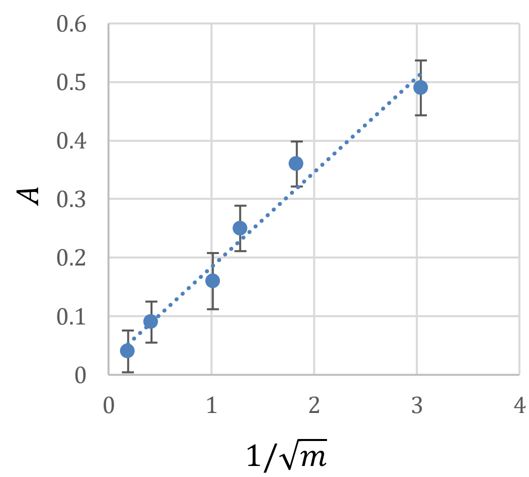
16. [4 pts] Consider two in-phase point-sources of water waves, L and R. The top view diagram at right shows the nodal lines (dashed) and antinodal lines (solid) due to these two sources. Consider point P on the diagram. The phasor of the wave from the right slit at point P is also shown at right. Which of the arrows (A to E) represent the phasor of the wave from the left slit at point P at the same instant?



A. Arrow A
B. Arrow B
C. Arrow C
D. Arrow D
E. Arrow E

Point P lies on a nodal line which indicates that the waves from both slits destructively interfere at this point. The sum of the two phasors at this point is zero. Only arrow A will sum to zero with the phasor shown for the right slit.

17. [4 pts] In lab A3 a group of students altered the mass m of the balls, which is the factor by which balls of the second half of the string was greater than the first half. The graph at right measures A, the amplitude of the transmitted pulse vs. $1/\sqrt{m}$.



Based on the graph, which of the following best matches conclusions the students could reach from their data?

A. The trend line not a good fit, as it does not go through all the uncertainty bars.
B. The trend line not a good fit, as it does not go through 2/3rds of the uncertainty bars.
C. The trend line is a good fit, as it goes through 2/3rds of the uncertainty bars.
D. The trend line not a good fit, as it goes through less than 2/3rds of the uncertainty bars.
E. The trend line is a good fit, as goes through less than 2/3rds of the uncertainty bars.

Lecture Free Response [16 pts total]

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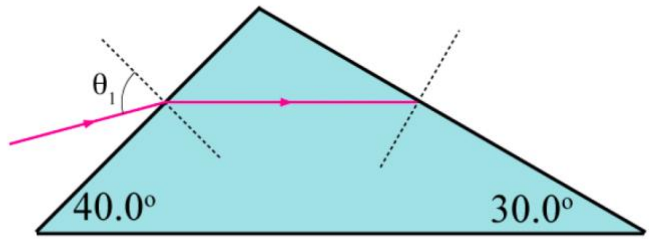
18. [4 pts] A light ray moving in air ($n_{\text{air}} = 1.00$) is incident at an angle θ_1 to a prism as shown. Upon entering the prism, the light ray refracts and travels *horizontally* as shown. If the index of refraction of the prism is 1.30, what is the angle θ_1? Show your work.



From the corresponding angles rule, we can determine that the refraction angle is $50°$ *(*$90° - 40°$*). We can solve for* θ_1 *using Snel's law:*

$$n_{air} \sin\theta_1 = n_{prism} \sin\theta_{refracted}$$

$$\theta_1 = \sin^{-1}\left(\frac{n_{prism} \sin\theta_{refracted}}{n_{air}}\right) = \sin^{-1}\left(\frac{1.3 \sin 50°}{1}\right) = 84.8°$$

19. [4 pts] Now consider the interaction of the light ray with the right slanted side of the prism. What is the angle of refraction as the light ray exits the prism? If the ray is totally internally reflected, state so explicitly. Show your work.

From the corresponding angles rule, we can determine that the incident angle to the right slanted side is $60°$ *(*$90° - 30°$*). We can solve for* $\theta_{refracted}$ *using Snel's law:*

$$n_{prism} \sin\theta_{incident} = n_1 \sin\theta_{refracted}$$

$$\theta_{refracted} = \sin^{-1}\left(\frac{n_{prism} \sin\theta_{incident}}{n_{air}}\right) = \sin^{-1}\left(\frac{1.3 \sin 60°}{1}\right) = error$$

When trying to solve for the refracted angle, you will get an error. This is indicative that the light will undergo total internal reflection. We can solve for the critical angle as follows:

$$\theta_c = \sin^{-1}\left(\frac{n_{air}}{n_{prism}}\right) = \sin^{-1}\left(\frac{1}{1.3}\right) = 50.3°$$

We can now see that the incident angle of $60°$ *is greater than the critical angle, which is further proof that the light ray will undergo total internal reflection.*

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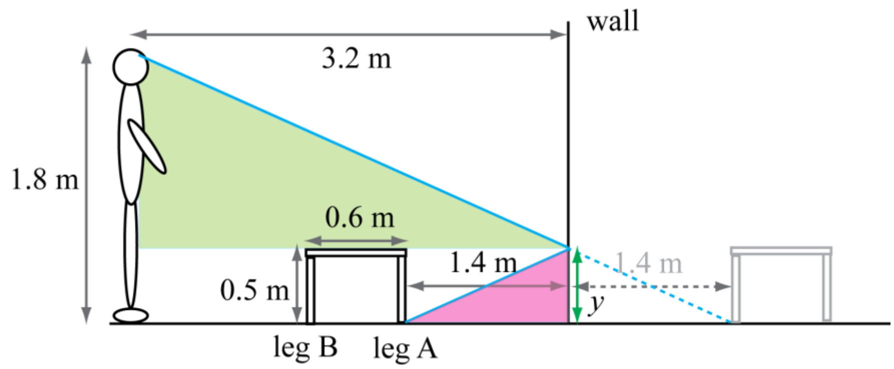
20. [4 pts] A person who is 1.8 m tall stands 3.2 m from a wall. On the wall there is a plane mirror that extends vertically upward from the floor. On the floor 1.4 m in front of the mirror is a small table that is 0.5 m tall and 0.6 m wide.



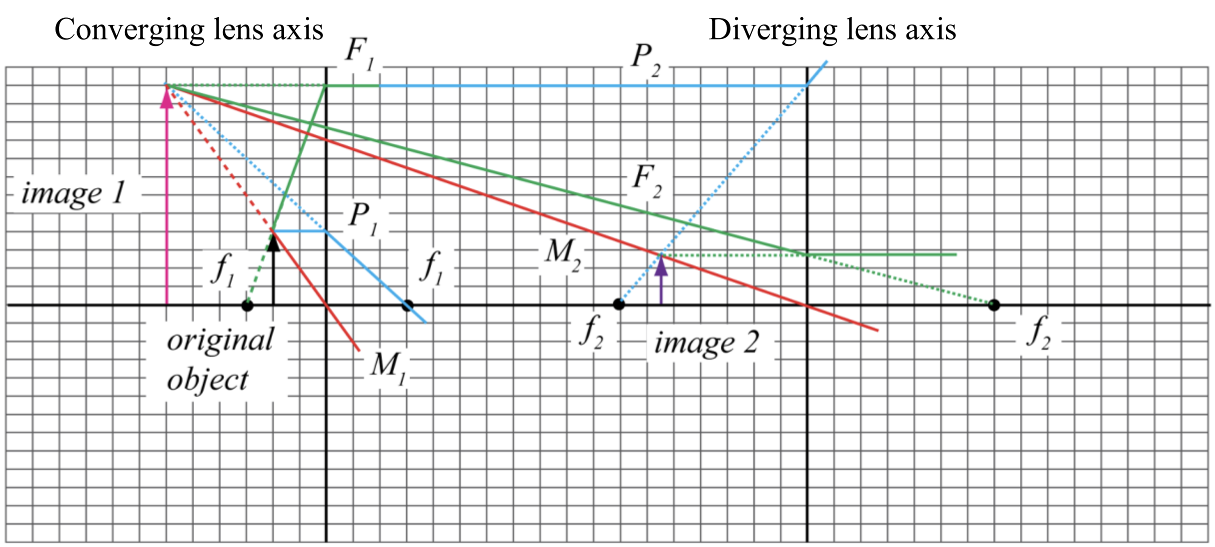
What is the minimum height the mirror must have for the person to see the bottom of leg A? Show your work.

The diagram above shows the image of the table and a light ray that would extend from the person's eye to the image of leg A. Various similar triangles can be formed to determine the height of the mirror. The ratios between the pink and green triangles are shown below.

$$\frac{y}{1.4\text{ m}} = \frac{(1.8\text{ m} - y)}{3.2\text{ m}} \qquad (3.2\text{ m})y = (1.8\text{ m})(1.4\text{ m}) - (1.4\text{ m})y$$

$$(4.6\text{ m})y = (1.8\text{ m})(1.4\text{ m}) \qquad y = \frac{(1.8\text{ m})(1.4\text{ m})}{4.6\text{ m}} = 0.55\text{ m}$$

21. [4 pts] Consider the system of two lenses below. The original object is shown to the left of the converging lens. On the diagram, accurately draw the final image produced by the two-lens system. Draw three principal/special rays for each lens.



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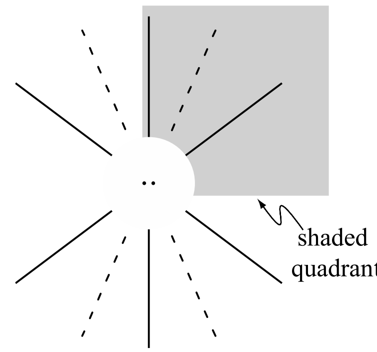
The diagram at right shows all the nodal lines (dashed) and all the antinodal lines (or lines of maximum constructive interference) (solid) due to two point sources that generate periodic waves in a tank of water.



22. [4 pts] Determine the source separation in terms of λ. If it is not possible to determine the source separation exactly, determine the source separation as closely as you can by giving the smallest range into which the source separation must fall. Explain.

The largest possible value of δs is d. Since there is no nodal line corresponding to $\delta s = 3\lambda/2$, we know that d must also be less than this distance. Since we see a line of maximum constructive interference corresponding to $\delta s = \lambda$ that is not along the line passing through both sources, we know that d must be larger than this distance. So then ***$\lambda < d < 3\lambda/2$****, where d is the source separation.*

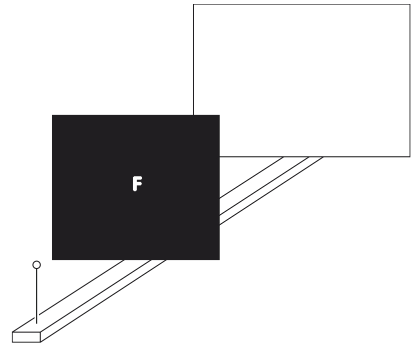
Suppose the previous experiment is changed so that the frequency of the waves generated by the two point sources is increased by a factor of 2.

23. [4 pts] How many antinodal lines (or lines of maximum constructive interference) will now appear in the shaded quadrant on the diagram? Explain.

The medium is unchanged, so the wave speed is the same as before. Since the frequency is doubled and $v = \lambda f$, the wavelength has decreased by a factor of two. The source separation is now twice as large in terms of the wavelength (i.e., if originally $d = C\lambda$ where C is some number, now $d = 2C\lambda$). In part i we found that $\lambda < d < 3\lambda/2$. So then in this new scenario, we know $2\lambda < d < 3\lambda$. Since d is the maximum value of δs, we will see lines of maximum constructive interference corresponding to ***$\delta s = 0$, $\delta s = \lambda$, and $\delta s = 2\lambda$, so three lines total.***

Name: ______________________________ UW NetID: ________________
First *Last*

24. [4 pts] A small bulb is placed in front of a mask with an "F" shaped hole as shown in the diagram at right.



The height of the "F" in the mask is 3.50 cm, and the bulb is placed 40.0 cm from the mask. If the screen is placed 50.0 cm behind the mask, what is the height of the image? Show your work.

We can use similar triangles to solve this problem.

$$\frac{3.50\text{ cm}}{40\text{ cm}} = \frac{h_{image}}{50.0\text{ cm} + 40.0\text{ cm}} \qquad h_{image} = \left(\frac{90.0\text{ cm}}{40.0\text{ cm}}\right) 3.50\text{ cm} = 7.88\text{ cm}$$

25. [4 pts] A mask with a small crescent-shaped hole is placed between a bulb in the shape of the number 7 and a screen, as shown as right. (Assume that the room is dark before the bulb is turned on and ignore any interference or diffraction effects.)

On the diagram, sketch what you will see on the screen when the bulb is lit.