IB Physics
FA12.0 - Basic Waves

Name__________________________

Favorite Vine____

Show your work, and circle your answers and use sig figs to receive full credit.

1. What is the frequency of a wave with a period of 0.00150150 s? What is the period of a 100. Hz wave?

2. What is the velocity of a wave that has frequency of 120. Hz and a wavelength of 2.85 m?

3. What is the wavelength of a light wave (v = 3.00×10^8 m/s) with a frequency of 4.50×10^{14} Hz?

4. What is the frequency of a sound wave with a velocity of 343 m/s, and a wavelength of 24.0 cm?

5. A wave with a period of 0.125 s has a wavelength of 8.20 m. What is its velocity?

Waves

Frequency and Period: $f = \frac{1}{T}$

80.0 Hz	1. A wave passes every 0.0125 seconds. What is the frequency with which waves pass?
0.00382 s	2. Middle C is 261.6 Hz. What is its period?
10. Hz	3. What is the frequency of a wave that has a period of 0.10 seconds?
0.37 Hz	4. An earthquake wave has a period of 2.7 seconds. What is its frequency?

Velocity, Frequency, and Wavelength: $v = f\lambda$ (looks like c = fλ in the data packet)

5400 m/s	5. What is the velocity of an earthquake wave that has a frequency of 12 Hz, and a wavelength of 450 m?
2540 Hz	6. What is the frequency of a sound wave (v = 343 m/s) that is 0.135 m long?
3.28 m	7. What is the wavelength of a, $91.5\text{x}10^{6}$ Hz (91.5 MHz) radio wave? (v = c = $3.00\text{x}10^{8}$ m/s)
3.3 m/s	8. What is the velocity of ocean waves if they have a wavelength of 13.2 meters, and a frequency of 0.25 Hz?
2.6 Hz	9. What is the frequency that 16 m long boxcars pass a crossing when the train is going 42 m/s?
1.31 m	10. What is the wavelength of a sound wave with a frequency of 261.6 Hz? (v = 343 m/s)
$7.14\text{x}10^{14}$ Hz	11. What is the frequency of a 420. nm ($420.\text{x}10^{-9}$ m) light wave? (v = c = $3.00\text{x}10^{8}$ m/s)

Velocity, Frequency, Period and Wavelength: $f = \frac{1}{T}$ $v = f\lambda$ so $v = \frac{\lambda}{T}$

72.5 m/s	12. What is the speed of a wave with a wavelength of 14.5 m, and a period of 0.20 s?
0.012 s	13. What is the period of a 4.2 m wavelength sound wave? (v = 343 m/s)
$3.0\text{x}10^{8}$ m/s	14. What is the speed of a wave with a wavelength of 150 m, and a period of 0.50μs ($0.50\text{x}10^{-6}$ s)?
$3.33\text{x}10^{-10}$ s $3.0\text{x}10^{9}$ Hz (3.0 GHz)	15. What is the period of an electromagnetic wave with a wavelength of 0.10 m? (v = c = $3.00\text{x}10^{8}$ m/s) What is the frequency?

Name_____________________________

Foreign Language Name____

Show your work, and circle your answers and use sig figs to receive full credit.

1-3. A guitar string has a length of 64.5 cm, and a fundamental frequency of 110. Hz.

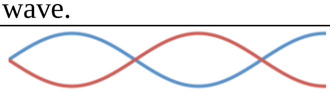
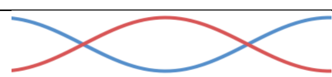
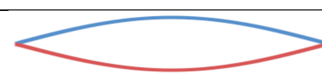
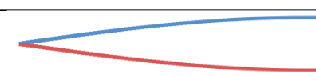
1. Draw the first three harmonics of vibration on the string below, and calculate the wavelength and frequency for each.

. .	. .	. .

2. What is the velocity of the waves on this string?

3. If this string is fingered 21.5 cm from one end (it is shortened by that amount). What is the frequency of the fundamental now?

4. Calculate the missing quantity below. "L" is the length of the waveform (the picture), λ is the wavelength of the wave.

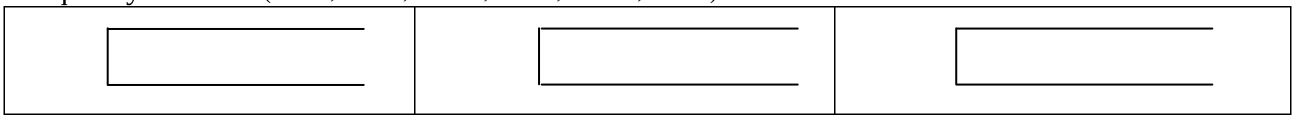
 L = 45 cm, λ = ?	 L = 2.67 m, λ = ?	 λ = 1.20 m, L =	 λ = 3.43 m, L =

5. Draw the second possible harmonic (The second lowest tone it can make.) of a one end fixed, one end open pipe. Calculate the frequency of this mode if the pipe is 13.2 cm long, and the speed of sound in the pipe is 317 m/s.

Standing Waves from 12.1

A1. A Pan pipe is 62.2 cm long, and has a wave speed of 321 m/s. It is a one end open, one end fixed pipe.

a. Draw the first three harmonics of vibration on the pipe below, and calculate the wavelength and frequency for each. (2.49 m, 129 Hz, 0.829 m, 387 Hz, 0.498 m, 645 Hz)

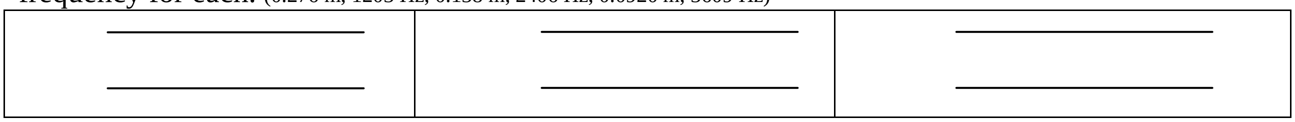


b. If the air in the pipe were heated, and the wave speed changed to 351 m/s, what would be the new fundamental frequency of the pipe? (141 Hz)

c. If I cut 12.1 cm from the open end of this pipe (The pipe is shortened by this much) what is the new fundamental frequency? (use v = 321 m/s) (160. Hz)

A2. A Pennywhistle is 13.8 cm long, and has wave speed of 332 m/s. It is a both ends open pipe.

a. Draw the first three harmonics of vibration on the pipe below, and calculate the wavelength and frequency for each. (0.276 m, 1203 Hz, 0.138 m, 2406 Hz, 0.0920 m, 3609 Hz)

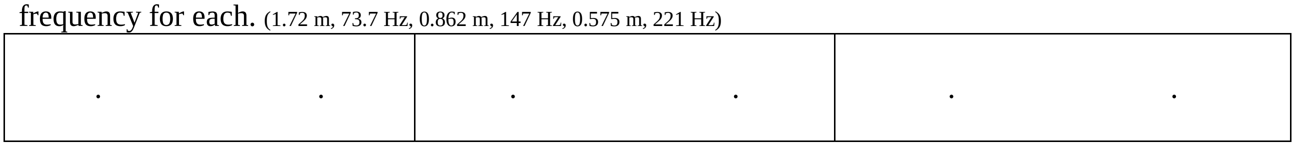


b. If the air in the pipe were cooled to make the wave speed 295 m/s, what would be the new fundamental frequency? (1069 Hz)

c. If I lift a finger off the whistle 1.8 cm from the end (The pipe is shortened by this much) what is the new fundamental frequency? (1383 Hz)

A3. A bass string has a length of 86.2 cm, and a wave speed of 127 m/s.

a. Draw the first three harmonics of vibration on the string below, and calculate the wavelength and frequency for each. (1.72 m, 73.7 Hz, 0.862 m, 147 Hz, 0.575 m, 221 Hz)

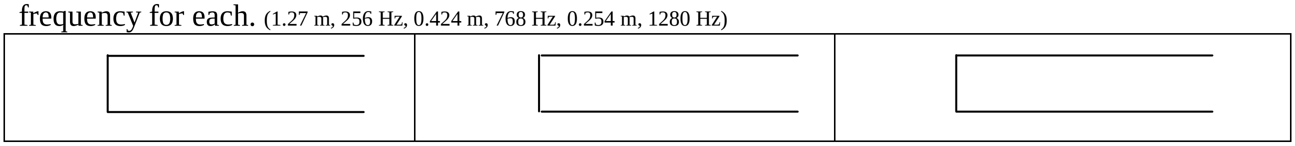


b. What would be the new fundamental (lowest) frequency if the string were tightened, making the wave speed 145 m/s? (84.1 Hz)

c. If this string is fingered 8.5 cm from one end (it is shortened by that amount). What is the frequency of the fundamental now? (use 127 m/s as the speed) (81.7 Hz)

A4. A Panpipe is 31.8 cm long, and has a fundamental frequency of 256 Hz. It is a one end open, one end fixed pipe.

a. Draw the first three harmonics of vibration on the pipe below, and calculate the wavelength and frequency for each. (1.27 m, 256 Hz, 0.424 m, 768 Hz, 0.254 m, 1280 Hz)

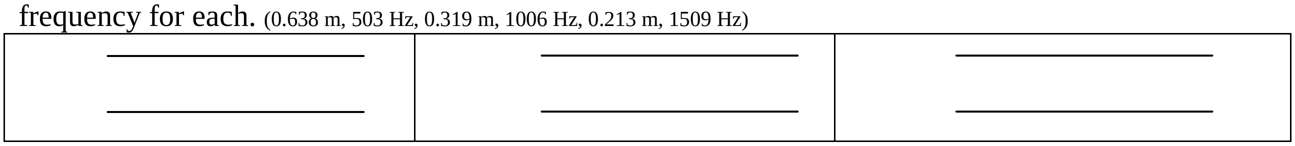


b. What is the velocity of the sound in this pipe? (326 m/s)

c. If I cut 3.2 cm from the open end of this pipe (The pipe is shortened by this much) what is the new fundamental frequency? (285 Hz)

A5. A Pennywhistle is 31.9 cm long, and has a fundamental frequency of 503 Hz. It is a both ends open pipe.

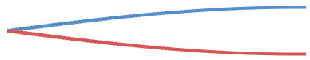
a. Draw the first three harmonics of vibration on the pipe below, and calculate the wavelength and frequency for each. (0.638 m, 503 Hz, 0.319 m, 1006 Hz, 0.213 m, 1509 Hz)



b. What is the velocity of the sound in this pipe? (321 m/s)

c. If I lift a finger off the whistle 4.7 cm from the end (The pipe is shortened by this much) what is the new fundamental frequency? (590. Hz)

Calculate the missing quantity below. L is the length of the waveform (the picture), λ is the wavelength.

	a	b	c	d
B1	 L = 193 cm, λ = ? (386 cm)	 L = 5.76 m, λ = ? (23.0 m)	 λ = 24.0 cm, L = ? (36.0 cm)	 λ = 65.0 cm, L = ? (81.3 cm)
B2	 L = 215 cm, λ = ? (215 cm)	 L = 4.32 m, λ = ? (5.76 m)	 λ = 24.0 cm, L = ? (24.0 cm)	 λ = 2.70 m, L = ? (4.05 m)
B3	 L = 73.0 cm, λ = ? (58.4 cm)	 L = 3.82 m, λ = ? (2.55 m)	 λ = 93.5 cm, L = ? (187 cm)	 λ = 2.40 m, L = ? (2.40 m)
B4	 L = 16.1 cm, λ = ? (9.20 cm)	 L = 3.45 m, λ = ? (1.725 m)	 λ = 183 cm, L = ? (91.5 cm)	 λ = 1.80 m, L = ? (1.35 m)
B5	 L = 32.5 cm, λ = ? (14.4 cm)	 L = 5.31 m, λ = ? (2.12 m)	 λ = 63.0 cm, L = ? (158 cm)	 λ = 72.0 cm, L = ? (108 cm)

Random Standing Waves Problems

C1. Draw the third harmonic (The third lowest tone it can make.) of a both ends open pipe. If the speed of sound is 323 m/s, and the pipe is 57.5 cm long, what is the frequency of this harmonic? (843 Hz)

C2. Draw the first harmonic (The lowest tone it can make.) of a tightly stretched string. If the string is 29.8 cm long, and the frequency of this harmonic is 322 Hz, what is the wave speed on the string? (192 m/s)

C3. Draw the third possible harmonic (The third lowest tone it can make.) of a one end fixed, one end open pipe. If the pipe is 34.1 cm long, and this harmonic has a frequency of 1092 Hz, what is the speed of sound in the pipe? (298 m/s)

C4. Draw the first harmonic (The lowest tone it can make.) of a both ends open pipe. If the speed of sound is 310. m/s, and the pipe is 42.1 cm long, what is the frequency of this harmonic? (368 Hz)

C5. Draw the third harmonic (The third lowest tone it can make.) a guitar string. If this harmonic has a frequency of 864 Hz, and the string is 68 cm long, what is the speed of the waves in the string? (392 m/s)

C6. What is the fifth harmonic (The fifth lowest tone it can make) of a 45.0 cm long panpipe? (one end fixed) if the fundamental is 180. Hz? (1620 Hz)

C7. A pennywhistle is a both ends open pipe. If the standing wave in the pipe is 17 cm long, what is the wavelength and frequency of the fundamental mode of vibration, and what is the frequency of the next two modes of vibration? (Use 343 m/s as the wavespeed) (0.34 m 1008.8 Hz 2017.6 Hz 3026.5 Hz)

C8. A violin has a 33 cm long string, and is tuned to A 440 Hz. (The fundamental frequency is 440 Hz, and it is a both ends fixed standing wave) What is the wavelength of the fundamental? What is the speed of waves along the string? What are the next two frequencies possible? (0.66 m 290.4 m/s 880 Hz 1320 Hz)

C9. An organ pipe is being designed to make a fundamental tone of 64 Hz. If the speed of sound is 320 m/s inside the pipe, and the pipe is a one end open and one end closed pipe, what length should it be? What are the next two frequencies it can make? (1.25 m 192 Hz 320 Hz)

C10. A horn is a both ends open pipe. If the third harmonic has a frequency of 698 Hz, and sound has a speed of 295 m/s inside the pipe, what is the wavelength of the sound in the horn, and what is the length of the standing wave in the horn? What is the next higher frequency it can generate? (0.423 m 0.634 m 930.7 Hz)

C11. A guitar has a wave speed of 485 m/s in its string, and a string length of 65 cm. What is the frequency of the fourth harmonic on this string? (1490 Hz)

C12. What length should a panpipe be (one end open, one end closed) if it is to create a fundamental tone of 261 Hz (middle C)? Use 343 m/s as the speed of sound in the pipe. What is the frequency of the third harmonic? (0.329 m, 1305 Hz)

IB Physics
FA12.2 - Interference and Doppler

Name ____

Dog or Cat Person?____

Show your work, round to the correct significant figures, circle your answers, and label them with units. **Use the speed of sound of 343 m/s**

1. Two speakers 4.00 m apart are in phase at 877.24 Hz. If I am 1.450 m from one speaker, and 3.210 m from the other, how many wavelengths difference is the distance, and is it constructive (loud) or destructive (quiet) interference?

2. A car with a horn that is 216 Hz is driving at 32.1 m/s away from you. What frequency do you hear?

3. If you hear the 216 Hz horn of the car at a frequency of 225 Hz, what is their velocity? Is it <u>away</u> from you or <u>toward</u> you?

4. You run at 12.5 m/s toward a stationary speaker that is emitting a frequency of 518 Hz. What frequency do you hear?

5. If you are moving so you hear the frequency of the 518 Hz speaker at a frequency of 557 Hz, what is your velocity? Is it <u>away</u> from or <u>toward</u> the speaker?

Doppler Effect Problems Like 12.2

A. Doppler Problems: (Use **343 m/s** as the speed of sound.)

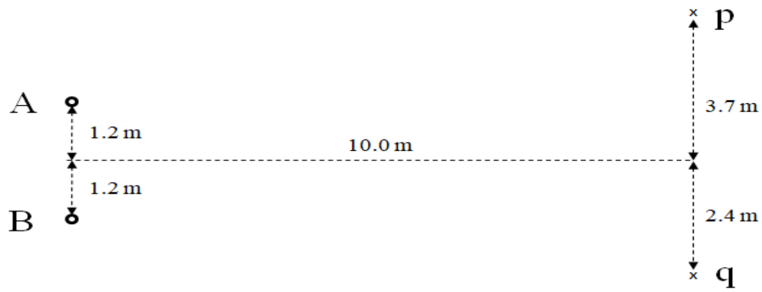
Moving Source: $f' = f\left(\dfrac{v}{v \pm u_s}\right)$ Moving Observer: $f' = f\left(\dfrac{v \pm u_o}{v}\right)$

262.2 Hz	1. A car with a horn frequency of 240 Hz approaches you at 29 m/s. What frequency do you hear?
136.1 Hz	2. A person hums at 150 Hz while driving away from you at 35 m/s. What frequency do you hear?
344.6 Hz	3. Your dad is singing at 356 Hz, and you run away from him at 11 m/s. What frequency do you hear?
995.5 Hz	4. You are riding on a train going 45 m/s. As you approach a crossing, there is a bell with a frequency of 880 Hz. What frequency do you hear?
187.3 Hz	5. A salsa band is running away from you at 14 m/s. If you hear a pitch of 180 Hz, what frequency are they really playing?
390.6 Hz	6. You hear a pitch of 420 Hz as a car with a man standing on the roof playing a flugelhorn approaches you at 24 m/s. What frequency is the man really creating?
442.5 Hz	7. You are riding a rocket-propelled skateboard at 57 m/s toward a television playing a Lawrence Welk re-run. If you hear a pitch of 516 Hz, what is the real pitch the television is making?
92.7 Hz	8. You are in a motorboat going 21 m/s away from a foghorn. You hear it at a pitch of 87 Hz, so what pitch is it really creating?
10.8 m/s away	9. If you hear a frequency of 253 Hz as you listen to a middle C (261 Hz) being played on a piano that is on a flatbed train car, is the car going toward you or away, and how fast?
9.2 m/s toward	10. If a car 217 Hz car horn is heard at 223 Hz, is the car approaching you or receding from you, and what is its speed?
17.5 m/s away	11. You are riding in a train with a blindfold on, and you hear an 880 Hz crossing bell, but it appears to have a pitch of only 835 Hz. Are you moving toward or away from the bell, and how fast?
27.3 m/s toward	12. How fast and in what direction (away or toward) do you have to run relative to a concertmaster playing an A 440 Hz so that you hear it at 475 Hz?
388.4 Hz	13. You are driving at 27 m/s toward an oncoming driver on a highway. They are approaching you at 43 m/s. (a tad in excess of the speed limit) You honk at them with your 318 Hz horn to indicate your dissatisfaction with their driving habits. What frequency do they hear?
453.4 Hz	14. You are driving your Porsche at 57 m/s on the Autobahn and you come behind a Prius in the left lane going only 35 m/s. You honk your 421 Hz horn at them. What frequency do they hear?
94,900.3 Hz	15. A bat flying at 17 m/s is approaching a moth flying toward the bat at 7.0 m/s. If the bat generates an echolocation frequency of 82,500 Hz, what frequency does the bat hear reflected off the moth?

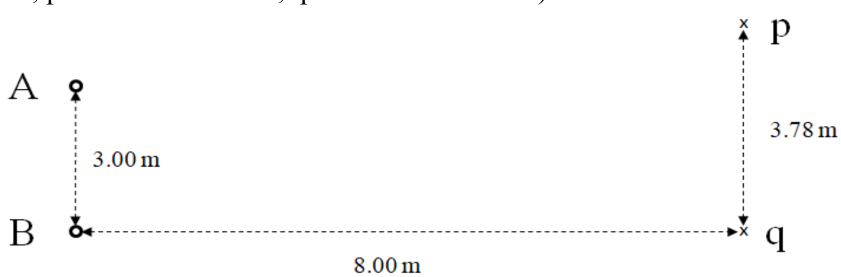
B. Interference Problems: (Use **343 m/s** as the speed of sound.)

1. Two speakers 4.10 m apart are in phase at 512 Hz. If I am 4.00 m from one speaker, and 6.68 m from the other, what is the wavelength, and how many wavelengths difference is the distance, and is it constructive (loud) or destructive (quiet) interference? (λ= 0.670 m, 4 λ, Constructive)
2. Two speakers 4.50 m apart are in phase at 256. Hz. If I am 3.00 m from one speaker, and 6.35 m from the other, what is the wavelength, and how many wavelengths difference is the distance, and is it constructive (loud) or destructive (quiet) interference? (λ= 1.34 m, 2.5 λ, Destructive)
3. Two speakers 5.00 m apart are in phase at 1024. Hz. If I am 8.42 m from one speaker, and 9.59 m from the other, what is the wavelength, and how many wavelengths difference is the distance, and is it constructive (loud) or destructive (quiet) interference? (λ= 0.335 m, 3.5 λ, Destructive)

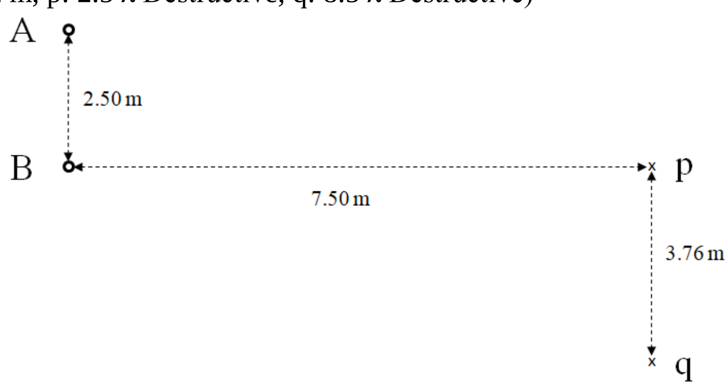
4. These two sources A and B are in phase, and generate a sound wave with a frequency of 625 Hz. Calculate the wavelength, and for the two positions p and q, indicate the path length difference in wavelengths, and whether it would be constructive or destructive interference.
(λ = 0.549 m, p: 1.5 λ Destructive, q: 1.0 λ Constructive)



5. These two sources A and B are in phase, and generate a sound wave with a frequency of 631 Hz. Calculate the wavelength, and for the two positions p and q, indicate the path length difference in wavelengths, and whether it would be constructive or destructive interference.
(λ = 0.544 m, p: 1.5 λ Destructive, q: 1.0 λ Constructive)



6. These two sources A and B are in phase, and generate a sound wave with a frequency of 2115 Hz. Calculate the wavelength, and for the two positions p and q, indicate the path length difference in wavelengths, and whether it would be constructive or destructive interference.
(λ = 0.162 m, p: 2.5 λ Destructive, q: 8.5 λ Destructive)



Name ____

Miyazaki or Disney?____

Show your work, round to the correct significant figures, circle your answers, and label them with units.

1-2: Two slits are separated by a distance of 0.112 mm and are illuminated by 512 nm light. The interference pattern falls on a screen that is 4.80 m away.

1. What distance separates the fringes on the screen?

2. What is the angle between the central maximum and the third order maximum?

3. A single slit has a diameter of 0.0450 mm and is illuminated by monochromatic light. A screen 1.85 m away has a central maximum pattern that is 2.10 cm wide. What is the wavelength of the light?

4-5: A diffraction grating has 2450 lines per cm. It is illuminated by a 632.8 nm light beam that is 1.70 mm wide.

4. What angle separates the first order and the fifth order fringes?

5. What is the closest shorter wavelength that can be resolved in the first order with this diffraction grating?

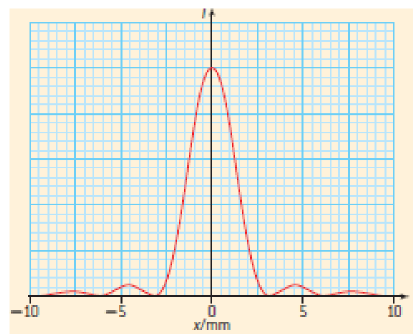
P12.2A – Diffraction Gratings

12F1 – Young's Double Slit

1. A parallel beam of light from a laser with a wavelength of 632.8 **nm** falls on two very narrow slits 0.0320 **mm** apart.
   a. The bright fringes are 6.7 cm apart on a screen some distance away. What is the distance to the screen? (3.39 m)
   b. What angle separates the central fringe, and the third order fringe? What distance is this on the screen? (3.40°, 20.1 cm)
2. Two narrow slits are separated by 0.0895 mm are illuminated by monochromatic light. The fringes on the screen 2.10 m away are 9.72 mm apart.
   a. What is the wavelength of light? (414 nm)
   b. What angle separates the central bright spot and the 4th order fringe? What distance is this on the screen? (1.06°, 3.89 cm)
3. Two slits make an interference pattern with 550. nm light on a screen that is 4.50 m away. The distance separating the third order fringe on the left from the third order on the right is 5.14 cm. What is the distance separating the slits? ($2.89\text{x}10^{-4}$ m or 0.289 mm)

12F2 – Single Slit Diffraction

4. If 410. nm light falls on a slit 0.0320 mm wide,
   a. What is the full angular width of the central diffraction peak? (0.0256 rad or 1.47°)
   b. What is its width on a screen that is 3.60 m away? (9.22 cm)
   c. What distance separates the central maximum from the next maximum on a screen 7.10 m away? (13.6 cm)
5. Light from a helium–neon laser passes through a narrow slit and is incident on a screen 5.20 m from the slit. The graph to the right shows the variation with distance x along the screen of intensity I of the light on the screen. The wavelength of the laser is 632.8 nm.
   a. Determine the width of the slit. (1.01 mm)
   b. What two changes would happen to the pattern if we were to increase this width? (central maximum: brighter, narrower)
   b. What would happen to the pattern if we were to increase the wavelength of the light? (central maximum: broader, other maxima more spread out)



12F3 – Diffraction Gratings

6. A diffraction grating produces a third order spectral line at 23.0° for 815 nm light.
   a. What is the distance between the slits or lines? ($6.26\text{x}10^{-6}$ m)
   b. How many lines are there per cm? (1598)
7. A diffraction grating has 640. lines per millimeter. It is illuminated by monochromatic light. There is an angle of 17.2° between the central maximum and the second order maximum on one side.
   a. What is the distance between the slits or lines? ($1.56\text{x}10^{-6}$ m)
   b. What is the wavelength of light being used? (231 nm)

12O – Diffraction Grating Resolvance

8. A diffraction grating is used to resolve two lines in a spectrum in the first order. The two lines have wavelengths of 632.185 nm and 631.341 nm. Determine the minimum number of slits in the grating that will enable the two lines to be resolved. (749 slits)
9. A 3.80 mm-wide beam of 432.7 nm light illuminates 1,112 slits in a diffraction grating.
   a. What is the smallest difference in wavelength from this wavelength that the grating can resolve in the second order? (0.195 nm)
   b. How many slits per cm does this grating have? (2930 lines per cm)

Name ____

Favorite mode of non-motorized transportation____

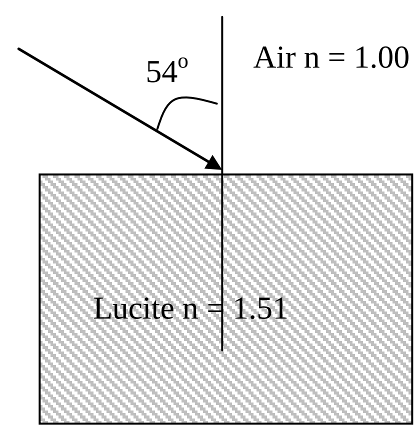
1. You hear the sound of a hammer striking concrete 1.21 seconds sooner in the concrete than through the air. If the speed of sound through the air is 339 m/s, and the hammer is 724 m away, what is the speed of sound in the concrete? (782 m/s)

Questions 2-5 are about the light from a 640 nm laser. (640 nm is its wavelength, 1 nm = 10^{-9} m)

2. What is the **speed** of the laser light in Lucite? (n = 1.51) (1.99×10^{8} m/s)

3. What is the **wavelength** and **frequency** of the light in Lucite? (n = 1.51) (424 nm, 4.69×10^{14} Hz)

4. The laser goes from air into the Lucite. It makes the angle shown in the diagram below. Calculate the **refracted angle** in the Lucite, **draw** the refracted beam, and label the angle. (32.4°)



5. What is the **critical angle** between air and Lucite? In which substance does it occur? (41.5° – in the Lucite)

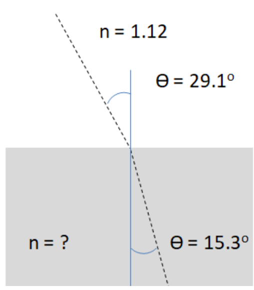
P12.3 – Refraction and Critical Angle Problems.

0. Sound travels at 1498 m/s in water, and 343 m/s in the air. An explosion occurs on the surface of the water 1250 m away. What time does it take the sound to reach you in the air? What time does it take the sound to reach you in the water? What amount of time separates the arrival of the sound in the water and in the air?
(Air: 3.644 s, Water: 0.834 s, Difference: 2.81 s)

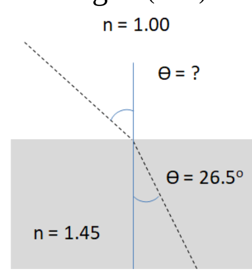
1. A 632.8 nm laser has an incident angle of 45.0^{o} in air and strikes some oil with an index of refraction of 1.54.
a. What is the frequency of the laser? (4.74×10^{14} Hz)
b. What is the wavelength of the laser in the oil? (411 nm)
c. What is the refracted angle in the oil? (27.3^{o})
d. What is the critical angle at the oil air interface? In which medium does the critical angle occur?
(40.5^{o}, in the oil – the slower medium)

2. Light has a wavelength of 356 nm in glass. It passes from the glass into water with an index of refraction of 1.33. The incident angle in the glass is 29.0^{o} and the refracted angle in the water is 37.0^{o}.
a. What is the index of refraction of the glass? (1.65)
b. What is the wavelength of the light in the water? (442 nm)
c. What is the critical angle of the glass water interface? In which medium does it occur?
(53.7^{o}, in the glass – the slower medium)

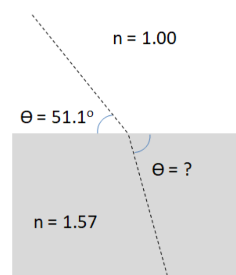
3. Find the index: (2.06)



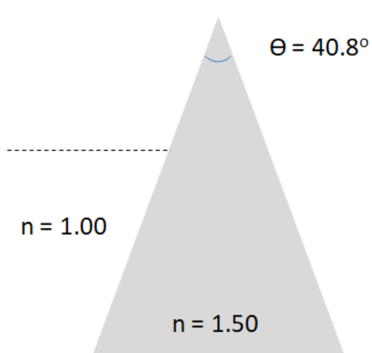
4. Find the angle: (40.3^{o})



5. Find the angle: (66.4^{o})



6. Super challenge. A horizontal beam of light strikes the isosceles prism below.
a. What angle does the emergent beam make with the horizontal? (23.2^{o} below the horizontal)
b. What maximum index of refraction can the prism have for the beam to exit the prism on the right side?
(1.97)



P12.NP – Rayleigh Criterion and Polarization

Rayleigh Criterion:

1. What is the smallest angle that can be resolved by the Karl G. Jansky Very Large Array in New Mexico? It has a possible aperture of 42 km, and uses a wavelength of 0.6 cm.
(2×10^{-7} radians, or about 0.04 arc seconds (1/3600 of a degree))
2. What size radar (λ = 1.2 cm) dish could resolve an aircraft that subtends an angle of 0.14^{o} (Convert that angle to radians) (6.0 m)
3. A spotting telescope has an aperture of 0.102 m and uses visible light (use 550. nm as the wavelength). What is its minimum resolution angle? What minimum size object can it resolve at a distance of 400. m?
(6.58×10^{-6} rad, 2.63 mm)
4. Looney Tunes who deny that the moon landing ever happened say that the Hubble could have been used to take pictures of the landing stages left behind by the Apollo missions. The landing stage was 9.4 meters wide, the moon is 384.4 million meters away, and the aperture of the Hubble is 0.305 m. Use 550 nm as the wavelength. Can the Hubble resolve an object that size on the moon? (Calculate the angle the landing stage subtends, calculate the minimum angle the Hubble can resolve.) What is the minimum size it can resolve?
(No, the angle is about 100x too small: 2.4×10^{-8} rad vs 2.2×10^{-6} rad. 846 m)

Polarization:

5. Vertically polarized light with an intensity of 430. W m^{-2} falls upon a perfect polarizing filter that makes an angle of 17.0^{o} with the vertical.
   a. What is the intensity of the light after the filter? (393 W m^{-2})
   b. At what angle would the intensity be 54.0 W m^{-2}? (69.2^{o})
6. Vertically polarized light strikes a filter that makes an angle of 48.0^{o} with the vertical. After the filter the intensity is 102 W m^{-2}. What was the intensity before the filter? (228 W m^{-2})
7. Unpolarized light with an intensity of 200. W m^{-2} falls upon a vertical polarizer that is 100% efficient. Behind that filter is another polarizing filter that has been rotated so its plane of polarization makes a 34.0^{o} angle with the vertical.
   a. What is the intensity after the first filter? (100. W m^{-2})
   b. What is the intensity after the second filter? (68.7 W m^{-2})
   c. What angle of rotation would you need to reduce the transmitted intensity to 50.0 W m^{-2}? (45.0^{o})
8. Unpolarized light falls on two polarizing filters that have their planes of polarization rotated 68.0^{o} from one another. After the two filters, the intensity is 62.0 W m^{-2}. What was the intensity before both filters?
(884 W m^{-2})