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University Physics Volume 3

Instructor Answer and Solution Guide

University Physics Volume III
Unit 1: Optics
Chapter 1: The Nature of Light

Conceptual Questions

1. Under what conditions can light be modeled like a ray? Like a wave?

Solution
Light can be modeled as a ray when devices are large compared to wavelength, and as a wave when devices are comparable or small compared to wavelength.

2. Why is the index of refraction always greater than or equal to 1?

Solution
The index of refraction is the ratio of the speed of light in a vacuum to the speed of light in a medium. Because the former is the fastest that the speed of light can be, this ratio is, by definition, greater than or equal to 1.

3. Does the fact that the light flash from lightning reaches you before its sound prove that the speed of light is extremely large or simply that it is greater than the speed of sound? Discuss how you could use this effect to get an estimate of the speed of light.

Solution
This fact simply proves that the speed of light is greater than that of sound. If one knows the distance to the location of the lightning and the speed of sound, one could, in principle, determine the speed of light from the data. In practice, because the speed of light is so great, the data would have to be known to impractically high precision.

4. Speculate as to what physical process might be responsible for light traveling more slowly in a medium than in a vacuum.

Solution
answers may vary

5. Using the law of reflection, explain how powder takes the shine off of a person's nose. What is the name of the optical effect?

Solution
Powder consists of many small particles with randomly oriented surfaces. This leads to diffuse reflection, reducing shine.

6. Diffusion by reflection from a rough surface is described in this chapter. Light can also be diffused by refraction. Describe how this occurs in a specific situation, such as light interacting with crushed ice.

Solution
Crushed ice has surface segments with a variety of orientations, resulting in refracted rays in many directions, creating a diffuse effect.

7. Will light change direction toward or away from the perpendicular when it goes from air to water? Water to glass? Glass to air?

Solution
"toward" when increasing n (air to water, water to glass); "away" when decreasing n (glass to air)

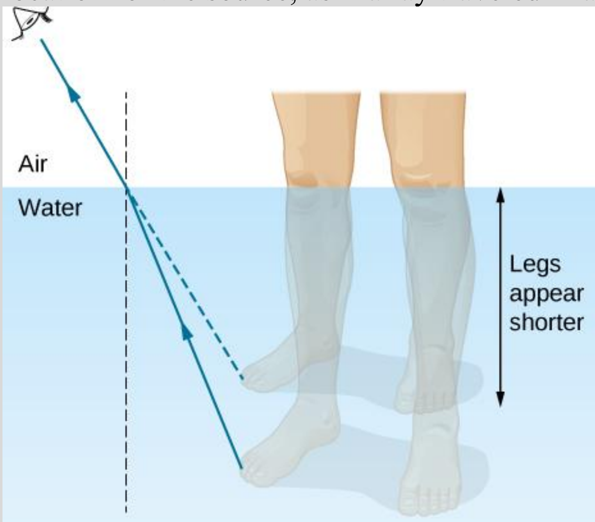
8. Explain why an object in water always appears to be at a depth shallower than it actually is?

Solution
Rays from underwater objects emerge from water subject to refraction. The observer in air perceives an apparent location for the source, which is different from the physical location.

9. Explain why a person's legs appear very short when wading in a pool. Justify your explanation with a ray diagram showing the path of rays from the feet to the eye of an observer who is out of the water.

Solution

A ray from a leg emerges from water after refraction. The observer in air perceives an apparent location for the source, as if a ray traveled in a straight line. See the dashed ray below.



10. Explain why an oar that is partially submerged in water appears bent.

Solution

Although rays from the parts of the oar above water travel straight to the observer's eye, rays from the underwater parts of the oar reach the eye after refraction, making them appear to come from another direction. This difference in direction appears as a bend in the oar.

11. A ring with a colorless gemstone is dropped into water. The gemstone becomes invisible when submerged. Can it be a diamond? Explain.

Solution

The gemstone becomes invisible when its index of refraction is the same, or at least similar to, the water surrounding it. Because diamond has a particularly high index of refraction, it can still sparkle as a result of total internal reflection, not invisible.

12. The most common type of mirage is an illusion that light from faraway objects is reflected by a pool of water that is not really there. Mirages are generally observed in deserts, when there is a hot layer of air near the ground. Given that the refractive index of air is lower for air at higher temperatures, explain how mirages can be formed.

Solution

A mirage can be regarded as a result of two layers of air: a hot layer near the ground (low *n*) and a cool layer above (high *n*). Rays originating in the cool layer can reflect back up due to an effect analogous to total internal reflection.

13. How can you use total internal reflection to estimate the index of refraction of a medium?

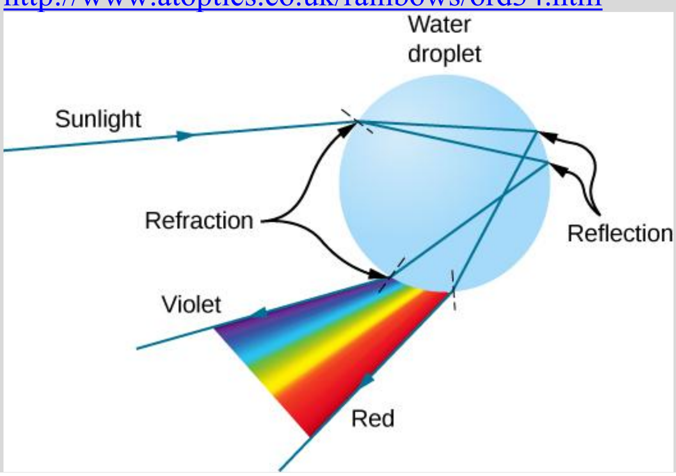
Solution

One can measure the critical angle by looking for the onset of total internal reflection as the angle of incidence is varied. $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$ for $n_1 > n_2$ can then be applied to compute the index of refraction.

14. Is it possible that total internal reflection plays a role in rainbows? Explain in terms of indices of refraction and angles, perhaps referring to that shown below. Some of us have seen the formation of a double rainbow; is it physically possible to observe a triple rainbow?

Solution

Total internal reflection is a feature at the back surface of the water droplets that form rainbows (see the following figure). When the figure is inverted, it illustrates the upper bow in a double rainbow. Third and higher-order rainbows can be caused by multiple internal reflections; see http://www.atoptics.co.uk/rainbows/ord34.htm



15. A high-quality diamond may be quite clear and colorless, transmitting all visible wavelengths with little absorption. Explain how it can sparkle with flashes of brilliant color when illuminated by white light.

Solution

In addition to total internal reflection, rays that refract into and out of diamond crystals are subject to dispersion due to varying values of n across the spectrum, resulting in a sparkling display of colors.

16. How do wave effects depend on the size of the object with which the wave interacts? For example, why does sound bend around the corner of a building while light does not?

Solution

Compare wavelength with the size of the object. Sound wavelengths are much larger than light wavelengths, making diffraction around objects the size of buildings observable.

17. Does Huygens's principle apply to all types of waves?

Solution

yes

18. If diffraction is observed for some phenomenon, it is evidence that the phenomenon is a wave. Does the reverse hold true? That is, if diffraction is not observed, does that mean the phenomenon is not a wave?

Solution

It could simply mean that diffraction exists but is too small to be observed. In any case, light that does not display diffraction can be reasonably modeled as rays.

19. Can a sound wave in air be polarized? Explain.

Solution

No. Sound waves are not transverse waves.

20. No light passes through two perfect polarizing filters with perpendicular axes. However, if a third polarizing filter is placed between the original two, some light can pass. Why is this? Under what circumstances does most of the light pass?

Solution

The third polarizer rotates the polarization axis such that it is no longer perpendicular to the second polarizer. Maximum transmission occurs at $45°$.

21. Explain what happens to the energy carried by light that it is dimmed by passing it through two crossed polarizing filters.

Solution

Energy is absorbed into the filters.

22. When particles scattering light are much smaller than its wavelength, the amount of scattering is proportional to $\frac{1}{\lambda}$. Does this mean there is more scattering for small λ than large λ? How does this relate to the fact that the sky is blue?

Solution

Small λ is indeed preferentially scattered. Within the visible spectrum, this results in more blue (small λ) than red (large λ) being scattered into the direction of our eyes, resulting in an overall blue color for the sky.

23. Using the information given in the preceding question, explain why sunsets are red.

Solution

Sunsets are viewed with light traveling straight from the Sun toward us. When blue light is scattered out of this path, the remaining red light dominates the overall appearance of the setting Sun.

24. When light is reflected at Brewster's angle from a smooth surface, it is 100% polarized parallel to the surface. Part of the light will be refracted into the surface. Describe how you would do an experiment to determine the polarization of the refracted light. What direction would you expect the polarization to have and would you expect it to be 100%?

Solution

The refracted light can be put through a polarizing filter to measure for polarization. A polarization direction perpendicular to that of the reflected light can be expected if the original source is unpolarized.

25. If you lie on a beach looking at the water with your head tipped slightly sideways, your polarized sunglasses do not work very well. Why not?

Solution

The axis of polarization for the sunglasses has been rotated $90°$.

Problems

26. What is the speed of light in water? In glycerine?

Solution

2.249×10^8 m/s; 2.035×10^8 m/s

27. What is the speed of light in air? In crown glass?

Solution

2.99705×10^8 m/s; 1.97×10^8 m/s

Use the following table for problems 28 and 29.

Medium	*n*
Gases at $0\ °C$, 1 atm	
Air	1.000293
Carbon dioxide	1.00045
Hydrogen	1.000139
Oxygen	1.000271
Liquids at $20\ °C$	
Benzene	1.501
Carbon disulfide	1.628
Carbon tetrachloride	1.461
Ethanol	1.361
Glycerine	1.473
Water, fresh	1.333
Solids at $20\ °C$	
Diamond	2.419
Fluorite	1.434
Glass, crown	1.52
Glass, flint	1.66
Ice (at $0\ °C$)	1.309
Polystyrene	1.49
Plexiglas	1.51
Quartz, crystalline	1.544
Quartz, fused	1.458
Sodium chloride	1.544
Zircon	1.923

28. Calculate the index of refraction for a medium in which the speed of light is 2.012×10^8 m/s, and identify the most likely substance based on the table above.

Solution

1.490; polystyrene

29. In what substance in the table above is the speed of light 2.290×10^8 m/s?

Solution

ice at $0\ °C$

30. There was a major collision of an asteroid with the Moon in medieval times. It was described by monks at Canterbury Cathedral in England as a red glow on and around the Moon. How long after the asteroid hit the Moon, which is 3.84×10^5 km away, would the light first arrive on Earth?

Solution
1.28 s

31. Components of some computers communicate with each other through optical fibers having an index of refraction $n = 1.55$. What time in nanoseconds is required for a signal to travel 0.200 m through such a fiber?

Solution
1.03 ns

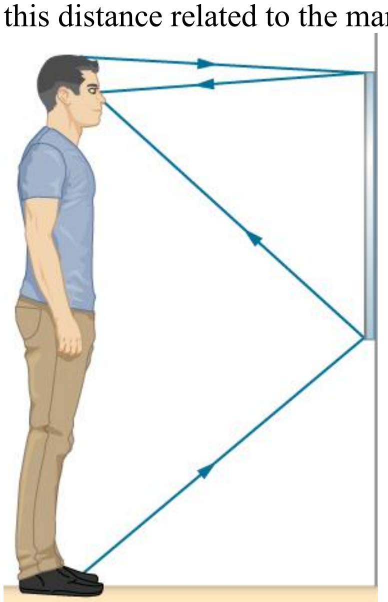
32. Compare the time it takes for light to travel 1000 m on the surface of Earth and in outer space.

Solution
0.977 ns slower on Earth's surface

33. How far does light travel underwater during a time interval of $1.50 \times 10^{-6}\,\text{s}$?

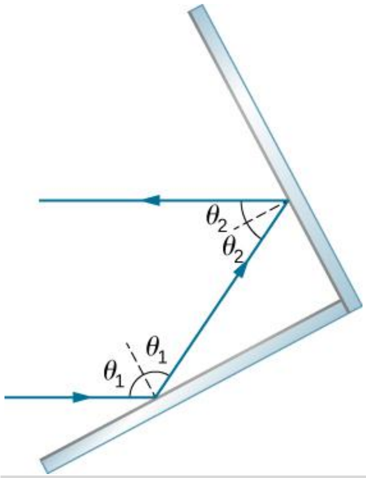
Solution
337 m

34. Suppose a man stands in front of a mirror as shown below. His eyes are 1.65 m above the floor and the top of his head is 0.13 m higher. Find the height above the floor of the top and bottom of the smallest mirror in which he can see both the top of his head and his feet. How is this distance related to the man's height?



Solution
The bottom is $b = 0.82\ \text{m}$ from the floor and the top is $b + L = 1.72\ \text{m}$ from the floor.

35. Show that when light reflects from two mirrors that meet each other at a right angle, the outgoing ray is parallel to the incoming ray, as illustrated below.

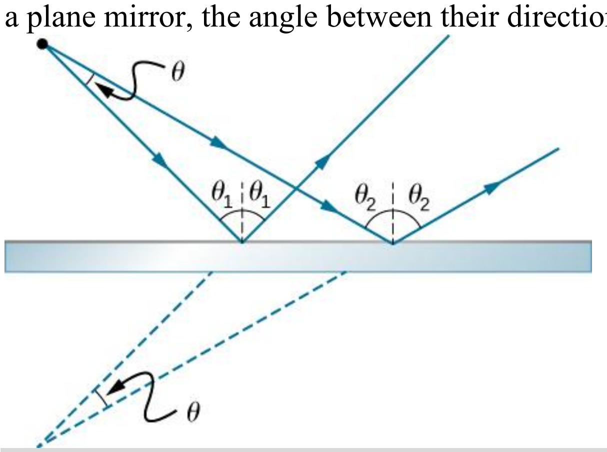


Solution
proof

36. On the Moon's surface, lunar astronauts placed a corner reflector, off which a laser beam is periodically reflected. The distance to the Moon is calculated from the round-trip time. What percent correction is needed to account for the delay in time due to the slowing of light in Earth's atmosphere? Assume the distance to the Moon is precisely 3.84×10^{8} m and Earth's atmosphere (which varies in density with altitude) is equivalent to a layer 30.0 km thick with a constant index of refraction $n = 1.000293$.

Solution
2.29×10^{-6} %

37. A flat mirror is neither converging nor diverging. To prove this, consider two rays originating from the same point and diverging at an angle θ (see below). Show that after striking a plane mirror, the angle between their directions remains θ.



Solution
proof

Unless otherwise specified, for problems 38 through 45, the indices of refraction of glass and water should be taken to be 1.50 and 1.333, respectively.

38. A light beam in air has an angle of incidence of $35°$ at the surface of a glass plate. What are the angles of reflection and refraction?

Solution
$35°$ and $22°$

39. A light beam in air is incident on the surface of a pond, making an angle of $20°$ with respect to the surface. What are the angles of reflection and refraction?

Solution
reflection, $70°$; refraction, $45°$

40. When a light ray crosses from water into glass, it emerges at an angle of $30°$ with respect to the normal of the interface. What is its angle of incidence?

Solution
$34°$

41. A pencil flashlight submerged in water sends a light beam toward the surface at an angle of incidence of $30°$. What is the angle of refraction in air?

Solution
$42°$

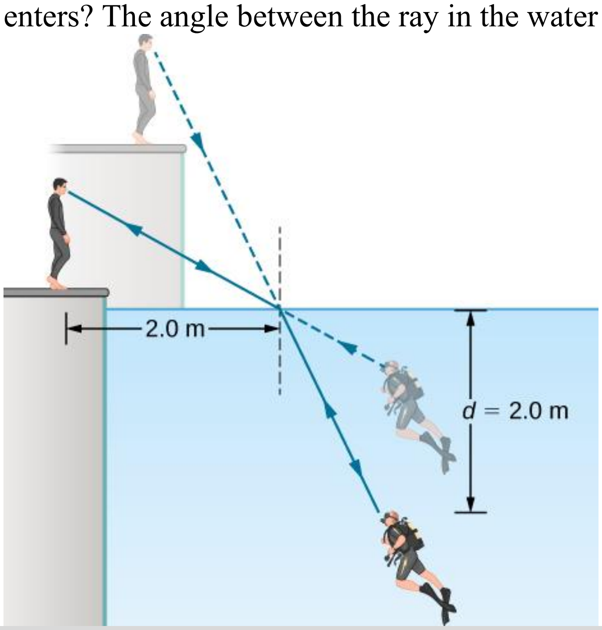
42. Light rays from the Sun make a $30°$ angle to the vertical when seen from below the surface of a body of water. At what angle above the horizon is the Sun?

Solution
$48°$

43. The path of a light beam in air goes from an angle of incidence of $35°$ to an angle of refraction of $22°$ when it enters a rectangular block of plastic. What is the index of refraction of the plastic?

Solution
1.53

44. A scuba diver training in a pool looks at his instructor as shown below. What angle does the ray from the instructor's face make with the perpendicular to the water at the point where the ray enters? The angle between the ray in the water and the perpendicular to the water is $25.0°$.



Solution
$34.3°$

45. (a) Using information in the preceding problem, find the height of the instructor's head above the water, noting that you will first have to calculate the angle of incidence. (b) Find the apparent depth of the diver's head below water as seen by the instructor.

Solution

a. 2.9 m; b. 1.4 m

46. Verify that the critical angle for light going from water to air is $48.6°$, as discussed at the end of Determining a Critical Angle, regarding the critical angle for light traveling in a polystyrene (a type of plastic) pipe surrounded by air.

Solution
$48.6°$

47. (a) At the end of Determining the Critical Angle, it was stated that the critical angle for light going from diamond to air is $24.4°$. Verify this. (b) What is the critical angle for light going from zircon to air?

Solution
a. $24.42°$; b. $31.33°$

48. An optical fiber uses flint glass clad with crown glass. What is the critical angle?

Solution
$66.3°$

49. At what minimum angle will you get total internal reflection of light traveling in water and reflected from ice?

Solution
$79.11°$

50. Suppose you are using total internal reflection to make an efficient corner reflector. If there is air outside and the incident angle is $45.0°$, what must be the minimum index of refraction of the material from which the reflector is made?

Solution
1.414

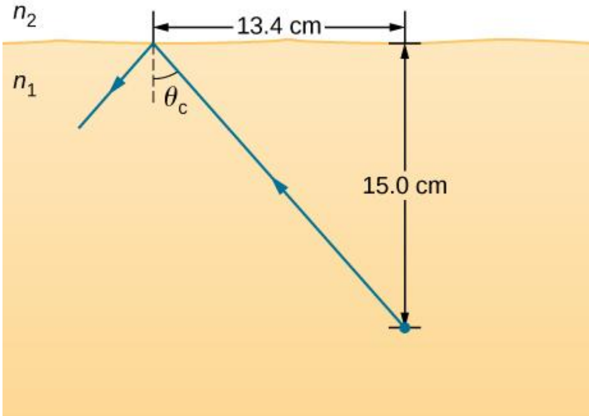
51. You can determine the index of refraction of a substance by determining its critical angle. (a) What is the index of refraction of a substance that has a critical angle of $68.4°$ when submerged in water? What is the substance, based on the following table? (b) What would the critical angle be for this substance in air?

Medium	n
Gases at $0\ °C$, 1 atm	
Air	1.000293
Carbon dioxide	1.00045
Hydrogen	1.000139
Oxygen	1.000271
Liquids at $20\ °C$	
Benzene	1.501
Carbon disulfide	1.628
Carbon tetrachloride	1.461
Ethanol	1.361
Glycerine	1.473
Water, fresh	1.333
Solids at $20\ °C$	
Diamond	2.419
Fluorite	1.434
Glass, crown	1.52
Glass, flint	1.66

Ice (at $0\ °C$)	1.309
Polystyrene	1.49
Plexiglas	1.51
Quartz, crystalline	1.544
Quartz, fused	1.458
Sodium chloride	1.544
Zircon	1.923

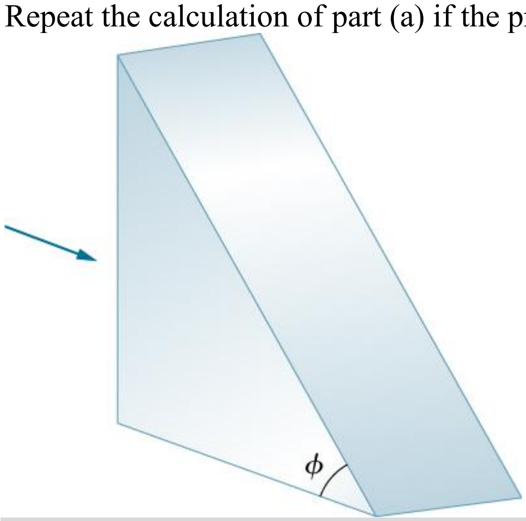
Solution
a. 1.43, fluorite; b. $44.2°$

52. A ray of light, emitted beneath the surface of an unknown liquid with air above it, undergoes total internal reflection as shown below. What is the index of refraction for the liquid and its likely identification?



Solution
1.50, benzene

53. Light rays fall normally on the vertical surface of the glass prism $(n = 1.50)$ shown below. (a) What is the largest value for ϕ such that the ray is totally reflected at the slanted face? (b) Repeat the calculation of part (a) if the prism is immersed in water.



Solution
a. $48.2°$; b. $27.3°$

54. (a) What is the ratio of the speed of red light to violet light in diamond, based on the following table? (b) What is this ratio in polystyrene? (c) Which is more dispersive?

Medium	Red (660 nm)	Orange 610 nm)	Yellow (580 nm)	Green (550 nm)	Blue (470 nm)	Violet (410 nm)
Water	1.331	1.332	1.333	1.335	1.338	1.342
Diamond	2.410	2.415	2.417	2.426	2.444	2.458
Glass, crown	1.512	1.514	1.518	1.519	1.524	1.530
Glass, flint	1.662	1.665	1.667	1.674	1.684	1.698
Polystyrene	1.488	1.490	1.492	1.493	1.499	1.506
Quartz, fused	1.455	1.456	1.458	1.459	1.462	1.468

Solution
a. 1.020; b. 1.012; c. diamond

55. A beam of white light goes from air into water at an incident angle of $75.0°$. At what angles are the red (660 nm) and violet (410 nm) parts of the light refracted?

Solution
$46.5°$ for red, $46.0°$ for violet

56. By how much do the critical angles for red (660 nm) and violet (410 nm) light differ in a diamond surrounded by air?

Solution
$0.51°$

57. (a) A narrow beam of light containing yellow (580 nm) and green (550 nm) wavelengths goes from polystyrene to air, striking the surface at a $30.0°$ incident angle. What is the angle between the colors when they emerge? (b) How far would they have to travel to be separated by 1.00 mm?

Solution
a. $0.04°$; b. 1.3 m

58. A parallel beam of light containing orange (610 nm) and violet (410 nm) wavelengths goes from fused quartz to water, striking the surface between them at a $60.0°$ incident angle. What is the angle between the two colors in water?

Solution
$0.1°$

59. A ray of 610-nm light goes from air into fused quartz at an incident angle of $55.0°$. At what incident angle must 470 nm light enter flint glass to have the same angle of refraction?

Solution

Fused quartz:
$$1.000\sin(55) = 1.456\sin(\theta_r)$$
$$\sin(\theta_r) = \frac{\sin(55)}{1.456}$$

Flint glass:
$$1.000\sin(\theta_i) = 1.684\sin(\theta_r) = \frac{1.684\sin(55)}{1.456}$$
$$\theta_i = \sin^{-1}\left(\frac{1.684\sin(55)}{1.456}\right) = 71.3$$

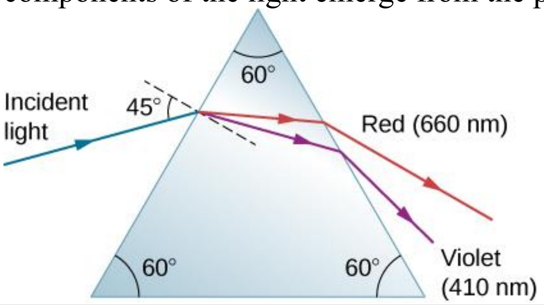
$71.3°$

60. A narrow beam of light containing red (660 nm) and blue (470 nm) wavelengths travels from air through a 1.00-cm-thick flat piece of crown glass and back to air again. The beam strikes at a $30.0°$ incident angle. (a) At what angles do the two colors emerge? (b) By what distance are the red and blue separated when they emerge?

Solution

a. $30.0°$; b. 3.09×10^{-5} m

61. A narrow beam of white light enters a prism made of crown glass at a $45.0°$ incident angle, as shown below. At what angles, θ_R and θ_V, do the red (660 nm) and violet (410 nm) components of the light emerge from the prism?



Solution

$53.5°$ for red, $55.2°$ for violet

62. What angle is needed between the direction of polarized light and the axis of a polarizing filter to cut its intensity in half?

Solution

$45.0°$

63. The angle between the axes of two polarizing filters is $45.0°$. By how much does the second filter reduce the intensity of the light coming through the first?

Solution

0.500

64. Two polarizing sheets P_1 and P_2 are placed together with their transmission axes oriented at an angle θ to each other. What is θ when only 25% of the maximum transmitted light intensity passes through them?

Solution

$60.0°$

65. Suppose that in the preceding problem the light incident on P_1 is unpolarized. At the determined value of θ, what fraction of the incident light passes through the combination?

Solution

0.125 or 1/8

66. If you have completely polarized light of intensity $150\ \text{W/m}^2$, what will its intensity be after passing through a polarizing filter with its axis at an $89.0°$ angle to the light's polarization direction?

Solution

$45.7\ \text{m W/m}^2$

67. What angle would the axis of a polarizing filter need to make with the direction of polarized light of intensity $1.00\ \text{kW/m}^2$ to reduce the intensity to $10.0\ \text{W/m}^2$?

Solution

$84.3°$

68. At the end of Calculating Intensity Reduction by a Polarizing Filter, it was stated that the intensity of polarized light is reduced to 90.0% of its original value by passing through a polarizing filter with its axis at an angle of $18.4°$ to the direction of polarization. Verify this statement.

Solution
proof

69. Show that if you have three polarizing filters, with the second at an angle of $45.0°$ to the first and the third at an angle of $90.0°$ to the first, the intensity of light passed by the first will be reduced to 25.0% of its value. (This is in contrast to having only the first and third, which reduces the intensity to zero, so that placing the second between them increases the intensity of the transmitted light.)

Solution
$0.250\ I_0$

70. Three polarizing sheets are placed together such that the transmission axis of the second sheet is oriented at $25.0°$ to the axis of the first, whereas the transmission axis of the third sheet is oriented at $40.0°$ (in the same sense) to the axis of the first. What fraction of the intensity of an incident unpolarized beam is transmitted by the combination?

Solution
0.383

71. In order to rotate the polarization axis of a beam of linearly polarized light by $90.0°$, a student places sheets P_1 and P_2 with their transmission axes at $45.0°$ and $90.0°$, respectively, to the beam's axis of polarization. (a) What fraction of the incident light passes through P_1 and (b) through the combination? (c) Repeat your calculations for part (b) for transmission-axis angles of $30.0°$ and $90.0°$, respectively.

Solution
a. 0.500; b. 0.250; c. 0.187

72. It is found that when light traveling in water falls on a plastic block, Brewster's angle is $50.0°$. What is the refractive index of the plastic?

Solution
1.59

73. At what angle will light reflected from diamond be completely polarized?

Solution
$67.54°$

74. What is Brewster's angle for light traveling in water that is reflected from crown glass?

Solution
$48.8°$

75. A scuba diver sees light reflected from the water's surface. At what angle relative to the water's surface will this light be completely polarized?

Solution
$53.1°$

Additional Problems

76. From his measurements, Roemer estimated that it took 22 min for light to travel a distance equal to the diameter of Earth's orbit around the Sun. (a) Use this estimate along with the known diameter of Earth's orbit to obtain a rough value of the speed of light. (b) Light actually takes 16.5 min to travel this distance. Use this time to calculate the speed of light.

Solution
a. 2.3×10^8 m/s; b. 3.03×10^8 m/s

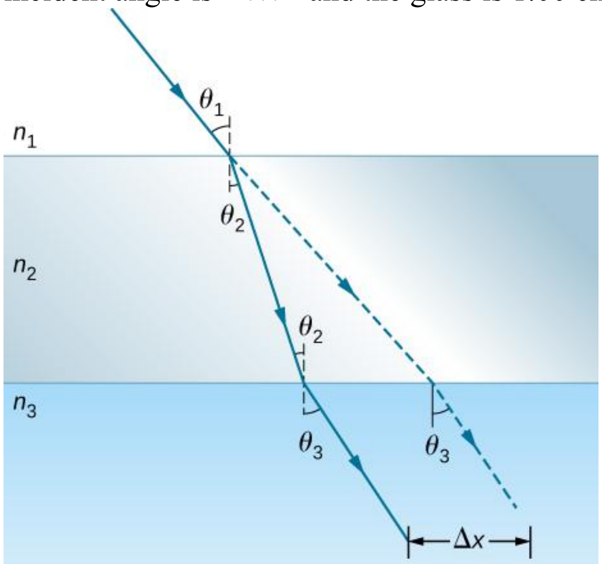
77. Cornu performed Fizeau's measurement of the speed of light using a wheel of diameter 4.00 cm that contained 180 teeth. The distance from the wheel to the mirror was 22.9 km. Assuming he measured the speed of light accurately, what was the angular velocity of the wheel?

Solution
114 radian/s

78. Suppose you have an unknown clear substance immersed in water, and you wish to identify it by finding its index of refraction. You arrange to have a beam of light enter it at an angle of $45.0°$, and you observe the angle of refraction to be $40.3°$. What is the index of refraction of the substance and its likely identity?

Solution
1.46, likely quartz, fused

79. Shown below is a ray of light going from air through crown glass into water, such as going into a fish tank. Calculate the amount the ray is displaced by the glass (Δx), given that the incident angle is $40.0°$ and the glass is 1.00 cm thick.



Solution
3.72 mm

80. Considering the previous problem, show that θ_3 is the same as it would be if the second medium were not present.

Solution
proof

81. At what angle is light inside crown glass completely polarized when reflected from water, as in a fish tank?

Solution
$41.2°$

82. Light reflected at $55.6°$ from a window is completely polarized. What is the window's index of refraction and the likely substance of which it is made?

Solution
1.46, and the substance is likely fused quartz

83. (a) Light reflected at $62.5°$ from a gemstone in a ring is completely polarized. Can the gem be a diamond? (b) At what angle would the light be completely polarized if the gem was in water?

Solution
a. 1.92. The gem is not a diamond (it is zircon). b. $55.2°$

84. If θ_{b} is Brewster's angle for light reflected from the top of an interface between two substances, and θ'_{b} is Brewster's angle for light reflected from below, prove that $\theta_{\mathrm{b}} + \theta'_{\mathrm{b}} = 90.0°$.

Solution
$90°$

85. **Unreasonable results** Suppose light travels from water to another substance, with an angle of incidence of $10.0°$ and an angle of refraction of $14.9°$. (a) What is the index of refraction of the other substance? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

Solution
a. 0.898; b. We cannot have $n < 1.00$, since this would imply a speed greater than *c*. c. The refracted angle is too big relative to the angle of incidence.

86. **Unreasonable results** Light traveling from water to a gemstone strikes the surface at an angle of $80.0°$ and has an angle of refraction of $15.2°$. (a) What is the speed of light in the gemstone? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?

Solution
a. $6.00 \times 10^7\ \mathrm{m/s}$; b. The speed of light is too slow and corresponds to index of refraction much greater than that for known materials. c. The angle of refraction is unreasonable relative to the angle incidence.

87. If a polarizing filter reduces the intensity of polarized light to 50.0% of its original value, by how much are the electric and magnetic fields reduced?

Solution
$0.707\ B_1$

88. Suppose you put on two pairs of polarizing sunglasses with their axes at an angle of $15.0°$. How much longer will it take the light to deposit a given amount of energy in your eye compared with a single pair of sunglasses? Assume the lenses are clear except for their polarizing characteristics.

Solution
$I / I_0 = 0.933$ and $t_2 = 1.07 t_1$

89. (a) On a day when the intensity of sunlight is $1.00\ \mathrm{kW/m^2}$, a circular lens 0.200 m in diameter focuses light onto water in a black beaker. Two polarizing sheets of plastic are placed in front of the lens with their axes at an angle of $20.0°$. Assuming the sunlight is unpolarized and the polarizers are 100% efficient, what is the initial rate of heating of the water in $°\mathrm{C/s}$, assuming it is 80.0% absorbed? The aluminum beaker has a mass of 30.0 grams and contains 250 grams of water. (b) Do the polarizing filters get hot? Explain.

Solution
a. $1.69 \times 10^{-2}\ °\mathrm{C/s}$; b. yes

Challenge Problems

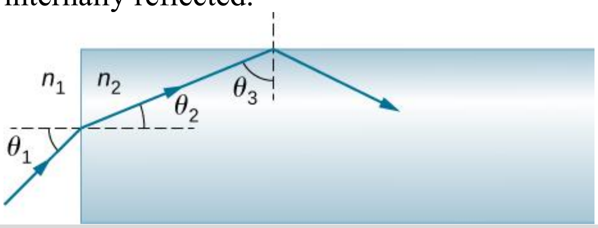
90. Light shows staged with lasers use moving mirrors to swing beams and create colorful effects. Show that a light ray reflected from a mirror changes direction by 2θ when the mirror is rotated by an angle θ.

Solution
proof

91. Consider sunlight entering Earth's atmosphere at sunrise and sunset—that is, at a $90.0°$ incident angle. Taking the boundary between nearly empty space and the atmosphere to be sudden, calculate the angle of refraction for sunlight. This lengthens the time the Sun appears to be above the horizon, both at sunrise and sunset. Now construct a problem in which you determine the angle of refraction for different models of the atmosphere, such as various layers of varying density. Your instructor may wish to guide you on the level of complexity to consider and on how the index of refraction varies with air density.

Solution
First part: $88.6°$. The remainder depends on the complexity of the solution the reader constructs.

92. A light ray entering an optical fiber surrounded by air is first refracted and then reflected as shown below. Show that if the fiber is made from crown glass, any incident ray will be totally internally reflected.

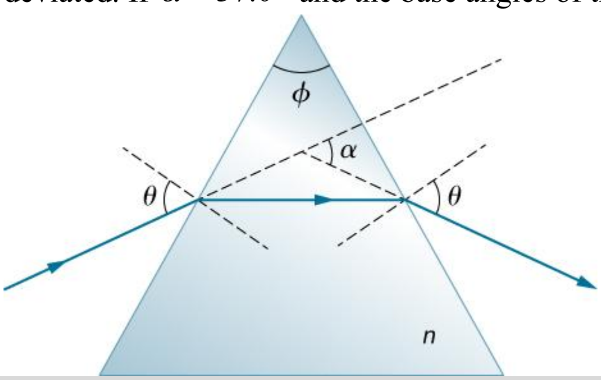


Solution
proof

93. A light ray falls on the left face of a prism (see below) at the angle of incidence θ for which the emerging beam has an angle of refraction θ at the right face. Show that the index of refraction n of the glass prism is given by

$$n = \frac{\sin\frac{1}{2}(\alpha + \phi)}{\sin\frac{1}{2}\phi}$$

where ϕ is the vertex angle of the prism and α is the angle through which the beam has been deviated. If $\alpha = 37.0°$ and the base angles of the prism are each $50.0°$, what is n?



Solution

proof; 1.33

94. If the apex angle ϕ in the previous problem is $20.0°$ and $n = 1.50$, what is the value of α?

Solution
$10.2°$

95. The light incident on polarizing sheet P_1 is linearly polarized at an angle of $30.0°$ with respect to the transmission axis of P_1. Sheet P_2 is placed so that its axis is parallel to the polarization axis of the incident light, that is, also at $30.0°$ with respect to P_1. (a) What fraction of the incident light passes through P_1? (b) What fraction of the incident light is passed by the combination? (c) By rotating P_2, a maximum in transmitted intensity is obtained. What is the ratio of this maximum intensity to the intensity of transmitted light when P_2 is at $30.0°$ with respect to P_1?

Solution
a. 0.750; b. 0.563; c. 1.33

96. Prove that if *I* is the intensity of light transmitted by two polarizing filters with axes at an angle θ and I' is the intensity when the axes are at an angle $90.0° - \theta$, then $I + I' = I_0$, the original intensity. (*Hint:* Use the trigonometric identities $\cos 90.0° - \theta = \sin\theta$ and $\cos^2\theta + \sin^2\theta = 1$.)

Solution
I_0