1. Mission Control sends a brief wake-up call to astronauts in a distant spaceship. Five seconds after the call is sent, Mission Control hears the waking groans of the astronauts. How far away (at most) from Earth is the spaceship?
A) $7.5 \times 10^8$ m  
B) $15 \times 10^8$ m  
C) $30 \times 10^8$ m  
D) $45 \times 10^8$ m  
E) The spaceship is on the moon.

2. Communications satellites are usually placed in geosynchronous orbits, a distance of $4.43 \times 10^7$ m from the center of Earth. What is the time lag for a signal sent from one point on Earth's surface to another via such a satellite? (The radius of Earth $R_E = 6.370 \times 10^6$ m.)
A) 0.13 s  
B) 0.25 s  
C) 0.51 s  
D) 0.29 s  
E) 0.15 s

3. Ultra fast pulse lasers can emit pulses of the order 10 fs. The length of each pulse that is 10 fs long is
A) $1.0 \mu m$  
B) $2.0 \mu m$  
C) $3.0 \mu m$  
D) $9.0 \mu m$  
E) $12.0 \mu m$

4. Ultra fast pulse lasers can emit pulses of the order 10 fs. If each pulse that is 10 fs long and the wavelength of the laser is 500 nm, the number of wavelengths in each pulse is
A) 6  
B) 10  
C) 12  
D) 50  
E) 120
5. An object leaves point A and travels to point B via path a.

In region I, the speed is 100 m/s while in region II, the speed is 71 m/s. How long does it take for the object to go from A to B?

A) 80.0 ms  
B) 60.8 ms  
C) 40.6 ms  
D) 32.4 ms  
E) 26.8 ms

6. An object leaves point A and travels in a straight line to point B via path b.

In region I, the speed is 100 m/s while in region II, the speed is 71 m/s. How long does it take for the object to go from A to B?

A) 82.0 ms  
B) 70.8 ms  
C) 61.3 ms  
D) 34.3 ms  
E) 27.7 ms
7. As light passes from one medium into another, the angle of refraction is _____ in the medium with the _____ index of refraction and _____ speed of light.
A) smaller; larger; lower
B) smaller; larger; higher
C) larger; smaller; lower
D) larger; larger; lower
E) smaller; smaller; higher

8. Light is incident on a piece of glass in air at an angle of 37.0° from the normal. If the index of refraction of the glass is 1.50, the angle that the refracted ray makes with the normal is approximately
A) 8.6°
B) 21.8°
C) 23.6°
D) 41.8°
E) 56.4°

9. A light wave traveling at speed $v_1$ in medium 1 passes into medium 2 where its speed is $v_2$. By which of the following equations is the frequency $f_1$ of the wave in medium 1 related to its frequency $f_2$ in medium 2? ($\theta_1$ and $\theta_2$ are the angles of incidence and refraction.)
A) $f_1 \sin \theta_1 = f_2 \sin \theta_2$
B) $f_1 v_2 = f_2 v_1$
C) $f_1 = f_2$
D) $f_1 v_1 = f_2 v_2$
E) $f_1 \sin \theta_2 = f_2 \sin \theta_1$

10. From directly above, you're watching a fish swim 1.83 m beneath the surface of a clear lake ($n = 1.33$). How far beneath the surface does the fish seem to be?
A) 0.914 m
B) 1.37 m
C) 1.83 m
D) 2.44 m
E) 2.93 m
11. You are trying to catch fish by using a spear. You observe a large fish a couple of meters in front of you and a meter below the water surface. In order to hit the fish with your spear you must aim (assume that the fish is stationary and does not swim away in fright)
A) directly at the point where you see the fish.
B) slightly above the point where you see the fish.
C) slightly below the point where you see the fish.
D) slightly to the left side of the point where you see the fish.
E) slightly to the right side of the point where you see the fish.

12. A ray of light passes from air into water, striking the surface of the water with an angle of incidence of 45°. Which of the following four quantities change as the light enters the water: (1) wavelength, (2) frequency, (3) speed of propagation, and (4) direction of propagation?
A) 1 and 2 only
B) 2, 3, and 4 only
C) 1, 3, and 4 only
D) 3 and 4 only
E) 1, 2, 3, and 4

13. A ray of light strikes a slab of glass at an angle of incidence of 35°. The angle of refraction in the glass is

A) 22°
B) 63°
C) 27°
D) 90°
E) None of these is correct.
14. The light ray in the figure is incident on a glass-air surface. The index of refraction of the glass is 1.74. The approximate critical angle for total internal reflection is

A) $48^\circ$
B) $35^\circ$
C) $30^\circ$
D) $22^\circ$
E) None of these is correct.

15. A light ray makes an angle of $42^\circ$ with the normal to a glass-water surface on the glass side of the surface. The angle $\theta$ in the water is

A) $42^\circ$
B) $36^\circ$
C) $63^\circ$
D) $49^\circ$
E) $27^\circ$

16. A ray of light strikes a water-glass interface at an angle of incidence of $35^\circ$. The angle of refraction is

A) $40.3^\circ$
B) $22.1^\circ$
C) $30.6^\circ$
D) $59.4^\circ$
E) $19.7^\circ$
17. The speed of yellow sodium light in a certain liquid is $1.92 \times 10^8$ m/s. With respect to air, the index of refraction of this liquid for sodium light is approximately

A) 1.92  
B) 1.56  
C) 1.23  
D) 0.64  
E) 1.33

18. Light travels in a medium of index of refraction $n'$, passes into a medium of index $n''$, where $n'' > n'$, and then into air, where $n_{\text{air}} < n' < n''$. The ray that correctly shows the light path is

A) 1  
B) 2  
C) 3  
D) 4  
E) 5

19. You shine light of frequency $4.00 \times 10^{14}$ Hz through a glass plate whose index of refraction for this light is 1.50. The wavelength of this light in the glass is approximately

A) 500 nm  
B) 110 nm  
C) 800 nm  
D) 425 nm  
E) 380 nm
20. For the prism immersed in water \((n = 1.33)\), the minimum index of refraction that will produce total reflection of the indicated ray is approximately

A) 0.94  
B) 1.28  
C) 1.50  
D) 1.65  
E) 1.88

21. The prism totally reflects some wavelengths of light as shown, but other wavelengths pass through. The index of refraction of this prism for the longest wavelengths that are totally reflected is approximately

A) 1.50  
B) 1.53  
C) 1.46  
D) 1.41  
E) 1.59
22. You place a point source of light at the bottom of a pool of water 1.00 m deep. The source emits rays upward in all directions. You notice that a circle of light is formed by the rays that are refracted into the air and that the rays outside of this circle are reflected back into the water. The index of refraction of water is 1.33. The radius $R$ of the circle at the surface of the water is approximately

A) 0.75 m  
B) 1.00 m  
C) 1.13 m  
D) 1.33 m  
E) infinite

23. The rays in the figure are reflected and refracted at the front and back surfaces of the glass. Which of the following is true of these rays?

A) $\angle 1 = \angle 2 = \angle 3 = \angle 4$  
B) $\angle 1 = \angle 2; \angle 3 = \angle 4; \text{but} \angle 1 \neq \angle 3$  
C) $\angle 1 = \angle 2 = \angle 3; \text{but} \angle 4 \neq \angle 1$  
D) $1 = 4; \text{but} \ 2 \neq 4$  
E) $1 \neq 2 \neq 3 \neq 4$

24. A light wave traveling in air impinges on an amber plate at an angle of incidence of $60^\circ$. If the angle of refraction is $34^\circ$, the velocity of light in amber must be approximately

A) $0.52 \times 10^8$ m/s  
B) $4.64 \times 10^8$ m/s  
C) $1.86 \times 10^3$ m/s  
D) $2.09 \times 10^8$ m/s  
E) $4.64 \times 10^{10}$ m/s
25. A ray of light is shown reflected and refracted at the surface of a liquid. From the diagram you can determine that the speed of light in this liquid is approximately

A) $1.83 \times 10^8$ m/s
B) $2.24 \times 10^8$ m/s
C) $3.00 \times 10^8$ m/s
D) $4.02 \times 10^8$ m/s
E) $2.50 \times 10^8$ m/s

26. The critical angle for light rays passing from flint glass ($n = 1.70$) into air is about

A) $3.4^\circ$
B) $36^\circ$
C) $44^\circ$
D) $54^\circ$
E) $90^\circ$

27. An “X” is marked on the bottom of a glass container. A microscope is adjusted so that it is focused on the “X.” A liquid is now poured into the glass to a depth of 6.00 cm. If the microscope has to be backed up by a distance of 1.50 cm to refocus on the “X,” then calculate the refractive index of the liquid.

A) 1.25
B) 4.00
C) 1.33
D) 0.75
E) 3.00
28. A fiber optic is made by cladding a thin fiber core of refractive index \( n_1 = 1.45 \) with a material of refractive index \( n_2 = 1.38 \).

![Diagram of a fiber optic](image)

The figure shows a cross-section of the fiber optic.

What is the maximum incident angle, \( \theta \), so that the light ray is totally internally reflected inside the fiber?

A) 24.1°
B) 26.4°
C) 28.2°
D) 30.3°
E) 32.7°

29. Two clear but non-mixing liquids each of depth 15 cm are placed together in a glass container. The liquids have refractive indices of 1.75 and 1.33. What is the apparent depth of the combination when viewed from above?

A) 19.8 cm
B) 23.1 cm
C) 17.7 cm
D) 9.9 cm
E) None of these is correct.

30. A column of liquid is 10 cm high. Viewed from above the liquid has an apparent depth of 6.77 cm. If the refractive index of the liquid is 1.33 at the top and increases uniformly to the bottom, then what is the refractive index at the bottom of the liquid?

A) 1.96
B) 2.95
C) 1.48
D) 1.62
E) None of these is correct.

31. A 60° prism has a refractive index of 1.52. Calculate the angle of incidence for the initial light ray that is then refracted inside the prism and just undergoes total internal reflection at the opposite face of the prism.

A) 41.1°
B) 18.9°
C) 29.4°
D) 30.6°
E) 60.6°
32. The dependence of the index of refraction on wavelength is called dispersion. A beam of light (in air) containing red and blue light is incident at an angle of 35° on a glass plate that has an index of refraction of 1.64 for blue light and 1.61 for red light. By what percent does the speed of the red light exceed that of the blue light inside the glass, i.e. calculate \((v(\text{red}) - v(\text{blue})) \times 100 / v(\text{red})\)?

A) 1.1%
B) 1.8%
C) 0.53%
D) The speed is the same for both colors.
E) 0.019%

33. A 60° prism has a refractive index of 1.64 for blue light and 1.61 for red light. Calculate the difference in the angle of emergence from the opposite face of the prism for a beam of red and a beam of blue light that are both incident at an angle of 60°.

A) 0.4°
B) 0.0°
C) 1.3°
D) 3.9°
E) 2.7°

34. Light is incident at an angle of 60° at an air to glass interface. If the angle of refraction inside the glass is 32°, then calculate the speed of light within the glass.

A) \(3.00 \times 10^8\) m/s
B) \(1.77 \times 10^8\) m/s
C) \(4.90 \times 10^8\) m/s
D) \(1.84 \times 10^8\) m/s
E) \(1.62 \times 10^8\) m/s

35. Light is an electromagnetic wave. When visible light is plane polarized,

A) the electric-field vector is parallel to the magnetic-field vector.
B) the electric-field vector is parallel to the direction of propagation.
C) the electric-field vector is in a fixed direction perpendicular to the direction of propagation, but the magnetic-field vector may be in any direction.
D) the electric-field vector is in a fixed direction perpendicular to the direction of propagation, and the magnetic-field vector is perpendicular to the electric-field vector.
E) None of these is correct.
36. Two polarizers have their transmission axes at an angle $\theta$. Unpolarized light of intensity $I$ is incident on the first polarizer. What is the intensity of the light transmitted by the second polarizer?
   A) $I \cos^2 \theta$
   B) $0.5I \cos^2 \theta$
   C) $0.25I \cos^2 \theta$
   D) $I \cos \theta$
   E) $0.25I \cos \theta$

37. Light is reflected from the surface of a lake ($n = 1.33$). What is the angle of incidence for which the reflected light is 100 percent polarized?
   A) $53^\circ$
   B) $49^\circ$
   C) $45^\circ$
   D) $41^\circ$
   E) $37^\circ$

38. The index of refraction of water is approximately 1.33. The angle of incidence for maximum polarization by reflection from water is approximately
   A) $57^\circ$
   B) $53^\circ$
   C) $45^\circ$
   D) $37^\circ$
   E) $33^\circ$

39. Two ideal polarizing sheets with their planes of polarization parallel to each other pass (initially unpolarized) light of intensity $I$. If the planes are rotated in such a way that their planes of polarization make an angle of $40.0^\circ$, the intensity is approximately
   A) $0.293I$
   B) $0.383I$
   C) $0.502I$
   D) $0.585I$
   E) $0.770I$
40. A ray of unpolarized light is incident on a glass block at an angle of incidence in such a way that the reflected ray is completely plane polarized. The ray that represents the refracted ray is

A) 1  
B) 2  
C) 3  
D) 4  
E) 5

41. If light reflected from a transparent substance at an angle of 58.0° is completely plane polarized, light incident at an angle of 32.0° is refracted at an angle of

A) 32.0°  
B) 58.0°  
C) 19.3°  
D) 90.0°  
E) 70.7°

42. When light is reflected from a plane surface of glass at the polarizing angle, the
A) reflected ray is at right angles to the incident ray.  
B) angle of reflection is equal to the angle of refraction.  
C) incident ray is at right angles to the refracted ray.  
D) reflected ray is at right angles to the refracted ray.  
E) intensity of the reflected light is a maximum.
43. A ray of light is shown being reflected at the surface of a material. If the reflected ray is completely plane polarized, the index of refraction of the material is approximately

A) 1.3
B) 1.9
C) 0.63
D) 0.80
E) 1.8

44. Four perfectly polarizing plates are stacked so that the axis of each plate is turned 30° clockwise with respect to that of the plate above it. The percentage of the incident unpolarized light that is transmitted by the stack is approximately

A) zero
B) 0.78%
C) 6.3%
D) 21%
E) 27%

45. The index of refraction of water is 1.33. The angle of incidence for maximum polarization by reflection is approximately

A) 57°
B) 53°
C) 45°
D) 37°
E) 33°
46. The principle of superposition states:
A) The effect observed at each point of a wave made up of two or more waves is the sum of the effects that the individual waves would produce at that point.
B) Huygens' wavelets cannot be allowed to extend across regions where the phase velocity of the wave changes abruptly.
C) Sources of radiation whose phase angles are maintained at constant differences are said to be coherent.
D) A characteristic phenomenon of wave propagation is the tendency of a wave to expand around and behind any obstacles it chances to encounter.
E) A good source of waves at a particular frequency is a good detector of waves at the same frequency.

47. White light is incident on a prism from the left. After it passes through the first prism, a color spectrum of light is observed. The spectrum is then passed through a second prism which is inverted compared to the first prism. The color light that exit from the second prism

A) is also a color spectrum and more spread out.
B) is also a color spectrum but less spread out.
C) is white in color.
D) has more colors than the first spectrum.
E) has less colors than the first spectrum.

48. The wavelength of light composed of photons with energy of 4.25 eV is
A) 292 nm
B) 973 nm
C) 706 nm
D) 1559 nm
E) None of these is correct.
49. The film shows the line spectrum of an unknown element. If the wavelengths of lines (a), (b) and (c) are 410 nm, 500 nm and 556 nm respectively, then the wavelength for line (d) is
A) 590 nm  
B) 600 nm  
C) 615 nm  
D) 625 nm  
E) 635 nm

50. A helium–neon laser emits light of wavelength 632.8 nm and has a power output of 1.5 mW. How many photons are emitted per second by this laser?
A) $1.34 \times 10^{14}$  
B) $2.56 \times 10^{15}$  
C) $3.09 \times 10^{15}$  
D) $4.22 \times 10^{15}$  
E) $4.78 \times 10^{15}$

51. Two plane mirrors make an angle of 120° as shown. An object is placed at O. When the eye is placed at E, it will observe images formed at
A) 1 and 2  
B) 2 and 3  
C) 3 and 4  
D) 1 and 4  
E) 1 and 3
52. A point object P is placed before two mirrors at right angles as shown. Images of the object are formed only at positions

A) 1, 2, and 3
B) 2, 3, and 4
C) 3, 4, and 5
D) 2 and 4
E) 1, 3, and 5

53. An object is placed 10 inches in front of a concave mirror that has a radius of curvature of 8 inches. The image is located
A) 4.75 inches in front of the mirror.
B) 4.75 inches behind the mirror.
C) 3 inches behind the mirror.
D) 6.67 inches behind the mirror.
E) 6.67 inches in front of the mirror.

54. The parallel rays incident on the surface of the concave spherical mirror in the figure converge to a point at

A) 1
B) 2
C) 3
D) 4
E) 5
55. A concave spherical mirror has a radius of curvature of 50 cm. The image of an object located 35 cm in front of the mirror is
A) real, inverted, magnified 2.5 times, and 87.5 cm from the mirror.
B) real, erect, magnified 2.5 times, and 87.5 cm from the mirror.
C) virtual, erect, magnified 3.3 times, and 117 cm from the mirror.
D) real, inverted, magnified 3.3 times, and 117 cm from the mirror.
E) real, inverted, diminished 0.42 times, and 14.6 cm from the mirror.

56. An object 25 cm from a convex mirror is observed to produce an image 13.6 cm behind the mirror. What is the focal length of the mirror?
A) 8.8 cm
B) –8.8 cm
C) 30 cm
D) –30 cm
E) –60 cm

57. When an object is closer to a convex mirror than the mirror's focal point, the
A) magnification is less than one.
B) image distance is greater than the object distance.
C) magnification is equal to one.
D) image is real.
E) image is inverted.

58. When an object is closer to a concave mirror than the mirror's focal point, the
A) magnification is less than one.
B) image distance is greater than the object distance.
C) magnification is equal to one.
D) image distance is negative.
E) image is inverted.

59. When an object is farther from a concave mirror than twice the mirror's focal length, the
A) magnification is less than one.
B) image is inverted.
C) image distance is less than the object distance.
D) image is real.
E) All of these are correct.
60. An object 0.50 cm high is 5.0 cm from a concave spherical mirror of focal length 20 cm. How high is the image and is it erect or inverted?
A) 0.40 cm, inverted
B) 0.67 cm, erect
C) 0.50 cm, inverted
D) 0.67 cm, inverted
E) 0.40 cm, erect

61. An object is located 7.62 cm from the surface of a silvered spherical glass Christmas tree ornament that is 7.62 cm in diameter. The image distance is approximately
A) 1.52 cm
B) –1.52 cm
C) 4.24 cm
D) –4.24 cm
E) infinity because no image is formed.

62. An object is placed between \(2f\) and infinity in front of a concave mirror of focal length \(f\). The image is located
A) behind the mirror, between \(2f\) and the mirror.
B) behind the mirror, between \(2f\) and infinity.
C) in front of the mirror, between the mirror and \(f\).
D) in front of the mirror, between \(f\) and the center of curvature.
E) in front of the mirror, between the center of curvature and infinity.

63. How far must a man's face be located in front of a concave spherical shaving mirror of radius 120 cm for him to see an erect image of his face four times its real size?
A) –75 cm
B) 45 cm
C) 75 cm
D) 90 cm
E) 150 cm
64. Two parallel mirrors are a distance \( d \) apart. An object is placed 1.0 inch in front of the right-hand mirror. After 5 reflections, with the first reflection from the right-hand mirror, an image is located 17 inches behind the right-hand mirror. Calculate the distance between the mirrors.
A) 5.3 in  
B) 3.2 in  
C) 6.0 in  
D) 4.0 in  
E) 3.6 in  

65. A cat is watching a goldfish in a spherical fishbowl of radius 15.0 cm. The goldfish is 5.00 cm from the side of the bowl nearest the cat. How far from the side of the bowl does the fish appear to be to the cat? (For water, \( n = 1.33 \).)
A) 7.5 cm  
B) 4.5 cm  
C) 4.1 cm  
D) 3.5 cm  
E) 2.5 cm  

66. Your eye looks into a thick glass slab at an air bubble located at point 3. The bubble appears to be at point

A) 1  
B) 2  
C) 3  
D) 4  
E) 5
67. Half-round slabs of glass or plastic are often used to trace rays. Pins are placed at points P and Q. For an observer to see the images of the pins in line, she should place her eye at point

A) 1  
B) 2  
C) 3  
D) 4  
E) 5

68. The lens of a slide projector has a focal length of +12.0 cm. A slide 12.6 cm to the left of the lens forms the object for the lens. The screen should be placed

A) 25 cm to the left of the lens.  
B) 25 cm to the right of the lens.  
C) 250 cm to the left of the lens.  
D) 250 cm to the right of the lens.  
E) 390 cm to the right of the lens.

69. When a real object is placed just inside the focal point F of a diverging lens, the image is

A) virtual, erect, and diminished.  
B) real, inverted, and enlarged.  
C) real, inverted, and diminished.  
D) virtual, erect, and enlarged.  
E) virtual, inverted, and diminished.
70. A negative lens with a focal length of \(-10.0\) cm is on the same axis as a positive lens with a focal length of \(+20.0\) cm as illustrated. The distance between the lenses is \(20.0\) cm. A real object \(3.00\) cm high is placed \(20.0\) cm to the left of the negative lens. After the light has passed through both lenses, the image is

A) \(3.0\) cm high and virtual.
B) \(1.0\) cm high and virtual.
C) \(1.0\) cm high and real.
D) \(3.0\) cm high and real.
E) None of these is correct.

71. A plano-concave lens has \(r_1 = 15\) cm and is constructed of a material with refractive index of \(1.5\). The focal length of the lens is

A) \(-15\) cm
B) \(15\) cm
C) \(-30\) cm
D) \(30\) cm
E) None of these is correct.

72. A negative lens with a focal length of \(-15\) cm is \(25\) cm from a positive lens with a focal length of \(+20\) cm on the same axis. Parallel light from the left is incident on the negative lens. The image formed by the positive lens is

\[
\begin{align*}
f_1 &= -15 \text{ cm} \\
f_2 &= +20 \text{ cm}
\end{align*}
\]

A) real and \(40\) cm from the positive lens.
B) virtual and \(20\) cm from the positive lens.
C) real and \(20\) cm from the positive lens.
D) real and \(13\) cm from the positive lens.
E) None of these is correct.
73. A positive lens of focal length 40 cm is placed 20 cm behind a negative lens of focal length \(-80\) cm. An object is placed 240 cm in front of the negative lens. The final image distance relative to the positive lens is
A) \(-40\) cm
B) 56 cm
C) \(-56\) cm
D) 80 cm
E) \(-80\) cm

74. An object placed 4 cm to the left of a positive lens of focal length 2 cm produces an image 4 cm to the right of the lens. A negative lens placed at the focal point of the positive lens as shown produces a final image 6 cm to the right of the negative lens. The negative lens has a focal length of

A) \(-1.5\) cm
B) \(-3.0\) cm
C) \(-6.0\) cm
D) 10 cm
E) \(-2.0\) cm

75. When a human eye that has a power of +60 D is fitted with a contact lens of \(-10\) D, the equivalent lens combination is
A) diverging and of focal length 2 cm.
B) converging and of focal length 50 cm.
C) converging and of focal length 2 cm.
D) focal length 0.02 cm.
E) focal length 0.2 cm.
76. The graph shows the reciprocal of the image distance plotted against the reciprocal of the object distance for a certain lens. From this graph it can be seen that this lens has a focal length of

![Graph showing reciprocal of image distance plotted against reciprocal of object distance.]

A) 0.20 m  
B) 1.0 m  
C) 4.0 m  
D) 0.25 m  
E) –1.0 m

77. An object is located 4 cm from a converging lens of focal length 3 cm. The magnitude of the magnification of the image is

A) 3  
B) 4  
C) 9  
D) 12  
E) 16

78. An object 5.0 cm tall is placed 15 cm in front of a converging lens of focal length 30 cm. The final image size is

A) 2.5 cm  
B) 3.3 cm  
C) 5.0 cm  
D) 7.5 cm  
E) 10 cm

79. The focal length of a converging lens that projects the image of a lamp, magnified 4 times, onto a screen 3.05 m from the lamp is approximately

A) 11.6 cm  
B) 48.8 cm  
C) –11.6 cm  
D) 2.04 m  
E) 19.2 cm
80. A double-convex lens is made of glass of index of refraction 1.60. If the radii of curvature of the two surfaces are 10 cm and 20 cm, the focal length of the lens in air is

\[
\text{focal length} = \frac{1}{\frac{1}{f_1} + \frac{1}{f_2}}
\]

A) 11.1 cm
B) -11.1 cm
C) 25 cm
D) 33.3 cm
E) -33.3 cm

81. A double-convex lens is made of glass of refractive index 1.50. The radii of curvature of the surfaces are 10 cm and 20 cm. The focal length of this lens is

\[
\text{focal length} = \frac{1}{\frac{1}{f_1} + \frac{1}{f_2}}
\]

A) 4.45 cm
B) 13.3 cm
C) -13.3 cm
D) 40 cm
E) -40 cm

82. The image produced by the converging lens is at point 3
83. The image of the encircled point on the object formed in the positive lens is at which circle?

A) 1  
B) 2  
C) 3  
D) 4  
E) 5

84. When the ray in the diagram is continued through the diverging lens, it passes through point

A) 1  
B) 2  
C) 3  
D) 4  
E) 5

85. One ray is shown as it leaves an object placed before a positive lens. If this ray were continued to show its path through the lens, it would pass through point

A) 1  
B) 2  
C) 3  
D) 4  
E) 5
86. A real object is placed 9.00 cm from a converging lens that has a focal length of 24.0 cm. The image is
A) 0.119 cm from the lens, real, and smaller than the object.
B) 0.119 cm from the lens, virtual, and smaller than the object.
C) 14.4 cm from the lens, real, and enlarged.
D) 14.4 cm from the lens, virtual, and enlarged.
E) 11.7 cm from the lens, virtual, and enlarged.

87. After passing through the thin converging lens, the two rays cross at point

A) 1
B) 2
C) 3
D) 4
E) 5

88. A diverging lens has a focal length of magnitude 20 cm. An object is placed 10 cm in front of the diverging lens. Calculate the magnification of the image and whether it is upright or inverted.
A) 0.67 upright
B) 0.52 upright
C) 0.67 inverted
D) 1.5 upright
E) 0.85 inverted

89. A 6-cm-high candle is placed in front of a converging lens with a focal length of magnitude 30 cm. If the image distance is +50 cm, then find the image height of the candle and whether it is upright or inverted.
A) 4.0 cm upright
B) 3.3 cm upright
C) 3.3 cm inverted
D) 4.0 cm inverted
E) None of these is correct.
90. An object is placed 5 m in front of a converging lens of focal length 11 cm. A diverging lens with focal length 11 cm is placed 6 cm behind the converging lens. Calculate the position of the final image produced by the two-lens system and state if this final image is real or virtual.
A) 5.3 cm real
B) 10 cm real
C) −5.3 cm virtual
D) −7.5 cm virtual
E) 7.5 cm real

91. An object is placed 20 cm to the left of a converging lens with a focal length of 8 cm. A second converging lens of focal length 12 cm is placed to the right of the first lens. If the final image of the combined lens system is virtual and 15 cm from the second lens, then calculate the distance between the two lenses.
A) 73.3 cm
B) 46.7 cm
C) 60.0 cm
D) 6.63 cm
E) 20.0 cm

92. White light falls on a thick lens. The red wavelength and the blue wavelength fall at different focuses. The lens is said to exhibit

A) hypermetropia.
B) myopia.
C) astigmatism.
D) chromatic aberration.
E) spherical aberration.

93. For a myopic eye that cannot focus on objects more than 25 cm in front of it, the power in diopters of the lens needed for distinct distant vision is
A) +25 diopters
B) +4.0 diopters
C) −4.0 diopters
D) −2.5 diopters
E) None of these is correct.
94. Your left eye can focus on objects a great distance away but cannot focus on objects that are closer than 125 cm to it. The power of the lens in diopters that you need for normal near vision (25 cm) is
A) +0.8 diopters
B) +3.2 diopters
C) +4.0 diopters
D) −4.0 diopters
E) None of these is correct.

95. Your hypermetropic eye cannot focus on objects that are more than 225 cm from it. The power in diopters of the lens you need for distinct distant vision is
A) +2.25 diopters
B) +4.4 \times 10^{-3} diopters
C) +3.6 diopters
D) −0.44 diopters
E) None of these is correct.

96. How much must the focal length of an eye change when an object, originally at 4.00 m, is brought to 40.0 cm from the eye?
A) 0.13 cm
B) 2.48 cm
C) 2.35 cm
D) 2.50 cm
E) 0.19 cm

97. Your farsighted friend requires lenses with a power of 1.67 diopters to read comfortably from a book that is 25.0 cm from her eyes. What is her near point without the lenses?
A) 17.6 cm
B) 4.00 cm
C) 59.9 cm
D) 42.9 cm
E) 36.2 cm

98. An object placed 7.62 cm from a simple magnifying glass of focal length 10.2 cm is magnified
A) 1×
B) 2×
C) 3×
D) 4×
E) 0.75×
99. A simple magnifier gives a magnification of 8 times when it is used by a person with a normal near point (25 cm). What is the magnifying power when it is used by a person whose near point is 15 cm?

A) 4.8  
B) 13  
C) 8.0  
D) 15  
E) 9.6

100. You have two lenses for making a compound microscope: \( f_o = 0.800 \text{ cm} \) and \( f_e = 1.20 \text{ cm} \). How far apart should you set the lenses to get a magnification of -300? (Assume the normal near point of 25.0 cm.)

A) 11.5 cm  
B) 12.7 cm  
C) 13.5 cm  
D) 13.9 cm  
E) 15.0 cm

101. Your microscope has an objective lens of focal length 1.20 cm and an eyepiece of focal length 2.40 cm separated by 16.0 cm. What is the magnifying power if your near point is 25.0 cm?

A) 150  
B) -150  
C) 136  
D) -75  
E) -108

102. A simple refracting telescope has an objective of focal length 75 cm and an eyepiece of focal length 3.0 cm. When viewed by the naked eye, the moon subtends an angle of about 0.009 radians. What angle is subtended by the moon when it is viewed through this telescope?

A) 0.022 rad  
B) 0.22 rad  
C) \( 3.6 \times 10^{-4} \) rad  
D) 0.078 rad  
E) \( 3.0 \times 10^{-3} \) rad
103. A two lens magnifying system uses lenses of focal lengths 2.5 and 9.5 cm for the objective and eyepiece respectively. The two lenses are positioned 23 cm apart. An object for study is placed 3.0 cm in front of the objective lens. Find the position of the final image relative to the eyepiece lens.

A) –27.7 cm  
B) –50.7 cm  
C) 15.0 cm  
D) –1.59 cm  
E) –35.3 cm

104. In the figure, a beam of light from an underwater source is incident on a layer of carbon disulfide and the glass bottom of the container. Some of the refracted and reflected rays are shown in the diagram. For the rays shown, the interface at which the reflected light changes phase is

A) 1 only  
B) 2 only  
C) 3 only  
D) 1 and 2  
E) 2 and 3

105. Two coherent sources of monochromatic light are located at S₁ and S₂ as shown. If the sources are in phase, the intensity at point P is a maximum when

A) \( d = \lambda \)  
B) \( r₂ + r₁ = \lambda \)  
C) \( r₂ - r₁ = \lambda \)  
D) \( r₂ + r₁ = \lambda /2 \)  
E) \( r₂ - r₁ = \lambda /2 \)
106. The minimum path difference that will produce a phase difference of 180° for light of wavelength 600 nm is
A) 600 nm
B) 500 nm
C) 300 nm
D) 200 nm
E) 100 nm

107. You create a wedge-shaped film of air between two flat plates of glass 2.5 cm wide by laying one on top of the other and placing a small slip of paper 1.0 mm thick between their edges at one end. You illuminate the glass plates with normally incident monochromatic light of unknown wavelength. Observing the reflection, you see dark fringes at both ends of the plates. Between the ends you see three other dark fringes. What is the wavelength of the incident light?
A) 250 nm
B) 400 nm
C) 440 nm
D) 500 nm
E) 620 nm

108. You place a convex lens on top of a flat plate of glass and illuminate it with monochromatic light of wavelength 600 nm. You observe a dark circle at the center of the lens, surrounded by a series of concentric dark rings. What is the thickness of the air space between the lens and the flat glass plate where you see the sixth dark ring?
A) 3.90 µm
B) 3.60 µm
C) 1.80 µm
D) 1.95 µm
E) 2.10 µm

109. You apply a material with $n = 1.25$ to a lens ($n_g = 1.5$) to make a nonreflective coating due to destructive interference at a wavelength (in a vacuum) of 555 nm. What is the minimum thickness of the coating that you need?
A) 56 nm
B) 110 nm
C) 220 nm
D) 280 nm
E) 140 nm
110. You deposit a thin film of magnesium difluoride on a glass lens \((n > 1.60)\), reducing the reflection of yellow light, at normal incidence, to a minimum. You find that the thinnest coating that accomplishes this is 106 nm thick. The index of refraction for \(\text{MgF}_2\) for yellow light \((\lambda = 585 \text{ nm})\) is

A) 1.50  
B) 1.38  
C) 1.15  
D) 1.00  
E) 0.707

111. At normal incidence, the minimum thickness of a soap film \((n = 1.33)\) that causes constructive interference when viewed by reflected light of wavelength 400 nm is

A) 225 nm  
B) 200 nm  
C) 100 nm  
D) 750 nm  
E) 570 nm

Use the following to answer question 112.

112. The interference pattern is from a spherical lens placed on a flat reflecting surface using a monochromatic light of wavelength \(\lambda = 550 \text{ nm}\). If the distance from the center to \(A\) is 0.6 mm, the radius of curvature of the lens is

A) 41.3 cm  
B) 82.5 cm  
C) 18.7 cm  
D) 37.4 cm  
E) 26.2 cm
113. Two parallel glass plates of index of refraction $n$ are separated by an air film of thickness $d$. Light of wavelength $\lambda$ in air, normally incident on the plates, is intensified on reflection when, for some integer $m$

![Diagram of two parallel glass plates with light incident at an angle.](image)

A) $2d = m\lambda$

B) $2d = m\lambda/n$

C) $2d = mn\lambda$

D) $2d = (m + 1/2)\lambda$

E) $2nd = m\lambda/2$

114. Two flat planes of glass are laid on top of one another. The upper plane is slightly raised due to the insertion of a thin piece of paper at one end and an air wedge is thus formed. Light of wavelength 500 nm is normally incident on the glass from above and interference fringes are observed by reflection with 2.5 fringes per cm. Calculate the angle of the wedge.

A) $6.3 \times 10^{-5}$ deg

B) $1.8 \times 10^{-3}$ deg

C) $4.0 \times 10^{-4}$ deg

D) $3.6 \times 10^{-3}$ deg

E) $5.7 \times 10^{-4}$ deg

115. If a thin soap film ($n = 1.36$) reflects predominately red light (about 680 nm), then what is the minimum thickness of the soap film?

A) $1.25 \times 10^{-7}$ m

B) $6.80 \times 10^{-7}$ m

C) $2.50 \times 10^{-7}$ m

D) $5.00 \times 10^{-7}$ m

E) None of these is correct.

116. The distance between the slits in a double-slit experiment is increased by a factor of 4. If the distance between the fringes is small compared with the distance from the slits to the screen, the distance between adjacent fringes near the center of the interference pattern

A) increases by a factor of 2.

B) increases by a factor of 4.

C) depends on the width of the slits.

D) decreases by a factor of 2.

E) decreases by a factor of 4.
117. When the slits in Young's experiment are moved closer together, the fringes
A) remains unchanged.
B) move closer together.
C) move further apart.
D) are less intense.
E) none of the above

118. Two slits separated by 1.0 mm are illuminated with light of a single unknown
wavelength. The tenth bright line from the central point of the interference pattern
is observed to be at an angle of 0.34°. What is the wavelength of the light?
A) 620 nm
B) 590 nm
C) 560 nm
D) 450 nm
E) 600 nm

119. You illuminate two slits 0.50 mm apart with light of wavelength 555 nm and
observe interference fringes on a screen 6.0 m away. What is the spacing between
the fringes on the screen?
A) 4.5 mm
B) 3.3 mm
C) 6.7 mm
D) 10 mm
E) 5.0 mm

120. A narrow, horizontal slit is 0.50 mm above a horizontal plane mirror. The slit is
illuminated by light of wavelength 400 nm. The interference pattern is viewed on a
screen 10.0 m from the slit. What is the vertical distance from the mirror to the first
bright line?

A) 1.0 mm
B) 2.0 mm
C) 3.0 mm
D) 4.0 mm
E) 1.2 mm
121. Light of wavelength 500 nm illuminates parallel slits and produces an interference pattern on a screen that is 1 m from the slits. In terms of the initial intensity $I_0$, the light's intensity in the interference pattern at a point for which the path difference is 100 nm is
A) $2.62 I_0$
B) $2.87 I_0$
C) $3.08 I_0$
D) $3.31 I_0$
E) $4.39 I_0$

122. You set two parallel slits 0.1 mm apart at a distance of 2 m from a screen and illuminate them with light of wavelength 450 nm. The distance between a bright spot in the interference pattern and the dark spot adjacent to it is
A) 0.560 mm
B) 1.12 mm
C) 2.25 mm
D) 4.50 mm
E) 9.00 mm

123. Two narrow slits, their centers separated by 15 cm, are illuminated by monochromatic radiation and produce the pattern in the figure on a distant screen. The wavelength of the radiation is
A) 0.52 cm
B) 1.0 cm
C) 1.6 cm
D) 2.1 cm
E) 3.0 cm

124. In a double slit experiment, a very thin plate of glass of refractive index 1.58 is placed in the light path of one of the slit beams. When this was done, the center of the fringe pattern was displaced by 35 fringe widths. Calculate the thickness of the glass plate if the wavelength of light is 680 nm.
A) $4.1 \times 10^{-5}$ m
B) $1.5 \times 10^{-5}$ m
C) $3.0 \times 10^{-5}$ m
D) $8.2 \times 10^{-5}$ m
E) $3.8 \times 10^{-5}$ m
125. A single-slit diffraction pattern is displayed on a screen 0.900 m away from the slit. If the wavelength of the light is 600 nm and the slit is $1.50 \times 10^{-4}$ m wide, the distance from the first minimum on the right to the first minimum on the left is
A) 0.164 mm
B) 1.83 mm
C) 3.99 mm
D) 7.20 mm
E) 7.98 mm

126. The diffraction pattern of a single slit is shown in the figure. The point at which the path difference of the extreme rays is two wavelengths is

![Diffraction Pattern]

A) 1
B) 2
C) 3
D) 4
E) 5

127. An easy way to distinguish whether the fringe pattern is the result of a single slit or from a double slit is
A) the intensity for each fringe is much stronger for a single slit than a double slit.
B) the intensity for each fringe is much stronger for a double slit than a single slit.
C) the width central maximum from a single slit is twice as wide as the other wide whereas the widths of all the fringes from a double slit are about the same width.
D) that there are many more fringes from a single slit than a double slit.
E) that there are many more fringes from a double slit than a single slit.

128. The fringes are the result of

![Fringes]

A) diffraction from a single slit.
B) interference from a double slit in addition to diffraction from the two slits.
C) interference from three slits.
D) diffraction from three slits.
E) None of these is correct.
129. Suppose you observe fifteen bright fringes in the central maximum of a double-slit interference pattern. If you know that the separation of the slits $d = 0.01$ mm, you can conclude that the width of each slit is

A) 0.63 mm  
B) 1.25 mm  
C) 1.68 mm  
D) 1.88 mm  
E) 1.99 mm

130. Which of the phasor diagrams shows the first minimum for five equally spaced in-phase sources?

A) 1  
B) 2  
C) 3  
D) 4  
E) 5

131. Five coherent sources are used to produce an interference pattern. The phasor diagram shown could be used to calculate the intensity of the

A) first minimum in the interference pattern.  
B) second maximum in an interference pattern.  
C) first maximum in an interference pattern.  
D) second minimum in an interference pattern.  
E) None of these is correct.
132. You illuminate a slit 0.20 mm wide with monochromatic light of wavelength 590 nm, and focus the Fraunhofer diffraction pattern on a screen with a lens of focal length 2.00 m. The distance between the two dark fringes on each side of the central bright fringe is
A) 0.295 cm
B) 0.590 cm
C) 1.18 cm
D) 2.95 cm
E) 5.90 cm

133. The headlights of an oncoming car are 1.2 m apart. What is the maximum distance from the car at which you can resolve the lights as two sources if the diameter of the pupil of your eye is 5.0 mm and the wavelength of the light is 555 nm?
A) 8.9 km
B) 22 km
C) 4.4 km
D) 5.4 km
E) 13 km

134. The pupil of the human eye has a diameter of about 5 mm. When the wavelength of light incident on the pupil is 500 nm, the smallest angular separation of two resolvable sources is approximately
A) 1"
B) 1'
C) 1°
D) 10°
E) 1 radian

135. A diffraction grating has 5000 lines per centimeter and is 1.5 centimeters wide. When radiation is incident upon the grating a second-order maximum is observed at an angle of 37°. The wavelength of this light is
A) 400 nm
B) 600 nm
C) 900 nm
D) 1200 nm
E) 2400 nm
136. For a given grating, it is observed that a third-order line \((m = 3)\) with \(\lambda = 465.3\) nm overlaps a second-order line (has the same \(\theta\) as a line with \(m = 2\)). The wavelength of the second-order line is
A) 304 nm
B) 698 nm
C) 913 nm
D) 152 nm
E) 372 nm

137. Monochromatic light of wavelength \(\lambda\) is normally incident on a plane diffraction grating, and three rays of light (A, B, and C) are observed. Of these three rays

A) A is the first order, B is the second order, and C is the third order.
B) B is the first order, and A and C are the second order.
C) A is the zero order, B is the first order, and C is the second order.
D) B is the zero order, and A and C are the first order.
E) A, B, and C are all the first order.

138. Red light \((\lambda = 700\) nm\) is incident normally on a diffraction grating having 1000 lines/cm. A maximum is observed at a deflection angle of 12°. The order in which this occurs is
A) 1
B) 2
C) 3
D) 4
E) 5

139. A discharge tube is known to produce two spectral lines, one at 640 nm and the other at 640.4 nm. The total number of rulings that a grating must have to just resolve these lines in the second order is
A) 400
B) 800
C) 1600
D) 3200
E) 6400
140. White light is in one case dispersed by refraction on passing through a glass prism and in a second case diffracted by means of a grating. When the red component and the blue component are considered, it is found that
A) red is both refracted and diffracted at greater angles than blue.
B) blue is both refracted and diffracted at greater angles than red.
C) red is refracted at a greater angle than blue, but blue is diffracted at a greater angle than red.
D) blue is refracted at a greater angle than red, but red is diffracted at a greater angle than blue.
E) both red and blue are refracted at the same angle and diffracted at the same angle.

141. Hydrogen emits violet light with a wavelength of 410 nm and red light with a wavelength of 656 nm. A parallel beam of hydrogen light is normally incident on a diffraction grating that has 5500 lines per cm. What is the angle between the second order red line and the third order violet line that appear close together?
A) 3.62 degrees
B) 2.58 degrees
C) 4.23 degrees
D) 5.79 degrees
E) None of these is correct.

142. A parallel beam of sodium light of wavelength 589 nm is normally incident on a diffraction grating. If the second order diffraction maximum is observed at 50.25 degrees to the normal, then calculate the number of lines per cm of the grating.
A) $5.69 \times 10^5$ cm$^{-1}$
B) $1.53 \times 10^6$ cm$^{-1}$
C) $6.53 \times 10^3$ cm$^{-1}$
D) $1.31 \times 10^6$ cm$^{-1}$
E) $1.31 \times 10^4$ cm$^{-1}$

143. The yellow line of a Sodium lamp is two lines very close together at $\lambda_1 = 589.592$ nm and $\lambda_2 = 588.995$ nm. If a diffraction grating has to resolve the first order diffraction lines by an angular separation of 0.1°, what is the least number of lines per cm for the diffraction grating?
A) $12,400$ cm$^{-1}$
B) $13,600$ cm$^{-1}$
C) $14,700$ cm$^{-1}$
D) $15,300$ cm$^{-1}$
E) $16,700$ cm$^{-1}$
Answer Key - practice questions for chapters 31-33

1. A
2. B
3. C
4. A
5. B
6. C
7. A
8. C
9. C
10. B
11. C
12. C
13. A
14. B
15. D
16. C
17. B
18. A
19. A
20. E
21. D
22. C
23. A
24. D
25. A
26. B
27. C
28. B
29. A
30. D
31. C
32. B
33. E
34. D
35. D
36. B
37. A
38. B
39. D
40. C
41. C
42. D