AP Physics Multiple Choice Practice – Waves and Optics – ANSWERS

SECTION A – Waves and Sound

	Solution	Answer
1.	Based on the formula $v = \sqrt{\frac{F_t}{m/l}}$	C
2.	The given diagram is the 3rd harmonic at 60 Hz. That means the fundamental is 20Hz. The other possible standing waves should be multiples of 20	A
3.	A fact, sound cannot be polarized since its longitudinal	C
4.	Use T = 1/f	E
5.	Frequency and wavelength are inverses	A
6.	From diagram, wavelength = 0.5 m. Find the frequency with v = f λ	D
7.	After waves interfere they move along as if they never met	B
8.	For an open–open pipe the harmonic frequency is given by. $f_n = \frac{nv}{2L}$ with n=1	C
9.	Based on $v = \sqrt{\frac{F_t}{m/l}}$ 4x the mass gives ½ the velocity	A
10.	Speed of sound is 340, use v = f λ	A
11.	When sound travels into less dense medium, its speed decreases (unlike light) … however, like all waves when traveling between two mediums, the frequency remains constant. Based on v = f λ, if the speed decreases and the frequency is constant then the λ must decrease also.	B
12.	Doppler effect. Since the passenger is on the train moving with the sound, the frequency is unaltered, but since the sound is moving away from the station, people at the station should hear a lower frequency.	E
13.	Open–closed pipes only have odd multiples of harmonic so next f is 3x f_1	E
14.	For a given medium, speed is constant. Doubling the frequency halves the wavelength	D
15.	Using $f_n = \frac{nv}{2L}$ with n = 1, solve for L	B
16.	The fourth overtone is the fifth harmonic, 5 x the fundamental.	D
17.	Determine each separate frequency using the speed of sound as 340 and v = f λ. Then subtract the two frequencies to get the beat frequency.	B
18.	Step the two pulses through each other a little bit at a time and use superposition to see how the amplitudes add. At first the amplitude jumps up rapidly, then the amplitude moves down as the rightmost negative pulse continues to propagate. At the very end of their passing the amplitude would be all the wave down and then once they pass the point will jump back up to equilibrium	C

19. Cx is only ¼ of a wavelength. To make a full wavelength you would need 4x the current length — E

20. Wavelengths of each are (dist/cycle) … 4L, 4/3 L, 4/5 L, L, 2/3 L … — D
Frequencies are $f = v/\lambda$.
v/4L, 3v/4L, 5v/4L, v/L, 3v/2L … Oy is 2x Cy

21. f = cycles / seconds — E

22. To use $v = f\lambda$, you also need the λ — D

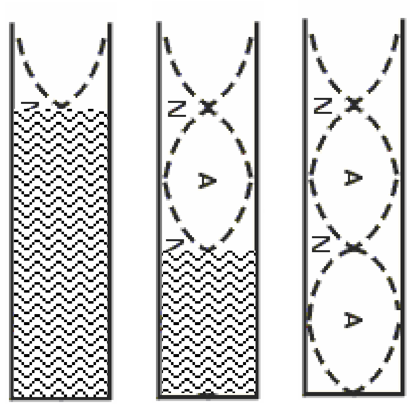
23. T = 1/f — E

24. To produce pipe harmonics, the ends are always antinodes. The first (fundamental) harmonic is when there are two antinodes on the end and one node in-between. To move to each next harmonic, add another node in the middle and fill in the necessary antinodes. (ex, 2nd harmonic is ANANA … So the 4th harmonic would be ANANANANA and have four nodes. *Alternative solution … if you know what the harmonics look like you can draw them and manually count the nodes.* — C

25. The Fundamental is given by $f_n = \frac{nv}{2L}$ (n=1), and the velocity is given by $v = \sqrt{\frac{F_t}{m/l}}$. — B

2x the density means 2x the m/L so that the velocity of the second string is smaller compared to the first string by $v_2 = v_1 / \sqrt{2}$. The first string length is $L_1 = 2f/v_1$, the second string length is $L_2 = 2f/(v_1 / \sqrt{2})$. So comparing the two we have $L_2 = L_1 / \sqrt{2}$

26. This is an open–closed pipe. Look at the harmonics shown below. Since the same tuning fork is used in each case, the frequency for all of them is the same, and since they all travel at the same speed with equal frequencies, the wavelength of each wave is also the same (though each has a different number of wavelengths fitting in the tube, the 'wavelength' of each is same). But, the lengths of the tubes vary using the water to make each successive harmonic and fit the necessary numbers of wavelengths in each tube. — C



Looking at the diagrams, we can see that each harmonic is ½ a wavelength longer than the next, regardless of which ones we are looking at. We don't have to know which harmonics we are looking at if we know the difference between any two of them because each harmonic has the same difference of ½ λ. So the difference in length between any two consecutive harmonics is equal to ½ the wavelength of the wave. $\Delta L = ½ \lambda$. Using this relationship, we have:

(65 cm – 39 cm) = ½ λ
λ = 52 cm

Now using $v = f\lambda$ we have 343 = f (0.52) → the frequency of the wave is 659.6 Hz.

27. Definition of a node — B

28. Since the medium stays the same the speed remains constant. Based on $v = f\lambda$, for constant speed, f and λ change as inverses. — E

29. Similar to problem 26, we should look at the harmonic shapes open–open vs open–closed. D

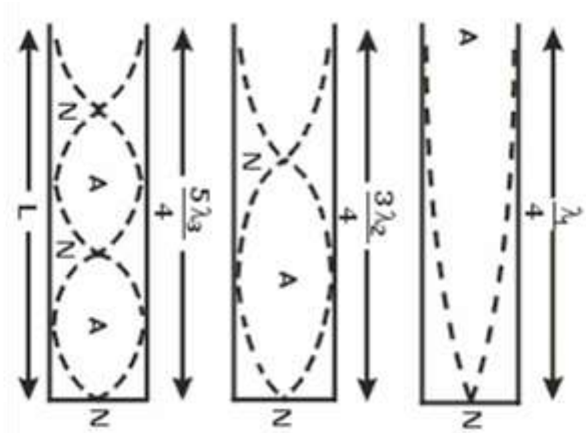
L_1 L_2

Comparing the fundamental harmonic of the open–open pipe to the closed–open pipe. The closed–open pipe should be half as long as the open–open pipe in order to fit the proper number of wavelengths of the same waveform to produce the given harmonic in each.

30. Two antinodes by definition will be ½ λ apart. So 20 cm = ½ λ, and the λ = 40 cm. Then using v = f λ we have 1200 = f (40) D

31. This is similar to question 26, except now the length of the tube remains constant and the wave is changing within the tube to make each successive waveform (this would be like using different tuning forks each time for the same tube). The diagrams would look like this now: E

5 3 1



Each λ is given by λ = dist / cycle
So
$\lambda_1 = 4L$
$\lambda_3 = 4/3\ L$
$\lambda_5 = 4/5\ L$

32. Doppler effect. The waves at right are compressed because the object is moving right. However, the waves are moving faster than the object since they are out in front of where the object is. B

33. The Fundamental is given by $f_n = \frac{nv}{2L}$ (n=1), and the velocity is given by $v = \sqrt{\frac{F_t}{m/l}}$. B

Doubling the tension, changes the speed to √2 v comparatively, and makes the frequency increase by the same amount.

34. The time to make 1 cycle, is also the time it takes the wave to travel 1 λ. A

35. Superpose the two waves on top of each other to get the answer. B

36. Use the Doppler equation B

$$f' = f\frac{(v \pm v_{obs})}{(v \mp v_{src})}$$

where $v = v_{snd}$ and we use the top signs of the denominator and numerator equation since we are moving towards the observer. The observer is not moving so $V_{obs} = 0$

f’ = 100Hz (330)/(330-30) = 110 Hz

37. This diagram is associated with beats. The increasing and decreasing amplitude caused by interference oscillates the volume up and down which creates the beat sound. — A

38. Based on the diagram, the λ is clearly 2m. Plug into v = f λ. — D

39. The diagram shows the second harmonic in the string. Since harmonics are multiples, the first harmonic would be half of this. — B

40. Simple fact — A

41. A fact about the Doppler effect. Can also be seen from the Doppler equation. — C

42. Use superposition and overlap the waves to see the resultant. — A

43. When hitting a fixed boundary, some of the wave is absorbed, some is reflected inverted. The reflected wave has less amplitude since some of the wave is absorbed, but since the string has not changed its properties the speed of the wave should remain unchanged. — B

44. Clearly at point C the waves are compressed so are more frequent. — C

45. Harmonics are multiples of the fundamental so the fundamental must be f/2. — B

46. Based on the Doppler effect, only speed matters. The faster a vehicle is moving, the closer together the sound waves get compressed and the higher the frequency. Take the case of a very fast vehicle traveling at the speed of sound; the compressions are all right on top of each other. So faster speed means closer compressions and higher frequencies. Choice I must be true because X is a higher frequency so must be going faster. Distance to the person affects the volume but not the pitch so choice II is wrong. III seems correct but its not. It doesn't matter whether you are speeding up or slowing down, it only matters who is going faster. For example, suppose truck X was going 5 mph and speeding up while truck Y was going 50 mph and slowing down, this is an example of choice III but would not meet the requirement that X has a higher frequency because only actual speed matters, not what is happening to that speed. — A

47. By inspection. — A

48. By inspection, the λ is 10 cm. f = 1 / T = 5, Then use v = f λ. — C

49. Based on $v = \sqrt{\frac{F_t}{m/l}}$, the tension changes the speed. Then based on $f_n = \frac{nv}{2L}$, this resulting speed change will effect the frequency also. But since the frequency increases in direct proportion to the speed, and v = f λ, the λ should remain unchanged. — C

50. This is the same as question 26. The length change corresponds to a ½ λ increase in length. ΔL = ½ λ … 0.5 = ½ λ … λ = 1 … then use v = f λ and solve for f. — C

SECTION B – Physical Optics

	Solution	Answer
1.	Using $m \lambda = d \sin \theta$, the value of $\sin \theta$ is the same for both sources since the location of the spot is the same, but the first source is at m=2, and the second source is at m=3. Equating $d \sin \theta$ for each gives $m_1 \lambda_1 = m_2 \lambda_2$ … $(2)(660) = 3 (\lambda_2)$ … $\lambda_2 = 440$ nm.	D
2.	Based on $m \lambda = dx / L$ we want to increase x. Only II does this.	B
3.	1000 lines/cm gives a line spacing d = 1/1000 cm/line = $1\text{x}10^{-5}$ m/line. $\lambda = 7\text{x}10^{-7}$ m. With diffraction gratings, we usually assume the small angle approximation does not work, so we find θ then use the geometry with tan θ or another trig function to find Y. Do this for each spot. m=1. $m \lambda = d \sin \theta$ $(1)(7\text{x}10^{-7}) = (1\text{x}10^{-5}) \sin \theta$ $\theta = 4.01°$ … tan θ = o/a … $Y_1 = 0.14$ m Repeat for m=3 … $Y_3 = 0.43$ m. Subtract $Y_3 - Y_1$ to find the distance between = 0.29 m *Note: Since the angle θ here actually came out to be small, the x/L small angle approximation could be used and the spacing x between spots could be assumed to be equal as well, so you could simply find x for the first spot and double it to find the spacing 1 to 3.*	B
4.	Single slit. With the given values, we can see the angle is small so we can use the small angle approximation and apply $m \lambda = dx / L$. Recall for single slits, the first maximum off center is at x=1.5 unlike double slits.	C
5.	From $m\lambda = dx / L$, d x2 needs L x2 also.	D
6.	Single Slit. Again based on the given values we can see the angle is small so we can use $m\lambda = dx / L$ … dark spot at m=1. Note: use L=100 cm to get an answer in cm.	D
7.	Radio wave is EM and travels at light speed. Use $c = f \lambda$ and solve.	A
8.	Radio wave is EM and travels at light speed. Use $c = f \lambda$ and solve.	B
9.	$\lambda = 4*4.5$, Radio wave is EM and travels at light speed. Use $c = f \lambda$ and solve.	C
10.	It travels at light speed and takes half the total time to travel the distance one way. Use v=d/t. Convert the time to seconds, find the distance in meters, then convert that to km.	B
11.	λ changes the opposite of frequencies (high freq = low λ) … based on this and knowledge of the EM spectrum, the answer is E.	E
12.	By definition, when the path difference equals ½ λ or any odd multiple of ½ λ's for sources of the same λ, there will be destructive interference.	D
13.	Using path diff = m λ, with m=1.5 for the 2^{nd} min, we have 4.5 cm = (1.5) λ.	D
14.	5000 lines/cm gives a line spacing d = 1/5000 cm/line = $2\text{x}10^{-6}$ m/line. Then use $m \lambda = d \sin \theta$, with m = 1 for the first max.	C
15.	Based on $m \lambda = dx / L$ we want to increase x. d is separation of slits and less d means more x	D
16.	Using $m\lambda = d \sin \theta$ … $(1)(0.02) = d (0.1)$	E
17.	Fact about single slits.	B

18. Known facts about the EM spectrum. B

19. Radar wave is EM and travels at light speed. Use $c = f\lambda$ and solve. E

20. Since the slits are narrow, we can use $m\lambda = d \sin\theta$, but since θ is clearly large we cannot use the x/L small angle approximation. From the given diagram, the geometry shows $\sin\theta = o/h = 3/5$ .. rather than finding θ, we will just use this value for $\sin\theta$ and plug in … D
$m\lambda = d \sin\theta$ … $(1)(0.12) = d(3/5)$

21. Radio waves are EM and travels at light speed. Use $c = f\lambda$ and solve. C

22. This is still a double slit pattern because there is still light making it through both slits. One of the light sources has reduced its amplitude; which means when it meets the second light source it will cause less interference than it originally did. This means less constructive interference and less destructive interference also. So bright spots become less bright, and dark spots become brighter. E

23. From the first scenario given. We can determine the angle of the first spot using $\tan\theta = o/a$. $\tan\theta = 10 / 100 = 5.71°$. The problem says the remaining spots are spaced equally, which is a rough approximation. The angles are relatively small, but if we wanted to get accurate results we should find each spacing with $d \sin\theta$, but, this is just an approximation for the first few spots. When the screen is moved closer, the angle of the light leaving the grating will not change, but the spacing on the screen will decrease. Think about a diagram of this setup and it is clear that this must be true. Based on $\tan\theta = o/a$ with the same angle θ but the adjacent side changed to 30 cm, we get a new location of the first spot at 3 cm, so the other spots will also approximately be located 3 cm apart as well for relatively small angles. C

SECTION C – Geometric Optics

	Solution	Answer
1.	Definition of critical angle.	D
2.	Using the math, $1/f = 1/d_o + 1/d_i$, and $M = -d_i / d_o$ … d_i +0.6 $M = -3$ …	C
3.	Plane mirrors always makes virtual, same size, upright images.	E
4.	Fiber optics involves reflecting light in a fiber strand as the light carries the signal along the fiber.	E
5.	Fact about diverging lens.	E
6.	Use $n_1 \lambda_1 = n_2 \lambda_2$	D
7.	More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's.	D
8.	If you look carefully you can see these are both 3–4–5 triangles and are also the same triangle flipped. The hypotenuse of each is 1.5 m. Using the sides of the triangles, we have $\sin \theta_1 = o/h = 0.8/1.5$ for the bottom triangle, and $\sin \theta_2 = o/h = 1.2/1.5$ for the top triangle. Now use $n_1 \sin \theta_1 = n_2 \sin \theta_2$ … $n_1 (0.8/1.5) = (1)(1.2/1.5)$ … $n_1 = 1.2/0.8 = 3/2 = 1.5$	B
9.	Less–More bend towards. But it can't be E because that would only happen if the incoming angle was also 0.	D
10.	The lens shown has thick in the center and thin on the outside which makes a converging lens. In converging lenses, all of the real images are inverted and can be any size, but the virtual images are formed in a magnifying lens scenario and are always larger and upright.	E
11.	A horizontal beam approaching a converging lens bends and converges through the focal point.	E
12.	More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's.	E
13.	Assuming total internal reflection didn't happen, More–Less dense bend away.	C
14.	Need a magnifying glass which is choice B.	B
15.	Use $n_i \sin \theta_c = n_r \sin (90)$, $n_r=1$ … $n_i = 2$, then $n = c / v$ to find v.	B
16.	Generally when we go from more–less we should always check the critical angle first rather than assuming the ray will refract and bend away. Choice D might be correct, but not until we first check the critical angle for total internal reflection. Use $n_i \sin \theta_c = n_r \sin (90)$, $n_i=1.5$, $n_r=1$ $\theta_c = 41.8°$. Since our incoming angle (60) is larger than the critical angle, total internal reflection will occur and you will get choice E.	E
17.	Using the math, $1/f = 1/d_o + 1/d_i$, and $M = -d_i / d_o$ … d_i +20 $M = -1$ …	A
18.	When light from multiple locations pass through a given part of a lens to form an image, only a small portion of a lens is needed to form the image. The more of a lens, the more light rays that can be bent by it to each image location. This simply makes the image brighter. By covering half the lens, all of the incoming rays still bend all the same ways but there are less total rays being bent to given locations on the image so it is dimmer. This can easily be seen by looking at a lens that has only horizontal rays approaching it. All of these rays converge to the focal point; covering a portion of the lens still focuses the rays on the focal point, just less of them.	A

19. Fact for refraction problems. A

20. Fact about specular reflection. A

21. More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's … this shows that $n_2 > n_1 > n_3$. More n means less speed so $v_3 > v_1 > v_2$ A

22. It's a diverging lens so light bends away from what the horizontal path would be without the lens. C

23. The focal point is = R/2. Then use the math $1/f = 1/d_o + 1/d_i$ … and $d_i = 10$ C

24. From n=c/v. $n_1 = c/v_1$ … $1.5 = c / v_X$ … $v_X = c / 1.5$ C
$n_2 = c/v_2$ … $2.0 = c / v_Y$ … $v_Y = c / 2$

The problem defines $v_Y = v$
So $v = c/2$, $c = 2v$ … then subbing that into the v_x equation we have $v_X = (2v) / 1.5 = 1.33$ v

25. First find the λ in the film. $n_{air}\ \lambda_{air} = n_{film}\ \lambda_{film}$ … $(1)(600) = (1.5)\ \lambda_{glass}$ … $\lambda_{glass} = 400$ nm B
As the light travels through the two boundaries, you get a ½ λ phase shift (flip) at the first boundary but no shift at the second boundary. Therefore, you need to make another ½ λ of phase difference total by traveling in the film thickness to produce constructive interference to reinforce the orange wavelength. When the glass thickness is ¼ of the λ in the glass, the light will travel up and down to make the extra ½ λ needed. So ¼ of the λ in the glass gives you 100 nm thickness needed.

26. Do the math twice. For the first lens. $1/f = 1/d_o + 1/d_i$ … $d_i = +\ 14$ cm (real). So this first 'pre–image' is formed 14 cm to the right of the first lens, which means it is 16 cm from the second lens. Now redo the math using this 'pre–image' as the object located 16 cm away from the second lens. $1/f = 1/d_o + 1/d_i$ … $d_i = +\ 26.67$ cm. C

27. Use $n_i \sin \theta_c = n_r \sin (90)$, diamond into air, so n_r=1 … $(2.42) \sin \theta_c = (1) \sin (90)$ … $\theta_c = 24.4°$ D

28. Fact about chromatic aberration. B

29. The magnification is M=2. Using $M = -\ d_i / d_o$ … $d_i = -\ 2d_o$ Lets assume a value of $d_o = 10$, then $d_i = -\ 20$, and from $1/f = 1/d_o + 1/d_i$, the focal point is 20. Now redo the math with the focal point for the diverging lens being negative and the new $d_i = -6.67$, giving a new M=0.67 C

30. Use $n_i \sin \theta_i = n_r \sin \theta_r$, air to water and find θ_r. That θ_r is the θ_i for the second water to glass interface. Then do $n_i \sin \theta_i = n_r \sin \theta_r$, water to glass and find θ_r E

31. Use $n_i \sin \theta_i = n_r \sin \theta_r$, air to material to find n of the material. Then redo the problem with θ_r as the unknown and solve for θ_r. B

32. A convex lens is a converging lens. When the object is in front of the focal point, it acts as a magnifying glass. A

33. Similar to question 25, except both boundaries undergo phase shifts, so 1 full extra wavelength is needed using the soap thickness. This requires the thickness to be ½ λ_{soap} giving the answer. B

34. Frequency are period are inverses. A

35. Draw ray diagrams for each, or make up numbers and do the math for each to see which works. D

36. When traveling between mediums, sound behaves opposite from light. As given in the problem the sound travels faster in the denser rock. When the sound speeds up, the wavelength increases and the frequency stays the same. D

37. This is a fact. B

38. The defect in a lens is chromatic aberration. C

39. Diverging lens always produces the same object type no matter what. B

40. The transmitted wave never has a phase change, but hitting the more dense block causes the reflection to flip 180 degrees. E

41. More–Less dense bend away, Less–More dense bend towards. The more the bend, the bigger the difference in n's … this shows $n_2 > n_1 > n_3$. More n means less speed, so $v_3 > v_1 > v_2$ but this is not a choice. Speed goes with wavelength, the larger the speed the more the λ, so $\lambda_3 > \lambda_1 > \lambda_2$ E

42. Based on various ray diagrams drawn with the object behind the focal point, the image is always real but its size depends on where it is in location to the focal point. B

43. First determine the λ_{film}. $n_1 \lambda_1 = n_{film} \lambda_{film}$ … $(1)(640) = (1.33) \lambda_{film}$ … $\lambda_{film} = 481$ nm. C

When the wave reaches each boundary is undergoes a ½ λ phase shift at each boundary so this essentially cancels out the phase shift. To not reflect any light, we want to have destructive interference. In order to get destructive interference we need to get a total of ½ λ or 1 ½ λ or 2 ½ λ … phase differences from moving in the film thickness. These phase differences require a thickness equal to $\frac{1}{4}\lambda_{film}$, $\frac{3}{4} \lambda_{film}$, $5/4\ \lambda_{film}$ … 360 nm thickness matches the $\frac{3}{4}\lambda_{film}$ possibility.

44. Longitudinal waves cannot be polarized A

45. For air–film–glass of progressively increasing index, to produce destructive interference we need ¼ of a wavelength in the coating. See question 43 for the reason. A

46. First use $n_i \sin \theta_i = n_r \sin \theta_r$ To find n_r. Then use $n = c / v$ to find v. B

47. Use $n_1 \lambda_1 = n_2 \lambda_2$ $(1)(500) = (1.25) \lambda_2$ B

48. For all three diagrams, there is a ½ λ phase shift when entering the film but no phase shift when exiting. To produce constructive interference, a total extra phase different of ½ λ from moving in the film thickness is needed so odd multiples of ¼ λ will produce constructive interference. A

49. $n_i \sin \theta_c = n_r \sin (90)$ $n_i \sin (30) = (1)$ $n_i = 2$ E

50. Draw a ray diagram. E

51. A magnifying glass is a lens, and is produced by a converging lens. It is virtual. A

52. All light waves are EM and travel at light speed. E

53. Using the math, $1/f = 1/d_o + 1/d_i$, and $M = -d_i / d_o$ … $d_i = -0.10$ m, $M = +0.33$ D

54. Converging lenses make real images but they are always inverted. D

55. When in front of the focal point of a converging lens, it acts as a magnifying glass. The other optical instruments can never make larger images. A

56. Using the math, $1/f = 1/d_o + 1/d_i$, $d_i = -60$, since its virtual, the image is on the same side as the object which is why it is in the left. You would look through this lens from the right side. A

57. A fact about refraction problems, the angles going one way would be the same as the angles going to other way assuming total internal reflection does not occur. E

58. Converging lenses have centers that are thick and top and bottom parts that are thinner. B

59. In flat (plane) mirrors, the image is simply flipped to the other side of the mirror. E

60. Choice I. is true because a soap bubble is a thin film. The colors produced are due to the reinforcement of different λ colors due to variations in the thickness of the soap bubble. In order to see these interference results, the thickness of the film must be similar in magnitude to the wavelength of the light. Since the film is so small, this shows that light has a very small wavelength. Choice II. also shows light has a very small wavelength because a diffraction grating has very tiny slits in it and to produce the pattern seen the wavelength of the light has to be on a similar scale as the size of the openings. Choice III. is not true because all waves regardless of their wavelength bend and it does not reflect on their wavelength size. C

61. From practicing ray diagrams, this should be known. Or a sample could be done to determine it. Mathematically this can be shown by using an extreme example. Suppose $d_o = 1000$, and $f = 10$. Using the lens equation, $d_i = 10.1$. Then decrease d_o down to 20 and $d_i = 20$. So for the range of values of d_o larger than 20, the image distance will fall between 10–20 which is between f and 2f. D

62. Light from a distant star is assumed to be all horizontal. Horizontal light hitting a concave mirror will all converge at the focal point to form an image of the star directly on the focal point. With a radius of curvature = 1m, the focal point is 0.5 m. B

63. When light goes in higher indices of refraction, it slows down. Since $v = f\lambda$ and f remains constant, when v decreases λ decrease with it. E

64. Using the math, $1/f = 1/d_o + 1/d_i$, $d_i = -18$ … then $M = -d_i / d_o$ … $M = 3$ D

65. Draw the ray diagram, or makeup some numbers and do the math. D

66. If the angle in equals the angle out in a 3 tier medium arrangement, then the substances on the outsides must be the same. A

67. The larger the difference between n's the more the rays bend. When the water is added, the difference between n's is less so the amount of bending is less. E

68. In a flat mirror, the image can be found by flipping the object to the other side, basically folding it over the mirror onto the other side. D

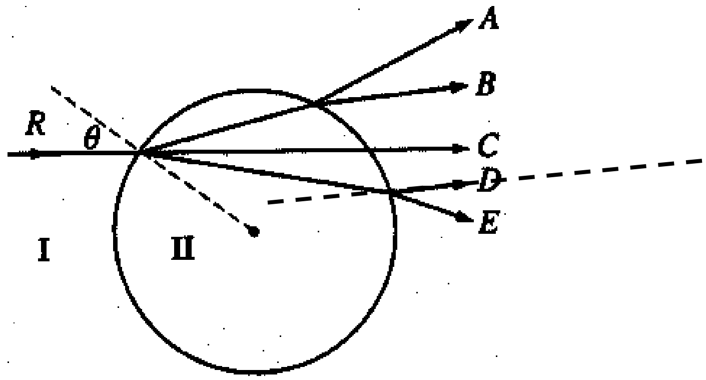
69. The focal point is half the center of curvature. B

70. When an object is placed in front of the focal point of a converging lens, the lens acts as a magnifying glass. A

71. All waves demonstrate interference. E

72. The film has a higher n compared to both sides, such as soap surrounded by air. So as the light ray hits the first boundary it makes a ½ λ phase flip, but does not make the flip at the second boundary. To be constructive, we need to cover a total of ½ λ extra phase shift due to traveling in the film thickness. So the thickness should be $\frac{1}{4}\lambda_{film}$. E

73. Medium I (air) is surrounding the sphere on both sides. As it enters the sphere, it goes less–more so bends towards the normal line (leaving D or E as the possibly answers). When the ray reaches the far edge of the sphere, it goes from more–less so should bend away from the normal line. Note the normal line drawn below. E



74. This should be the opposite of the scenario in the last question. A

75. Using the math, $1/f = 1/d_o + 1/d_i$, $d_i = 2.67$. E

76. Same as question 18. D

77. All waves demonstrate the listed choices. E

78. Bending of a wave (refraction) is due to the speed change at an angle. The more the speed change, the more the bending. Hence, the violet bends more so must have a larger speed change (more slowing), so the red is faster. *Additionally, we can note that since the violet slows and bends more, the index of refraction in glass for a violet light is higher than the index for a red light.* B

79. Based on the law of reflection, the angle of reflection must be the same as the incoming angle. When the light enters the ice it is going more–less so bends away from the normal. This means that θ_r is larger than θ_i. A

80. Using the math, $1/f = 1/d_o + 1/d_i$, $d_i = -1.2$. Its virtual so its on the same side as the object, which puts the image on the left side of the lens. A

81. This is a magnifying glass, which can be memorized or the math can be done to prove the answer. D

82. The time for the sound to travel the one way distance to the shore is half of the total time (6/2 =3 sec). Then use v= d /t to determine the distance. C

83. From the diagram, the angle at the bottom of the small top triangle is 30° so when we draw the normal line on that slanted interface, the angle of incidence there is 60°. We are told this is the critical angle which means the angle of refraction of the scenario is 90°. Now we use C

$$n_i \sin\theta_c = n_r \sin(90) \quad \ldots \quad n_i \sin(60) = (1)(1) \quad \ldots \quad n_i = 1/\sin 60 \quad \ldots \quad n_i = \frac{1}{\left(\frac{\sqrt{3}}{2}\right)}$$

Rationalizing gives us the answer.