Physics 1CH, Spring 2022

Sample Concept Questions II + Answers

For each question, you need to explain your answer.

1) A watchmaker uses diverging eyeglasses for driving, no glasses for reading, and converging glasses in occupational work. Is the watchmaker nearsighted or farsighted? Explain.

Nearsighted. *A person who is nearsighted cannot see objects well at a distance and needs a diverging lens to provide correction. For reading the object is relatively close and nearsighted people can read without glasses. For watchmaking work, the object is very close and thus a magnifying class (converging lens) is needed.*

2) True or False? Chromatic aberration can occur in simple lenses, but not in ordinary mirrors. Explain your answer - i.e. if true, you need explain why chromatic aberration occurs in one but not the other; if false, you need to explain why it is false.

True. Chromatic aberration occurs in lenses because of dispersion, or the change in index of refraction with wavelength. This leads to a change in the focal length of a lens with wavelength. Mirrors make use of reflection which does not depend on the index of refraction and hence the focal properties of a mirror do not depend on wavelength and there is no chromatic aberration.

3) True or False? Longitudinal waves, such as sound, cannot be polarized.

True. *Polarization describes the orientation of a transverse disturbance. For a longitudinal wave, the disturbance is along the direction of propagation and there is no variation in the orientation. (In certain circumstances, e.g. in certain solids, transverse sound waves can exist and could, in principle, be polarized, but the answer to this question remains the same).*

4) Can a standing wave be produced on a string by the superposition of two waves traveling in opposite directions with the same frequency but different (absolute) amplitudes? Why or why not? Can a standing wave be produce by the superposition of two waves traveling in the opposite directions with different frequencies but the same (absolute) amplitude? Why or why not?

a) Different amplitudes: ***no, a standing wave cannot be produced***. *The two waves will not completely cancel each other to make nodes (stationary points) that are required in a standing wave.*

b) Different frequencies: ***no, a standing wave cannot be produced***. *You will get a beat pattern and the beat envelope will travel, so again no nodes.*

5) True or False? Since a standing wave does not travel, it is not truly a wave and does not satisfy the wave equation.

False. *A standing wave is a wave and it does satisfy the wave equation. Standing waves occur from the superposition of equal-amplitude right and left moving traveling waves. Since the right* *and left waves satisfy the wave equation, their sum does as well. A standing wave is not a traveling wave.*

6) Two closely spaced flashlights shine on a screen some distance away. True or False? The main reason why we do not see an interference pattern on the screen is because we need monochromatic light to make such patterns. Explain your answer and, if false, discuss what the main reason is.

***False**. The main reason we do not see an interference pattern is because the two sources of light are not coherent. Two coherent white light sources will create an interference pattern, as Young originally demonstrated.*

7) True or False? The beat frequency between two sound waves of nearly equal frequencies equals the difference in the frequencies of the individual waves.

***True**. The beat frequency is what you would hear and is equal to the difference of the two component frequencies. The beat frequency is twice the modulation frequency.*

8) You have two radio antennas that emit linearly polarized EM waves of the same frequency and same polarization. The antennas emit at the same power and their emission is in-phase. You stand at location P that is equidistant from both antennas and measure the irradiance. Then, one antenna is changed to emit a wave polarized orthogonal to the other antenna. What happens to the irradiance you measure at location P? Does it: a) increase, b) decrease, or c) stay the same? Explain your answer and, in the case of a) or b), estimate the relative change in the irradiance.

***The answer is b) decrease**. Let E_0 (I_0) be the E-field amplitude (irradiance) measured from either source. In the initial configuration, we add two E_0 phasors in phase to get 2 E_0 and hence 4 I_0 for the irradiance. In the final configuration, we add two E_0 phasors out of phase by 90^o to get sqrt(2) E0 or 2 I_0 for the irradiance. **The irradiance decreases by a factor of two**.*

9) Imagine a soap bubble formed in air. As the bubble is just about to pop (i.e. as its thickness goes to zero), will the reflected light appear bright, dark, or neither of these? Explain your answer.

***Dark.** For a soap bubble in air, there is a relative phase shift of π between the rays reflecting off the top side and back side of the bubble. Thus, for very thin films ($d \rightarrow 0$), there is no physical path difference between the two rays and the two rays simply have a phase difference of π, which means destructive interference or dark on reflection.*

10) True or False? The speed of sound at an air temperature of 20^o C is twice that at an air temperature of 5^o C.

***False**. When calculating the speed of sound the absolute temperature is needed. Here, the speed of sound at 20^o C would be1.027 times the speed at 5^o C.*

11) In the Mexico City earthquake of September 19, 1985, areas with high damage alternated with areas of low damage. Also, buildings between 5 and 15 stories high sustained the most damage. Provide some possible reasons why these effects occurred.

For example, see:

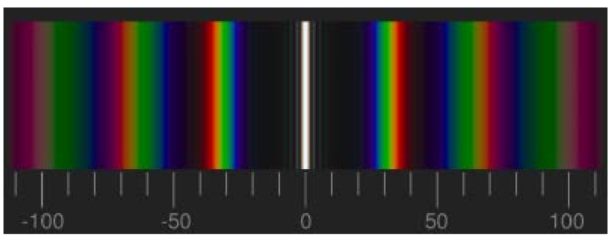
Link1

Link2

The earthquake set up standing waves (resonance) where some regions were nodes (very little amplitude of vibration) and other regions were anti-nodes (large amplitude). Thus, regions of high damage alternated with regions of low damage. Near the anti-nodes, the wave had a characteristic frequency or wavelength of compression/expansion. This wavelength was comparable to the scale of 30-40 m, which corresponded to buildings of the height mentioned.

12) A student is working with a double-slit interference experiment. Instead of using light of a single wavelength, a light source having wavelengths of 400 nm, 500 nm, and 600 nm is used. Describe the interference pattern you would see on the screen, if any. You can assume that the light hitting the two slits is coherent and has the same linear polarization.

You would see an interference pattern. The center would be a maximum for all wavelengths - i.e. a white fringe. Away from the center, you would see separate bright fringes, first blue (400 nm), then green (500 nm) and then red (600 nm). The center would also be brighter than the fringes on the side. The figure below shows white light interference but the basic pattern is the same as in this problem.



13) In what way is a widely separated pair of small radio telescopes superior to a single large one? In what way is it inferior?

With two telescopes you can do interferometry and get high angular resolution (here the resolution depends on the baseline between the telescopes). With a single large telescope you collect more light and can see fainter objects (i.e. more distant objects).

14) In single-slit diffraction, what is the effect of increasing: a) the wavelength of the light used and b) the slit width?

Increasing the wavelength will broaden out the pattern on the screen – i.e. the main diffraction peak on the screen will extend to larger angles. Increasing the slit width will shrink the pattern on the screen.

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Sample Problems II + Answers

Numerical answers can be given to two significant figures.

1) Physics student Chuck moonlights as a security guard at a retirement community. While he is driving slowly through the community, he turns on the car siren for fun. The siren operates at a characteristic frequency of 600 Hz. As he approaches a reflective wall directly in front of him, Chuck hears a sound pattern having 18 beats per second. How fast is he going in km/hr? (Make sure to state the physics principles involved and to show your work).

***The physics principles are Doppler shift and beats**. A key point is that there are two Doppler shifts - the car emits f_0, the wall sees f' and Chuck in the car receives f''. Take speed of sound v = 340 m/s and let v_c be the speed of the car. The numbers are: f_0 = 600 Hz, f'' = 618 Hz (because the beat frequency is 18 Hz). Writing down the two Doppler shifts, you can express f'' in terms of f_0, both of which you know. From this you can solve for **v_c = 5.025 m/s or 18.1 km/hr**. The intermediate f' = 609 Hz.*

2) Consider two point sources, S1 and S2, that emit waves of the same frequency and amplitude (A). Assume that the waves are emitted in phase and that this phase relation at the sources is maintained over time. Consider a point P a distance r_1 from S1 and r_2 from S2, where r_1 is nearly equal to r_2.

(a) Derive an expression for how the amplitude of the superposition of these two waves varies with the position P (i.e. as a function of r_1 and r_2).

Write down the two waves $\Psi_1 = (A/r_1)\cos(kr_1-\omega t)$ and $\Psi_2 = (A/r_2)\cos(kr_2-\omega t)$, and add them. Use the trig identity for the sum of cosines and take $r \sim r_1 \sim r_2$ in the denominator. The spatially varying portion of the sum of the two waves is:

$$\Psi_{tot} = (2A/r) \cos [k/2 (r_1-r_2)]$$

(b) Determine the locations of P where there is total constructive interference and total destructive interference. What is the shape of the locus of points of constructive interference?

You get total constructive interference when $r_1-r_2 = 2n\lambda$ for n an integer. The locus of points that have a fixed difference in distance between two points describe a hyperbola.

You get total destructive interference when when $r_1-r_2 = 2(n+1/2)\lambda$ for n an integer. The locus of points that have a fixed difference in distance between two points describe a hyperbola.

(c) What happens at points P where r_1 and r_2 are not approximately equal?

Here you get only partial cancellation - neither total construction nor total destruction. The reason is that A/r_1 is no longer approximately equal to A/r_2 and you no longer have complete cancellation when you add the contributions from the two sources.

3) Natural light of irradiance 3.0 W/m^2 is incident on two polarizing filters whose transmissions axes make an angle of 60^o. What is the irradiance of the light transmitted by both filters?

Let the initial irradiance be I_0 = 3.0 W/m^2. Then going through the first filter we get $I_0/2$ transmitted. For the second filter we can use Malus' law and calculate that 0.25 gets transmitted. ***Hence the final irradiance is $I = I_0/8$ = 0.375 W/m^2.***

4) A double-slit experiment produces interference fringes for sodium light (λ = 589 nm) that are 0.20^o apart. For what wavelength would the angular separation be 10% greater? (You can assume that the angle θ is small).

Using the small angle approximation, you have the angles on the screen $\theta_m \approx m\lambda/a$. Take m=1 here. An angle that is 10% larger means a wavelength that is 10% larger, or 647.9 mm = ***648 nm****.*

5) A violin is a complex musical instrument and with specific bow movements it is possible to generate different harmonics (i.e. different normal modes of vibration). Suppose that a violin string with a mass of 0.8 g and a tension of 50 N emits successive harmonic frequencies of 860 Hz and 1075 Hz.

a) What is the fundamental frequency of the string and which overtones do 860 Hz and 1075 Hz correspond to?

Let f_m = 860 Hz for some mode number m. Then f_{m+1} = 1075 Hz. Hence f_1 = 215 Hz and m_v=4. The two frequencies are the fourth and fifth harmonics (third and fourth overtones).

b) What is the length of the violin string, L_v?

Remember $v = sqrt(T/\rho) = f_m\ \lambda_m$.

Here T = 50 N and $\rho = m/L_v$.

For the fundamental $\lambda_1 = 2L_v$, f_1 = 215 Hz. Substituting and solving, we get Lv = 34 cm.

c) The sound from the violin is used to excite the normal modes of an open-closed pipe of length L_p. Assuming that the second harmonic frequency of the violin excites the fundamental frequency of the pipe, what is the length of the pipe? What other harmonics of the violin excite harmonics of the pipe? Identify the harmonics of the violin and the pipe by their mode numbers, m_v and m_p, respectively.

We are told that f_2 = 430 Hz of the violin excites the pipe.

Hence for the pipe, the fundamental is f_1 = 430 Hz.

For an open-closed pipe: $\lambda_{mp} = (4\ L_p) / m_p$, m_p = 1, 3, 5 ...

For m_p = 1, f_1 = 430 Hz, $f_1\ \lambda_1 = v_{sound}$ = 340 m/s (use the speed of sound!), so λ_1 = 0.79 m and Lp = 0.20m or 20 cm. Excited modes of the pipe are mp odd and hence $2m_p$ values for m_v, The frequencies are 430 Hz, 1290 Hz, 2150 Hz ...

6) Plane waves of monochromatic light of wavelength λ = 500 nm illuminate three narrow slits. The spacing between adjacent slits is a = 0.2 mm. The resulting interference/diffraction pattern is displayed on a screen 80 cm from the slits. Let y be the coordinate on the screen, where the position y = 0 is level with the central slit.

For this part, assume that the slit width is very small so that diffraction effects can be ignored (i.e. the pattern on the screen is due to three point-like sources). Describe the interference pattern you would see on the screen, both qualitatively and quantitatively. A figure and words are needed. For the qualitative portion, you need to make it clear if there are maxima and minima in the pattern and, if so, how the maxima/minima are arranged on the screen. For the quantitative portion, you need specify the locations (in y) of the maxima and determine the irradiance of the maxima.

Notes:
1) if you use a small angle approximation you need to indicate that and
make the case why the approximation is valid.
2) Determining the positions of the mimina is a bit difficult and so only do that
if you have enough time.
3) if you are running out of time, the qualitative description is more important than
the quantitative answers.

The second part of the question specified a width for the slits and asked about the combined interference-diffraction you would see. We have not yet covered this sufficiently well.

Qualitative:

Draw a picture of the three slides and label the optical path difference, Δ, between rays from slit 1 and slit 2 and from slit 2 and slit 3. Hence the optical path difference between 1 and 3 is 2Δ. Suppose beams 1 and 2 satisfy $\Delta = m\lambda$ for constructive interference. Then beams 1 and 3 will also satisfy this since 2Δ is a multiple of Δ. ***The primary maxima positions are the same as for the double slit.***

When $\Delta = m(\lambda/2)$, for m a non-zero integer, two of the rays (say 1 and 2) have destructive interference, but the third ray is unaffected. ***Hence, there are secondary maxima halfway between the primary maxima.***

Finally, there will be minima between the primary and secondary maxima.

Quantitative:

The primary maxima will have irradiance 9 I_0 *(3 beams) and* ***the secondary maxima will have irradiance I_0*** *(1 beam). The primary maxima will be at the center and at spacings of $\pm\lambda/a$ in $\sin(\theta)$ on either side of the central maximum. The secondary maxima will be at spacings of $\pm\lambda/2a$ in $\sin(\theta)$ on other side of the central maximum. For the numbers given, the y spacings on the screen will be ±1.0 mm to the secondary maxima on either side of the central maximum and ±2.0 mm to the primary maxima on either side of the central maximum. The positions of the minima are harder to get (they do not lie exactly halfway between primary and secondary maxima). In the review session, we cover the phasor approach to getting out the exact numbers.*