Test 3 Practice Problems
Chapters 34 and 35
Version 2 : Thu 07 Oct 2024 (with answers)

Here are a few practice problems to get started with. Some are from the homework and some are from old tests. The last page has the equation sheet that will be included with the test.

Chapter 34 : Interference

1. Two speakers, separated by exactly 120 cm are hooked up to a tone generator and are each emitting sound (in phase with one another) with a wavelength of exactly 40 cm (i.e. a frequency of exactly $f = 857.5\ Hz$). If I move along the x axis shown in the figure (where $x = 0$ corresponds to being right up next to speaker 1), (a) at what locations will the sound be extra loud (i.e. where along x will constructive interference occur) and (b) at what locations where complete destructive interference occur?
   Find all such locations (hint: each list is very short). (All these locations will be too close to use either far-field or small-angle approximations.)

2. A laser pointer from the physics lab is marked as producing 632.8 nm light (red). When light from this laser falls on two closely spaced slits, an interference pattern formed on a wall two (2) meters away has bright fringes spaced 6.00 mm apart near the center of the pattern. When the laser is replaced by a small laser pointer, the fringes are 5.04 mm apart. What is the wavelength of light produced by the pointer? ____________ nm

3. Water waves having parallel crests 4.5 cm apart pass through **two** openings 7.5 cm apart in a board. At a point 3 m beyond the board, at what angle(s) relative to the 'straight-through' direction would there be little or no wave action? At what angle(s) would the wave amplitude be high? ________________________ deg

4. A physics professor wants to perform a lecture demonstration of Young's double-slit experiment for her class using the 520 nm light from a green laser pointer. Because the lecture hall is large, the interference pattern will be projected on a wall that is 4.6 m from the slits, and for easy viewing by all students in the classroom, the professor wants the distance between the $m = 0$ and $m = 1$ maxima to be 25 cm. What slit separation is required to produce this? ____________ m

5. If a soap bubble is 120 nm thick, what wavelength(s?) of visible light (i.e. between $\lambda = 390\ nm$ to 750 nm) would be strongly reflected at the center of the outside surface when illuminated by white light? (Assume the index of refraction of the soapy water is $n = 1.35$.) ____________ nm

6. A lens (made of glass with $n = 1.56$) has a thin coating applied to it (the coating has an index of refraction of $n = 1.25$). When white light **reflects** off the lens it appears greenish-yellow ($\lambda = 570\ nm$) in color. How thick is the coating on the lens? (Give the thinnest two possible thicknesses it might be.) (Be sure to draw a diagram showing any sign-flip(s) involved here and be sure to explain how/why you decided to use the equation you chose to analyze this problem.)
______________________ m

7. We want to use two Polaroid filters to reduce the intensity of incoming unpolarized light by 90% (i.e. we want the resulting intensity to be one tenth of it's original intensity). At what angle should the two filters be adjusted relative to one another? ___________ deg

8. Stealth aircraft are designed to not reflect radar, whose wavelength is typically 2 cm, by using an antireflective paint coating. If the paint consists of a polymer with an index of refraction of $n = 1.70$, what is the minimum thickness of paint needed? (Assume the index of refraction of the metal making up the surface of the plane itself is higher than the index of refraction of the pain.)
___________ cm

   (At what radar wavelength would this coating cause the plane to be highly reflective and thus actually be easier to detect? ___________ cm)

Chapter 35 : Diffraction

1. Water waves having parallel crests 4.5 cm apart pass through a **single** opening 7.5 cm wide in a board. At a point 3 m beyond the board, at what angle(s) relative to the 'straight-through' direction would there be little or no wave action? ____________________ deg

2. If a single slit diffracts 580 nm light so that the diffraction maximum is 6.0 cm wide on a screen 2.50 m away, what will be the width of the diffraction maximum for light with a wavelength of 460 nm? __________ cm

3. The nearest neighboring star to the Sun is actually the triple-star system α-Centauri, about 4.3 light-years away from us. One of the stars is too dim to see, but the two bright stars orbitting one another are just 23 AU apart (which means they're separated by a distance a little less than the distance from the Sun to the planet Neptune). If we look at these stars with our naked eye (pupil diameter about 4 mm at night in the dark) do we see these as two very close but separate stars or do they merge into a single blob? (Assume the light emitted by the star and planet has a wavelength of 550 nm.)

   NOTE: 1 AU is the distance from the Earth to the Sun (about 93 millions miles), and one light-year (LY) is the distance light would travel in an Earth year (about 5.88×10^{12} $miles$).

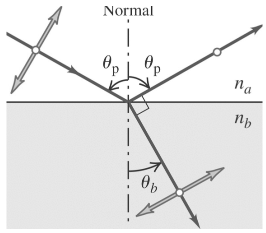
4. A 3800 $slit/cm$ grating produces a third-order fringe at a 35^o angle. What wavelength of light is being used? __________ nm

5. A tungsten-halogen bulb emits a continuous spectrum of ultraviolet, visible, and infrared light over a broad range of wavelengths: 360 nm to 2000 nm. When this light passes through a diffraction grating with slit spacing d, the first order brightness maximum for $\lambda = 1200$ nm occurs at some angle θ. What **other** wavelengths (there may be more than 1) within the spectrum emitted by this bulb would also fall at the same angle? (Optical filters are used to deal with this bothersome effect when a broad continuous spectrum of light is to be measured with a spectrometer.) ____________________ nm

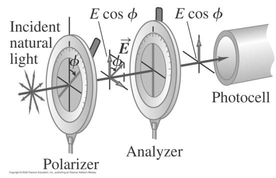
6. Several 'corner reflectors' have been placed on the Moon going back to the late 1960's and Earth-based lasers routinely use these mirrors to measure the distance from the Earth to the Moon. The same single-slit and circular aperture equations for diffraction are involved here, so suppose we fire a 633 nm red laser at the Moon via a telescope that uses a 40 cm diameter mirror. How wide will the laser 'spot' be when it reaches the Moon, approximately $380,000$ km from the Earth? __________ m

7. Redo problem 4 from the Chapter 34 practice problems (see first page of this pdf) but this time assume a **diffraction grating** is being used. How many lines/mm does the grating need to have?

8. Newspapers are actually printed as tiny dots with 85 dots per inch. How far away do you have to hold the newspaper so you can't see the dots? (Assume we're in a bright light environment, so we have a pupil diameter of 2 mm and $\lambda = 550$ nm.)

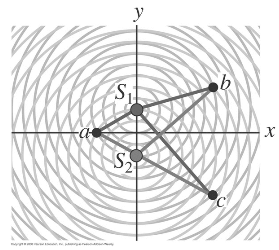


Polarization by reflection
$\tan\theta_p = n_b/n_a$



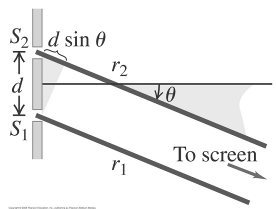
Outgoing light polarized at filter angle
If polarized in: $I = I_o \cos^2\phi$
If unpolarized in: $I = \frac{1}{2} I_o$

2-source interference (general)

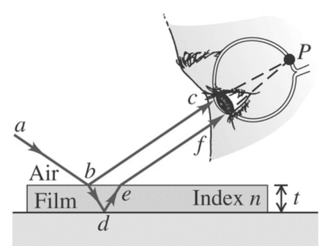


Path difference: Δs
Constructive: $\Delta s = m\lambda$
Destructive: $\Delta s = (m+\frac{1}{2})\lambda$

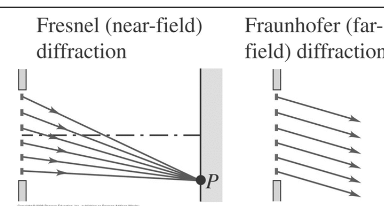
2-source interference (far-field)
(far-field: $R > 10d$)
Constructive Interference:
$d\sin\theta = m\lambda$ for $m = 0, \pm1, \pm2, ..$
Destructive Interference:
$d\sin\theta = (m+\frac{1}{2})\lambda$ for $m = 0, \pm1, \pm2, ..$
Bright fringes (small θ : $d > 10\lambda$):
$y_m = m\frac{R\lambda}{d}$ for $m = 0, \pm1, \pm2, ...$



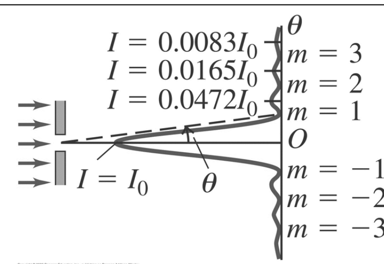
Thin film interference if **NO** relative phase shift
Constructive Interference: $2t = m\lambda_{film}$ for $m = \pm1, \pm2, ..$
Destructive Interference: $2t = (m+\frac{1}{2})\lambda_{film}$ for $m = 0, \pm1, \pm2, ..$
Thin film interference **WITH** half-cycle phase shift
Constructive Interference: $2t = (m+\frac{1}{2})\lambda_{film}$ for $m = 0, \pm1, \pm2, ..$
Destructive Interference: $2t = m\lambda_{film}$ for $m = \pm1, \pm2, ..$
HALF-CYCLE phase shift will occur for reflections
at interface where n increases.
WARN: λ_{film} is wavelength IN MEDIUM, so $\lambda_{film} = \lambda_o/n_{film}$



Diffraction : waves pass through aperture or around an edge.
· Fresnel: nearby source or observer.
· Fraunhofer (typical case): source and observer far away (relative to size of slit)



Single Slit Diffraction (far-field: $R > 10D$)
monochromatic waves (light, etc), slit width D
DARK fringes at: $\sin\theta = m\frac{\lambda}{D}$ for $m = \pm1, \pm2, ..$
Small angles: $y_m = m\frac{R\lambda}{D}$ for $m = \pm1, \pm2, ..$
$I(\theta) = I_o snc^2(\beta/2)$ where $snc(x) \equiv \frac{\sin x}{x}$ and $\beta = \frac{2\pi D\sin\theta}{\lambda}$
Intensity at BRIGHT fringes: $I_m \approx \frac{I_o}{(m+\frac{1}{2})^2\pi^2}$ for $m = 1, 2, 3..$



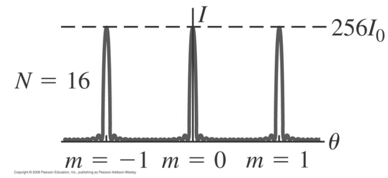
Diffraction Grating (far-field)

large number of parallel slits separated by d

Sharp BRIGHT fringes at: $d\sin\theta = m\lambda$ for $m = 0, \pm1, \pm2, ..$

Small angles: $y_m = m\frac{R\lambda}{d}$ for $m = 0, \pm1, \pm2, ..$

Same effect with REFLECTION grating formed from tiny thin strips of reflecting material (d now being distance between centers of reflecting strips)



Rayleigh resolution limit (Note: $\sin\theta \approx \theta$ if θ is small and in radians)

single slit of width D : $\sin\theta = \lambda/D$ circular aperture of diameter D : $\sin\theta = 1.22\lambda/D$

Miscellaneous

Speed of sound in air: $v \approx 343\ m/s$ Speed of sound in water: $v \approx 1500\ m/s$

Speed of light in vacuum: $v = c = 2.998 \times 10^8\ m/s$ ($c = 3 \times 10^8\ m/s$ is good enough)

Light year: $1\ LY = 9.461 \times 10^{15}\ m$

Energy: $1\ eV = 1.602 \times 10^{-19}\ J$ $K = \frac{1}{2}mv^2$

Typical indices of refraction: $n_{air} = 1.00$, $n_{water} = 1.33$, $n_{glass} = 1.5\ to\ 1.8$

Visible light: 390 nm to 750 nm

Audible range (humans): $f = 20\ Hz$ to $f = 20,000\ Hz$

Colors: Red: 700 nm, Yellow: 580 nm, Green: 525 nm, Blue: 475 nm, Violet: 400 nm

Nanometer: $1\ nm\ =\ 10^{-9}\ m$ Frequency, wavelength and wave speed: $v = \lambda/T = \lambda f$.

Arc-length: $s = r\theta$ (angle in radians)

Quadratic equation: if $ax^2 + bx + c = 0$ then $x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$

Far Field : $R > 10d$ or $R > 10D$ with R being the distance away from the slit/aperture/grating

Small Angle : $d > 10\lambda$ or $D > 10\lambda$

(We didn't develop near-field equations for single slit or diffraction gratings, so it's OK to use the far-field equations for those.)

Chapter 34 : Interference and Polarization

1. Speakers: CON at (a) 160 cm, 50 cm, and 0 cm; (b) DES at 90 cm and 22 cm.
2. Double slit : far field and small angle here. $\lambda = 531.55\ nm$. Set up as a ratio problem and you don't need d (which is $2.109 \times 10^{-4}\ m$ if you do go down that path).
3. Double slit with water waves : d much smaller than distance to beach, so far field (but not small angle here). CON at $\theta = 0$ and 36.87^o; DES at $\theta = \pm 17.46^o$ and $\pm 64.16^o$.
4. Lecture demo (double slit) : exact 2-source (far field) equation yields $d = 9.582 \times 10^{-6}\ m$; small angle (which it is here) approximation yields $d = 9.568 \times 10^{-6}\ m$.
5. Soap bubble (thin film) : only $\lambda = 648\ nm$ (red)
6. Lens coating (thin film) : thickness would be any integer multiple of 228 nm.
7. First filter reduces I by half; the pair of filters reduce the now polarized light's intensity by $\cos^2 \phi$ and we want the final intensity to be 0.1 of the original, so overall we need $(0.5)\cos^{\phi} = 0.1$ or $\phi = 63.4^o$.
8. Stealth radar paint : (a) $t_{min} = 0.294\ cm$ (pretty thick coating). (b) Highly reflective at $\lambda = 1\ cm, 0.5\ cm, ...$ basically any wavelength equal to $(1.0\ cm)/m$ for $m = 1, 2, 3, ...$

Chapter 35 : Diffraction

1. Single slit (water waves) : 'dark line' (no wave action) at $\pm 36.87^o$ (no other angles)

2. Single slit (light) : can use small angle approx here, and can set up as ratio leading to a width of 4.758.. cm. (Using full equation and skipping small angle approx yields a width of 4.758.. cm also - the angles here are really tiny.)

3. Resolving double-star system : Very small angles here; angular size is star separation divided by how far away they are from us so $\theta = 8.46 \times 10^{-5}\ rad$ (after converting AU and LY to standard units). Eye with 4 mm pupil yields $\theta_{min} = 1.68 \times 10^{-4}\ rad$ which is about twice as large, so we can't see them as two separate stars using just our eyes.

4. Diffraction grating : 3800 $slits/cm$ means $d = 2.6316 \times 10^{-6}\ m$ or $d = 2631.6\ nm$. Ultimately $\lambda = 503.14\ nm$ (in the green range).

5. Diffraction grating : $d \sin\theta = m\lambda$ and the left hand side isn't changing here, so the $m = 1, \lambda = 1200\ nm$ will land at the same location as the $m = 2, \lambda = (1200/2) = 600\ nm$ line, and the $m = 3, \lambda = (1200/3) = 400\ nm$ line. (That's it since the $m = 4$ case would yield $\lambda = 1200/4 = 300\ nm$ which is outside the wavelengths emitted by the bulb.)

6. Moon laser : beam spreading angle $\theta_{min} = 1.22\lambda/D = 1.93 \times 10^{-6}\ rad$; $s = r\theta$ so at the Moon's distance the beam would spread over a circular disk with a radius of about 734 m, or a width of 1467 m (about 0.9 $miles$ across). (The reflected light spread out too on its way back to Earth, so the signal received is extremely weak.)

7. Practice problem **34-4** as a diffraction grating : get the same $d = 9.568 \times 10^{-6}\ m = 9.568 \times 10^{-3}\ mm$ but now that's the distance between each slit in the grating. The inverse of that will be the slits per mm, so 104.5 $slits/mm$. (Easy to do photographically; the little slide version I showed in class had 1000 $lines/mm$.)

8. Newspaper: watch units; 85 dpi yields a distance from the center of one dot to the center of the 'next' dot of $2.988 \times 10^{-4}\ m$. Yields a reading distance of about 89 cm. (Fortunately each 'dot' is big enough they run into one another and we can't see them as dots unless we hold the paper much closer. Look at a newspaper in a magnifying glass and you should be able to see the dots.)