

37. A beam of 580-nm light passes through two closely spaced glass plates, as shown in Figure P37.37. For what minimum nonzero value of the plate separation d is the transmitted light bright?

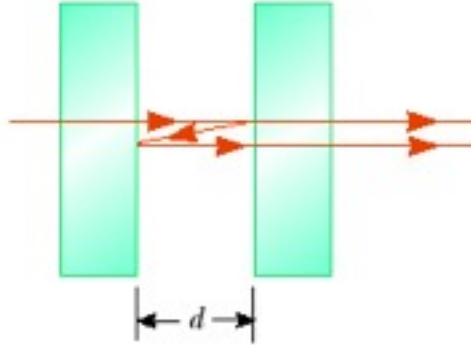


Figure P37.37

P37.37 If the path length difference $\Delta = \lambda$, the transmitted light will be bright. Since $\Delta = 2d = \lambda$,

$$d_{\min} = \frac{\lambda}{2} = \frac{580 \text{ nm}}{2} = \boxed{290 \text{ nm}}.$$

50. A certain crude oil has an index of refraction of 1.25. A ship dumps 1.00 m³ of this oil into the ocean, and the oil spreads into a thin uniform slick. If the film produces a first-order maximum of light of wavelength 500 nm normally incident on it, how much surface area of the ocean does the oil slick cover? Assume that the index of refraction of the ocean water is 1.34.

P37.50 Since $1 < 1.25 < 1.34$, light reflected from top and bottom surfaces of the oil undergoes phase reversal. The path difference is then $2t$, which must be equal to

$$m\lambda_n = \frac{m\lambda}{n}$$

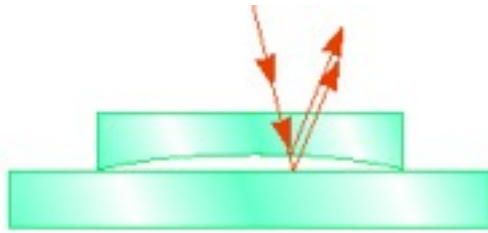
for maximum reflection, with $m = 1$ for the given first-order condition and $n = 1.25$. So

$$t = \frac{m\lambda}{2n} = \frac{1(500 \text{ nm})}{2(1.25)} = 200 \text{ nm}.$$

The volume we assume to be constant: $1.00 \text{ m}^3 = (200 \text{ nm})A$

$$A = \frac{1.00 \text{ m}^3}{200(10^{-9} \text{ m})} = 5.00 \times 10^6 \text{ m}^2 = \boxed{5.00 \text{ km}^2}.$$

64. A plano-concave lens having refractive index 1.50 is placed on a flat glass plate, as shown in Figure P37.64. Its curved surface, with radius of curvature 8.00 m, is on the bottom. The lens is illuminated from above with yellow sodium light of wavelength 589 nm, and a series of concentric bright and dark rings is observed by reflection. The interference pattern has a dark spot at the center, surrounded by 50 dark rings, of which the largest is at the outer edge of the lens. (a) What is the thickness of the air layer at the center of the interference pattern? (b) Calculate the radius of the outermost dark ring. (c) Find the focal length of the lens.



***P37.64** Light reflecting from the upper interface of the air layer suffers no phase change, while light reflecting from the lower interface is reversed 180° . Then there is indeed a dark fringe at the outer circumference of the lens, and a dark fringe wherever the air thickness t satisfies $2t = m\lambda$, $m = 0, 1, 2, \dots$

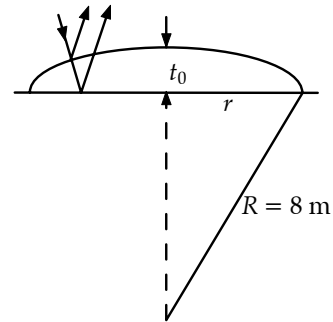


FIG. P37.64

(a) At the central dark spot $m = 50$ and

$$t_0 = \frac{50\lambda}{2} = 25(589 \times 10^{-9} \text{ m}) = \boxed{1.47 \times 10^{-5} \text{ m}}.$$

(b) In the right triangle,

$$(8 \text{ m})^2 = r^2 + (8 \text{ m} - 1.47 \times 10^{-5} \text{ m})^2 = r^2 + (8 \text{ m})^2 - 2(8 \text{ m})(1.47 \times 10^{-5} \text{ m}) + 2 \times 10^{-10} \text{ m}^2.$$

The last term is negligible. $r = \sqrt{2(8 \text{ m})(1.47 \times 10^{-5} \text{ m})} = \boxed{1.53 \times 10^{-2} \text{ m}}$

(c)
$$\frac{1}{f} = (n-1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right) = (1.50-1) \left(\frac{1}{\infty} - \frac{1}{8.00 \text{ m}} \right)$$

$$\boxed{f = -16.0 \text{ m}}$$

15. Narrow, parallel, glowing gas-filled tubes in a variety of colors form block letters to spell out the name of a night club. Adjacent tubes are all 2.80 cm apart. The tubes forming one letter are filled with neon and radiate predominantly red light with a wavelength of 640 nm. For another letter, the tubes emit predominantly violet light at 440 nm. The pupil of a dark-adapted viewer's eye is 5.20 mm in diameter. If she is in a certain range of distances away, the viewer can resolve the separate tubes of one color but not the other. Which color is easier to resolve? The viewer's distance must be in what range for her to resolve the tubes of only one color?

***P38.15** By Rayleigh's criterion: $\theta_{\min} = \frac{u}{L} = 1.22 \frac{\lambda}{D}$, where θ_{\min} is the smallest angular separation of two objects for which they are resolved by an aperture of diameter D , d is the separation of the two objects, and L is the maximum distance of the aperture from the two objects at which they can be resolved.

Two objects can be resolved if their angular separation is greater than θ_{\min} . Thus, θ_{\min} should be as small as possible. Therefore, the smaller of the two given wavelengths is easier to resolve, i.e.

violet.

$$L = \frac{Dd}{1.22\lambda} = \frac{(5.20 \times 10^{-3} \text{ m})(2.80 \times 10^{-2} \text{ m})}{1.22\lambda} = \frac{1.193 \times 10^{-4} \text{ m}^2}{\lambda}$$

Thus $L = 186 \text{ m}$ for $\lambda = 640 \text{ nm}$, and $L = 271 \text{ m}$ for $\lambda = 440 \text{ nm}$. The viewer can resolve adjacent tubes of violet in the range $186 \text{ m to } 271 \text{ m}$, but cannot resolve adjacent tubes of red in this range.

18. A binary star system in the constellation Orion has an angular interstellar separation of $1.00 \times 10^{-5} \text{ rad}$. If $\lambda = 500 \text{ nm}$, what is the smallest diameter the telescope can have to just resolve the two stars?

$$\text{P38.18} \quad D = 1.22 \frac{\lambda}{\theta_{\min}} = \frac{1.22(5.00 \times 10^{-7})}{1.00 \times 10^{-5}} \text{ m} = 6.10 \text{ cm}$$

24. Light from an argon laser strikes a diffraction grating that has 5 310 grooves per centimeter. The central and firstorder principal maxima are separated by 0.488 m on a wall 1.72 m from the grating. Determine the wavelength of the laser light.

P38.24 The principal maxima are defined by
 $d \sin \theta = m \lambda \quad m = 0, 1, 2, \dots$

For $m = 1$, $\lambda = d \sin \theta$

where θ is the angle between the central ($m = 0$) and the first order ($m = 1$) maxima. The value of θ can be determined from the information given about the distance between maxima and the grating-to-screen distance. From the figure,

$$\tan \theta = \frac{0.488 \text{ m}}{1.72 \text{ m}} = 0.284$$

so $\theta = 15.8^\circ$

and $\sin \theta = 0.273$.

The distance between grating "slits" equals the reciprocal of the number of grating lines per centimeter

$$d = \frac{1}{5\,310 \text{ cm}^{-1}} = 1.88 \times 10^{-4} \text{ cm} = 1.88 \times 10^3 \text{ nm}.$$

The wavelength is $\lambda = d \sin \theta = (1.88 \times 10^3 \text{ nm})(0.273) = \boxed{514 \text{ nm}}$.

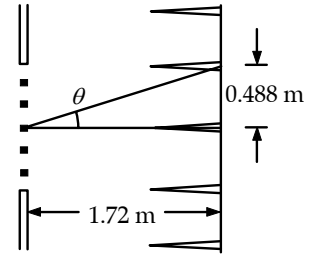


FIG. P38.24

28. Show that, whenever white light is passed through a diffraction grating of any spacing size, the violet end of the continuous visible spectrum in third order always overlaps with red light at the other end of the second-order spectrum.

P38.28 $\sin \theta = \frac{m \lambda}{d}$

Therefore, taking the ends of the visible spectrum to be $\lambda_v = 400 \text{ nm}$ and $\lambda_r = 750 \text{ nm}$, the ends the different order spectra are:

End of second order: $\sin \theta_{2r} = \frac{2 \lambda_r}{d} = \frac{1\,500 \text{ nm}}{d}$.

Start of third order: $\sin \theta_{3v} = \frac{3 \lambda_v}{d} = \frac{1\,200 \text{ nm}}{d}$.

Thus, it is seen that $\theta_{2r} > \theta_{3v}$ and these orders must overlap regardless of the value of the grating spacing d .

Chapter 38

30. The laser in a CD player must precisely follow the spiral track, along which the distance between one loop of the spiral and the next is only about $1.25 \mu\text{m}$. A feedback mechanism lets the player know if the laser drifts off the track, so that the player can steer it back again. Figure P38.30 shows how a diffraction grating is used to provide information to keep the beam on track. The laser light passes through a diffraction grating just before it reaches the disk. The strong central maximum of the diffraction pattern is used to read the information in the track of pits. The two first-order side maxima are used for steering. The grating is designed so that the first-order maxima fall on the flat surfaces on both sides of the information track. Both side beams are reflected into their own detectors. As long as both beams are reflecting from smooth nonpitted surfaces, they are detected with constant high intensity. If the main beam wanders off the track, however, one of the side beams will begin to strike pits on the information track and the reflected light will diminish. This change is used with an electronic circuit to guide the beam back to the desired location. Assume that the laser light has a wavelength of 780 nm and that the diffraction grating is positioned $6.90 \mu\text{m}$ from the disk. Assume that the first-order beams are to fall on the disk $0.400 \mu\text{m}$ on either side of the information track. What should be the number of grooves per millimeter in the grating?

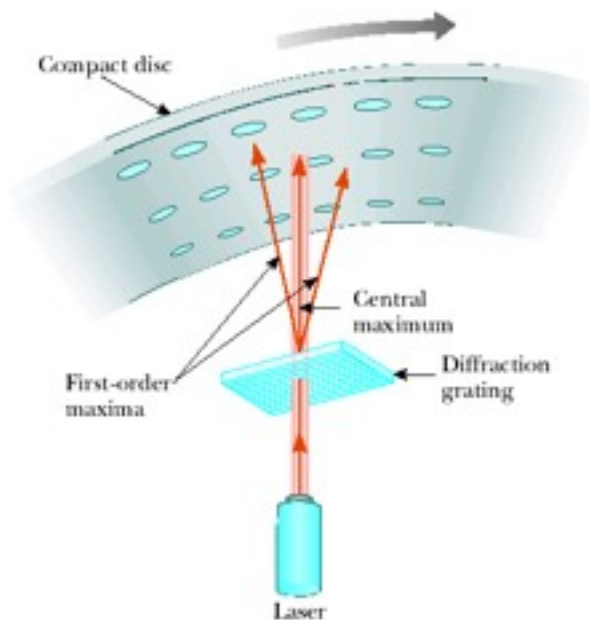


Figure P38.30

* P38.30 For a side maximum,

$$\tan \theta = \frac{y}{L} = \frac{0.4 \mu\text{m}}{6.9 \mu\text{m}}$$

$$\theta = 3.32^\circ$$

$$d \sin \theta = m\lambda \quad d = \frac{(1)(780 \times 10^{-9} \text{ m})}{\sin 3.32^\circ} = 13.5 \mu\text{m}.$$

$$\text{The number of grooves per millimeter} = \frac{1 \times 10^{-3} \text{ m}}{13.5 \times 10^{-6} \text{ m}} = \boxed{74.2}.$$

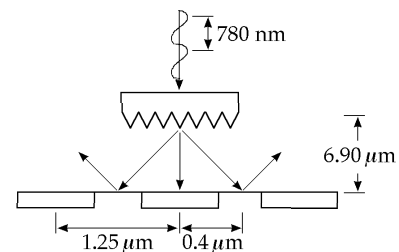


FIG. P38.30

56. Iridescent peacock feathers are shown in Figure P38.56a. The surface of one microscopic barbule is composed of transparent keratin that supports rods of dark brown melanin in a regular lattice, represented in Figure P38.56b. (Your fingernails are made of keratin, and melanin is the dark pigment giving color to human skin.) In a portion of the feather that can appear turquoise, assume that the melanin rods are uniformly separated by $0.25 \mu\text{m}$, with air between them. (a) Explain how this structure can appear blue–green when it contains no blue or green pigment. (b) Explain how it can also appear violet if light falls on it in a different direction. (c) Explain how it can present different colors to your two eyes at the same time—a characteristic of iridescence. (d) A compact disc can appear to be any color of the rainbow. Explain why this portion of the feather cannot appear yellow or red. (e) What could be different about the array of melanin rods in a portion of the feather that does appear to be red?

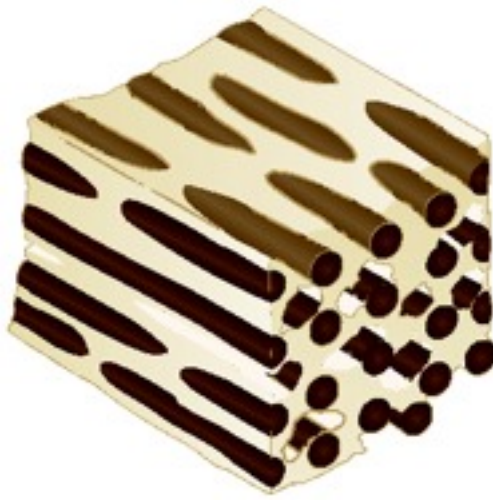
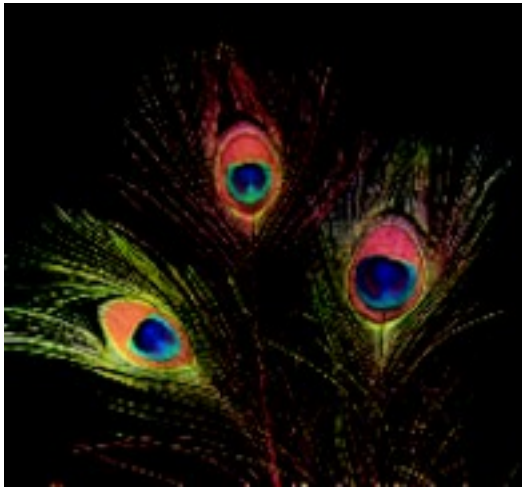


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Figure P38.56: (a) Iridescent peacock feathers. (b) Microscopic section of a feather showing dark melanin rods in a pale keratin matrix.

- *P38.56** (a) Bragg's law applies to the space lattice of melanin rods. Consider the planes $d = 0.25 \mu\text{m}$ apart. For light at near-normal incidence, strong reflection happens for the wavelength given by $2d \sin \theta = m\lambda$. The longest wavelength reflected strongly corresponds to $m = 1$:
- $$2(0.25 \times 10^{-6} \text{ m}) \sin 90^\circ = 1\lambda \quad \lambda = 500 \text{ nm. This is the blue-green color.}$$
- (b) For light incident at grazing angle 60° , $2d \sin \theta = m\lambda$ gives
- $$1\lambda = 2(0.25 \times 10^{-6} \text{ m}) \sin 60^\circ = 433 \text{ nm. This is violet.}$$
- (c) Your two eyes receive light reflected from the feather at different angles, so they receive light incident at different angles and containing different colors reinforced by constructive interference.
- (d) The longest wavelength that can be reflected with extra strength by these melanin rods is the one we computed first, 500 nm blue-green.
- (e) If the melanin rods were farther apart (say $0.32 \mu\text{m}$) they could reflect red with constructive interference.