Section 27.1 The Principle of Linear Superposition
Section 27.2 Young’s Double Slit Experiment

1. Complete the following sentence: The term coherence relates to
   (a) the phase relationship between two waves. (d) the amplitude of two waves.
   (b) the polarization state of two waves. (e) the frequency of two waves.
   (c) the diffraction of two waves.

2. Two identical light waves, \( A \) and \( B \), are emitted from different sources and meet at a point \( P \). The distance from the source of \( A \) to the point \( P \) is \( \ell_A \); and the source of \( B \) is a distance \( \ell_B \) from \( P \). Which of the following statements is necessarily true concerning the interference of the two waves?
   (a) \( A \) and \( B \) will interfere constructively because their amplitudes are the same.
   (b) \( A \) and \( B \) will interfere constructively if \( \ell_A = \ell_B \).
   (c) \( A \) and \( B \) will interfere destructively if \( \ell_A - \ell_B = m\lambda \) where \( m = 0, 1, 2, 3, ... \)
   (d) \( A \) and \( B \) will interfere destructively if \( \ell_A \) is not equal to \( \ell_B \).
   (e) \( A \) and \( B \) will interfere constructively because their wavelengths are the same.

3. Which one of the following statements provides the most convincing evidence that visible light is a form of electromagnetic radiation?
   (a) Two light sources can be coherent.
   (b) Light can be reflected from a surface.
   (c) Light can be diffracted through an aperture.
   (d) Light can form a double-slit interference pattern.
   (e) Light travels through vacuum at the same speed as X-rays.

4. Which one of the following statements best explains why interference patterns are not usually observed for light from two ordinary light bulbs?
   (a) Diffraction effects predominate.
   (b) The two sources are out of phase.
   (c) The two sources are not coherent.
   (d) The interference pattern is too small to observe.
   (e) Light from ordinary light bulbs is not polarized.

5. A double slit is illuminated with monochromatic light of wavelength \( 6.00 \times 10^2 \) nm. The \( m = 0 \) and \( m = 1 \) bright fringes are separated by 3.0 cm on a screen which is located 4.0 m from the slits. What is the separation between the slits?
   (a) \( 4.0 \times 10^{-5} \) m
   (b) \( 8.0 \times 10^{-5} \) m
   (c) \( 1.2 \times 10^{-4} \) m
   (d) \( 1.6 \times 10^{-4} \) m
   (e) \( 2.4 \times 10^{-4} \) m

6. What does one observe on the screen in a Young’s experiment if white light illuminates the double slit instead of light of a single wavelength?
   (a) a white central fringe and no other fringes
   (b) a dark central fringe and a series of alternating white and dark fringes on each side of the center
   (c) a white central fringe and a series of colored and dark fringes on each side of the center
   (d) a continuous band of colors with no dark fringes anywhere
   (e) a dark screen since no constructive interference can occur
7. In two separate double slit experiments, an interference pattern is observed on a screen. In the first experiment, violet light ($\lambda = 754$ nm) is used and a second-order bright fringe occurs at the same location as a third-order dark fringe in the second experiment. Determine the wavelength of the light used in the second experiment.

(a) 1320 nm  
(b) 862 nm  
(c) 594 nm  
(d) 431 nm  
(e) 388 nm

8. Two slits separated by $2.00 \times 10^{-5}$ m are illuminated by light of wavelength 500 nm. If the screen is 8.00 m from the slits, what is the distance between the $m = 0$ and $m = 1$ bright fringes?

(a) 1.25 cm  
(b) 2.50 cm  
(c) 5.00 cm  
(d) 10.0 cm  
(e) 20.0 cm

9. Two slits are separated by $2.00 \times 10^{-5}$ m. They are illuminated by light of wavelength $5.60 \times 10^{-7}$ m. If the distance from the slits to the screen is 6.00 m, what is the separation between the central bright fringe and the third dark fringe?

(a) 0.421 m  
(b) 0.224 m  
(c) 0.168 m  
(d) 0.084 m  
(e) 0.070 m

10. In a Young's double slit experiment, the separation between the slits is $1.20 \times 10^{-4}$ m; and the screen is located 3.50 m from the slits. The distance between the central bright fringe and the second-order bright fringe is 0.0415 m. What is the wavelength of the light used in this experiment?

(a) 428 nm  
(b) 474 nm  
(c) 517 nm  
(d) 642 nm  
(e) 711 nm

11. Light is incident on two slits that are separated by 0.2 mm. The figure shows the resulting interference pattern observed on a screen 1.0 m from the slits. Determine the wavelength of light used in this experiment.

(a) 0.05 nm  
(b) 0.50 nm  
(c) 50 nm  
(d) 500 nm  
(e) 5000 nm

12. The figure shows the interference pattern produced when light of wavelength 500 nm is incident on two slits. Fringe A is equally distant from each slit. By what distance is fringe B closer to one slit than the other?

(a) 250 nm  
(b) 500 nm  
(c) 750 nm  
(d) 1000 nm  
(e) 1500 nm
13. In a Young’s double slit experiment, green light is incident on the two slits. The interference pattern is observed on a screen. Which one of the following changes would cause the fringes to be more closely spaced?
(a) Reduce the slit separation distance. (d) Move the screen farther away from the slits.
(b) Use red light instead of green light. (e) Move the light source farther away from the slits.
(c) Use blue light instead of green light.

14. Light of wavelength 530 nm is incident on two slits that are spaced 1.0 mm apart. How far from the slits should the screen be placed so that the distance between the \( m = 0 \) and \( m = 1 \) bright fringes is 1.0 cm?
(a) 7.9 m  (c) 16 m  (e) 36 m
(b) 9.5 m  (d) 19 m

Questions 15 through 20 pertain to the interference pattern shown below:

The figure shows the interference pattern obtained in a double-slit experiment using light of wavelength 600 nm.

15. Which fringe is the same distance from both slits?
(a) A  (c) C  (e) E
(b) B  (d) D

16. Which fringe is the third order maximum?
(a) A  (c) C  (e) E
(b) B  (d) D

17. Which fringe is 300 nm closer to one slit than to the other?
(a) A  (c) C  (e) E
(b) B  (d) D

18. Which fringe results from a phase difference of \( 4\pi \)?
(a) A  (c) C  (e) E
(b) B  (d) D

19. Which one of the following phenomena would be observed if the wavelength of light were increased?
(a) The fringes would be brighter.
(b) More bright fringes would appear on the screen.
(c) The distance between dark fringes would decrease.
(d) Single-slit diffraction effects would become non-negligible.
(e) The angular separation between bright fringes would increase.

20. Which one of the following phenomena would be observed if the distance between the slits were increased?
(a) The fringes would become brighter.
(b) The central bright fringe would change position.
(c) The distance between dark fringes would increase.
(d) The distance between bright fringes would increase.
(e) The angular separation between the dark fringes would decrease.
Section 27.3 Thin-film Interference
Section 27.4 The Michelson Interferometer

21. A 4.0 x 10^2-nm thick film of kerosene \((n = 1.2)\) is floating on water. White light is normally incident on the film. What is the visible wavelength in air that has a maximum intensity after the light is reflected? Note: the visible wavelength range is 380 nm to 750 nm.
(a) 380 nm  
(b) 430 nm  
(c) 480 nm  
(d) 530 nm  
(e) 580 nm

22. A portion of a soap bubble appears green \((\lambda = 500.0\text{ nm in vacuum})\) when viewed at normal incidence in white light. Determine the two smallest, non-zero thicknesses for the soap film if its index of refraction is 1.40.
(a) 89 nm and 179 nm  
(b) 89 nm and 268 nm  
(c) 125 nm and 250 nm  
(d) 125 nm and 375 nm  
(e) 170 nm and 536 nm

23. Light of wavelength \(\lambda\) in vacuum strikes a lens that is made of glass with index of refraction 1.6. The lens has been coated with a film of thickness \(t\) and index of refraction 1.3. For which one of the following conditions will there be no reflection?
(a) \(2t = \frac{\lambda}{2}\)  
(b) \(2t = \frac{\lambda}{1.33}\)  
(c) \(2t = \frac{\lambda}{1.6}\)  
(d) \(2t = \frac{1}{2}\left(\frac{\lambda}{1.6}\right)\)  
(e) \(2t = \frac{1}{2}\left(\frac{\lambda}{1.3}\right)\)

24. What is the minimum (non-zero) thickness of a benzene \((n = 1.501)\) thin film that will result in constructive interference when viewed at normal incidence and illuminated with orange light \((\lambda_{\text{vacuum}} = 615\text{ nm})\)? A glass slide \((n_g = 1.620)\) supports the thin film.
(a) 51.0 nm  
(b) 306 nm  
(c) 204 nm  
(d) 102 nm  
(e) 76.0 nm

25. Light of wavelength 650 nm is incident normally upon a glass plate. The glass plate rests on top of a second plate so that they touch at one end and are separated by 0.0325 mm at the other end as shown in the figure. Which range of values contains the horizontal separation between adjacent bright fringes?
(a) 1.1 mm to 1.4 mm  
(b) 1.4 mm to 2.8 mm  
(c) 2.8 mm to 4.2 mm  
(d) 4.2 mm to 5.6 mm  
(e) 5.6 mm to 7.0 mm

26. A transparent film \((n = 1.4)\) is deposited on a glass lens \((n = 1.5)\) to form a non-reflective coating. What thickness would prevent reflection of light with wavelength 5.00 x 10^2 nm in air?
(a) 89 nm  
(b) 125 nm  
(c) 170 nm  
(d) 250 nm  
(e) 357 nm
27. A lens that has an index of refraction of 1.61 is coated with a non-reflective coating that has an index of refraction of 1.45. Determine the minimum thickness for the film if it is to be non-reflecting for light of wavelength $5.60 \times 10^2$ nm.

(a) $1.93 \times 10^{-7}$ m  
(b) $3.86 \times 10^{-7}$ m  
(c) $4.83 \times 10^{-8}$ m  
(d) $9.66 \times 10^{-8}$ m  
(e) $8.69 \times 10^{-8}$ m

28. Two glass plates, each with an index of refraction of 1.55, are separated by a small distance $D$. The space between them is filled with water ($n = 1.33$) as shown. For which one of the following conditions will the reflected light appear green? **Note:** The wavelength of green light is 460 nm in vacuum.

(a) $D = \left(\frac{460 \text{ nm}}{2}\right)$
(b) $2D = \left(\frac{460 \text{ nm}}{1.33}\right)$
(c) $2D = \left(\frac{460 \text{ nm}}{1.55}\right)$
(d) $2D = \frac{1}{2} \left(\frac{460 \text{ nm}}{1.33}\right)$
(e) $2D = \frac{1}{2} \left(\frac{460 \text{ nm}}{1.55}\right)$

29. The table lists the range of wavelengths in vacuum corresponding to a given color. If under white light one looks at a film that has a refractive index of 1.33 and thickness of 183 nm, which color is missing from the light reflected from the film?

<table>
<thead>
<tr>
<th>Color</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>780 - 622</td>
</tr>
<tr>
<td>orange</td>
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</tr>
<tr>
<td>yellow</td>
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</tr>
<tr>
<td>blue</td>
<td>492 - 455</td>
</tr>
<tr>
<td>violet</td>
<td>455 - 390</td>
</tr>
</tbody>
</table>

(a) red  
(b) yellow  
(c) blue  
(d) green  
(e) orange

30. Monochromatic light of wavelength $\lambda_{\text{film}}$ is normally incident on a soap film in air. In terms of the wavelength, what is the thickness of the thinnest film for which the reflected light will be a maximum?

(a) $\frac{\lambda_{\text{film}}}{4}$  
(b) $\frac{\lambda_{\text{film}}}{2}$  
(c) $3\frac{\lambda_{\text{film}}}{4}$  
(d) $\lambda_{\text{film}}$  
(e) $3\frac{\lambda_{\text{film}}}{2}$

31. A Michelson interferometer is used to measure the wavelength of light emitted from a monochromatic source. As the adjustable mirror is slowly moved through a distance $D_A = 0.0265$ mm, an observer counts 411 alternations between bright and dark fields. What is the wavelength of the monochromatic light used in this experiment?

(a) 193 nm  
(b) 227 nm  
(c) 258 nm  
(d) 346 nm  
(e) 369 nm
Section 27.5 Diffraction

32. Which one of the following statements best explains why the diffraction of sound is more apparent than the diffraction of light under most circumstances?
(a) Sound requires a physical medium for propagation.
(b) Sound waves are longitudinal, and light waves are transverse.
(c) Light waves can be represented by rays while sound waves cannot.
(d) The speed of sound in air is six orders of magnitude smaller than that of light.
(e) The wavelength of light is considerably smaller than the wavelength of sound.

33. Light of wavelength 700.0 nm passes through a diffraction grating. The $m = 0$ and $m = 1$ bright spots are 6.0 cm apart on a screen positioned 2.0 cm from the grating. What is the spacing between the slits in the grating?
(a) 233 nm  
(b) 420 nm  
(c) 467 nm  
(d) 738 nm  
(e) 1240 nm

34. Light of wavelength 625 nm shines through a single slit of width 0.320 mm and forms a diffraction pattern on a flat screen located 8.00 m away. Determine the distance between the middle of the central bright fringe and the first dark fringe.
(a) 0.156 cm  
(b) 0.516 cm  
(c) 1.56 cm  
(d) 5.16 cm

35. Light of 600.0 nm is incident on a single slit of width 6.5 $\mu$m. The resulting diffraction pattern is observed on a nearby screen and has a central maximum of width 3.5 m. What is the distance between the screen and the slit?
(a) 9.5 m  
(b) 19 m  
(c) 38 m  
(d) 57 m  
(e) 76 m

36. Light from a red laser passes through a single slit to form a diffraction pattern. If the width of the slit is increased by a factor of two, what happens to the width of the central maximum?
Note: Assume that the angle $\theta$ is sufficiently small so that $(\sin \theta)$ is nearly equal to $\theta$.
(a) The width of the central maximum increases by a factor of 2.
(b) The width of the central maximum decreases by a factor of 2.
(c) The width of the central maximum decreases by a factor of 4.
(d) The width of the central maximum increases by a factor of 2.
(e) The width of the central maximum does not change.

37. Light of wavelength 600 nm is incident upon a single slit with width $4 \times 10^{-4}$ m. The figure shows the pattern observed on a screen positioned 2 m from the slits.

Determine the distance $s$.
(a) 0.002 m  
(b) 0.003 m  
(c) 0.004 m  
(d) 0.006 m  
(e) 0.008 m

38. Light of 600.0 nm is incident upon a single slit. The resulting diffraction pattern is observed on a screen that is 0.50 m from the slit. The distance between the first and third minima of the diffraction pattern is 0.80 mm. Which range of values listed below contains the width of the slit?
(a) 0.1 mm to 0.4 mm  
(b) 0.4 mm to 0.8 mm  
(c) 0.8 mm to 1.2 mm  
(d) 1.2 mm to 1.6 mm  
(e) 1.6 mm to 2.0 mm
39. A monochromatic beam of microwaves with a wavelength of 0.052 m is directed at a rectangular opening of width 0.35 m. The resulting diffraction pattern is measured along a wall 8.0 m from the opening. What is the distance between the first- and second-order dark fringes?
(a) 1.3 m  
(b) 1.8 m  
(c) 2.1 m  
(d) 2.5 m  
(e) 3.7 m

40. The table lists the range of wavelengths in vacuum corresponding to a given color. Which one of these colors will produce a diffraction pattern with the widest central maximum, assuming all other factors are equal?
(a) red  
(b) yellow  
(c) green  
(d) blue  
(e) violet

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41. Diffraction occurs when light passes through a single slit. Rank the following three choices in decreasing order, according to the extent of the diffraction that occurs (largest diffraction first):
- A - blue light, narrow slit
- B - red light, narrow slit
- C - blue light, wide slit

Note: The blue light referred to in choices A and C is the same. Also, the narrow slit referred to in choices A and B is the same.
(a) A, B, C  
(b) B, A, C  
(c) C, A, B  
(d) A, C, B  
(e) B, C, A

42. Light with a wavelength of 644 nm uniformly illuminates a single slit. What is the width of the slit if the first-order dark fringe is located at θ = 0.125°?
(a) $9.42 \times 10^{-4}$ m  
(b) $7.60 \times 10^{-4}$ m  
(c) $4.71 \times 10^{-4}$ m  
(d) $3.80 \times 10^{-4}$ m  
(e) $2.95 \times 10^{-4}$ m

43. When light with a wavelength of 425 nm uniformly illuminates a single slit, the central bright fringe, observed on a screen located 0.630 m from the slit, has a width of 0.0166 m. What is the width of the slit?
(a) $1.61 \times 10^{-5}$ m  
(b) $3.23 \times 10^{-5}$ m  
(c) $4.84 \times 10^{-5}$ m  
(d) $8.07 \times 10^{-5}$ m  
(e) $1.09 \times 10^{-4}$ m

Section 27.6 Resolving Power

44. The Hubble Space Telescope in orbit above the Earth has a 2.4 m circular aperture. The telescope has equipment for detecting ultraviolet light. What is the minimum angular separation between two objects that the Hubble Space Telescope can resolve in ultraviolet light of wavelength 95 nm?
(a) $4.8 \times 10^{-8}$ rad  
(b) $7.0 \times 10^{-8}$ rad  
(c) $1.9 \times 10^{-7}$ rad  
(d) $1.5 \times 10^{-7}$ rad  
(e) $3.3 \times 10^{-9}$ rad

45. A spy satellite is in orbit at a distance of $1.0 \times 10^6$ m above the ground. It carries a telescope that can resolve the two rails of a railroad track that are 1.4 m apart using light of wavelength 600 nm. Which one of the following statements best describes the diameter of the lens in the telescope?
(a) It is less than 0.14 m.  
(b) It is greater than 0.14 m and less than 0.23 m.  
(c) It is greater than 0.23 m and less than 0.35 m.  
(d) It is greater than 0.35 m and less than 0.52 m.  
(e) It is greater than 0.52 m.
46. The headlights of a car are 1.6 m apart and produce light of wavelength 575 nm in vacuum. The pupil of the eye of the observer has a diameter of 4.0 mm and a refractive index of 1.4. What is the maximum distance from the observer that the two headlights can be distinguished?
   (a) 8.0 km  (c) 11 km  (e) 16 km
   (b) 9.1 km  (d) 13 km

47. Two stars are just barely resolved by a telescope with a lens diameter of 0.500 m. Determine the angular separation of the two stars. Assume incident light of wavelength 500.0 nm.
   (a) $1.22 \times 10^{-6}$ rad  (c) $2.44 \times 10^{-7}$ rad  (e) $1.22 \times 10^{-7}$ rad
   (b) $5.66 \times 10^{-5}$ rad  (d) $4.88 \times 10^{-5}$ rad

48. The wavelength of light emitted from two distant objects is 715 nm. What is the minimum angle at which these objects can just be resolved when using binoculars with a 50-mm objective lens?
   (a) $10^{-2}$ degrees  (c) $10^{-4}$ degrees  (e) $10^{-6}$ degrees
   (b) $10^{-3}$ degrees  (d) $10^{-5}$ degrees

49. Two candles are lit and separated by 0.10 m. If the diameter of the pupil of an observer’s eye is 3.5 mm, what is the maximum distance that the candles can be away from the observer and be seen as two light sources? Use 545 nm for the wavelength of light in the eye.
   (a) 170 m  (c) 530 m  (e) 850 m
   (b) 340 m  (d) 680 m

Section 27.7 The Diffraction Grating
Section 27.8 Compact Discs, Digital Video Discs, and the Use of Interference

50. A 30.0-mm wide diffraction grating produces a deviation of 30.0° in the second order principal maxima. The wavelength of light is 600.0 nm. What is the total number of slits on the grating?
   (a) 10 000  (c) 12 500  (e) 15 000
   (b) 11 500  (d) 14 000

51. A beam of light that consists of a mixture of red light ($\lambda = 660$ nm in vacuum) and violet light ($\lambda = 410$ nm in vacuum) falls on a grating that contains $1.0 \times 10^4$ lines/cm. Find the angular separation between the first-order maxima of the two wavelengths if the experiment takes place in a vacuum.
   (a) 11°  (c) 24°  (e) 65°
   (b) 17°  (d) 41°

52. Red light of wavelength 600.0 nm is incident on a grating. If the separation between the slits is $5.0 \times 10^{-5}$ m, at what angle does the first principal maximum occur?
   (a) $0.6 \times 10^{-2}$ rad  (c) $1.2 \times 10^{-2}$ rad  (e) $5.0 \times 10^{-2}$ rad
   (b) $0.8 \times 10^{-2}$ rad  (d) $3.6 \times 10^{-2}$ rad

53. A diffraction grating that has 4500 lines/cm is illuminated by light that has a single wavelength. If a second order maximum is observed at an angle of 42° with respect to the central maximum, what is the wavelength of this light?
   (a) 1500 nm  (c) 930 nm  (e) 740 nm
   (b) 370 nm  (d) 1100 nm
54. Light from two sources, $\lambda_1 = 623$ nm and $\lambda_2 = 488$ nm, is incident on a diffraction grating that has 5550 lines/cm. What is the angular separation, $\theta_1 - \theta_2$, of the second order maxima of the two waves?
(a) 11.0°  
(b) 15.0°  
(c) 25.0°  
(d) 32.8°  
(e) 43.8°

55. Light from a laser ($\lambda = 640$ nm) passes through a diffraction grating and spreads out into three beams as shown in the figure. Determine the spacing between the slits of the grating.
(a) 240 nm  
(b) 410 nm  
(c) 500 nm  
(d) 680 nm  
(e) 800 nm

56. Visible light of wavelength 589 nm is incident on a diffraction grating that has 3500 lines/cm. At what angle with respect to the central maximum is the fifth order maximum observed?
(a) 17.9°  
(b) 23.8°  
(c) 35.7°  
(d) 71.3°  
(e) A fifth order maximum cannot be observed.

57. White light is passed through a diffraction grating that has $2.50 \times 10^5$ lines/m. On each side of the white central maximum, a spectrum of colors is observed. What is the wavelength of the light observed at an angle of 7.00° in the first-order bright fringes?
(a) 487 nm  
(b) 589 nm  
(c) 632 nm  
(d) 668 nm  
(e) 731 nm

Additional Problems

58. Which one of the following statements provides the most convincing evidence that electromagnetic waves have a transverse character?
(a) Electromagnetic waves can be refracted.  
(b) Electromagnetic waves can be reflected.  
(c) Electromagnetic waves can be polarized.  
(d) Electromagnetic waves can be diffracted.  
(e) Electromagnetic waves exhibit interference.

59. Light of wavelength 530 nm is incident on two slits that are spaced 1.0 mm apart. If each of the slits has a width of 0.10 mm, how many interference maxima lie within the central diffraction peak?
(a) 1  
(b) 4  
(c) 12  
(d) 21  
(e) infinity