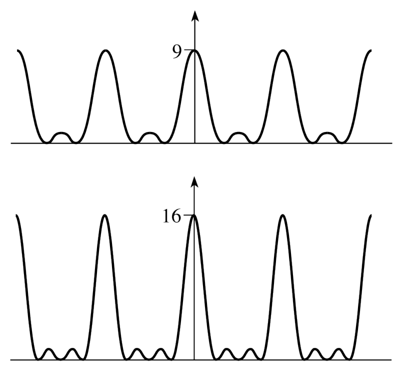
Exam V: Chapters 23–24

1. Two typical incandescent flashlights shine onto the surface of a white screen. When the circles of light overlap,
   A) an interference pattern is formed. Bright and dark fringes form concentric circles around the overlapping beams.
   B) an interference pattern is formed. Blue light forms a fringe on one side of the overlapping beams, and a red fringe forms on the other side.
   C) no interference pattern will form. The flashlight beams are neither spatially coherent nor monochromatic, so there can be no interference between them.
   D) no interference pattern forms, because flashlights only emit light in the form of particles. Interference is an example of wave behavior, not particle behavior.

2. Spatial coherence?
   A) All light incident on an object (therefore landing at the same point in space) is spatially coherent.
   B) All light emitted by the same source (and therefore propagating away from the same point in space) is spatially coherent.
   C) Light waves which have a direction of oscillation parallel to the direction of propagation are spatially coherent.
   D) Light waves traveling through a medium (regardless of wavelength) are spatially coherent if they have the same direction of propagation and are in phase.

3. A red laser pointer has a wavelength $\lambda = 650\text{nm}$. The light emitted by the pointer
   A) is both monochromatic and spatially coherent.
   B) is monochromatic, but not spatially coherent.
   C) is spatially coherent, but not monochromatic.
   D) is neither spatially coherent no monochromatic.

4. A red laser has $\lambda = 650\text{nm}$. It is projected onto a white screen, and its intensity is measured to be I_o. When the same laser light is passed through a double slit, the intensity of the resulting maxima on the same screen will be
   A) $\frac{1}{4}I_o$ B) $\frac{1}{2}I_o$ C) I_o D) $2I_o$ E) $4I_o$



5. Interference patterns are shown on the right for two different multi-slit gratings. Compare the number of slits which formed each pattern.
   A) The top pattern must have been made using a larger number of slits, because the maxima are wider, and have lower intensity.
   B) The bottom pattern must have been made using a larger number of slits. Increasing the number of slits increases the intensity of the maxima.
   C) Both patterns were created using the same number of slits. The only difference is the distance from the slit to the screen. The bottom pattern, being brighter, must mean the slits were closer to to the screen.

6. According to the figure on the right, using a different number of slits while maintaining the same slit spacing d results in maxima having the same location on the screen. Is this an accurate representation?
   A) Yes. If the slit spacing d remains the same, increasing the number of slits does not alter the positions of the maxima.
   B) No. The figure is inaccurate. At the same slit spacing, more slits must result in greater distance between maxima.
   C) No. If the slit spacing remains constant, more slits will result in a pattern of decreasing distance between maxima.

7. (3 points) Find the angular location θ_2 of the second maxima for a grating with $d = 200\mu$. The light used is a green laser with $\lambda = 530\text{nm}$. Answer numerically with three sig figs. $\theta_2 = 0.304°$

$$\sin\theta = \frac{m\lambda}{d} \implies \theta = \sin^{-1}\left(\frac{m\lambda}{d}\right)$$

$$\theta = \sin^{-1}\left(\frac{(2)(5.30\times10^{-7}\text{m})}{(200\times10^{-6}\text{m})}\right) = 0.304°$$

8. When creating a diffraction grating to use (for example, to use in a spectrometer for as astronomical telescope), you want to maximize the angular separation of the colors by wavelength.
   A) Increase the distance L from the grating to the screen. Larger L means greater θ.
   B) Decrease the slit spacing d. The smaller the spacing, the greater θ.
   C) Increase the slit width. The wider the slit, the more the colors will separate.

9. When white light is passed through a diffraction grating having 150 slits/mm, what happens?
   A) Nothing. Because the white light is not a laser, there will be no diffraction. Just uniform white light on the screen.
   B) Something. The angle of the diffracted beam depends on wavelength; longer wavelength, greater angle.
   C) The other thing. There angle depends inversely on wavelength! Longer wavelength means smaller angle!

10. (3 points) Light from a helium emission tube is passed through a grating spectrometer with 150 slits/mm, and strikes a screen located $L = 1.5\text{m}$ from the grating. The first bright line is measured at $y = 0.097\text{m}$ from the central maximum. Calculate the wavelength of this line, and answer numerically. Include units! $\lambda = 431\text{nm}$

$$d = \frac{1}{150\text{slits/mm}} = 6.67\times10^{-6}\text{m}$$

$$\lambda = \frac{yd}{L} = \frac{(0.097\text{m})(6.67\times10^{-6}\text{m})}{(1.5\text{m})} = 431\text{nm}$$

11. What color is this emission line? It is closest in color to
    A) violet. B) green. C) orange. D) red.

12. Single slit diffraction
    A) is an observable effect with sound waves, but not light waves.
    B) is easily observable for sound waves. It can also be observed and measured for light waves.
    C) is not a thing. You can't have a diffraction effect with any wave unless you have at least two or more slits.

13. For single-slit diffraction, what happens if the slit width is much larger than the wavelength propagating through it?
    A) Increasing the slit with relative to the wavelength is a great idea! Bigger width, more diffraction.
    B) If the slit width is large compared to the wavelength, diffraction will be minimized.
    C) Trick question! The diffraction does depend on the wavelength, but it does not depend on the slit width

14. (3 points) A single-slit plate has a slit width $w = 0.02\text{mm}$. A teal-blue laser ($\lambda = 520\text{nm}$) is projected through the slit and onto a screen $L = 2.0\text{m}$ away. Calculate the width of the central bright maximum ($2y_1$). Answer numerically. $2y_1 = 0.052\text{m}$

$$w\sin\theta_m = m\lambda \quad \text{and} \quad \sin\theta_m = \frac{y_m}{L} \implies y_1 = \frac{\lambda L}{w}$$

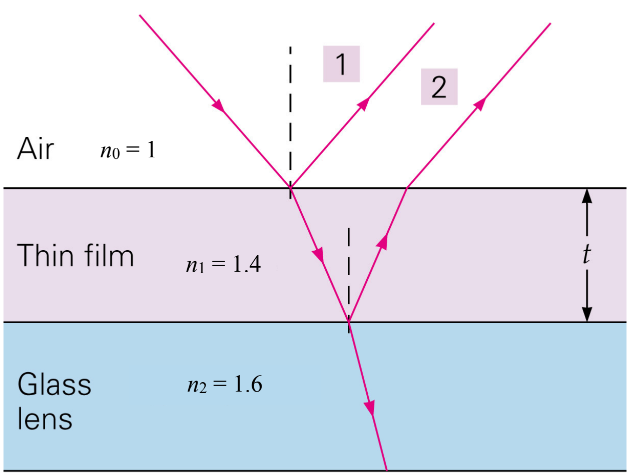
$$2y_1 = 2\frac{(520\times10^{-9}\text{m})(2.0\text{m})}{(0.02\times10^{-3}\text{m})} = 0.052\text{m}$$

15. What is an additive primary color of light?
    A) Additive primary colors of light are any three colors that are 120° apart on an artist's color wheel.
    B) Two colors that can be mixed together to make red, orange, yellow, green, blue, or violet light.
    C) Any two colors that can be mixed together to make red, blue, or yellow are additive primaries.
    D) The additive primary colors can be combined to make black light.
    E) The additive primary colors can be combined to make white light.

16. The additive primary colors of light
    A) are red, blue, and yellow.
    B) are red, green, and yellow.
    C) are cyan, magenta, and yellow.
    D) are red, green, and blue.

17. What is a subtractive primary color?
    A) A color formed by subtracting two colors from white light: white - red - blue = green.
    B) A color formed by subtracting white from red, green, or blue: red - white = magenta.
    C) A color formed by subtracting one color from white light: white - blue = yellow.
    D) Black. Black is the one and only subtractive color, because you only get it when you remove or subtract all light, of every color.

18. Words in yellow ink are written on a white page. A red light shines on the paper, and there are no other sources of light.
    A) The page looks red, because it reflects red. The ink disappears because it absorbs the red light.
    B) The page looks red because it reflects red, and the ink looks yellow because it reflects yellow.
    C) The page looks yellow, and so does the ink. Both absorb the red, so you can't tell them apart.
    D) Page and ink both appear red, so the ink seems to disappear. Both absorb the red light.
    E) Page and ink both appear red because they both reflect all the red light that strikes.



A thin film coating covers a pane of glass as shown on the left. Assume the index of refraction for air is $n_o = 1$. The film has index $n_1 = 1.4$, and the glass has index $n_2 = 1.6$. Incident light with wavelength $\lambda = 550\text{nm}$ strikes the film as shown.

19. True or false: Ray 1 will undergo a 180° phase change ($\lambda/2$) when it reflects off the top surface of the film.

20. True or false: Ray 2 will undergo a 180° phase change ($\lambda/2$) when it reflects off the glass lens.

21. True or false: Ray 2 will undergo a 180° phase change ($\lambda/2$) when it is transmitted from the thin film back into the air.

$$\lambda' = \frac{\lambda}{n} = \frac{(550\text{nm})}{1.4} = 393\text{nm}$$

22. (3 points) Calculate the wavelength of the light λ' as it passes through the thin film. Answer numerically, and include units. $\lambda' = 393\text{nm}$

23. True or false: The frequency of the light will decrease as well as the wavelength when the light passes from the faster air into the slower medium of the thin film.

24. If incident light with $\lambda = 550\text{nm}$ (green) will interfere destructively, what color fringe will an observer see?
    A) Red.
    B) Green.
    C) Blue.
    D) Cyan.
    E) Magenta.
    F) Yellow.
    G) White.
    H) Black.

25. White light from an incandescent source is passed through a polarizing filter. What happens?
    A) The filter acts as a color selector. A blue polaroid only allows blue light through, and a red polaroid only permits red light to pass though.
    B) **The filter acts as a directional selector. The polaroid allows only vibrations with a specific orientation (relative to the filter) to pass. The transmitted light is not color-filtered.**
    C) The filter acts as an energy selector. Only photons having a specific energy are permitted through the filter. It does not select for color or directionality.

26. True or false: A pair of parallel polaroids permits no light to pass. (Say that fast five times!)

27. True or false: A pair of perpendicular polaroids permits no light to pass.

28. When a third polarizing filter is inserted between two perpendicular polaroids, what happens?
    A) Nothing. No matter how the filter is oriented, no light will emerge through the final filter.
    B) Everything. Regardless of its orientation, the middle filter cancels out the effects of the other two.
    C) **Maybe something. If it is aligned perpendicular to the first filter, all light remains blocked. But turning it so that it is at 45° with respect to each filter suddenly allows light through again!**

29. How can you determine if a light source is polarized?
    A) You can't. Most light sources are polarized, so it's typically just assumed that all light is polarized.
    B) **Most light isn't polarized! If you use a polarizing filter, you should notice that polarized light will get dimmer (until it is blocked) as you rotate the filter. There will be no change with unpolarized light.**
    C) Answer B above is backwards; unpolarized light will dim noticeably when you rotate the filter. The polarized light will remain at a constant intensity, no matter how you rotate the filter.

30. Polaroid sunglasses: Science or scam?
    A) **Science. The lenses are oriented to decrease the glare of light reflected from horizontal surfaces.**
    B) Scam. The lenses are no different than any other pair of sunglasses. Simply decreasing the overall amount of light that gets transmitted through the lens to your eye is all any pair of sunglasses can hope to do.

31. The idea that the speed of light is a constant that could be measured
    A) dates back to Democritus, who hypothesized that atoms move at the speed of light.
    B) **goes back as far as Galileo, but he was not able to make the measurement accurately.**
    C) is laughable, because we know now that light travels instantaneously through any medium.
    D) was disproved conclusively with Maxwell's equations.

32. Maxwell's equations: What's the point?
    A) **Extremely compact, extremely symmetric, amazingly powerful and predictive. Plays well with relativity. What's not to love?**
    B) These equations exist only as historical artifacts; they were disproven long ago, but are useful as rough estimates.
    C) None, really. They are an exercise in self-indulgent and utterly unnecessary partial differential equations.

33. What was the significance of Hertz's experiment in 1887? It showed that
    A) a beam of light knocks electrons o! a metal foil, proving that light and electricity were related.
    B) alpha particles are deflected by atomic nuclei, proving that the nucleus is positively charged.
    C) **radio waves are electromagnetic, opening the door for Marconi and wireless communication.**
    D) an oscillating circuit creates gravitational waves, demonstrating that gravity is magnetic in nature.

34. Electromagnetic waves
    A) are longitudinal and require a medium to travel through.
    B) are transverse and require a medium to travel through.
    C) are longitudinal and do not require a medium to travel through.
    D) **are transverse and do not require a medium to travel through.**

35. The electromagnetic spectrum includes
    A) radio, television, and sound waves.
    B) visible light, but no other types of waves.
    C) radio, sound, and seismic waves.
    D) **radio, infrared, ultraviolet, and gamma rays.**

36. The electromagnetic spectrum is
    A) discrete: you can only have wavelengths or frequencies that are whole numbers.
    B) **continuous: there are no "forbidden" values for wavelength or frequency.**
    C) garbled: there are certain frequencies that correspond to more than one wavelength.

37. Compare the speed of radio waves to the speed of x-rays traveling through the vacuum of space.
    A) Radio waves travel faster because they have a longer wavelength.
    B) Radio waves travel more slowly because they have a lower frequency.
    C) X-rays travel more slowly because they have a shorter wavelength.
    D) X-rays travel faster because they have a higher frequency.
    E) **The speed is the same for both, $c = 3\times10^8$m/s.**

38. Compare the energy of infrared radiation to ultraviolet.
    A) Infrared radiation has a lower frequency and therefore less energy.
    B) Infrared radiation has a longer wavelength, and therefore more energy.
    C) The energy of both depends on speed (you know, $E = mc^2$), so they have the same energy.

39. True or false: Gamma rays have about double the frequency of microwave radiation.

40. (3 points) Compute the wavelength λ of microwaves having a frequency $f = 5\times10^{10}$Hz.
Answer numerically, and include units! $\lambda = 0.006$m

$$c=\lambda f \implies \lambda=\frac{c}{f}$$

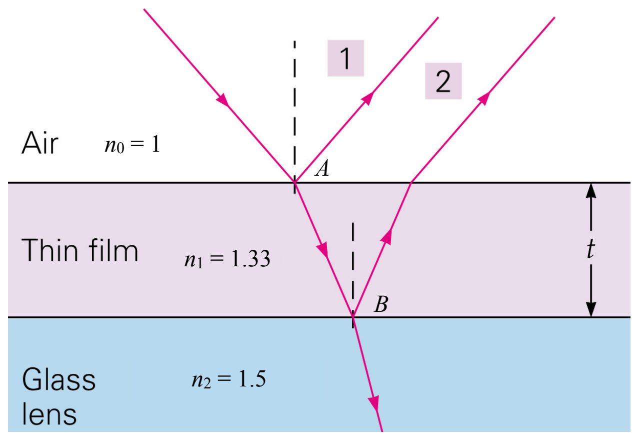
$$\lambda=\frac{(3\times10^{8}\text{m/s})}{(5\times10^{10}\text{Hz})}=6.0\times10^{-3}\text{m}$$

$$E=hf$$

$$E=(6.63\times10^{-34}\text{J}\cdot\text{s})(5\times10^{10}\text{Hz})=3.32\times10^{-23}\text{J}$$

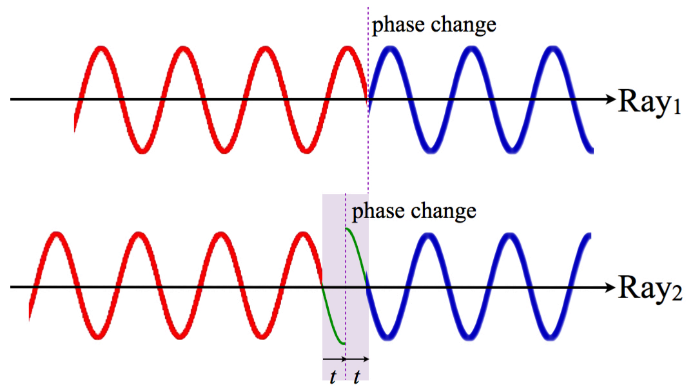
41. (3 points) Compute the energy E of microwaves having a frequency $f = 5\times10^{10}$Hz.
Planck's constant $h = 6.63\times10^{-34}$J·s. Answer numerically. $E = 3.32\times10^{-23}$J

42. A thin film of water ($n_1 = 1.33$) covers a flat glass ($n_2 = 1.5$) lens. Light having a wavelength λ strikes at point A. Part of the incoming light is reflected immediately (**Ray**$_1$), and part (**Ray**$_2$)is transmitted through the water, reflecting off the glass at point B.



A) (2 points) Identify whether the rays undergo phase change at points A and B.
   A: $n_1 > n_0$, so **Ray**$_1$ changes phase by 180°
   B: $n_2 > n_1$, so **Ray**$_2$ changes phase by 180°

B) (4 points) Show with a sketch what the total path length difference Δ between **Ray**$_1$ and **Ray**$_2$ must be if light of wavelength λ is to interfere destructively.



C) (4 points) Calculate the minimum film thickness t required for $\lambda = 550$nm green light to cancel.

$$2t=\frac{\lambda'}{2} \implies t=\frac{\lambda}{4n_1}$$

$$t=\frac{(550\times10^{-9}\text{m})}{4(1.33)}=103.4\text{nm}$$

D) (4 points) Calculate the minimum thickness required if a red light ($\lambda = 650$nm) is meant to interfere constructively.

$$2t=\lambda' \implies t=\frac{\lambda}{2n_1}$$

$$t=\frac{(650\times10^{-9}\text{m})}{2(1.33)}=244.4\text{nm}$$

43. (4 points) A $P = 75$W lightbulb is $d = 2.0$ m from a screen. What is the intensity I of light incident on the screen?

$$I=\frac{P}{A}=\frac{P}{4\pi r^2}$$

$$I=\frac{(75\text{W})}{4\pi(2.0\text{m})^2}=1.49\text{W/m}^2$$

44. (4 points) Unpolarized light passes through three polarizers. The second makes an angle $\theta_2 = 25°$ relative to the first, and the third makes an angle of $\theta_3 = 45°$ relative to the first. The intensity of light measured after the third polarizer is $I_3 = 40$ W/m^2. Determine the intensity of the unpolarized light incident on the first polarizer.

$$I_1 = \frac{I_0}{2} \implies I_0 = 2I_1$$

$$I_2 = I_1 \cos^2\theta_{2/1} \quad \text{and} \quad I_3 = I_2 \cos^2\theta_{3/2}$$

$$I_3 = (I_1 \cos^2\theta_{2/1}) \cos^2\theta_{3/2}$$

$$I_0 = 2I_1 = 2\left[\frac{I_3}{\cos^2\theta_{2/1} \cos^2\theta_{3/2}}\right]$$

$$I_0 = 2\left[\frac{(40\text{W/m}^2)}{\cos^2(25°) \cos^2(45° - 25°)}\right]$$

$$I_0 = 110.3\text{W/m}^2$$

Formula Sheet

Electromagnetic Waves: $v = c = \lambda f$

$c = 3 \times 10^8 \ \frac{\text{m}}{\text{s}}$

Electromagnetic Energy: $E = hf$

$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$

Law of Reflection: $\theta_i = \theta_r$

Index of Refraction: $n = \frac{c}{v}$

Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Critical Angle for Total Internal Reflection: $\sin\theta_c = \frac{n_2}{n_1}$

Wavelength Change With Medium Change: $\lambda' = \frac{\lambda}{n}$

Small Angle Approximation: $\tan\theta \cong \sin\theta$

Double-Slit Interference:

Path Length Difference: $\Delta = L_2 - L_1 = d\sin\theta$

$\tan\theta = \frac{y}{L} \cong \sin\theta$

Constructive Interference: $\Delta = m\lambda = d\sin\theta$

Destructive Interference: $\Delta = \frac{(2m+1)\lambda}{2}$

Lateral Distance to Bright Fringe: $y_n = \frac{n\lambda L}{d}$

Distance Between Adjacent Fringes:

Diffraction Grating Maxima: $\sin\theta_m = m\lambda/d = y/L$

Single-Slit Diffraction Minima: $w\sin\theta_m = m\lambda$

$\sin\theta_m = \frac{y_m}{L}$

Thin-Film Interference:

$n_o < n_1 > n_2$: Constructive: $2t = (2m+1)(\lambda/2n_1)$
Destructive: $2t = m(\lambda/n_1)$

$n_o < n_1 < n_2$: Constructive: $2t = m(\lambda/n_1)$
Destructive: $2t = (2m+1)(\lambda/2n_1)$

Single Polarizing Filter: $I = I_0/2$

Multiple Polarizing Filters: $I = I_{0/2}\cos^2\theta$