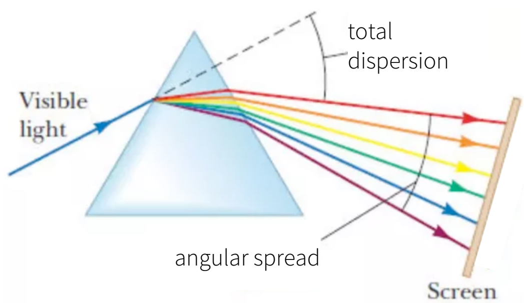
Exam IV: Chapters 21–23

1. You are watching your favorite goldfish in his tank. Because of the refraction of light, he appears
   A) larger and deeper than he actually is.
   B) smaller and deeper than he actually is.
   C) larger and shallower than he actually is.
   D) smaller and shallower than he actually is.
   E) no different than if he was out of the water.

2. Total internal reflection may be observed when a light ray strikes the boundary traveling
   A) from a slower medium to a faster medium.
   B) from a faster medium to a slower medium.
   C) at an angle of exactly 45° with respect to the normal, moving from a faster to a slower medium.
   D) at an angle of more than 45° with respect to the normal. The indices of refraction of the media do not matter.

3. You are driving I-40 across New Mexico. It's gorgeous! You see ahead of you a shimmering near the surface of the road.
   A) The road is wet with condensation. Or something. You are seeing moisture evaporating.
   B) The road is dry, and you are seeing a mirage because the air is hotter near the surface of the road. The sunlight refracts as it crosses from cooler to warmer air.
   C) The road is dry, but the air above it is moist. A mirage is the result of the water vapor in the air acting like millions of tiny prisms, and the shimmering effect is the vibration of the molecules as the light reflects off the surface.

4. According to the figure on the right, when white light enters a prism,
   A) white light emerges. The path of the light has been unaltered.
   B) white light emerges, but the path has been laterally displaced. The emergent beam is parallel to the incident beam.
   C) white light is separated into its constituent colors. Each color experiences equal refraction, but unequal lateral displacement. Red is least shifted, blue is most shifted.
   D) the colors are refracted in order of increasing frequency. Red, with the lowest frequency, is least refracted, while violet light has the highest frequency and experiences greatest refraction.



5. When you view a single (primary) rainbow, the colors are in ROY G BIV order from the top to the bottom of the bow. When you see a double rainbow, the secondary colors (from top to bottom of the bow) are in what order?
   A) ROY G BIV B) VIB G YOR C) BRI G VOY D) GIB V YOR
   B) The colors might appear in any order at all. It depends on the index of refraction of the glass used to make the prism.

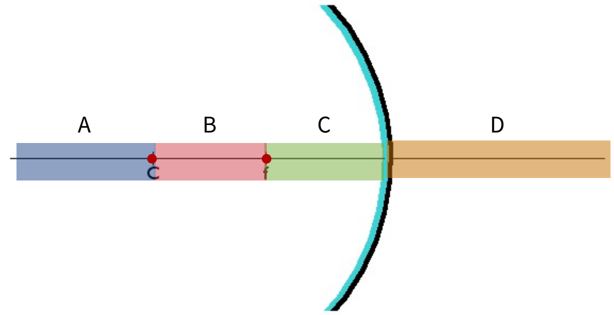
6. You have a really tall friend. Really, really tall: he is 80 inches tall, head to toe. As you are walking through the Target store, he suddenly remembers that he needs a full-length mirror. They have several to choose from, and he picks the one that is 36” because it’s the least expensive.
   A) The Target is amazing. They always have exactly what you need. The 36” mirror is perfectly adequate, no matter how tall you are. He just needs to mount it higher on the wall than a shorter person would.
   B) The mirror is too short for him. He needs a longer mirror to be able to see his full image. He needs an 80” mirror to match his 80” height, so he probably should return that 36” mirror.
   C) The 36” mirror is shorter than he is, but if he steps away from the mirror he will see his entire image. He just needs to stand at a distance twice his height away from the mirror.
   D) Tell your friend to return the 36” mirror and get a 48” instead. He doesn’t actually need a full 48”, but a 4-ft mirror is definitely large enough for him to see a full-length image of himself, even if he decides to wear a tall tophat of the style favored by Abraham Lincoln.

7. You are standing 24 inches in front of the bathroom mirror. Your reflected image appears
   A) 24 inches behind the mirror.
   B) 24 inches in front of the mirror.
   C) 12 inches behind the mirror.
   D) 12 inches in front of the mirror.

8. You are holding your toothbrush, which happens to be 7” long. The image of the toothbrush is
   A) 3.5” long. B) 7” long. C) 14” long. D) 49” long.

9. If a mirror has a spherically curved shape,
   A) the law of reflection states that the angle of reflection is always smaller than the angle of incidence. This is why curved mirrors can only make smaller reflected images.
   B) the law of reflection states that the angle of reflection is always larger than the angle of incidence. This is why the images formed are always magnified larger than the object.
   C) the angle of reflection may be larger or smaller than the angle of incidence. It will depend on the object distance from the mirror. When $\theta_i < \theta_r$ you see a magnified image, but when $\theta_i > \theta_r$ when the reflected image is smaller.
   D) the law of reflection is the same as for any other shape mirror: $\theta_i = \theta_r$.

10. A concave mirror
    A) is also known as a converging mirror.
    B) affects light the same way a converging lens does.
    C) can be used to form an image exactly the same height as the object.
    D) All of the above.
    E) None of the above.



11. In order to form an image that is inverted, where should you position an object? Use the concave mirror shown on the right, and assume the light source is on the left side of the mirror. If you think more than one of the marked regions is appropriate, list them all. If you think none of the locations is correct, please write 'none.'

    Object location(s) = A or B

12. What happens if you position an object precisely at the focal point *f* of the concave mirror shown above?
    A) An upright image will be located at the center of curvature *C*.
    B) An inverted image will be found somewhere in region *D*.
    C) No image can be found, since the image distance d_i will be literally infinite.
    D) The mirror explodes, and the resulting mushroom cloud can be seen for miles.

13. (3 points) A **concave mirror** has a radius of curvature $R = +18\text{cm}$.
    What is the focal length of this mirror? Answer numerically, **including sign**. $f =$ $R/2 = 9\text{cm}$

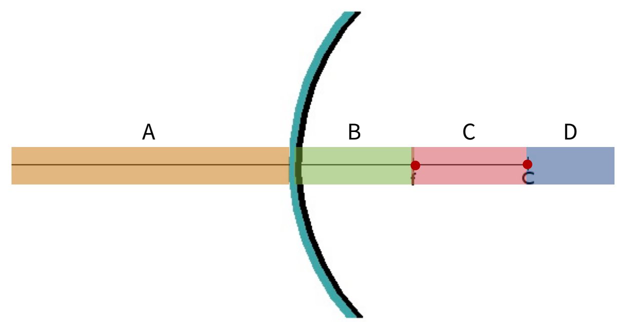
14. (3 points) An object is placed at $d_o = 25\text{cm}$ in front of a concave mirror with a focal length $f = 15\text{cm}$. Calculate the image distance d_i. Answer numerically, including sign. $d_i =$ 37.5cm

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \Rightarrow \frac{1}{25\text{cm}}+\frac{1}{d_i}=\frac{1}{15\text{cm}}$$

$$d_i=[0.0667-0.04]^{-1}=37.5\text{cm}$$

15. In order to form an image that is upright, where should you position an object? Use the convex mirror shown on the right, and assume the light source is on the left side of the mirror. If you think more than one of the marked regions is appropriate, list them all. If you think none of the locations is correct, please write 'none.'

    Object location(s) = A



16. True or false: Cosmetic mirrors are always convex, because convex mirrors are best for creating magnified images.

17. True or false: A convex mirror cannot form an inverted image.

18. A real image
    A) appears where real light rays intersect.
    B) is always inverted and must be magnified.
    C) cannot be inverted, it is always upright.
    D) cannot be magnified, it is always mini-fied.

19. A virtual image
    A) appears where real light rays intersect.
    B) is always inverted and magnified.
    C) cannot be inverted, it is always upright.
    D) cannot be seen, so does not really exist.

20. Which of the light rays is correctly drawn for the **convex** lens shown on the right?

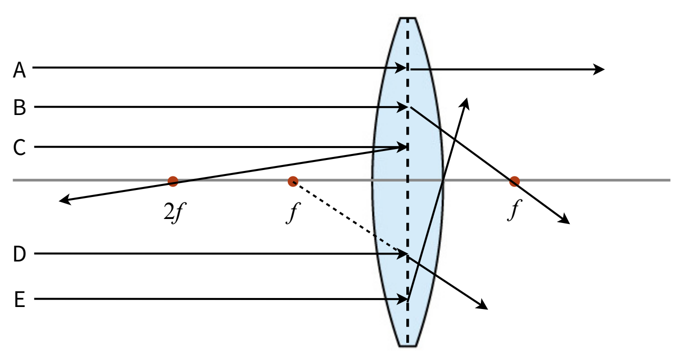
    Ray = B

21. (3 points) An object is placed at $d_o = +30\text{cm}$ in front of a convex lens. A real image is found at $d_i = +25\text{cm}$. Calculate the focal length *f*. Answer numerically (three sig figs), including sign.

    $f =$ 13.6cm

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \Rightarrow \frac{1}{30\text{cm}}+\frac{1}{25\text{cm}}=\frac{1}{f}$$

$$f=[0.0333+0.04]^{-1}=13.6\text{cm}$$



Questions 20 and 21

22. Which of the light rays is correctly drawn for the **concave** lens shown on the right?

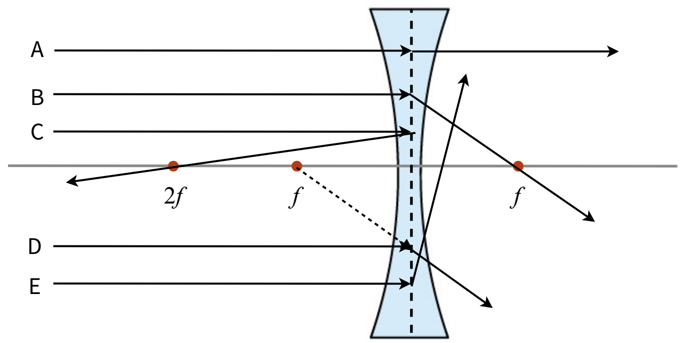
Ray = ______D______

23. (3 points) An object is placed at $d_o = 25\text{cm}$ in front of a concave lens with a focal length $f = -15\text{cm}$. Calculate the image distance d_i. Answer numerically (three sig figs), including sign.

d_i = ______–37.5cm______

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \Rightarrow \frac{1}{25\text{cm}}+\frac{1}{d_i}=\frac{1}{-15\text{cm}}$$

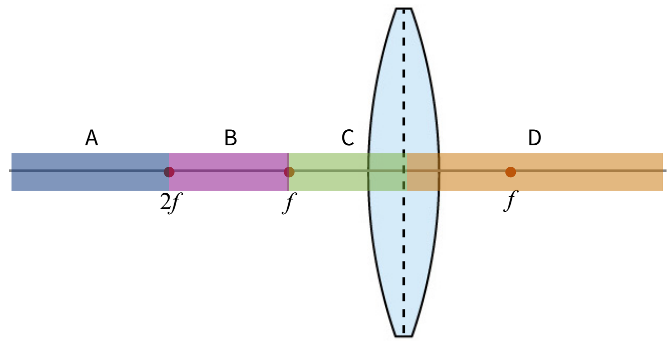
$$d_i=[-0.0667-0.04]^{-1}=-37.5\text{cm}$$



Questions 22 and 23

24. In order to form an image that is inverted, where should you position an object? Use the convex lens shown on the right, and assume the light source is on the left side of the mirror. If you think more than one of the marked regions is appropriate, list them all. If you think none of the locations is correct, please write 'none.'

Object location(s) = ______A or B______



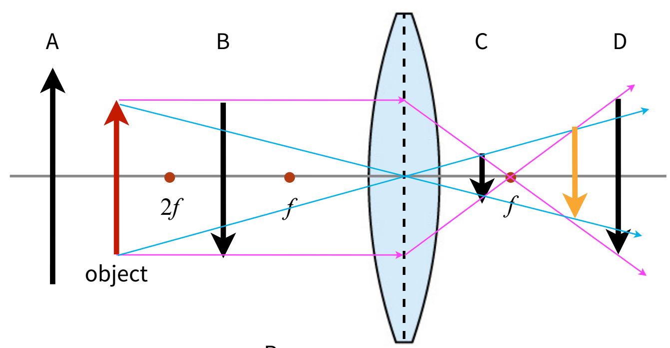
Question 24

25. An object is placed in front of converging lens as shown below on the right. Where will the image form? Use the multiple choices on the figure; if you do not think any of them are correct, write 'none.'

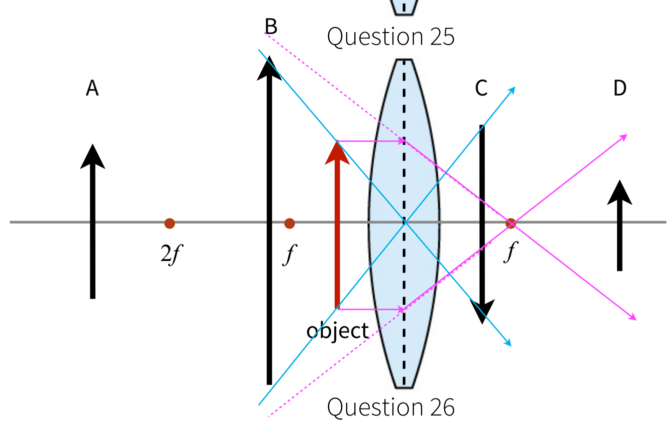
Image location(s) = ______D______

26. An object is placed in front of converging lens as shown below on the right. Where will the image form? Use the multiple choices on the figure; if you do not think any of them are correct, write 'none.'

Image location(s) = ______B______



Question 25



Question 26

27. Your friend (the really tall one) just came home from the eye doctor, and tells you his prescription is –2.8. What does this even mean?
    A) Nothing; it's a random number. Optometrists are secretive people, and they like to use code a lot.
    B) The negative means he's near-sighted. The lens power translates into an $f = -28\text{cm}$.
    C) The negative means he's near-sighted. But the lens power translates into an $f = -36\text{cm}$.
    D) The negative means he's far-sighted. The lens power means he cannot see things closer than 2.8m.
    E) The negative means he's far-sighted. The lens power means he cannot see things closer than 28cm.

28. True or false: Light is a particle.

29. True or false: Light is a wave.

30. Young's double–slit experiment
    A) demonstrates convincingly that light is a particle. The pattern created on a screen shows two bright fringes that line up exactly with the position of each slit. There is a dark fringe on center, which you would expect since no particle passing through a slit could actually hit the center of the screen.
    B) demonstrates conclusively that light is a wave. The alternating pattern of bright and dark fringes on the screen show how two light waves interfere. The max-min pattern proves that the light can't be a particle.
    C) proves that light is a particle. When a bright light shines on a metal foil, the photons crash into the surface and knock electrons right off. Young observed that a wave could not do this, but he could not explain why. Einstein actually explained it, and won a Nobel Prize for his mathematical proof of Young's hypothesis.
    D) showed that light has a dual wave–particle nature. Newton first suggested this, but got distracted by trying to turn lead into gold before he could prove it. Young's experiment laid the groundwork for Maxwell, whose equations finally proved that electricity is a wave and magnetism is a particle.

31. The condition for **constructive interference** requires that the path length difference Δ be equal to
    A) zero.
    B) ¼ the wavelength.
    C) ½ the wavelength.
    D) one whole wavelength.
    E) only odd multiples of ½ wavelengths.

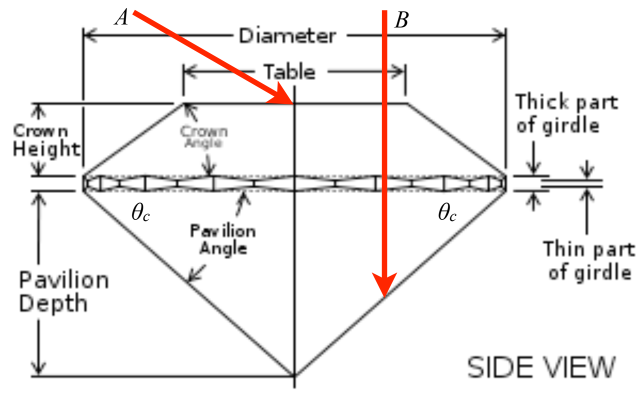
32. Compare the index of refraction of red light to that of blue light, moving through the same non-vacuum medium.
    A) All frequencies of light will have the same index of refraction, regardless of the medium.
    B) Blue light will have a smaller index than red light through the same medium.
    C) Blue light will have a greater index than red light through the same medium.

Part II: Problem Solving

Solve each of the following problems to the best of your ability. Please work in the space provided, and if you need scratch paper, it will be provided for you. Please work as neatly as you can, and make your reasoning/logic/math as clear as possible.

33. Sapphire has an index of refraction $n = 1.762$ (for air, $n = 1$).
    A) (5 points) White light (*Ray A*) incident on the table of the gemstone strikes at $\theta_i = 20°$. Find the angle of refraction θ_r.

$$n_i \sin\theta_i = n_r \sin\theta_r$$
$$(1)\sin 20° = (1.762)\sin\theta_r$$
$$\theta_r = 11.2°$$



    B) (5 points) Calculate the minimum pavilion angle θ_c for the gemstone such that a ray of white light entering along any normal to the table (*Ray B*) will be totally internally reflected.

$$\sin\theta_c = \frac{n_r}{n_i} = \frac{1}{1.762}$$
$$\theta_c = 34.6°$$

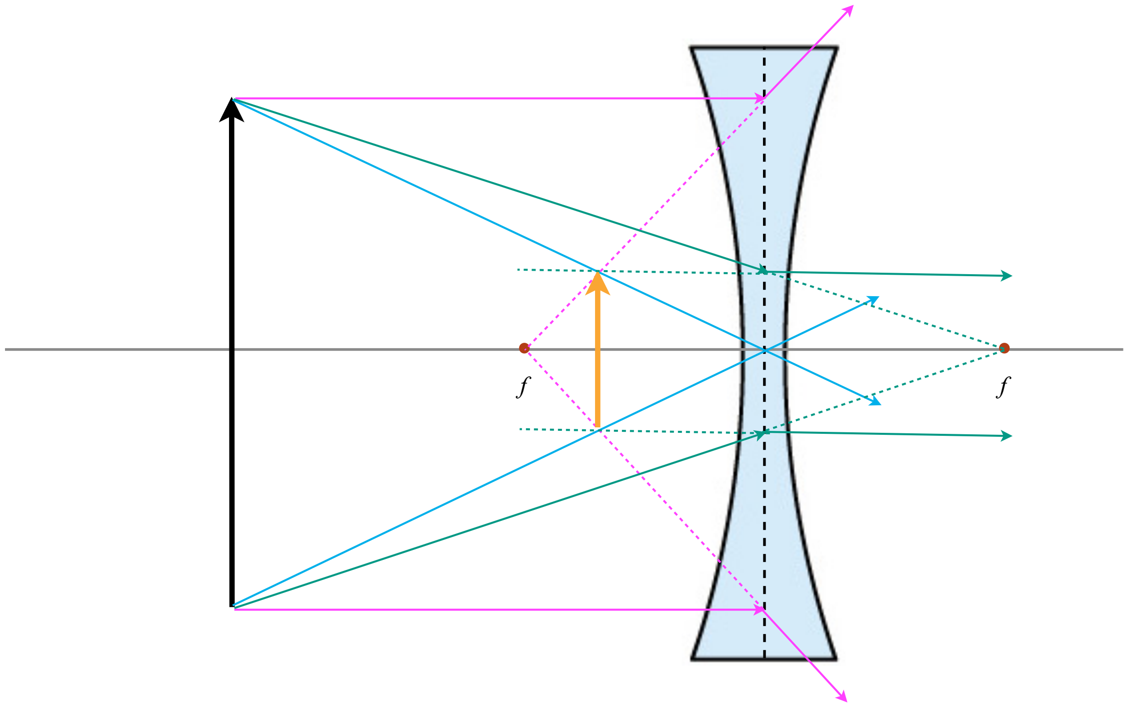
    C) (5 points) The white light is replaced by a red laser having a wavelength $\lambda = 650\text{nm}$. Calculate the frequency f of this laser light.

$$c = \lambda f \Rightarrow f = \frac{c}{\lambda} = \frac{3\times10^8 \text{m/s}}{650\times10^{-9}\text{m}} = 4.62\times10^{14}\text{Hz}$$

    D) (5 points) What is the new wavelength λ' of the laser in the sapphire?

$$\lambda' = \frac{\lambda}{n} = \frac{650\times10^{-9}\text{m}}{1.762} = 369\text{nm}$$

34. An object is placed as shown (d_o = 27.5cm)before a concave lens with focal length f = –12.5cm.
A) (5 points) Carefully construct the ray diagram to locate the position and orientation of the image formed by the lens.



B) (5 points) Calculate the image distance d_i.

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \Rightarrow \frac{1}{27.5\text{cm}}+\frac{1}{d_i}=\frac{1}{-12.5\text{cm}}$$
$$d_i=[-0.08-0.0364]^{-1}=-8.59\text{cm}$$

C) (5 points) Calculate the magnification M of the image. If the original object is h_o = 26.5cm tall, how tall is the image (h_i)?

$$M=-\frac{d_i}{d_o}=-\frac{-8.59\text{cm}}{27.5\text{cm}}=0.312$$
$$M=\frac{h_i}{h_o} \Rightarrow h_i=Mh_o=(0.312)(26.5\text{cm})=8.28\text{cm}$$

35. Red light with a wavelength $\lambda = 650\text{nm}$ is incident on two slits separated by $d = 0.25\text{mm}$. The light is projected on a screen located $L = 2.0\text{m}$ from the slits.

A) (5 points) Calculate the angular deflection θ to the center of the **0th** order ($m = 0$) dark fringe.

TYPO! The question ***should*** have read ***first*** order ($m = 1$)! If you put a zero into the proper equation and got a result of 0°, you received full credit. But if you put zero into something else that made no sense, or used zero in the proper equation but somehow got a non-zero numeric result, you did not. If you used $m = 1$ and got the proper answer, you received full credit—but if you used $m = 1$ and got some other numeric answer, you did not.

$$\frac{m\lambda}{2} = d\sin\theta \quad\Rightarrow\quad \sin\theta = \frac{m\lambda}{2d}$$

$$\sin\theta = \frac{m\lambda}{2d} = \frac{(650\times10^{-9}\text{m})}{2(0.25\times10^{-3}\text{m})}$$

$$\theta = 0.0745°$$

B) (5 points) Determine the angular deflection θ to the center of the second order ($m = 2$) bright fringe.

$$m\lambda = d\sin\theta \quad\Rightarrow\quad \sin\theta = \frac{m\lambda}{d}$$

$$\sin\theta = \frac{m\lambda}{d} = \frac{2(650\times10^{-9}\text{m})}{(0.25\times10^{-3}\text{m})}$$

$$\theta = 0.298°$$

C) (5 points) What is the spatial separation y on the screen from the 0^{th} order fringe to the 2^{nd}?

$$y = L\sin\theta \quad\Rightarrow\quad \sin\theta = \frac{m\lambda}{d}$$

$$y = \frac{m\lambda L}{d} = \frac{2(650\times10^{-9}\text{m})(2\text{m})}{(0.25\times10^{-3}\text{m})}$$

$$y = 0.0104\text{m} = 10.4\text{mm}$$

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: $\sin\theta_c = \frac{n_2}{n_1}$

Radius of Curvature of Spherical Mirror: $R = 2f$

Lens and Mirror Equation: $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$

Sign Convention:

converging $f > 0$ — diverging $f < 0$

real object/image $d_o > 0,\ d_i > 0$ — virtual object/image $d_o < 0,\ d_i < 0$

Magnification: $M = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$

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

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

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

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

$m = 1, 2, 3, \ldots$

Destructive Interference: $\Delta = m\left(\frac{\lambda}{2}\right) = d\sin\theta$

$m = 1, 3, 5, 7, \ldots$

Lateral Distance to Fringe: $y_m = L\sin\theta = L\left(\frac{\Delta}{d}\right)$

Use appropriate Δ for bright or dark

Distance Between Adjacent Fringes: $s = \frac{\lambda L}{d}$

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