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PHYSICS FOR THE LIFE SCIENCES

Solution Manual

Created by WebStraw

Physics for the Life Sciences – Optics Solutions

Introduction:

Dear student,

Thank you for opening this solution manual for the Optics chapter of the Physics for the Life Sciences Question Manual. This resource has been created by members of the Education Team at WebStraw who have previously taken an introductory university physics course.

Purpose:

This resource is meant to supplement the Physics for the Life Sciences Question Manual, by providing solutions to select questions. To access the full question manual, please click here.

Instructions

We recommend first trying to complete the problems in the question manual on your own. If you get stuck, you can use this resource to view the solution provided by one of our Education Team members. Once you are confident you understand how to solve that question, we recommend solving additional related problems in order to successfully master the topic.

Disclaimer

This resource assumes that you have a basic understanding of key concepts related to the Optics unit in physics. If you are looking to improve your understanding of specific physics content, check out the additional resources provided at the end of the question manual.

Note: There may be more than one correct method to solve some of the problems outlined in the question manual. Thus, the solutions provided may not represent the only acceptable solution.

If you have any comments or feedback regarding this resource or the solutions contained in it, please do not hesitate to contact us at team@webstraw.ca

We wish you the best of luck on your learning journey!

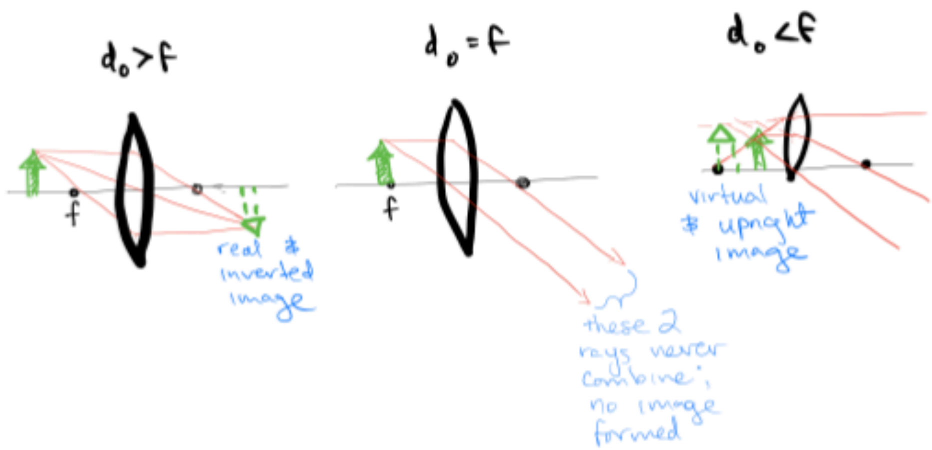
- The WebStraw Education Team

J1. A real image occurs when light rays actually intersect at the image and is inverted (upside down). A virtual image is when light rays do not actually meet at the image and is upright.

- in a concave mirror:
  - the image is REAL if the $d_o > f$
  - the image is VIRTUAL if $d_o < f$
- in a convex mirror
  - always VIRTUAL

J3. When a ray changes mediums, its frequency is its only characteristic that remains unchanged. However, the speed of the travelling ray and the wavelength of the ray are two characteristics that do change. Speed and wavelength are directly proportional, as seen through the universal wave equation $v = f\lambda$, therefore, if the speed of a ray increases as it crosses the boundary between 2 mediums, its wavelength also increases.

J5. For image to not be real & inverted with converging lens, object should be placed so that $d_o \leq f$



J7. Nearsighted people have an overly curved cornea which leads to an decrease of the focal length. Therefore, LASIK would need to straighten out the cornea to allow for an increase in focal length to correct the nearsightedness.

J9. White light is made of several colors combined (ROYGBIV). Each color has a different wavelength ($\lambda_r = \sim 700nm$, $\lambda_v = \sim 450nm$, etc.). Since light speed depends on λ, each color actually travels at a different speed; this is not obvious b/c they are travelling parallel. However, when the rays must refract through a prism, they bend at different angles (shorter wavelengh = more deviation) since angle of deviation is also dependent on speed

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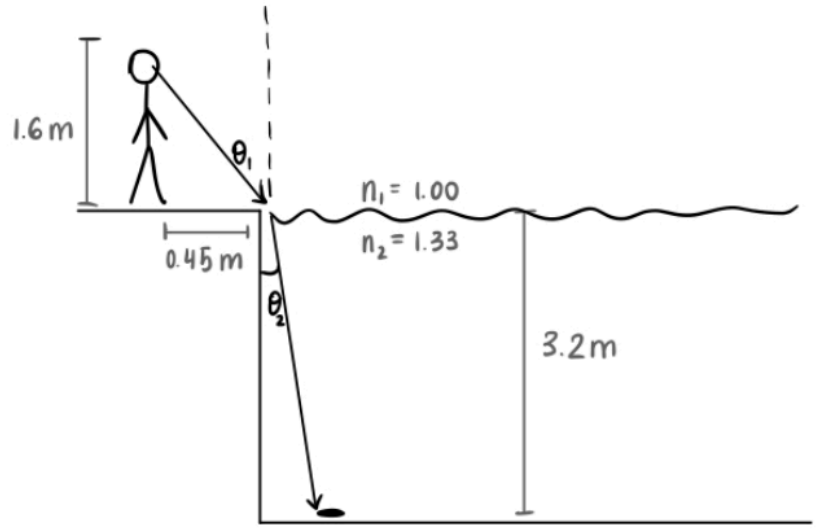
J11. Apparatus of camera like iris, retina to film of camera, cornea similar to lens.

J13. Farsighted means unable to see objects close clearly but objects in distance clearly. The near point cannot converge enough rays from a close object to connect with the retina, so the closest point Jisoo can see is 25 cm and requires diverging eyewear to correct.

J15.



①

$$\tan ø = \frac{1.6}{0.45}$$

$$ø = \tan^{-1}\left(\frac{1.6}{0.45}\right)$$

$$ø = 74.3°$$

② $\theta = 90° - 74.3° = 15.7°$

③ Snell's Law:

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

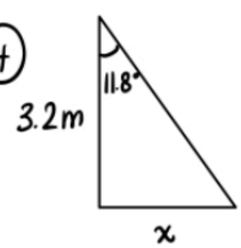
$$\frac{1.33}{1.00} = \frac{\sin 15.7°}{\sin\theta_2}$$

$$\sin\theta_2 = 0.203$$

$$\theta_2 = \sin^{-1}(0.203)$$

$$\theta_2 = 11.8°$$

④



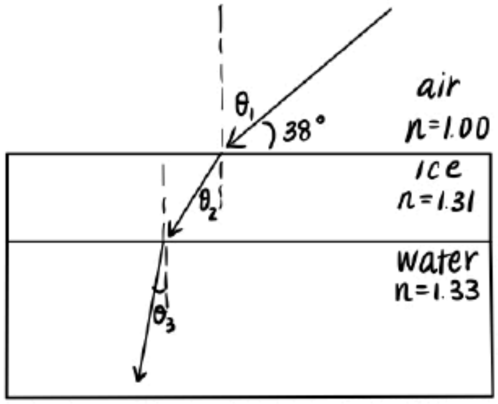
$$\tan 11.8° = \frac{x}{3.2}$$

$$x = 3.2 \tan 11.8°$$

$$\boxed{x = 0.67\text{ m}}$$

∴ The minimum distance the coin can lie and still be visible is 0.67m (67 cm) from the pool wall.

J17.



① $\theta_1 = 90° - 38.0° = 52.0°$

② $\dfrac{\sin\theta_1}{\sin\theta_2} = \dfrac{n_2}{n_1}$

$\dfrac{\sin 52°}{\sin\theta_2} = \dfrac{1.31}{1.00}$

$\theta_2 = \sin^{-1}(0.6015)$

$\theta_2 = 37.0°$

③ $\dfrac{n_2}{n_1} = \dfrac{V_1}{V_2}$

$\dfrac{1.31}{1.00} = \dfrac{3.00 \times 10^8 \text{ m/s}}{V_2}$

$V_2 = 2.290 \times 10^8 \text{ m/s}$

④ passing from ice to water

$\dfrac{n_3}{n_2} = \dfrac{\sin\theta_2}{\sin\theta_3}$

$\dfrac{1.33}{1.31} = \dfrac{\sin(37°)}{\sin\theta_3}$

$\theta_3 = \sin^{-1}(0.5928)$

$\boxed{\theta_3 = 36.4°}$

⑤ $\dfrac{n_3}{n_2} = \dfrac{V_2}{V_3}$

$\dfrac{1.33}{1.31} = \dfrac{2.290 \times 10^8 \text{ m/s}}{V_3}$

$\boxed{V_3 = 2.26 \times 10^8 \text{ m/s}}$

∴ when the ray enters the water it is deflected 36.4° from the normal and it travels at 2.26×10^8 m/s.

J19.

Distance from earth (r) = 300 km = 3×10^5 m

Diameter of lens (d) = 40.0 cm = 0.40 m

λ = 550 nm = 550×10^{-9} m

X = seperation btwn light

$\theta = 1.22 \frac{\lambda}{d} = 1.68 \times 10^{-6}$

relation btwn θ, r => $x = r\theta$

$x = 0.504$m

∴ seperation of green-yellow light is 0.504m on surface

J21. $D = 10.0$ m

$\lambda = 600 \times 10^{-9}$ m

$r = 3.91 \times 10^{8}$ Km

$\theta = 1.22 \frac{\lambda}{D}$

$\theta = 1.22(6.0 \times 10^{-8}) = 7.32 \times 10^{-8}$ rad

Seperation = $r\theta$

$S = 28.6$ km

∴ seperation of object 28.6 km apart

J23. Concave mirror

$f = 0.87\text{m} = 87\text{cm}$

$R_c = ?$

$f = \frac{1}{2} R_c$

$R_c = 2f$

$= 2(87\text{cm})$

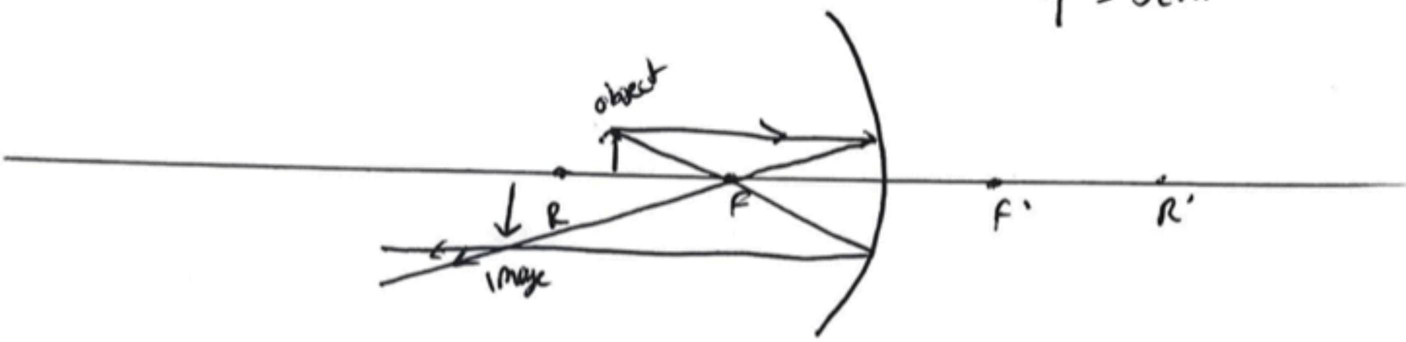
$= 174\text{cm}$ or 1.74 m

* Since concave, focal point is in front of mirror (can use + sign convention)

∴ the Radius of Curvature is 1.74 m

J25.

Given:
$d_o = 5\text{cm}$
$h_o = 2\text{ cm}$
$f = 3\text{cm}$



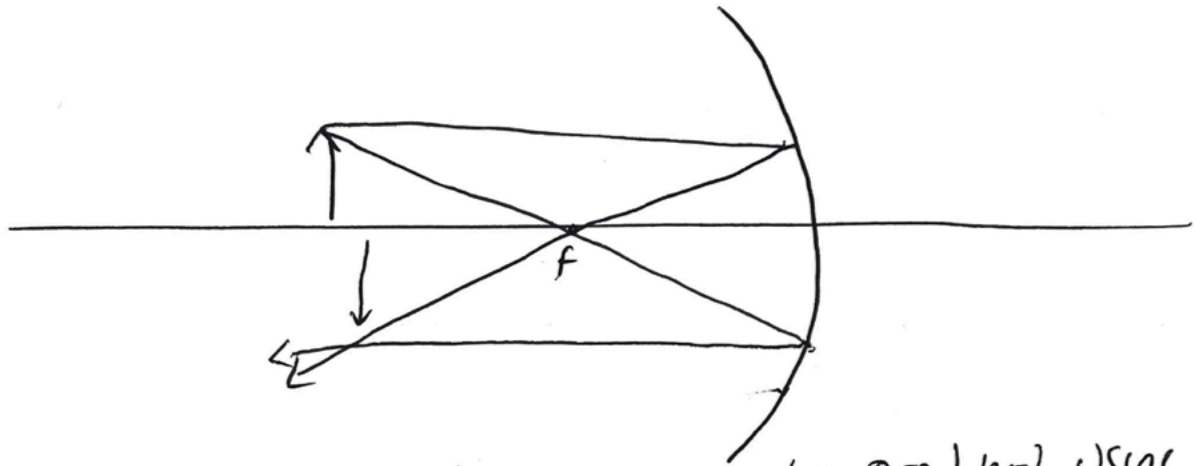
$$d_i = \frac{d_o f}{d_o - f}$$
$$= \frac{(5\text{cm})(3\text{cm})}{5\text{cm} - 3\text{cm}}$$
$$= 7.5\text{ cm}$$

$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$
$$h_i = \frac{-7.5\text{cm}}{5\text{cm}}(2\text{cm})$$
$$h_i = -3\text{cm}$$

image is inverted and larger than object height

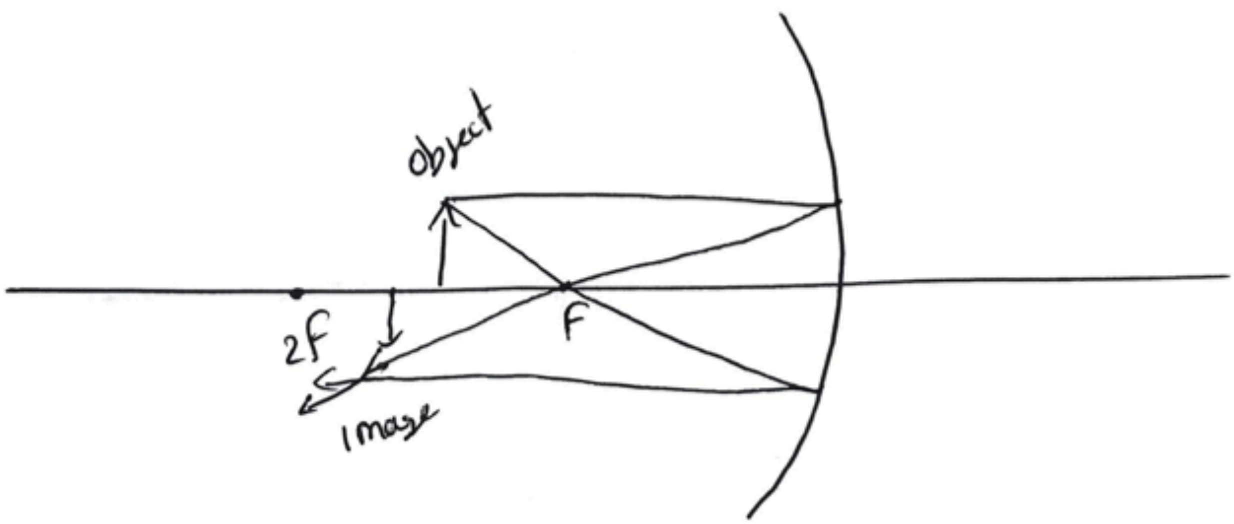
∴ the height of the image is 3cm and inverted, the image is also real (in front of mirror).

J27.



A real and inverted image can be produced using a concave mirror, when the object is placed outside of the focal point.

J29.



The above situation shows how a concave mirror with an object placed between the focal point and centre of curvature can produce a real and inverted image

J31. Given:

$d_o = 10cm$

$d_i = -5cm$ *negative because image is behind the mirror

Asked for:

$f = ?$

Formula: * negative because convex mirror

$$-\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$$

$$-\frac{1}{f} = \frac{d_o + d_i}{d_i d_o}$$

$$f = \frac{-d_i d_o}{d_o + d_i}$$

$$= \frac{-(-5cm)(10cm)}{10cm - 5cm}$$

$$= \frac{50cm^2}{5cm}$$

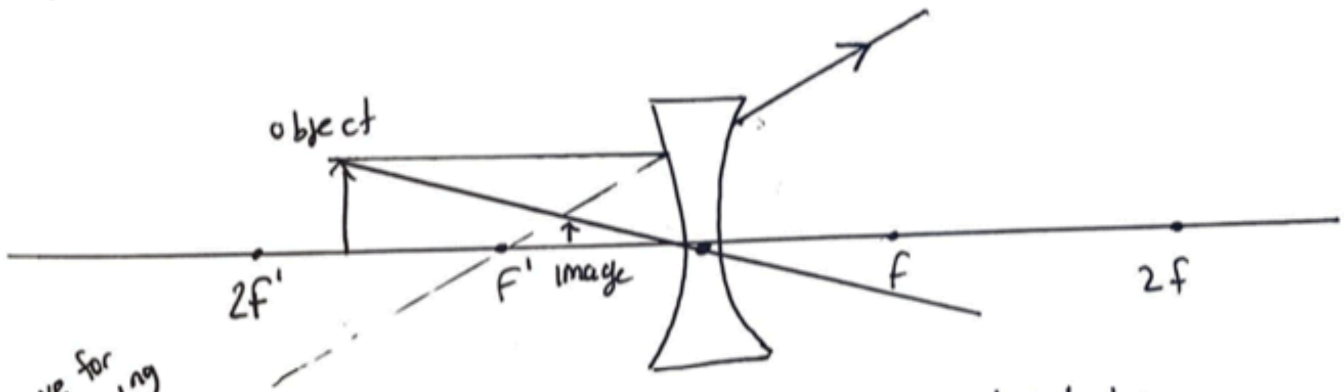
$$= 10cm$$

∴ the focal point is 10cm and the object is located directly on the focal point.

J33.

A 24 cm ball is 60cm away from a concave lens w̄ a 35cm focal length.

a)



* virtual image

b)

-ve for diverging

$$-\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$-\frac{1}{35cm} = \frac{1}{60cm} + \frac{1}{d_i}$$

$$-\frac{1}{35cm} - \frac{1}{60cm} = \frac{1}{d_i}$$

$$d_i = -22.1\,cm$$

-ve indicates image is in front of lens (w̄ object)

Virtual image is displayed 22.1cm from lens (Before f).

c) The equation used is independent of height so if the object decreased in height it would not affect its location.

J35. Given:

$h_i = 10cm$

$M = 30$

Asked For:

$h_o = ?$

Formula: $M = \frac{h_i}{h_o}$

$$h_o = \frac{h_i}{M}$$

$$= \frac{10cm}{30}$$

$$= 0.3\bar{3}cm$$

$\therefore$ the height of the object is 0.33 cm.

J37.

$$M = -\frac{d_i}{d_o}$$

$$= -\frac{3\cancel{d}}{\cancel{d}}$$

$$= -3$$

Given: $d_o = d$

$d_i = 3d$

$|M| = |-3| = 3 > 0$ thus the image is enlarged.

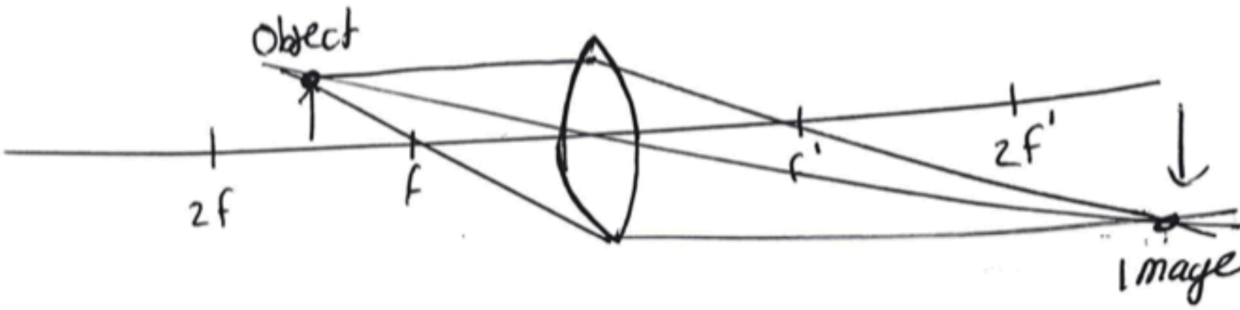
$\therefore$ if $d_o = d$, $d_i = 3d$ magnification is -3 and its magnitude 3 shows that the image is enlarged by a factor of 3.

J39. $f = 3cm$

$h_o = 1.5cm$

$d_o = 4.5cm$

∴ Based on the Ray Diagram the image produced is real and inverted



To confirm that the diagram is correct, consider:

$$d_i = \frac{d_o f}{d_o - f} = \frac{(4.5cm)(3cm)}{4.5cm - 3cm} = 9\ cm$$

← +ve indicates behind lens meaning real image

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

$$h_i = \frac{h_o(-d_i)}{d_o}$$

$$= \frac{(1.5cm)(-9cm)}{4.5Cm}$$

$$= -3cm$$

← -ve indicates inverted image

∴ Calculations confirm the nature of the image that was seen using a ray diagram.

J41. a) $m = \frac{f_{obj}}{f_{eye}}$

$D = 2.00m$ $f_{obj} = 25.0m$ $f_{eye} = 0.03m$

$m = 833.3$ $\therefore$ magnification is 833x

b) astro telescope are inverted => image upside down

J43. $m = 300$ $m_1 = 15$ $m_2 = \frac{0.25}{f_{eye}}$

$f_{eye} = ?$ $m = m_1 \cdot m_2$

$m = m_1 \left(\frac{0.25}{f_{eye}}\right)$

$f_{eye} = \frac{m_1 \cdot 0.25}{m}$

$f_{eye} = 0.013m$

$\therefore$ to achieve 300x magnification eyepeice focal length needs 0.013m

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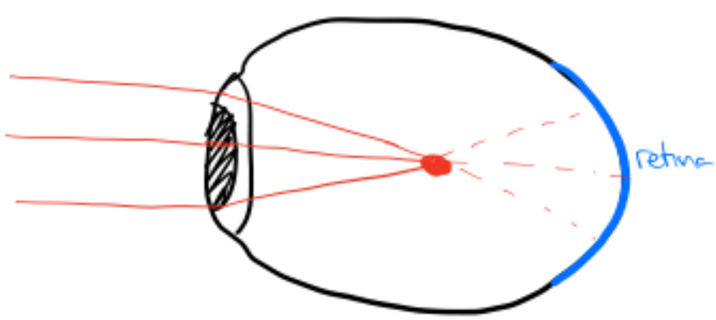
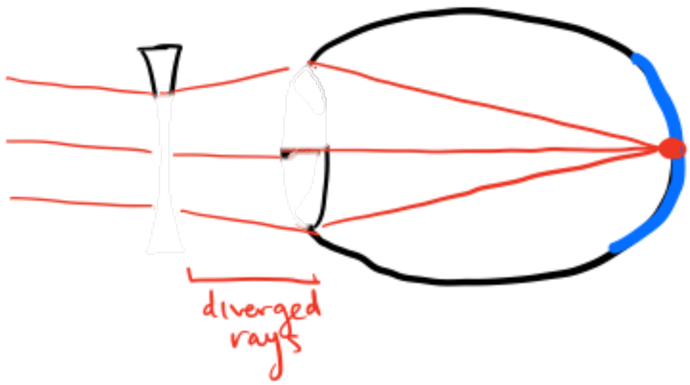
J45. Myopia = focal length too short ; light (& image) focuses in front of retina



Adding diverging lens increases focal length so image lands on retina



J47.

$$F = \frac{1}{P}$$

$P_1 = +1.8 \Rightarrow F_1 = \frac{1}{P_1} = 0.55m$

$P_2 = +3.6 \Rightarrow F_2 = \frac{1}{P_2} = 0.27m$

Overall mag $= \dfrac{f_{obj}}{f_{eye}}$

bc $f_1 > f_2$ using f_2 as eyepiece is better

$m_1 = \dfrac{f_1}{f_2} = 2.01$ $\quad\therefore$ max magnification is 2x

J49. thin lens eqn

$\frac{1}{f} = \cancel{\frac{1}{p}} + \frac{1}{q}$ assume $p = \infty$ bc distant obj

$f = q = 0.10m$

lens as simple magnifier near point is $-20.0cm = -0.20m$

again thin lens eqn

$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \Rightarrow p = \frac{fq}{q-f}$

$f = 0.10m$

$q = -0.20m$

$p = \frac{1}{15} m$

max mag $= \frac{-q}{p}$

$M = +3.0$ $\quad \therefore$ max magnification is 3x

J51. thin lens eqn

$\frac{1}{f} = \cancel{\frac{1}{p}} + \frac{1}{q}$

assume $p = \infty$

$q = f = -0.30m$ -ve bc virtual image @ far point

$\therefore$ lens w/ focal lens of $-0.30m$

$P = \frac{1}{f} = -3.33$ diopter

$\therefore$ power of lens needs -3.33 diopter

J53. a) Cannot see beyond 10.0cm $\Rightarrow$ far point = 20.0cm

$p = \infty$

$q = -20.0cm$ (-ve be virtual)

thin lens eqn $\frac{1}{f} = \cancel{\frac{1}{p}} + \frac{1}{q}$

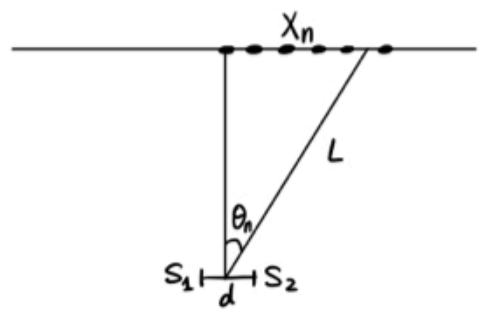
$\therefore f = -20.0cm = -0.20m$

$P = \frac{1}{f} = 5D$

b) -ve focal length ⇒ correction needs diverging lens

J55.

$\lambda = 620 \times 10^{-9}$ m
$d = 3.0 \times 10^{-4}$ m
$L = 4.0$ m
$n = 5$



a)

$$\sin\theta_n = \frac{(n-\frac{1}{2})\lambda}{d}$$

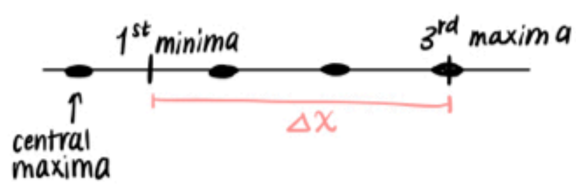
$$\sin\theta_n = \frac{(5-\frac{1}{2})(620\times10^{9}\text{ m})}{3.0\times10^{-4}\text{ m}}$$

$$\theta_n = \sin^{-1}(0.0093)$$

$$\boxed{\theta_n = 0.53°}$$

∴ The 5^{th} order minima is 0.53° away from the central maxima.

b)



① 3^{rd} order maxima

$$\frac{m\lambda}{d} = \frac{X_m}{L}$$

$$\frac{3(620\times10^{-9}\text{m})}{3.0\times10^{-4}\text{ m}} = \frac{X_m}{4.0\text{ m}}$$

$$X_3 = 0.0248\text{ m}$$

② 1^{st} order minima

$$\frac{(n-\frac{1}{2})\lambda}{d} = \frac{X_n}{L}$$

$$\frac{(1-\frac{1}{2})(620\times10^{-9}\text{m})}{3.0\times10^{-4}\text{ m}} = \frac{X_n}{4.0\text{m}}$$

$$X_1 = 4.13\times10^{-3}\text{ m}$$

$$\Delta X = X_m - X_n = 0.0248\text{ m} - (4.13\times10^{-3}) \boxed{= 0.021\text{ m} \; (2.1\text{ cm})}$$

∴ It is 2.1 cm from the first order minima to the third order maxima.

c) red light (original)

$$\frac{m\lambda}{d} = \frac{X_m}{L}$$

$$\frac{2(620 \times 10^{-9}\,m)}{3.0 \times 10^{-4}\,m} = \frac{X_m}{4.0\,m}$$

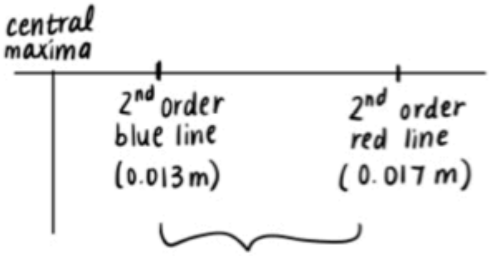
$$X_m = 0.01653\,m$$

blue light

$$\frac{m\lambda}{d} = \frac{X_m}{L}$$

$$\frac{2(475 \times 10^{-9}\,m)}{3.0 \times 10^{-4}\,m} = \frac{X_m}{4.0\,m}$$

$$X_m = 0.01267\,m$$



$$\Delta X = 0.01653\,m - 0.01267\,m = \boxed{\begin{array}{l} 0.0039\,m \\ (0.39\,cm) \end{array}}$$

The second order maxima would move 0.39 cm toward the central maxima if switched from red light to blue light.