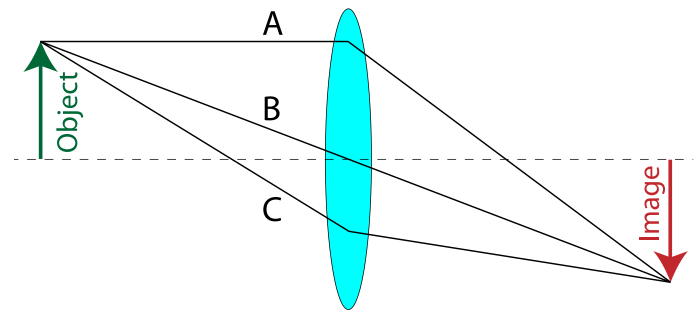
AP2 Optics

Light from an object passes through a converging lens and is focused to form an image as shown in the diagram at right. Which light ray reaches the image plane in the least amount of time?



(A) Ray A
(B) Ray B
(C) Ray C
(D) They all take the same amount of time.

Answer: (D) They all take the same amount of time. Light traveling between any two points always takes the path that takes the least amount of time. Since light from the object reaches the image plane by all three paths, no one path can take any longer than the others, or light wouldn't travel that path.

EK: 6.E.3 When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 6.E.3.1 The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. 6.E.3.3 The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation.

AP2 Optics

Light of frequency 1.5×10^{14} Hz travels through air and enters glass perpendicular to its surface. Which of the following changes occur to the ray of light as it enters the glass? Choose two correct answers.

(A) wavelength decreases
(B) speed of the ray of light decreases
(C) light ray bends toward the normal
(D) frequency of the ray of light increases

Answer: (A) and (B) are correct.

A is correct because wavelength is inversely proportional to the index of refraction.
B is correct because the velocity is inversely proportional to the index of refraction.
C is incorrect because no refraction occurs when the angle of incidence is 0 degrees.
D is incorrect because frequency depends on the source of light.

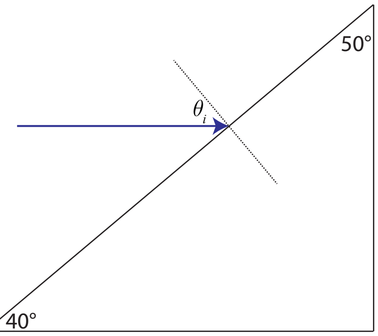
EK: 6.E.1 When light travels from one medium to another, some of the light is transmitted, some is reflected, and some is absorbed. 6.E.3 When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 6.E.1.1 The student is able to make claims using connections across concepts about the behavior of light as the wave travels from one medium into another, as some is transmitted, some is reflected, and some is absorbed. 6.E.3.1 The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. 6.E.3.3 The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation.

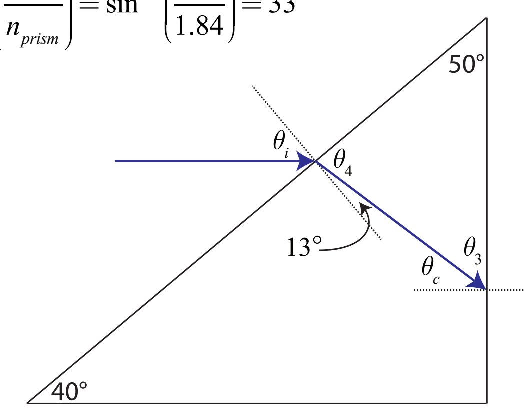
A right angle prism with an index of refraction of n=1.84 is shown at right.

What is the maximum angle of incidence on the prism face such that total internal reflection does **not** occur on the back face of the prism?



Answer: 24.4°

First find the critical angle for the back face: $\sin\theta_C = \frac{1}{n_{prism}} \rightarrow \theta_C = \sin^{-1}\left(\frac{1}{n_{prism}}\right) = \sin^{-1}\left(\frac{1}{1.84}\right) = 33°$



Next, note that a ray incident on this back face at this angle would make an angle of 57° with the back face (θ_3).

This would lead to a refracted angle of 13° at the prism face (θ_4=73°).

Applying Snell's Law, the incident angle is determined as 24.4°.

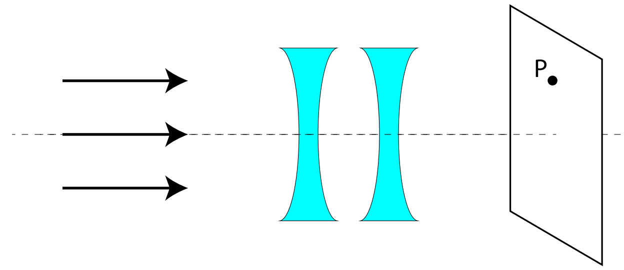
EK: 6.E.3 When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 3.3 The student can evaluate scientific questions. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.1 The student can connect phenomena and models across spatial and temporal scales.

LO: 6.E.3.3 The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation.

AP2 Optics

Parallel rays of monochromatic light are incident upon two identical diverging lenses in series before reaching a white sheet of paper. The intensity of the light upon the paper as measured at Point P is



(A) greater in this configuration than with only a single lens.
(B) less in this configuration than with only a single lens.
(C) the same in this configuration than with only one lens.
(D) more information needed.

Answer: (B) Two diverging lens in series spread out the light more than a single diverging lens; therefore, the energy of the light incident upon the paper is spread out over a larger area with two diverging lenses, resulting in less intensity as measured at point P.

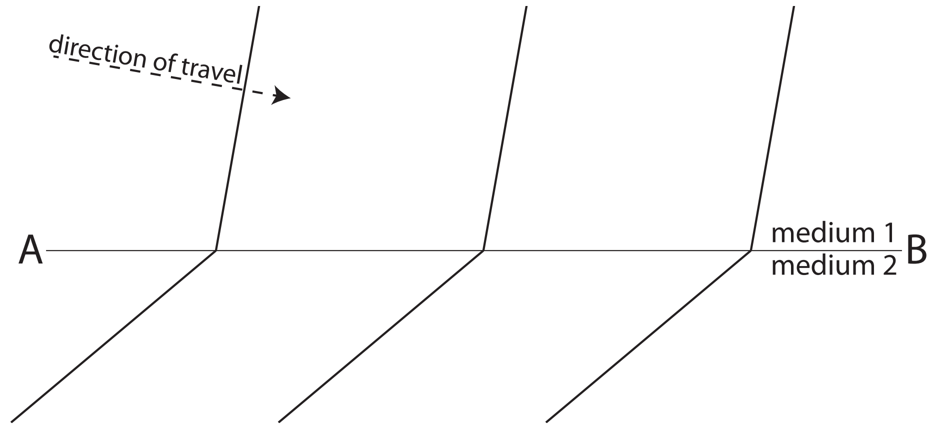
EK: 6.E.3 When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 6.E.3.1 The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media. 6.E.3.3 The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation.

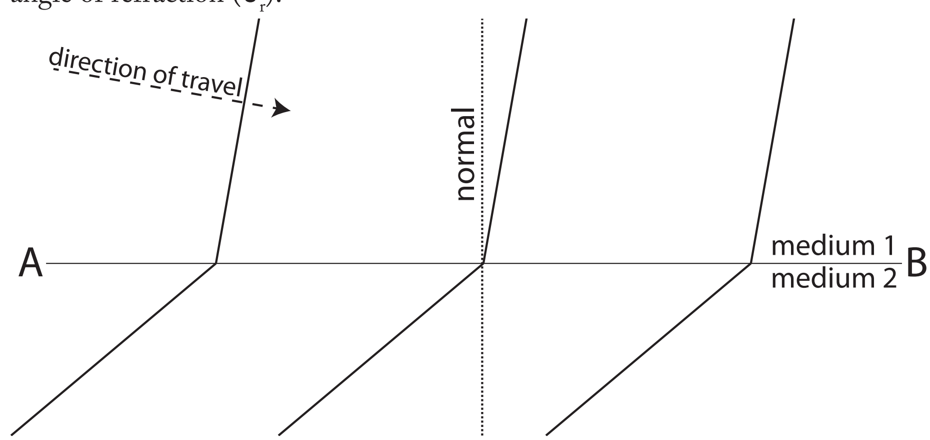
AP2 Optics

The diagram below shows plane wave fronts as they travel from medium 1 to medium 2 across the boundary AB. The wave fronts are drawn to scale.



(a) Explain and justify how one could use a ruler to show that the speed in medium 2 is less than in medium 1.

(b) A normal line has been drawn at one of the intersections of the wave fronts in each medium and the boundary AB. Draw appropriate incident and refracted rays at this normal and label the angle of incidence (θ_i) and angle of refraction (θ_r).

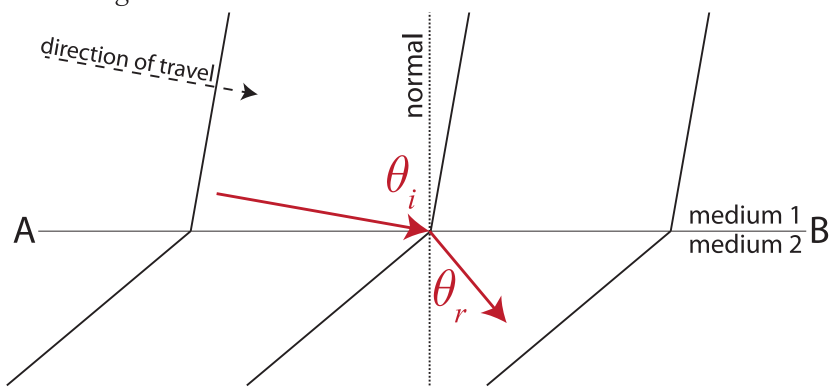


(c) Explain and justify how one could use a protractor to show that speed of the wave in medium 2 is less than in medium 1.

Answer:

(a) Lay the ruler perpendicular to the wave fronts in each medium and measure the distance between two successive waves. This gives the wavelength of each. The wavelength in medium 2 is less than in medium 1, therefore its speed is less as well (wavelength is proportional to velocity according to the wave equation v=f λ.

(b) The rays should be perpendicular to the wave fronts and angles measured relative to the normal line as shown in the diagram below.



(c) Use a protractor to measure the angles of incidence and refraction. Since $\theta_r < \theta_i$, the speed in medium 2 is less than the speed in medium 1, consistent with Snell's Law.

EK: 6.E.3 When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 6.E.3.2 The student is able to plan data collection strategies as well as perform data analysis and evaluation of the evidence for finding the relationship between the angle of incidence and the angle of refraction for light crossing boundaries from one transparent material to another (Snell's law). 6.E.3.3 The student is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation.

An electromagnetic wave travels through space. Which of the following best describe the orientation of the magnetic field? Select two answers.

(A) The magnetic field is parallel to the velocity of the wave.
(B) The magnetic field is perpendicular to the velocity of the wave.
(C) The magnetic field is parallel to the electric field.
(D) The magnetic field is perpendicular to the electric field.

Answer: (B) & (D). The magnetic field is oriented perpendicular to both the velocity of the wave and the electric field.

EK: 6.A.1 Waves can propagate via different oscillation modes such as transverse and longitudinal. 6.F.2 Electromagnetic waves can transmit energy through a medium and through a vacuum.

SP: 1.2 The student can describe representations and models of natural or man–made phenomena and systems in the domain.

LO: 6.A.1.3 The student is able to analyze data (or a visual representation) to identify patterns that indicate that a particular mechanical wave is polarized and construct an explanation of the fact that the wave must have a vibration perpendicular to the direction of energy propagation. 6.F.2.1 The student is able to describe representations and models of electromagnetic waves that explain the transmission of energy when no medium is present.

AP2 Optics

Light of wavelength λ in a vacuum has what wavelength in a material with index of refraction n?

(A) $n\lambda$

(B) $\frac{n}{\lambda}$

(C) $\frac{\lambda}{n}$

(D) $\frac{n}{c\lambda}$

Answer: (C) $n=\frac{c}{v}\xrightarrow{v=f\lambda}n=\frac{c}{f\lambda_{new}}\rightarrow\lambda_{new}=\frac{c}{fn}\xrightarrow{c=f\lambda}\lambda_{new}=\frac{f\lambda}{fn}=\frac{\lambda}{n}$

EK: 6.E.3 When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 6.E.3.1 The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media.

AP2 Optics

Green monochromatic light of wavelength 550 nm passes through a diffraction grating of 2000 lines/cm. Determine the distance between the first and second bright spots on a screen 1 m from the grating.

(A) 5×10^{-6} m
(B) 0.115 m
(C) 0.226 m
(D) 0.639 m

Answer: (B) 0.115 m
First find the distance between the diffraction grating slits.

$$d = \frac{1}{2000\,{}^{lines}\!/_{cm}} = 5\times10^{-4}\,{}^{cm}\!/_{line} \times \frac{1m}{100cm} = 5\times10^{-6}\,{}^{m}\!/_{line}$$

Next, find the angle for the first order bright spot.

$$m\lambda = d\sin\theta \rightarrow \sin\theta = \frac{m\lambda}{d} \rightarrow \theta = \sin^{-1}\left(\frac{m\lambda}{d}\right) = \sin^{-1}\left(\frac{550\times10^{-9}\,m}{5\times10^{-6}\,{}^{m}\!/_{line}}\right) = 6.32°$$

With this angle, you can find the vertical displacement of the first order bright spot.

$$\tan\theta = \frac{opp}{adj} \rightarrow opp = adj\tan\theta = 1m\tan(6.32°) = 0.111m$$

Then, find the angle for the second order bright spot.

$$\theta = \sin^{-1}\left(\frac{m\lambda}{d}\right) = \sin^{-1}\left(\frac{2\times550\times10^{-9}\,m}{5\times10^{-6}\,{}^{m}\!/_{line}}\right) = 12.71°$$

With this angle, find the vertical displacement of the second order bright spot.

$$opp = adj\tan\theta = 1m\tan(12.71°) = 0.226m$$

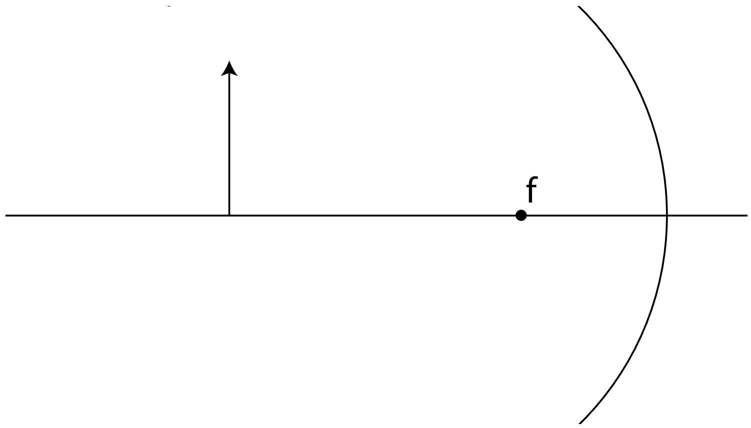
The distance between the bright spots is therefore 0.226m-0.111m=0.115m

EK: 6.C.3 When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 6.C.3.1 The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared to the wavelength of the waves.

A concave spherical mirror with a 10-cm radius of curvature sits on a principal axis as shown.
An object of height 6 cm is placed 15 cm to the left of the mirror.



(a) On the diagram above, locate the image by ray tracing.
(b) Calculate the position of the image.

(c) Characterize the image as real or virtual, upright or inverted.

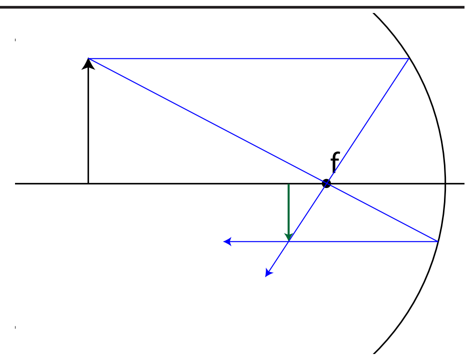
(d) Determine the height of the image.

Answers:

(a) See diagram at right
(b) First find the focal length of the mirror as half the radius:
f = R/2 = 10 cm/2 = 5 cm.

$$\frac{1}{f}=\frac{1}{d_o}+\frac{1}{d_i}\rightarrow\frac{1}{5cm}=\frac{1}{15cm}+\frac{1}{d_i}\rightarrow d_i=7.5cm$$

(c) The image is inverted and real.
(d) $m=\frac{-d_i}{d_o}=\frac{h_i}{h_o}\rightarrow\frac{-7.5cm}{15cm}=\frac{h_i}{6cm}\rightarrow h_i=-3cm$



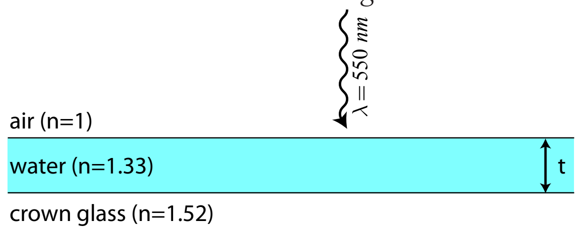
EK: 6.E.4 The reflection of light from surfaces can be used to form images.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 6.E.4.2 The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the reflection of light from surfaces.

AP2 Optics

A sheet of crown glass (n=1.52) is coated with a thin transparent film of water (n=1.33). A beam of green monochromatic light of wavelength 500nm strikes the surface at an angle of 90°.



(a) What is the frequency of the light in the air?

(b) What is the frequency of the light in the thin film of water?

(c) What is the wavelength of the light in the thin film of water?

(d) What is the minimum thickness of water that will minimize reflection of this light?

Answers:

(a) $v = f\lambda \rightarrow f = \frac{v}{\lambda} = \frac{3\times10^{8}\ m/s}{550\times10^{-9}\,m} = 5.45\times10^{14}\,Hz$

(b) Same as a.

(c) $\lambda_{film} = \frac{\lambda}{n} = \frac{550\times10^{-9}\,m}{1.33} = 414nm$

(d) For destructive interference, the total optical path difference should be half the wavelength of the light in the film. Since the light reflects off higher-index materials twice, an even number, there is no phase shift.

$$OPD = 2t = \frac{\lambda_{film}}{2} \rightarrow t = \frac{\lambda_{film}}{4} = \frac{414nm}{4} = 103.5nm$$

EK: 6.C.1 When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 6.C.1.1 The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves.

AP2 Optics

Observations that indicate visible light has a wavelength much shorter than a centimeter include which of the following? (Select two answers.)

(A) A colored pattern is observed when light reflects off a thin film.
(B) Bright and dark fringes are observed when laser light passes through a diffraction grating.
(C) Light is polarized through a liquid crystal display (LCD).
(D) Redshift is observed when observing a receding galaxy.

Answer: (A) and (B). Thin films and the spacing between slits in a diffraction grating are on the order of microns, which correspond to wavelengths of light. Neither phenomenon can occur if light had wavelengths greater than a centimeter. Choices (C) and (D) are not wavelength dependent.

EK: 6.C.1 When two waves cross, they travel through each other; they do not bounce off each other. Where the waves overlap, the resulting displacement can be determined by adding the displacements of the two waves. This is called superposition. 6.C.3 When waves pass through a set of openings whose spacing is comparable to the wavelength, an interference pattern can be observed. Examples should include monochromatic double-slit interference.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions. 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.

LO: 6.C.1.1 The student is able to make claims and predictions about the net disturbance that occurs when two waves overlap. Examples should include standing waves. 6.C.3.1 The student is able to qualitatively apply the wave model to quantities that describe the generation of interference patterns to make predictions about interference patterns that form when waves pass through a set of openings whose spacing and widths are small compared to the wavelength of the waves.

AP2 Optics

Which of the following optical instruments can produce images that are the same size as the object and can be projected onto a screen? Select two answers.

(A) concave mirror
(B) concave lens
(C) plane mirror
(D) convex lens

Answer: (A) & (D). For projection onto a screen, the image needs to be real. Only concave mirrors and convex lenses can produce real images.

EK: 6.E.4 The reflection of light from surfaces can be used to form images. 6.E.5 The refraction of light as it travels from one transparent medium to another can be used to form images.

SP: 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 6.E.4.2 The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the reflection of light from surfaces. 6.E.5.1 The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the refraction of light through thin lenses.

AP2 Optics

Mr. Plow wants to build a compound microscope using two lenses so that he can view snowflakes in greater detail than his eyes would normally allow. The two lenses are arranged in such a way that each one can produce magnification.

(a) Which type of lenses would he need to achieve this double magnification?

(b) With reference to the focal lengths of either lens, describe where the first lens (objective lens) should be placed relative to the snowflake, and where the second lens (eyepiece) should be placed relative to the objective lens.

(c) Explain why this placement of objective lens and eyepiece should produce double magnification. Use relevant terms such as object and image distance.

Answers:

(a) 2 convex lenses -- convex lenses are the only lenses that can produce magnification by themselves.

(b) The objective would be placed such that the snowflake is between the lens's focal point and its center of curvature. The eyepiece would be placed such that the real image produced by the objective is within the focal point of the eyepiece.

(c) Placing an object between f and 2f of a convex lens produces a real image beyond 2f on the image side of the objective lens, therefore the image distance is greater than the object distance. Because the magnitude of magnification is image distance divided by object distance, the first image is magnified. By placing the eyepiece so that the image from the objective is within its focal length, a virtual image with an image distance greater than the object distance is produced. This second image is also magnified.

EK: 6.E.4 The reflection of light from surfaces can be used to form images.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 6.E.4.2 The student is able to use quantitative and qualitative representations and models to analyze situations and solve problems about image formation occurring due to the reflection of light from surfaces.

 Difficulty: 2