Science Olympiad - Optics - Geometric and Physical Optics [Answer Strip] **ID: A**

D 3. A 8.

A 1.

C 4. B 9.

D 5.

A 10.

E 6.

E 2.

A 7.

To All—
The rationale presented for each question/solution is my own. If you have questions or comments, I invite you to contact me at rob.culbertson@fcps.edu

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Science Olympiad - Optics - Geometric and Physical Optics

Answer Section

MULTIPLE CHOICE

1. A

By definition, $n = \frac{c}{v}$, where n is a medium's index of refraction, c is the speed of light, and v is the speed of light in the medium

2. E

By Snell's Law $n_1 \sin\theta_1 = n_2 \sin\theta_2$, the relationship defining the angular shift occurring at the interface is independent of direction

The following are incorrect as follows

* *The index of refraction is the same for the two media* - If so, the path would not change at the interface. If $n_1 = n_2$, then $n_1 \sin\theta_1 = n_2 \sin\theta_2$ simplifies to $\sin\theta_1 = \sin\theta_2$, indicating that the incident and "refracted" rays make the same angle with respect to the normal - no change in path

* *Light travels faster in medium 2 than in medium 1* - By definition $n = \frac{c}{v}$, thus,

  $n_1 \sin\theta_1 = n_2 \sin\theta_2 \;\Rightarrow\; \frac{c}{v_1} \sin\theta_1 = \frac{c}{v_2} \sin\theta_2 \;\Rightarrow\; \frac{\sin\theta_1}{v_1} = \frac{\sin\theta_2}{v_2} \;\Rightarrow\; \frac{v_2}{v_1} = \frac{\sin\theta_2}{\sin\theta_1}$ Given that $\theta_1 > \theta_2$ (as measured from the normal), then $\sin\theta_1 > \sin\theta_2 \;\therefore\; v_1 > v_2$

* *Snell's Law breaks down at the interface - it* was devised precisely in order to describe what happens at the interface

* *Light would arrive at Y in less time by taking a straight line path from X to Y than it does taking the path shown above* - Fermat's Principle of "least time" (which serves as the basis for Snell's Law) dictates that the path taken between two points by a ray of light is the path that can be traversed in the least time.

3. D

Radio waves, through infrared radiation, visible light, and ultaviolet radiation to gamma radiation, result from progressively greater rates of vibration, or *frequency*. Photon energy correlates positively with wavelength and thus also increases progressively Wavelength by definition varies inversely with frequency.

4. C

$c = \lambda f \;\Rightarrow\; \lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \text{m/s}}{88.5 \times 10^6 \text{s}^{-1}} = 3.39 \text{ m}$

5. D

Some fraction of light energy reflects off both the "front" and "back" of a layer at its interface with the media on either side of it. The colors patterns indicated in statements I and II result from interference patterns, which only occur when wavelengths (of light in this case) are similar in size to the thickness of the layer. Since the thickness of a bubble is very small (as are the etched lines in a diffraction grating), it follows that wavelengths of light are also very small. "The bending of light when it passes from one medium to another medium" is due to the differing speeds of light in various media and can be quantified by Snell's Law.

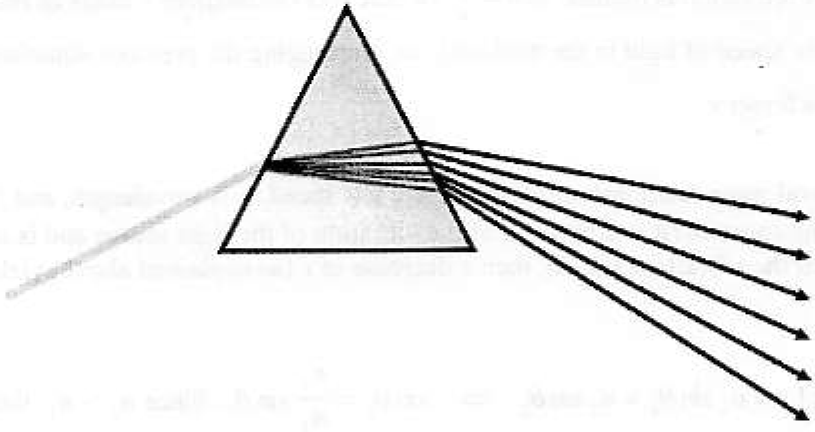
6. E
   As light passes through air to water, it enters a medium with a higher index of refraction, which is generally related to the density of the medium.

   Speed: A medium's index of refraction is defined as $n = \frac{c}{v}$ (where n is the medium's index of refraction, c is the speed of light, and v is the speed of light in the medium), so, rearranging the previous equation yields $v = \frac{c}{n}$, so a greater n yields a lesser v.

   Wavelength: Given the general wave relationship $v = \lambda f$ (where v is speed, λ is wavelength, and f is frequency), and that f remains constant (it is a function of the vibration of the light source and is independent of the medium through which the vibrations travel), then a decrease in v (as explained above) yields a decrease in λ..

   Bends: According to Snell's Law $n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad \Rightarrow \quad \sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$. Since $n_2 > n_1$, then $\sin\theta_2 < \sin\theta_1$ and $\theta_2 < \theta_1$ (as measured from the normal), then the light has been bent *toward* the normal.
7. A
   Total internal reflection occurs when light does not exit the first medium because its angle of refraction is 90° from the normal, or parallel to the surface. All light, either reflected or refracted, remains within the initial medium.
8. A
9. B
   Optical abberations in general occur because not all rays passing through a lens (or reflecting off a mirror) converge or focus perfectly at one point. In the case of lenses in particular, because different wavelengths of light refract at slightly different angles (dispersion), light through a lens is subject to *chromatic* abberation. (i.e. Red and blue light from the same object passing through a lens follow slightly different paths and are, thus, slightly out of common focus, "smearing" the colors.)
10. A
    Wave phenomena of all sorts exhibit the Doppler effect when the wave source S is in motion relative to the observer O. The apparent frequency is increased if S and O are approaching one another (resulting in higher pitch for sound/ "bluer" color for light), and decreased if they are moving away from each other (resulting in lower pitch for sound/ "redder" color for light).

PROBLEM



11.

The figure above depicts a beam of white light entering and exiting a prism. From the choices below, fill in each of the following blanks with the correct color. Next to each color, indicate an approximate wavelength in nanometers.

A.) Violet ≈ 400 nm

B.) Blue ≈ 460 nm

C.) Green ≈ 520 nm

D.) Yellow ≈ 580 nm

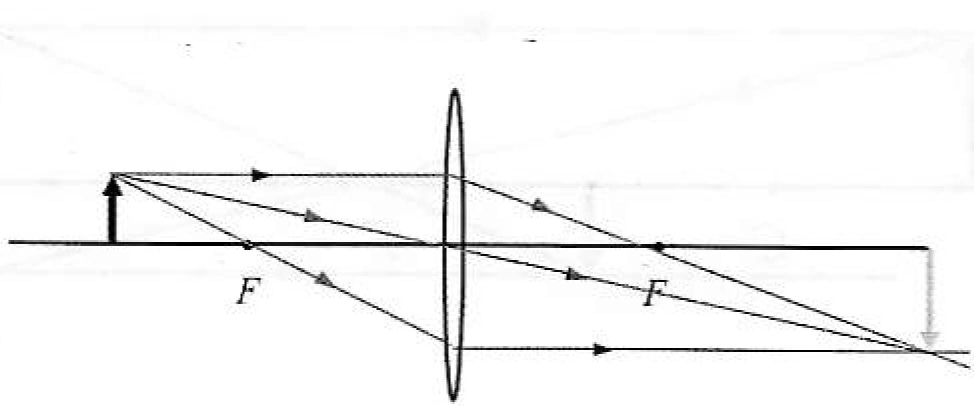
E.) Orange ≈ 640 nm

F.) Red ≈ 700 nm

Wavelength values for intermediate colors are approximate and subject to fairly liberal interpretation, but the limits of human senitivity are well established at 400 - 700 nm.

The appearance of the visible spectrum is the result of the spatial sorting of white light according to its wavelength. What is the name of the physical phenomenon by which this "spreading out" occurs?

G.) Dispersion .



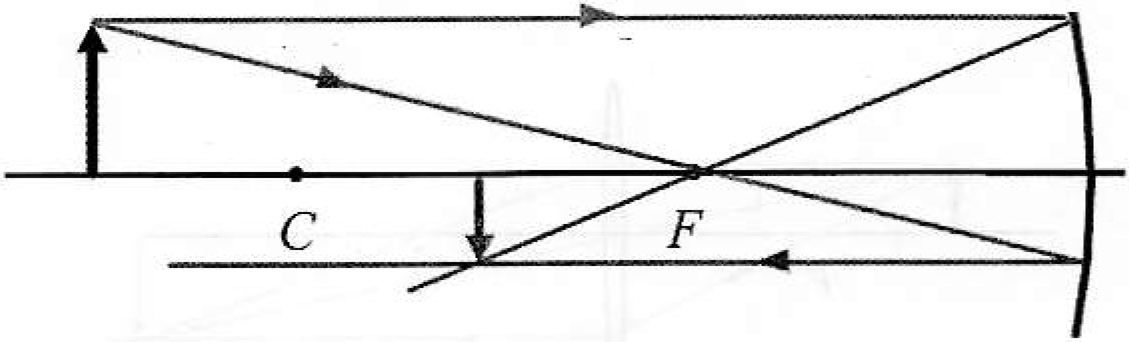
12.

According to the Thin Lens Equation, $\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$, where d_o is the distance from the lens to the object, d_i is the distance from the lens to the image, and f is the focal length of the lens.

$$d_i=\left(f^{-1}-d_o^{-1}\right)^{-1}=\left(3\text{cm}^{-1}-5\text{cm}^{-1}\right)^{-1}=7.5\text{cm}$$

According to the magnification equation, $m=\frac{h_i}{h_o}=-\frac{d_i}{d_o}=-\frac{7.5\text{cm}}{5\text{cm}}=-1.5$ (The negative sign indicates that the image is inverted.)

By convention, $+d_i$ indicates a ***real*** image - one that passes *through* the lens and forms a "real" image that could be pojected onto a screen or piece of paper.



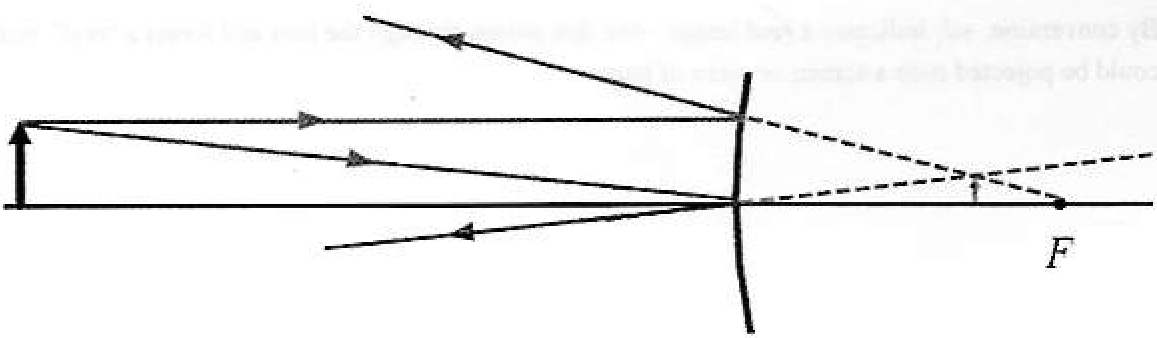
13. Again,

$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$ (The "Mirror Equation" - same relationships as the Thin Lens Equation)

$d_i=\left(f^{-1}-d_o^{-1}\right)^{-1}=\left(12\text{cm}^{-1}-30\text{cm}^{-1}\right)^{-1}=20\text{cm}$

The magnification equation yields, $m=-\frac{d_i}{d_o}=-\frac{20\text{cm}}{30\text{cm}}=-0.67$ (Again, the negative sign indicates that the image is inverted.)

By convention, $+d_i$ for mirrors indicates a ***real*** image - one that forms on the same side of the mirror as the object and could be pojected onto a screen or piece of paper.



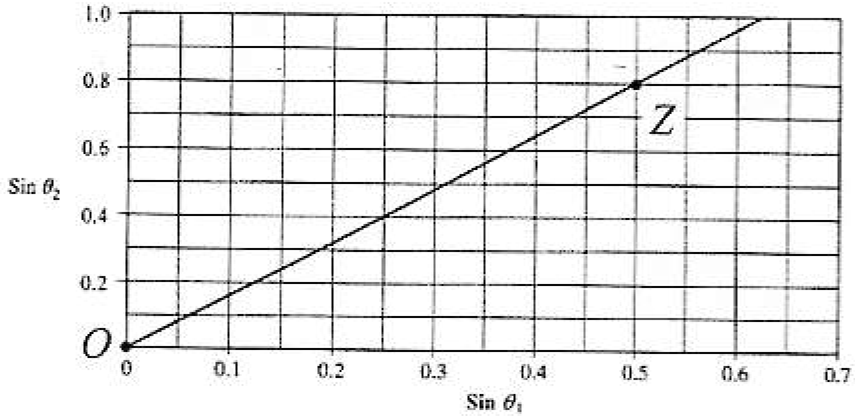
14. Again,

$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \Rightarrow d_i=\left(f^{-1}-d_o^{-1}\right)^{-1}=\left(\text{-8cm}^{-1}-18\text{cm}^{-1}\right)^{-1}=-5.5\text{cm}$

The magnification equation yields, $m=-\frac{d_i}{d_o}=-\frac{5.5\text{cm}}{18\text{cm}}=0.31$ (Positive sign indicates that the image is upright.)

By convention, $-d_i$ for mirrors indicates a ***virtual*** image - one that forms on the opposite side of the mirror as the object and could not be pojected onto a screen or piece of paper placed there.

15.



a. The slope of the line is $\frac{\sin\theta_2}{\sin\theta_1}$, so from Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2 \Rightarrow \frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2}$.

Since $n_2 = n_{air} = 1$, then $\frac{n_1}{1} = n_1 = \frac{\sin\theta_2}{\sin\theta_1} = \text{slope} = \frac{0.8}{0.5} =$ **1.6** as taken between points *O* and *Z*. (Similar to a borosilicate glass (Pyrex®), so a reasonable value.)

b.(i) $c = \lambda f \Rightarrow f = \frac{c}{\lambda} = \frac{3.0\times10^8 \text{ m/s}}{675 \text{ nm}} = \frac{3.0\times10^8 \text{ m/s}}{6.75\times10^{-7}\text{m}} = 4.4\times10^{14}\text{s}^{-1}\text{(Hz)}$

(ii) By definition, $n = \frac{c}{v} \Rightarrow v = \frac{c}{n} = \frac{3.0\times10^8 \text{ m/s}}{1.6} = 1.9\times10^8\text{m/s}$

(iii) Defining λ' as the wavelength in glass, and keeping in mind that *f* is constant,

$c = \lambda f$ and $v = \lambda' f$

$\frac{c}{\lambda} = \frac{v}{\lambda'} \Rightarrow c\lambda' = v\lambda \Rightarrow c\lambda' = \frac{c}{n}\lambda \Rightarrow c\lambda' = \frac{c}{n}\lambda \Rightarrow \lambda' = \frac{\lambda}{n}$

$\lambda' = \frac{\lambda}{n} = \frac{675 \text{ nm}}{1.6} = 422 \text{ nm}$

c. For the critical angle $\theta_1 = \theta_c$, by definition, $\theta_2 = 90 \therefore \sin\theta_2 = 1$

Given that the slope of the graph is $m = \frac{\sin\theta_2}{\sin\theta_1}$, when

$\theta_1 = \theta_c,\ m = \frac{1}{\sin\theta_1} \Rightarrow \sin\theta_1 = \frac{1}{m} \Rightarrow \theta_1 = \sin^{-1}\left(\frac{1}{m}\right) = \sin^{-1}\left(\frac{5}{8}\right) = 38.7°$