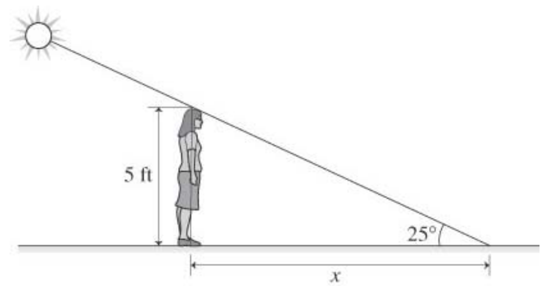
P18.3. **Prepare:** This problem employs the fact that rays travel in straight lines.



Solve: Remember that for right triangles $\tan\theta = \text{opp/adj}$. In our case $\theta = 25°$ and $\text{opp} = 5$ ft.

$$x = \frac{5\ \text{ft}}{\tan 25°} = 11\ \text{ft}$$

where we have rounded to two significant figures.

Assess: When the sun is less than 45° above the horizon we expect the shadow to be longer than the height of
the object.

P18.5. Prepare: Simple ray tracing and ratios in similar triangles will give us the answer.
Solve: (a) Draw a quick ray diagram similar to Figure 18.35; you really only need to draw one ray from the top (head) of the friend through the center of the lens to the bottom (head) of the image. Notice the similar triangles and set up ratios.

$$\frac{h'}{s'} = \frac{h}{s}$$

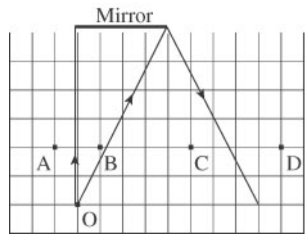
We want to know h'. We are given $h = 1.8$ m, $s = 7.4$ m, and $s' = 24$ mm.

$$h' = s'\frac{h}{s} = 24 \text{ mm}\frac{1.8 \text{ m}}{7.4 \text{ m}} = 5.8 \text{ mm}$$

(b) The object must be getting closer as the image on the retina gets bigger; and that is exactly how your brain interprets this information. As s decreases then h' (on the retina) increases when s' and h are constant.
Assess: Your brain deduces so much about the world from the way the images on the retina move and change size. The numbers in this problem are real-life numbers.

P18.7. **Prepare:** We'll use the law of reflection and see where rays of light coming from object O and reflecting in the mirror can go.

Solve:

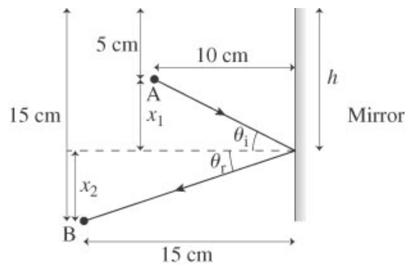


The figure shows rays coming from O and hitting each end of the mirror. It is clear that object O can be seen in the mirror from any location between the outer rays, which includes locations B and C. However, at location A object O can't be seen in the mirror because there is no way for a ray to obey the law of reflection from O and get to A. If the mirror extended further to the left, then A could see O. A similar argument can be made that object O can't be seen in the mirror from position D.

In summary, the object's image is visible from B and C.

Assess: Your intuition in looking at the original diagram confirms what the ray tracing tells us.

P18.8. Prepare: Light rays travel in straight lines and follow the law of reflection. We will also use the geometry of the diagram to solve this problem.



Solve: We are asked to obtain the distance $h = x_1 + 5.0$ cm. From the geometry of the diagram,

$$\tan\theta_i = \frac{x_1}{10\text{ cm}} \quad \tan\theta_r = \frac{x_2}{15\text{ cm}} \quad x_1 + x_2 = 10\text{ cm}$$

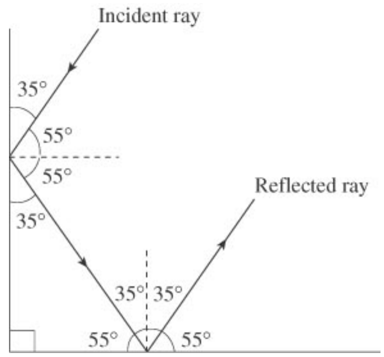
Because $\theta_r = \theta_i$, we have

$$\frac{x_1}{10\text{ cm}} = \frac{x_2}{15\text{ cm}} = \frac{10\text{ cm} - x_1}{15\text{ cm}} \Rightarrow (15\text{ cm})\,x_1 = 100\text{ cm}^2 - 10\,x_1 \Rightarrow x_1 = 4.0\text{ cm}$$

Thus, the ray strikes a distance 9.0 cm below the top edge of the mirror.

Assess: From geometry, x_1 and x_2 were expected to be on the order of 5 cm. The obtained value of $x_1 = 4.0$ cm is thus reasonable.

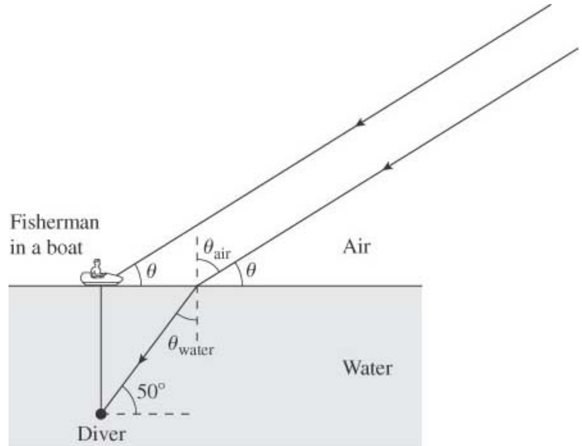
P18.10. Prepare: The key to this problem is the knowledge that the angle of reflection is equal to the angle of incidence. Figure P18.10 illustrates this and provides the answer.



Solve: Both the incident and reflected rays make an angle of $35°$ with respect to the vertical, therefore they are parallel. The solution is essentially general. We could replace the $35°$ angle everywhere with a label, say θ, and the $55°$ angle everywhere with $90° - \theta$. When we get done, both the incident and reflected rays will make an angle of θ with the vertical, therefore they are parallel.

Assess: Physics will help you develop the skill of going from a particular solution to a more general one.

P18.12. **Prepare:** Use the ray model of light. The sun is a point source of light. A visual overview of the problem is shown below in which the first four steps of the Tactics Box 18.1 have been identified. A ray that arrives at the diver 50° above horizontal is refracted into the water at $\theta_{water} = 40°$.



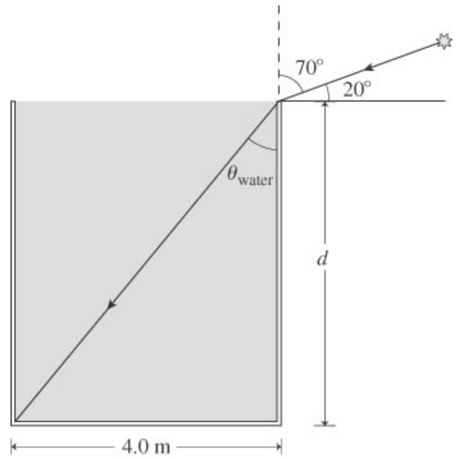
Solve: Using Snell's law at the water-air boundary

$$n_{air} \sin\theta_{air} = n_{water} \sin\theta_{water} \Rightarrow \sin\theta_{air} = \frac{n_{water}}{n_{air}} \sin\theta_{water} = \left(\frac{1.33}{1.0}\right) \sin 40° \Rightarrow \theta_{air} = 58.7°$$

Thus the height above the horizon is $\theta = 90° - \theta_{air} = 31.3°$. Because the sun is far away from the fisherman (and the diver), the fisherman will see the sun at the same angle of 31.3° above the horizon.

Assess: θ_{air} is larger than θ_{water} as we would have expected.

P18.15. Prepare: Use the ray model of light and the law of refraction. Assume the sun is a point source of light. Use the ray model of light. When the bottom of the pool becomes completely shaded, a ray of light that is incident at the top edge of the swimming pool does not reach the bottom of the pool after refraction. A visual overview of the problem is shown below in which the first four steps of Tactics Box 18.1 have been identified.



Solve: The depth of the swimming pool is $d = 4.0\ \text{m}/\tan\theta_{water}$. We will find the angle by using Snell's law. We have

$$n_{water}\sin\theta_{water} = n_{air}\sin 70° \Rightarrow \theta_{water} = \sin^{-1}\left(\frac{\sin 70°}{1.33}\right) = 44.95° \Rightarrow d = \frac{4.0\ \text{m}}{\tan 44.95°} = 4.0\ \text{m}$$

Assess: A depth of 4.0 m for the pool's depth is reasonable. Also, note that the angles of incidence and refraction are measured from the normal.

P18.17. Prepare: Before we run the numbers we need to establish whether you should fill the room or the cave with water. Continue the dotted line marking the hole in the cave to act as the normal from which we compute our angles. We see that you want the laser beam to bend away from the normal at the hole; this means the light needs to go from a higher index of refraction to a lower. Therefore you need to fill the room in which you are chained with water, not the cavern.

We now have $n_1 = 1.33$ (where you are), $\theta_1 = 20°$, and $n_2 = 1.00$.

Solve: From the right triangle formed from the width of the box and the height of the switch above the hole, you see the laser beam needs to angle up from the normal at $\theta_2 = \tan^{-1}(5.1\text{ m}/10\text{ m}) = 27°$.

Now solve Snell's law to see if the required angle can be obtained.

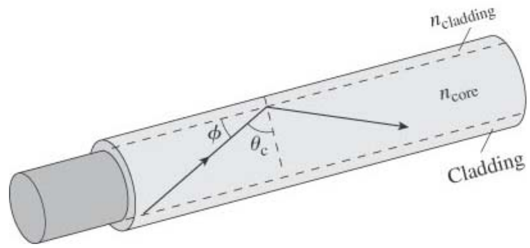
$$\theta_2 = \sin^{-1}\left(\frac{n_1 \sin\theta_1}{n_2}\right) = \sin^{-1}\left(\frac{1.33\sin 20°}{1.00}\right) = 27°$$

It appears that you can release your chains and flee the dragon by filling the room you are in with water (wear scuba gear so you can breathe). Whew!

Assess: Physics can save you in many dangerous situations!

You can see that the distances and angles were rigged to make this work just right. Had the switch been lower than 5.1 m above the switch but still too high to hit straight on you might have had to figure out some further physics to save you.

P18.18. Prepare: Use the ray model of light. For an angle of incidence greater than the critical angle, the ray of light undergoes total internal reflection. The critical angle of incidence is given by Equation 18.3.



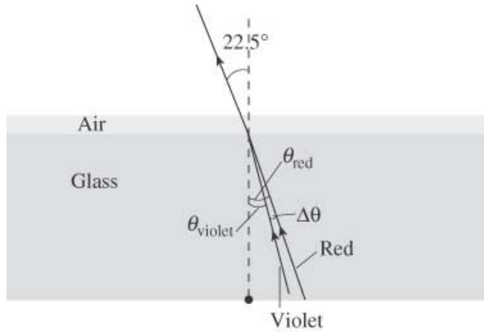
Solve:

$$\theta_c = \sin^{-1}\left(\frac{n_{\text{cladding}}}{n_{\text{core}}}\right) = \sin^{-1}\left(\frac{1.48}{1.60}\right) = 67.7°$$

Thus, the maximum angle a light ray can make with the wall of the core to remain inside the fiber is 90° − 67.7° = 22.3°.

Assess: We can have total internal reflection because $n_{\text{core}} > n_{\text{cladding}}$.

P18.22. Prepare: We know that violet light is refracted more than red (this is reflected in the given values for n), so we draw a diagram with the violet ray in the glass closer to the normal then the red ray. But they emerge together at the same point and in the same direction.



We are given $n_{red} = 1.54$, $n_{violet} = 1.59$, and $\theta_{air} = 22.5°$. We also know $n_{air} = 1.00$.

The strategy will be to solve Snell's law for θ_{violet} and θ_{red} in the glass and then find $\Delta\theta$ as the difference of the two angles.

$$n_{air} \sin\theta_{air} = n_{violet} \sin\theta_{violet} = n_{red} \sin\theta_{red}$$

Solve: Solve Snell's law for θ_{violet} and θ_{red} in the glass.

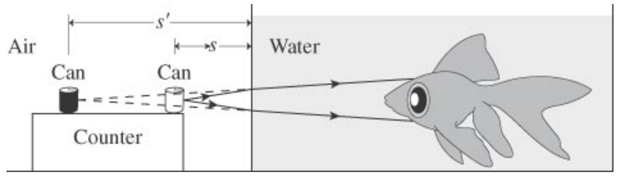
$$\theta_{violet} = \sin^{-1}\left(\frac{n_{air} \sin\theta_{air}}{n_{violet}}\right) = \sin^{-1}\left(\frac{1.00 \sin 22.5°}{1.59}\right) = 13.93°$$

$$\theta_{red} = \sin^{-1}\left(\frac{n_{air} \sin\theta_{air}}{n_{red}}\right) = \sin^{-1}\left(\frac{1.00 \sin 22.5°}{1.54}\right) = 14.39°$$

The difference between these angles (i.e., the angle between the two rays in the glass) is $\Delta\theta = 14.39° - 13.93° = 0.462°$.

Assess: The angle between the two rays is very small, but that is to be expected since the index of refraction isn't very different for the two rays.

P18.23. Prepare: Represent the can as a point source and use the ray model of light. Paraxial rays from the can refract into the water and enter into the fish's eye. The ray diagram is shown below.



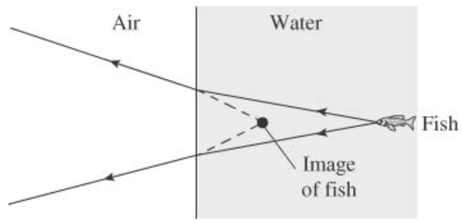
Solve: The object distance from the edge of the aquarium is *s*. From the water side, the can appears to be at an image distance s' = 30 cm. Using Equation 18.7,

$$s' = \frac{n_2}{n_1} s = \frac{n_{\text{water}}}{n_{\text{air}}} s = \left(\frac{1.33}{1.0}\right) s \Rightarrow s = \frac{30 \text{ cm}}{1.33} = 23 \text{ cm}$$

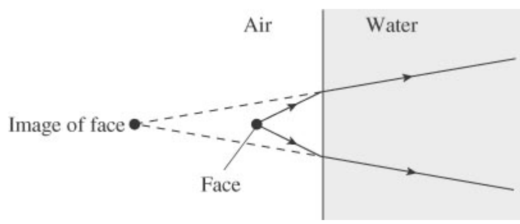
Assess: The ray diagram above and the indices of refraction for water and air indicate the actual distance to be less than 30 cm. A value of 23 cm is reasonable.

P18.25. **Prepare:** We will ignore the pane of plastic itself and draw diagrams for light going from water into air and then light going from air into water.

Solve: **(a)** Because the rays from the fish bend away from the normal at the interface, the image of the fish is closer to your face than the fish actually is.

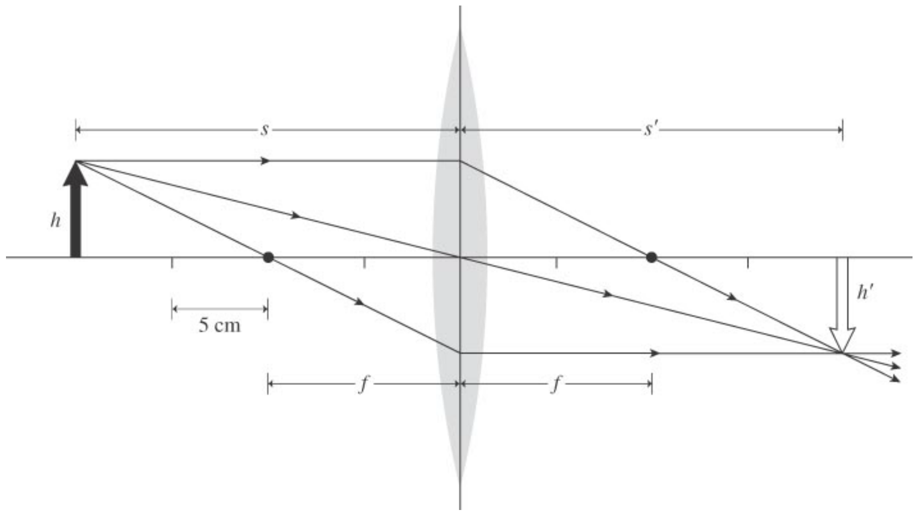


(b) Because the rays from your face bend toward the normal at the interface, the image of your face is farther from the fish than your face actually is.



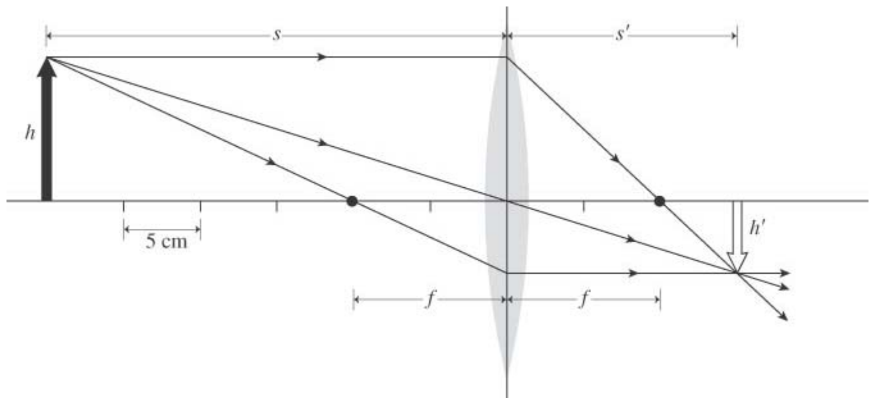
Assess: Only a couple of the many rays were shown in each case.
See if you can verify these conclusions next time you go swimming.

P18.26. Prepare: Use ray tracing to locate the image. The figure shows the ray-tracing diagram using the steps of Tactics Box 18.2.
Sovle:



You can see from the diagram that the image is in the plane where the three special rays converge. The image is inverted and is located at $s' = 20.0$ cm to the right of the converging lens. The image is real because after refraction the three rays converge to make the image.
Assess: Ray tracing must be done to scale to obtain useful answers.

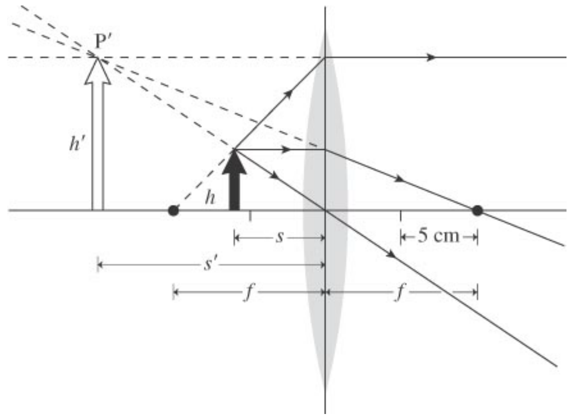
P18.27. **Prepare:** Use ray tracing to locate the image. The figure below shows the ray-tracing diagram using the steps of Tactics Box 18.2.
Solve:



You can see from the diagram that the image is in the plane where the three special rays converge. The image is located at $s' = 15$ cm to the right of the converging lens, and is inverted and real.
Assess: Ray tracing must be done to scale to obtain useful answers.

P18.28. Prepare: Use ray tracing to locate the image. The figure shows the ray-tracing diagram using the steps of Tactics Box 18.2.

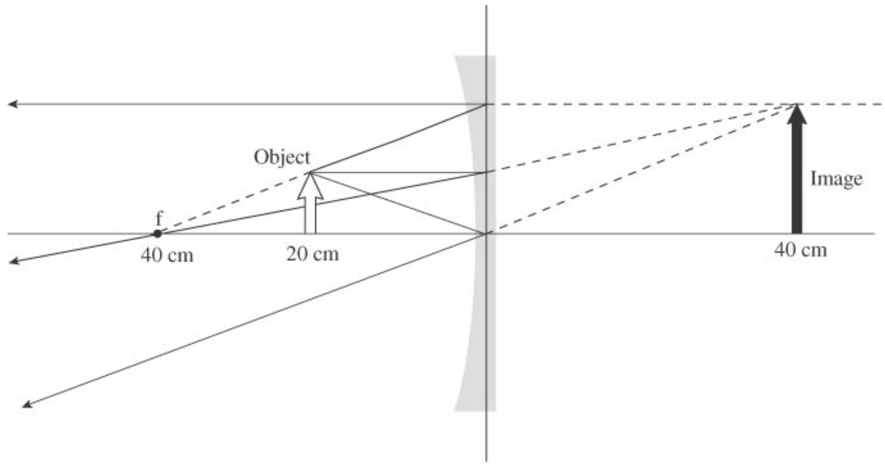
Solve:



You can see that the rays after refraction do not converge at a point on the refraction side of the lens. On the other hand, the three special rays, when extrapolated backward toward the incidence side of the lens, meet at P′ which is 15 cm from the lens. That is, $s' = -15$ cm. The image is upright and virtual.

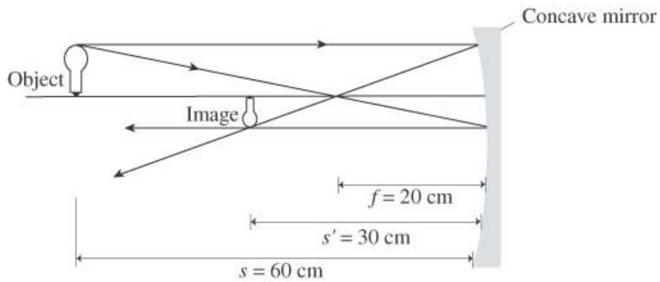
Assess: Ray tracing must be done to scale to obtain useful answers.

P18.31. Prepare: Carefully draw this to scale.
Solve:



As seen in the figure, the image is located 40 cm behind the mirror; it is also twice as tall as the object. The image is upright and virtual.
Assess: You may have seen one of these make-up mirrors in your home or a hotel; if not look in a large fairly flat soup spoon with your eye very close to the spoon. The image is upright and magnified—just what people want for putting on make-up.

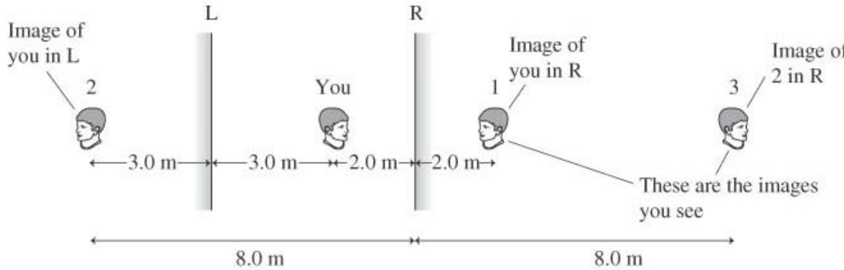
P18.32. **Prepare:** Two rays are needed to determine the location of the image. A ray incident parallel to the optic axis will be reflected back through the focal point and a ray incident through the focal point will be reflected back parallel to the optic axis. Real images are formed when the reflected light actually passes through the site of the image.



Solve: The figure shows that the image is at a distance of 30 cm from the mirror. Since it has an orientation opposite that of the object, it is inverted. The image is real since the reflected rays actually pass through the image (we could see the image on a screen placed at this location). Finally, since the image is smaller than the object, the magnification is less than one.

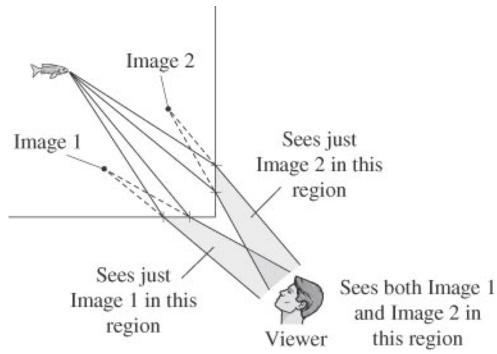
Assess: While ray tracing is relatively simple, it can yield a lot of information.

P18.44. Prepare: For a mirror, the image distance behind the mirror equals the object's distance in front of the mirror.



Solve: Your face is 2.0 from the mirror into which you are looking. The image of your face (image 1) is 2.0 m behind the mirror, or 4.0 m away. Behind you, the image of the back of your head (image 2) is 3.0 m behind the mirror on the other wall. You can't see this image because you're looking to the right. However, the reflected rays that appear to come from image 2 (a virtual image) act just like the rays from an object—that is, just as the rays would if the back of your head were really at the position of image 2. These rays reflect from the mirror 2.0 m in front of you into which you're staring and form an image (image 3) 8.0 m behind the mirror. This is the image of the back of your head that you see in the mirror in front of you. Since you're 2.0 m from the mirror, the image of the back of your head is 10.0 m away.

P18.50. Prepare: As a light ray that originates on the fish exits the tank, it will change directions and the angle of refraction in air will be greater than the angle of incidence in water.
Solve: The sketch below shows how the single object in the fish tank could have two images to an outside viewer.



Assess: For clarity, the angles are greatly exaggerated—however the point that two images are possible is made.

P18.72. **Prepare:** Since light travels faster in the air near the surface of the hot road, this air has a smaller index of fraction than the air above it. This is a gradual change and not an abrupt change such as traveling from one material to another. Since the air closer to the surface has a smaller index of refraction, we have a situation where total internal reflection can occur.
Solve: When you think you see water you are seeing an image of the sky that has experienced total internal reflection. The figure below shows how this can happen.

The correct choice is A.
Assess: The brain interprets the rays coming upward into the eye as coming from the ground even though they actually originate from the sky. What looks like a body of water on the ground is actually a image of blue sky overhead.

P18.73. **Prepare:** If we model the mirage as total internal reflection then we need to refer to Equation 18.3:

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

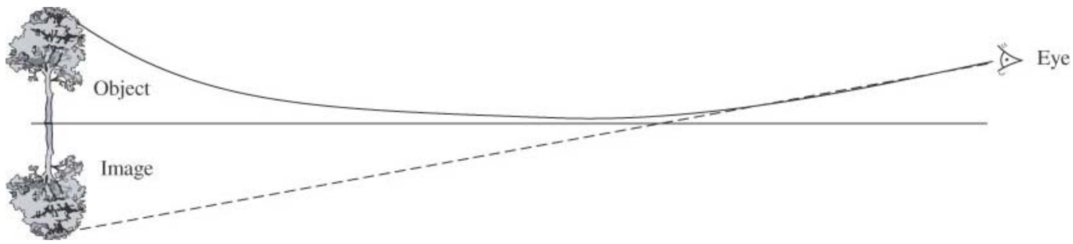
where n_2 is the index of refraction of the hot air and n_1 the index of the cool air.

Solve: To be able to get closer to the mirage before it disappears is equivalent to decreasing the critical angle (which is measured from the normal). Increasing the temperature difference between the hot and cold air will increase the difference between n_2 and n_1. This reduces n_2/n_1 and thereby decreases θ_c.

The correct choice is C.

Assess: So the ideal conditions for mirages are when the ground and the air right next to it are very hot (black asphalt absorbs a lot of sunlight and gets pretty hot) and yet the air above is cool, maybe due to a gentle breeze.

P18.74. Prepare: The mirage is an example of total internal reflection. The air above a hot surface has a smaller index of refraction which will allow total internal reflection to occur. The figure below shows how this can occur.



Solve: As the figure shows, the image of an object that was reflected by a mirage is inverted, the same size as the object and at the same location as the object. The correct choice is B.

Assess: The brain interprets the rays coming upward into the eye as coming from the ground, even though they actually originate from the sky. This creates an inverted image.

Q18.1. Reason: The Greek hypothesis does not explain why we can’t see in the dark. Nor would it explain the different appearance of objects viewed under different colored lights.
Furthermore, you could show a Young’s double-slit experiment to the Greeks and ask them to explain the interference pattern you see on the screen in terms of visual rays emitted by the eyes. It would also be difficult to explain single-slit diffraction and polarization.
Assess: The ancient Greeks had IQs as high as ours; in fact some of them were brilliant. But that doesn’t keep them from being wrong. It is possible to be brilliant and wrong. Future science will say the same about us and some of our science. However, we do firmly believe that science is a positive, self-correcting process that really does make progress. We know much more about nearly everything scientific than the ancient Greeks did, as much as we revere them. Our current understanding of light may not be final or complete, but it is better and more full than the ideas of the ancient Greeks. Our understanding explains a wider range of phenomena and makes more accurate predictions.

Q18.2. Reason: The property that distinguishes a light ray emitted from a light bulb and one that has been diffusely reflected from a book is luminous. The light bulb is a self-luminous object in that it actually creates the rays of light originating from it. The piece of paper does not create light, but reflects the light from another source.
Assess: Self-luminous objects are sources of light.

Q18.3. Reason: If the viewing screen is fairly close to a hole or gap in a barrier, then the spot of light on the viewing screen will have the shape of the gap or hole. But if the viewing screen (in this case the ground) is far away, then the gap acts like a pinhole camera and the image on the screen looks like an inverted image of the object. The illuminated spots are circles because the sun is round.

Assess: The spots may not appear as extremely sharp circles because of diffraction and the size of the holes. In a strict ray model with a very small pinhole the image would be sharp.

When I happened to be visiting San Antonio during a recent partial solar eclipse, I noticed that the spots of light on the ground made by sunlight coming through the leaves were crescent-shaped. I also had two cards, one with a pinhole and one as the screen, with me to view the eclipse. The image on the card was sharper than the spots on the ground because the pinhole was smaller than the gaps between the leaves. Of course, the smaller the pinhole, the dimmer the image because less light gets through.

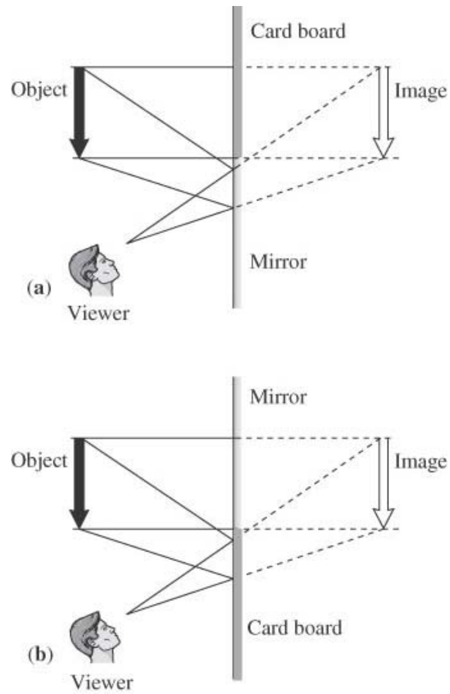
Q18.4. Reason: Light travels in a straight line from a point on the object, through the pinhole, and to a point on the image. The light from a small region of the object goes to a corresponding region of the image. If the pinhole is small and the screen for the image fairly close to the pinhole, the regions are fairly uniformly illuminated by the light from the object. If the pinhole is square rather than round, the light to those regions hits the screen at more of an angle and hence is spread out over a larger region. This will cause the image in the corners to be dim.
Assess: You can try this.

Q18.5. Reason: There is already so much ambient scattered light reflected from the road that the little bit more added by your headlights is not noticeable.
Assess: You've probably noticed this at dusk. Even after the sun goes down but it isn't really dark yet we turn on our lights, but this is more to be visible by other drivers than to help us see the road better. As it gets darker and darker our eyes adjust to the lesser amount of light and our own headlights reflecting from the road ahead make more and more of a beneficial difference.

Q18.6. **Reason:** Particulate matter in the atmosphere scatters the light from the sun numerous times, as a result we do not see rays coming from the sun. If a beam of light encounters particles suspended in the atmosphere, the light will scatter off the particles, allowing us to see what looks like a beam of light. We aren't actually seeing a beam of light, we are seeing the light scattered off particles in the beam of light.
Assess: This is also easy to see in a dusty garage, not to mention your room.

Q18.7. Reason: The water-filled potholes appear darker because the light from your flashlight reflects off the smooth water surface into the forward direction rather than reflecting from a rough surface in fairly random directions—some of which would be back to your eye—as is the case on the rest of the dirt road.
Assess: If someone else were approaching you on the dirt road they could see the water puddles as bright if the angle of reflection from your flashlight beam is such as to get the light into their eyes.

Q18.8. Reason: Light is scattered off all points of the pencil and into all directions of space. If light directed toward the mirror is reflected into your eye, you see the image of the pencil. **(a)** As part **(a)** of the figure shows, if the top half of the mirror is covered, light scattered from the pencil and reflected off the mirror can enter your eye and you will see the image of the pencil. **(b)** As part **(b)** of the figure shows, if the bottom half the mirror is covered, light scattered from the pencil cannot be reflected off the mirror in such a manner that it enters your eye. You cannot see the image of the pencil.



Assess: Since reflection is involved, the key to the question is the knowledge that the angle of reflection is equal to the angle of incidence.

Q18.9. Reason: Follow the path of the light. It originates at some source (possibly the sun) and reflects from the face of Venus. Some of that reflected light hits the mirror, but it must then obey the law of reflection to get into our eyes. If we can see Venus' face in the mirror, then she would be able to see ours (or Velázquez's in the late 1640s) in the same mirror!

Assess: If Venus were seeing her own face in the mirror (those light rays would be normal to the mirror), then we would be seeing something off to her (and our) right.

Q18.10. Reason: The mirror is not parallel to the bar. If it were, the image of the barmaid would be behind the barmaid rather than being offset. If you do a bird's-eye view, the mirror is closer to the bar at the left of the barmaid. Knowing that for a plane mirror the object distance is equal to the image distance and that the image is on a line drawn from the object perpendicular to the mirror, the man is to the barmaids left. If he was to her right, he would be on her other side in the mirror. If he was in front of her, we would not see his image in the mirror.
Assess: It's just a matter of angle of reflection equals angle of incidence, i.e., the mirror thing.

Q18.11. Reason: The word is printed backward (or in “mirror writing”) so it can easily be read in a rearview mirror by drivers just ahead.
Assess: Leonardo da Vinci was fond of writing his notebooks in mirror writing, maybe in hopes that it would be harder for others to read. Some people think mirrors reverse left and right but not up and down; actually they reverse front and back.

Q18.12. **Reason:** The speed of light in a medium is a function of the index of refraction of that medium ($v = c/n$). If you use optic fiber at the center (which has a smaller travel distance) with a larger index of refraction, you will slow the light down and it will get to the viewing sight closer to the time the other light gets there.
Assess: This is a very clever solution to the problem.

Q18.13. Reason: The card is red because it reflects red light and absorbs the other colors. When it is illuminated by red light, the red light reflects off the card into your eyes and you see the red card as red.
If the card is illuminated with blue light the light is all absorbed. No light is reflected, so the card looks black.
Assess: If you illuminate the card with white light and look at it through a blue filter it will again look black because the red light reflected by the card is not passed by the blue filter.

Q18.14. Reason: (a) The image of a point on the object is found by keeping track of light rays leaving that point of the object and refracting through the lens. The image is someplace along the refracted ray. If we consider just one ray, we don't know where the image is—just that it is somewhere along that ray. If we consider a second ray, the image is somewhere along that refracted ray. The only way the image can be along both rays is to be at the point of intersection of the rays. The point of intersection pins down the image of the object. The minimum number of rays needed to locate the image of a point is two.
(b) Light rays are scattered off each point of an object into all directions in space. Only those rays that pass through the lens ultimately form the image. Numerous rays from each point of the object strike the lens and refract to the image point.
Assess: When locating the image of an object, always pick the two simplest rays you can find.

Q18.15. **Reason:** The spoon acts like a concave mirror and, as Figure 18.45 shows, the image is inverted when $s > f$. A careful ray tracing diagram will convince you of this (as will the equations in the next chapter).

Assess: It should be noted that this is only true for $s > f$; when the object is closer to the spoon than the focal distance, $s < f$, than the image is upright. Magnifying mirrors, such as make-up mirrors are concave like this and have a large focal length so that your face is within the focal length of the mirror; the image is virtual and behind the mirror. If you put the spoon very close to your eye you will notice this.

Q18.16. Reason: While the law of refraction depends in the index of the media, the law of reflection does not. Under water the angle of incidence will still be equal to the angle of reflection. There is no reason for a ray to travel a different path in water than in air in this case. Hence, the sun's rays will be focused the same distance from the mirror.

Assess: Of course the preceding analysis is not true for light passing through a lens that might be immersed in either water or air; in that case the index of refraction matters. But with a mirror the water doesn't change anything.

Q18.17. **Reason:** The lower ray is the ray through the center of the lens and does not bend; consequently, it could have come from either arrow, so it doesn't help us determine which arrow is the object and which is the image.
Therefore the upper ray must be the key. If the larger arrow on the left were the object then that upper ray should refract at the lens and go in a different direction, but the diagram doesn't show this.
The only other option is that the smaller arrow on the right is the object. We see the ray parallel to the optic axis, which is then refracted through the far focal point. The upper ray from the lens back to the large arrow should be dotted since the light doesn't really traverse that path, but it does help us locate the image (which is the larger arrow on the left).
The parallel ray (from the smaller arrow—the object) refracts down through the far focal point because the lens is a *converging* lens.
In summary, the object is the smaller arrow closest to the lens, and the lens is a converging lens.
Assess: We can even further deduce that $s < f$; this matches Figure 18.38 exactly. The image is virtual.

Q18.18. Reason: For the reflected ray the angle or reflection is equal to the angle if incidence, hence $\theta_1 = 90° - 50° = 40°$. The correct choice is A.

Assess: For reflection the angle of reflection is equal to the angle of incidence.

Q18.19. Reason: We want to apply Snell's law, but in that law the angles are measured from the normal (the vertical in this picture).
Since the subscripts 1 and 2 are already used in the figure, we will use a and b in Snell's law. (Label these on your sketch.): $\theta_2 = 90° - \theta_b$ and $n_a \sin\theta_a = n \sin\theta_b$.
where $n_a = 1.00$, $n_b = 1.53$, and $\theta_a = 50°$.

$$\theta_b = \sin^{-1}\left(\frac{n_a \sin\theta_a}{n_b}\right) = \sin^{-1}\left(\frac{1.00 \sin 50°}{1.53}\right) = 30°$$

$\theta_2 = 90° - \theta_b = 90° - 30° = 60°$
The correct choice is D.
Assess: We can eliminate two of the choices without any calculations. Since the beam is going into a medium with a higher index of refraction it will bend toward the normal. So θ_b must be less than $50°$. If $\theta_b < 50°$, then $\theta_2 > 40°$, so that eliminates choices A and B.

Q18.20. Reason: Since the index of refraction of air is less than the index of refraction of glass, total internal reflection will not occur as light travels from air to glass. The correct choice is C.
Assess: If the situation is turned around and the light is traveling from glass to air, total internal reflection can occur.

Q18.21. **Reason:** Draw a quick ray diagram similar to Figure 18.35; you really only need to draw one ray from the top (head) of the man through the center of the lens to the bottom (head) of the image. The film is in the image plane. Notice the similar triangles and set up ratios.

$$\frac{h'}{s'} = \frac{h}{s}$$

We want to know h'. We are given $h = 2.0$ m, $s = 5.0$ m, and $s' = 50$ mm.

$$h' = s' \frac{h}{s} = 50 \text{ mm} \frac{2.0 \text{ m}}{5.0 \text{ m}} = 20 \text{ mm}$$

The correct choice is B.

Assess: Notice the answer is in the range that could really fit on film; these numbers are realistic. A pinhole camera would produce the same answer as the converging lens.

Q18.22. **Reason:** You are 2.4 m in front of the mirror and you are photographing an image that appears to be 2.4 m behind the mirror: Adjust the focus of the camera for an object distance of 4.8 m. The correct choice is D.
Assess: The object isn't actually there, it just appears to be there. For example you cannot focus this image onto a screen because it is not real.

Q18.23. **Reason:** Many, many rays from all parts of the object will still hit the uncovered part of the lens, refract, and form the image, but there will simply be half the light, so the image will be dimmer.
The correct choice is E.
This is correct when, as stated in the question, you cover half the lens (i.e., the cardboard is near the lens, not near the object).
Assess: You ought to try this simple experiment at home or in the physics lab.
In contrast to above, if you cover half the object (i.e., the cardboard is near the object, not near the lens), then half the image will vanish because rays from that half of the object can't reach the lens.
After some thought, you should be able to reason out an explanation as to why choices A–D are incorrect in the original situation.

An extension of the original situation would be to cover just the center of the lens with a circular piece of cardboard, or, conversely, to cut a hole in a piece of cardboard and let the light through the center of the lens while covering the outer parts of the lens. Pay attention to the focus of the image on the screen as you try these two situations.

Q18.24. **Reason:** Only the converging lens can form a real image. A real image is the case where light that leaves the object actually goes through the image. The correct choice is A.
Assess: A concave mirror will also form real images.

Q18.25. Reason: The real image from a converging lens will be inverted. 90 cm is the distance from the object to the image, so the image distance (from the lens) is only $90\text{ cm} - 30\text{ cm} = 60\text{ cm}$.

The magnification is given by Equation 18.9.

$$m = -\frac{s'}{s} = -\frac{60\text{ cm}}{30\text{ cm}} = -2.0$$

It is negative because the image is inverted.
The correct choice is B.

Assess: We did not need the specific value of the focal length, as long as $s > f$ so we would get the inverted real image.