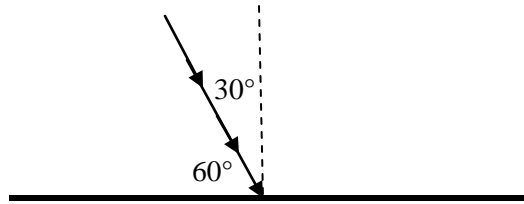Optics Basics
Student Worksheet

Answer the following questions during or after your studies of optics.

1. Compare the brightness of a 100 W light bulb 1.0 m away from your desk and a 100 W light bulb 3.0 m away from your desk.

2. What is the angle of incidence in the following diagram? Draw the reflected ray, and label the angle of reflection.

3. What does it mean if a surface is "smooth?" How does it depend on the wavelength of the light being reflected?

4. Compare the smoothness of a radio telescope to that of a UV telescope.

5. What is the focal length of a curved mirror? What does it depend on?

6. What is the ratio of the light gathering power of the Mount Wilson Observatory 100-inch diameter telescope to that of its 60-inch diameter telescope?

7. What is the ratio of the resolution of the two telescopes in the previous problem, assuming they are looking at the same wavelength signal? Which has better resolution?

8. Why do biologists sometimes illuminate their microscopes with blue light instead of simply white light?

9. A spherical concave mirror with a radius of curvature of 40.0 cm is used to produce an image of a cell phone 3.0 cm tall. Determine the type of image, image distance, size of image, and magnification if the cell is phone is the following distances away from the mirror. Verify your answers by drawing an approximate ray diagram

   a. 10.0 cm

   b. 20.0 cm

   c. 30.0 cm

   d. 40.0 cm

   e. 60.0 cm

10. A reflective sphere with a radius of 1.0 m is shiny on the outside. If a person 2.0 m tall stands 3.0 m away from the sphere, where will the image of the person appear? How big will the image be? Will it be upright or inverted?

11. If the person in the problem above (2.0 m tall) wants to see their whole body in a flat mirror, how large must the mirror be? Where should the person position the mirror? (A ray diagram might be helpful for answering this question.)

12. Why are car headlamps parabolic?

13. Why do Direct TV dishes often look like their pointing at the ground?

14. What is the speed of light in zircon?

15. A ray of light coming from air at an angle of incidence of 40° refracts in an unknown material at an angle of 25°. What is the index of refraction of that material? What material might it be?

16. What is the critical angle when light passes from diamond to air? What happens for an angle of incidence less than, equal to, and greater than this value?

17. A magnifying glass (a convex lens) produces an inverted image of a candle that is 50.0 cm away from the lens. If the image is projected on a screen 10.0 cm away from the lens, determine the focal length of the magnifying glass and the magnification of the image.

18. Fred's glasses are concave lenses with a focal length of -12.0 cm. They are used to create an image of a nearby bluebird. What type of image will be produced? If the image is to be half the size of the actual bird, where should the lens be positioned relative to the bird?

19. Why does your GPS work less reliably when solar activity is changing?

20. Why are most large telescopes reflectors rather than refractors?

21. Define the following:
   a. Fermat's Principle of Least Time:

   b. Specular Reflection:

   c. Diffuse Reflection:

   d. Spherical Aberration:

   e. Dispersion:

   f. Chromatic Aberration:
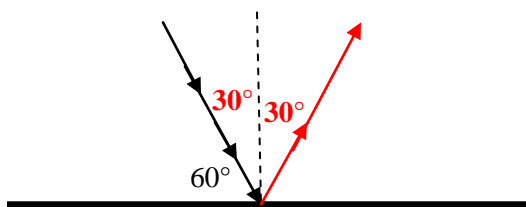
Optics Basics WS
Teacher Notes

This worksheet is intended to accompany the Optics Basics PowerPoint (Optics Basics.pptx) created as part of Haystack Observatory's RET 2010 project on Physics and MOSAIC. The PowerPoint can be used as an in-class presentation, but also could be re-envisioned as a Webquest-type activity of self-directed learning.

Answers and explanations to the questions

1. Compare the brightness of a 100 W light bulb 1.0 m away from your desk and a 100 W light bulb 3.0 m away from your desk.
   Because of the inverse square law, although both bulbs emit the same intensity of light (the same number of photons per second), the one that is 3 times as far away will have 1/9 the brightness. So, the bulb at 3.0 meters is 1/9 as bright as the bulb at 1.0 meter.

2. What is the angle of incidence in the following diagram? **(30°)** Draw the reflected ray, and label the angle of reflection.

   This question is intended to get students to realize that the incident and reflected angles must be measured from the normal, and to apply the law of reflection.

3. What does it mean if a surface is "smooth?" How does it depend on the wavelength of the light being reflected?
   A surface is smooth if the irregularities on the surface are smaller than the wavelengths of the waves being reflected. Thus, what seems smooth to a radio wave will not necessarily seem smooth to visible light.

4. Compare the smoothness of a radio telescope to that of a UV telescope.
   A radio telescope will be much less smooth than a UV telescope, since the UV telescope needs to have irregularity smaller than the wavelength of UV, which is much, much smaller than the wavelength of radio waves.

5. What is the focal length of a curved mirror? What does it depend on?
   The focal length is the distance from the mirror to the location where incoming parallel light rays converge. It depends on the radius of curvature of the mirror; mirrors coming from smaller spheres will have small focal lengths than those coming from larger spheres.

6. What is the ratio of the light gathering power of the Mount Wilson Observatory 100-inch diameter telescope to that of its 60-inch diameter telescope?
LGP is proportional to diameter^2, so $(100/60)^2 = (5/3)^2 = 25/9 = 2.78$

7. What is the ratio of the resolution of the two telescopes in the previous problem, assuming they are looking at the same wavelength signal? Which has better resolution?
Resolution improves proportional to diameter, so the 100 inch telescope has better resolution. It is 100/60 or 1.67 times better than the 60 inch telescope.

8. Why do biologists sometimes illuminate their microscopes with blue light instead of simply white light?
Resolution improves as wavelength decreases, so blue light (which has a smaller wavelength than other parts of the visible spectrum) provides better resolving power than if an object is illuminated in ambient white light.

9. A spherical concave mirror with a radius of curvature of 40.0 cm is used to produce an image of a cell phone 3.0 cm tall. Determine the type of image, image distance, size of image, and magnification if the cell is phone is the following distances away from the mirror. Verify your answers by drawing an approximate ray diagram.
Since r = 40 cm, **f = 20 cm**. The cell phone is 3.0 cm tall, so **h_o = 3.0 cm.**
The qualitative parts of these problems can often be answered before the quantitative parts if a good ray diagram is drawn, or if students are familiar with the different cases discussed in the lesson.

   a. 10.0 cm
   d_o = 10 cm; object is inside the focal point, so **virtual, upright, larger** image
   $1/f = 1/d_o + 1/d_i$; $1/20 = 1/10 + 1/d_i$; **d_i= -20 cm**
   $m = -d_i / d_o = -(-20)/10 =$ **m = 2.0** $= h_i / h_o$; so $2 = h_i / 3$; **h_i = 6.0 cm** (positive, since upright)

   b. 20.0 cm
   d_o = 20 cm; object is located at the focal point, so **no image** is produced.

   c. 30.0 cm
   d_o = 30 cm; object is between f and 2f, so **real, inverted, larger** image
   $1/f = 1/d_o + 1/d_i$; $1/20 = 1/30 + 1/d_i$; **d_i= 60 cm**
   $m = -d_i / d_o = -60/30 =$ **m = -2.0** $= h_i / h_o$; so $-2 = h_i / 3$; **h_i = -6 cm** (negative, since inverted)

   d. 40.0 cm
   d_o = 40 cm; object is at C (2 x focal length), so **real, inverted, same-size** image
   $1/f = 1/d_o + 1/d_i$; $1/20 = 1/40 + 1/d_i$; **d_i= 40 cm**
   $m = -d_i / d_o = -40 / 40 =$ **m = -1.0** $= h_i / h_o$; so $-1 = h_i / 3$; **h_i = -3.0 cm** (negative, since inverted)

e. 60.0 cm

$d_o = 60$ cm; object is beyond C (2 x focal length), so **real, inverted, smaller** image
$1/f = 1/d_o + 1/d_i$; $1/20 = 1/60 + 1/d_i$; $d_i = 30$ cm
$m = -d_i / d_o = -30/60 = m = -0.5 = h_i / h_o$; so $-0.5 = h_i / 3$; $h_i = -1.5$ cm (negative, since inverted)

10. A reflective sphere with a radius of 1.0 m is shiny on the outside. If a person 2.0 m tall stands 3.0 m away from the sphere, where will the image of the person appear? How big will the image be? Will it be upright or inverted?
Radius of the sphere is 1.0, so focal length is -0.5 m (negative, since convex mirror).
It's a convex mirror, image will be **virtual, upright, and smaller**.
$f = -0.5$ m, $h_o = 2.0$ m, $d_o = 3.0$ m
$1/f = 1/d_o + 1/d_i$; $1/(-0.5) = 1/3 + 1/d_i$; $d_i = -0.43$ m
$m = -d_i /d_o = -(-0.43) / 3 = 0.14$; $m = h_i / h_o = 0.14 = h_i / 2$; $h_i = 0.29$ m (positive, since upright)

11. If the person in the problem above (2.0 m tall) wants to see their whole body in a flat mirror, how large must the mirror be? Where should the person position the mirror? (A ray diagram might be helpful for answering this question.)
The mirror must be 1.0 meter tall (half the height of the person). The mirror should be positioned so that the bottom of the mirror is halfway between the ground and the height of the person's eyes, while the top of the mirror will be halfway between the top of the person and eye level. This is so that a light ray from the person's foot can reflect off the mirror and reach the person's eye and so that a light ray from the top of the person's head can reflect off the mirror and reach their eye.

12. Why are car headlamps parabolic?
The parabolic shape allows light rays leaving the lightbulb at the focal point to reflect off the mirrored surface of the headlight as parallel rays, directed somewhat downward, so as to illuminate the road, but not the eyes of oncoming traffic.

13. Why do Direct TV dishes often look like their pointing at the ground?
They are offset parabolas, which means that only part of the parabola is present, often the part above the focal point. This means that the part of the parabola that is present appears to be pointed downward, even though it is actually part of a larger parabola directed upward to receive radio signals from satellites.

14. What is the speed of light in zircon?
$n = c/v$, so $1.92 = 3.0$ x 10^8 m/s / v, or $v = 3.0$ x 10^8 m/s / $1.92 = 1.56$ x 10^8 m/s

15. A ray of light coming from air at an angle of incidence of 40° refracts in an unknown material at an angle of 25°. What is the index of refraction of that material? What material might it be?

Use Snell's Law to solve this problem, combined with the knowledge that n for air = 1.0. $n_1\sin\theta_1=n_2\sin\theta_2$, so 1.0 sin 40° = n_2 sin 25°, or n_2 = sin 40°/sin 25° = 1.52. This is close to the index of refraction of crown glass, per the table included in the powerpoint.

16. What is the critical angle when light passes from diamond to air? What happens for an angle of incidence less than, equal to, and greater than this value?

Using Snell's Law ($n_1\sin\theta_1=n_2\sin\theta_2$) and looking up values for n for diamond and air, we can say that, 2.42 sin θ_c = 1.00 sin 90°. (This is because the critical angle is the value of the angle of incidence that gives an angle of refraction of 90 degrees.)

So, sin θ_c = 1/ 2.42 = 0.413; θ_c = $\sin^{-1}$ (0.413) = 24.4°.

When an angle is incident between diamond and air with an angle less than 24.4°, it is refracted away from the normal and enters the air. When an angle is incident at 24.4°, the refracted ray travels along the boundary between the diamond and the air. When the angle of incidence is greater than 24.4°, the ray undergoes total internal reflection, with none of the light reaching the air, and all the light reflecting within the diamond. This relatively small critical angle helps explain why diamonds are so sparkly.

17. A magnifying glass (a convex lens) produces an inverted image of a candle that is 50.0 cm away from the lens. If the image is projected on a screen 10.0 cm away from the lens, determine the focal length of the magnifying glass and the magnification of the image.

d_o = 50.0 cm; d_i = 10.0 cm (positive, since real image projected on screen)

$1/f = 1/d_o + 1/d_i$; $1/f = 1/50 + 1/10$; **f = 50/6 cm = 8.33 cm** (positive, since convex lens)

m = $-d_i / d_o$ = - 10/50 = **-0.2 = m**

18. Fred's glasses are concave lenses with a focal length of -12.0 cm. They are used to create an image of a nearby bluebird. What type of image will be produced? If the image is to be half the size of the actual bird, where should the lens be positioned relative to the bird?

f = -12.0 cm; because the lens is concave (diverging), the image will be **virtual, upright, and smaller.**

If m = 0.5 = $-d_i / d_o$; d_i = -0.5 d_o; $1/f = 1/d_o + 1/d_i$, so 1/-12 = $1/d_o$ + 1/-0.5d_o; solve for d_o

d_o = 12.0 cm, so the lens should be positioned 12 cm away from the bird.

19. Why does your GPS work less reliably when solar activity is changing?

Solar activity changes the amount and behavior of charged particles in the upper atmosphere, which, in turn, changes the dispersive properties of the atmosphere to radio waves. This means that GPS navigation systems on Earth, which rely on the reception of radio waves from space, cannot accurately interpret how far away the satellite sending the signal was, since it can't predict exactly how much the radio wave was slowed in the atmosphere.

20. Why are most large telescopes reflectors rather than refractors?
This is a pretty straightforward question, direct from one of the slides, but I find that students have a hard time keeping track of the different reasons and their physical basis. First of all, all refracting telescopes have chromatic aberration, which can only be partially corrected. Reflecting telescopes don't have this problem, provided they are made parabolic and not spherical. Second, refracting telescopes are made of glass, which is a very viscous fluid that sags over time. Third, there is the problem of supporting the glass lens for the refracting telescope. Reflectors can be supported from beneath, while reflectors need to allow a clear path for light to pass through them while also maintaining a stable position for the (very heavy in the case of a large telescope) glass. Finally, reflectors are more simple to produce, since they require only one surface to be perfectly shaped. Refractors require two smooth surfaces, plus there is the bulk of glass that must be free from imperfections.

21. Define the following:
    a. Fermat's Principle of Least Time: of all possible paths between two points, light will follow the one that requires the least time of travel.
    b. Specular Reflection: reflection where incident parallel rays remain parallel upon reflection; occurs off "smooth" surfaces; will look shiny.
    c. Diffuse Reflection: reflection where incident parallel rays do not remain parallel upon reflection; occurs off rough surfaces; will not look shiny.
    d. Spherical Aberration: imperfection in focal point for a curved mirror that is made in spherical shape; not all incoming rays will focus to same point; can be corrected with a parabolic mirror.
    e. Dispersion: difference in index of refraction for different wavelengths (or frequencies) of light.
    f. Chromatic Aberration: due to dispersion, the difference in focal length of different wavelengths of light passing through a lens.