23-1 The Ray Model of Light

Figure 23.1: The photograph shows rays of light passing through openings in clouds above the Washington Monument. Each ray follows a straight line. (Photo credit: public-domain photo from Wikimedia Commons)

We will start our investigation of geometrical optics (optics based on the geometry of similar triangles) by learning the basics of the ray model of light. We will then apply this model to understand reflection and mirrors, in this chapter, and refraction and lenses, in chapter 24. Using the triangles that result from applying the ray model, we will derive equations we can apply to predict where the image created by a mirror or lens will be formed.

A **ray** is as a narrow beam of light that tends to travel in a straight line. An example of a ray is the beam of light from a laser or laser pointer. In the ray model of light, a ray travels in a straight line until it hits something, like a mirror, or an interface between two different materials. The interaction between the light ray and the mirror or interface generally causes the ray to change direction, at which point the ray again travels in a straight line until it encounters something else that causes a change in direction. An example in which the ray model of light applies is shown in Figure 23.1, in which the beams of sunlight travel in straight lines.

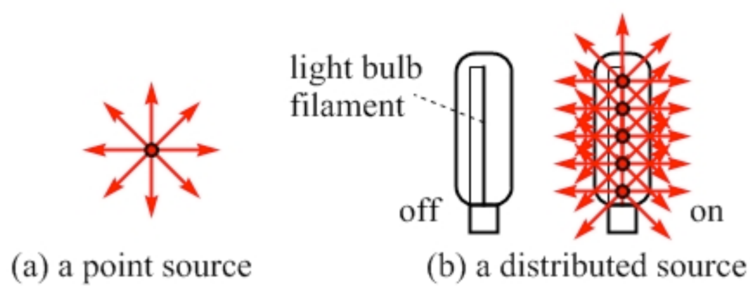


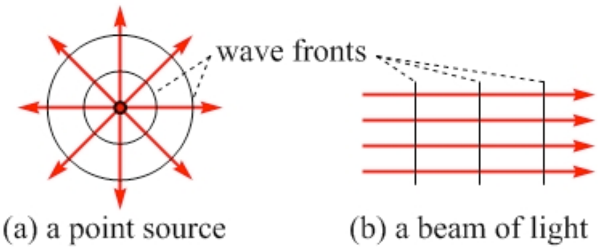
Figure 23.2: (a) A point source of light emits light uniformly in all directions. (b) A distributed source of light, such as a light-bulb filament in the shape of a line, can generally be treated as a collection of point sources.

A laser emits a single ray of light, but we can also apply the ray model in situations in which a light source sends out many rays, in many directions. Examples of such sources include the filaments of light bulbs, and the Sun. If we are far away from such a source, in relation to the size of the source itself, we often treat the source as a **point source**, and assume that the source emits light, usually in all directions, from a single point. Light bulbs, and the Sun, are often treated as point sources. In other situations, such as when we are close to a light bulb that has a long filament, we treat the source as a **distributed source**. Each point on the source can be treated as a point source, so a distributed source is like a collection of point sources, as shown in Figure 23.2.

Wave fronts

In addition to rays of light, we will also mention wave fronts. A wave front is a surface connecting light that was emitted by the light source at the same time. As shown in Figure 23.3, the wave fronts for a point source are spherical shells centered on the source, which propagate away from the source at the speed of light. For a beam of light, like that from a flashlight, in which the rays are parallel, the wave fronts are parallel lines that are perpendicular to the beam.

Figure 23.3: (a) For a point source, the wave fronts are spherical shells that are centered on the source. The larger the radius of the wave front, the more time has passes since the light was emitted. (b) When the rays are part of a beam of light that is traveling in a particular direction, the wave fronts are parallel lines that are perpendicular to the beam.



Shadows

The ray model of light can also be used to understand shadows. Figure 23.4 shows how the shadow cast by a point source can be larger than the object creating the shadow, while that from parallel rays is the same size as the object, as long as the surface on which the shadow is cast is perpendicular to the direction of the rays. Distributed sources create more complicated shadows, but they can be understood as the superposition of the shadows from multiple point sources.

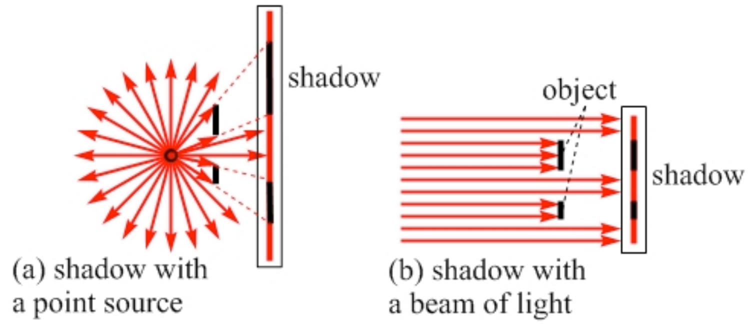


Figure 23.4: We can use the ray model of light, in which travels in straight lines, to explain shadows. When the light source is a point source (a), the shadow is generally larger than the object casting the shadow. When the light rays are all going in the same direction, however, the shadow is the same size of the object when the shadow is cast on a surface that is perpendicular to the light rays.

Treating sources that do not themselves emit light as light sources

In some cases, we will use objects that actually emit light, such as a light bulb or the Sun, as the objects that send light toward a mirror or lens. In other cases we will use objects, such as you, that do not emit light themselves. How can we do this? In general, objects that do not emit light themselves are illuminated by other light sources. As shown in Figure 23.5, such sources can be treated as if they emit light, because they scatter much of the light incident on them in many different directions.

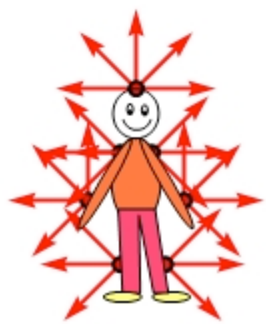


Figure 23.5: An illuminated object can itself be treated as a source of light, because much of the light shining on it is scattered off the object in all directions.

How we see objects

To see an object, rays of light need either to be emitted by, or reflected from, the object, and then pass into our eyes. Our brains assume that the rays of light travel in straight lines, so we trace the rays of light back until they meet at the location of the object, as shown in Figure 23.6.

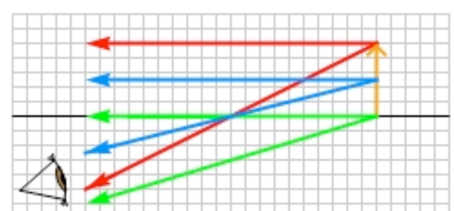


Figure 23.6: Objects send out light in many directions. We see the object if enough of this light enters our eye. Only a small number of the rays are shown for this object, color-coded red for rays from the top, blues for rays from the middle, and green for rays from the bottom of the object.

Related End-of-Chapter Exercises: 3, 4, 30.

Essential Question 23.1: The Sun is a very large object, much larger than the Earth. Give an example in which we can treat the Sun as a point source when applying the ray model. Give an example in which the Sun must be treated as a distributed source of light.