

### 27.7 Thin Film Interference

- Discuss the rainbow formation by thin films.

### 27.8 Polarization

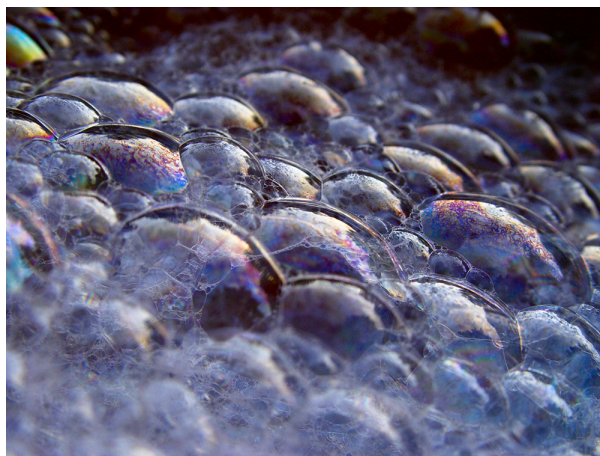
- Discuss the meaning of polarization.
- Discuss the property of optical activity of certain materials.

### 27.9 \*Extended Topic\* Microscopy Enhanced by the Wave Characteristics of Light

- Discuss the different types of microscopes.

**INTRODUCTION TO WAVE OPTICS** Examine a compact disc under white light, noting the colors observed and locations of the colors. Determine if the spectra are formed by diffraction from circular lines centered at the middle of the disc and, if so, what is their spacing. If not, determine the type of spacing. Also with the CD, explore the spectra of a few light sources, such as a candle flame, incandescent bulb, halogen light, and fluorescent light. Knowing the spacing of the rows of pits in the compact disc, estimate the maximum spacing that will allow the given number of megabytes of information to be stored.

If you have ever looked at the reds, blues, and greens in a sunlit soap bubble and wondered how straw-colored soapy water could produce them, you have hit upon one of the many phenomena that can only be explained by the wave character of light (see [Figure 27.2](#)). The same is true for the colors seen in an oil slick or in the light reflected from a compact disc. These and other interesting phenomena, such as the dispersion of white light into a rainbow of colors when passed through a narrow slit, cannot be explained fully by geometric optics. In these cases, light interacts with small objects and exhibits its wave characteristics. The branch of optics that considers the behavior of light when it exhibits wave characteristics (particularly when it interacts with small objects) is called wave optics (sometimes called physical optics). It is the topic of this chapter.



**Figure 27.2** These soap bubbles exhibit brilliant colors when exposed to sunlight. How are the colors produced if they are not pigments in the soap? (credit: Scott Robinson, Flickr)

## 27.1 The Wave Aspect of Light: Interference

We know that visible light is the type of electromagnetic wave to which our eyes respond. Like all other electromagnetic waves, it obeys the equation

$$c = f\lambda,$$

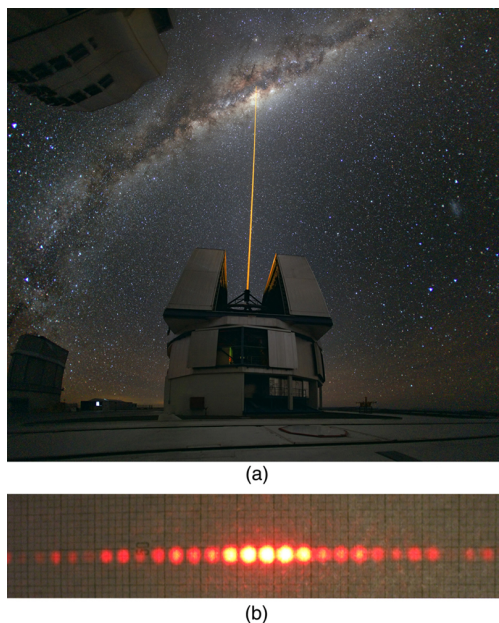
27.1

where  $c = 3 \times 10^8$  m/s is the speed of light in vacuum,  $f$  is the frequency of the electromagnetic waves, and  $\lambda$  is its wavelength. The range of visible wavelengths is approximately 380 to 760 nm. As is true for all waves, light travels in straight lines and acts like a ray when it interacts with objects several times as large as its wavelength. However, when it interacts with smaller objects, it displays its wave characteristics prominently. Interference is the hallmark of a wave, and in [Figure 27.3](#) both the ray and wave characteristics of light can be seen. The laser beam emitted by the observatory epitomizes a ray, traveling in a straight line. However, passing a pure-wavelength beam through vertical slits with a size close to the wavelength of the beam reveals the wave character of light, as the beam spreads out horizontally into a pattern of bright and dark regions caused by

systematic constructive and destructive interference. Rather than spreading out, a ray would continue traveling straight ahead after passing through slits.

### Making Connections: Waves

The most certain indication of a wave is interference. This wave characteristic is most prominent when the wave interacts with an object that is not large compared with the wavelength. Interference is observed for water waves, sound waves, light waves, and (as we will see in [Special Relativity](#)) for matter waves, such as electrons scattered from a crystal.



**Figure 27.3** (a) The laser beam emitted by an observatory acts like a ray, traveling in a straight line. This laser beam is from the Paranal Observatory of the European Southern Observatory. (credit: Yuri Beletsky, European Southern Observatory) (b) A laser beam passing through a grid of vertical slits produces an interference pattern—characteristic of a wave. (credit: Shim'on and Slava Rybka, Wikimedia Commons)

Light has wave characteristics in various media as well as in a vacuum. When light goes from a vacuum to some medium, like water, its speed and wavelength change, but its frequency  $f$  remains the same. (We can think of light as a forced oscillation that must have the frequency of the original source.) The speed of light in a medium is  $v = c/n$ , where  $n$  is its index of refraction. If we divide both sides of equation  $c = f\lambda$  by  $n$ , we get  $c/n = v = f\lambda/n$ . This implies that  $v = f\lambda_n$ , where  $\lambda_n$  is the **wavelength in a medium** and that

$$\lambda_n = \frac{\lambda}{n},$$

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where  $\lambda$  is the wavelength in vacuum and  $n$  is the medium's index of refraction. Therefore, the wavelength of light is smaller in any medium than it is in vacuum. In water, for example, which has  $n = 1.333$ , the range of visible wavelengths is  $(380 \text{ nm})/1.333$  to  $(760 \text{ nm})/1.333$ , or  $\lambda_n = 285$  to  $570 \text{ nm}$ . Although wavelengths change while traveling from one medium to another, colors do not, since colors are associated with frequency.

## 27.2 Huygens's Principle: Diffraction

[Figure 27.4](#) shows how a transverse wave looks as viewed from above and from the side. A light wave can be imagined to propagate like this, although we do not actually see it wiggling through space. From above, we view the wavefronts (or wave crests) as we would by looking down on the ocean waves. The side view would be a graph of the electric or magnetic field. The view from above is perhaps the most useful in developing concepts about wave optics.