Answer to Essential Question 22.6 If the light is originally unpolarized, then the intensity is reduced to 50% of the incident intensity when the light passes through the first polarizer. The fact that the final intensity is larger than 50% tells us that the incident light could not be unpolarized, and thus it must be linearly polarized.

Chapter Summary

Essential Idea: Electromagnetic Waves.
Electromagnetic waves of various frequencies fill the air around us, including light waves that help us to see, radio waves that can bring us music and news, infrared waves that help to keep us warm, and waves traveling to and from our cell phones. It's hard to imagine life without all the modern conveniences related to electromagnetic waves, but it was only in the 19th century that EM waves were theoretically predicted and then, over 20 years later, detected experimentally.

Maxwell's Equations
James Clerk Maxwell wrote down four equations that summarized much of electricity and magnetism. With Maxwell's addition to one of the equations, he was able to predict the existence of electromagnetic (EM) waves, show that light was a form of EM wave, and show that electricity, magnetism, and optics were all linked. Maxwell's contributions rank among the most important contributions to physics of all time.

Energy, Momentum, and Radiation Pressure
Electromagnetic waves consist of oscillating electric and magnetic fields that travel at the speed of light. We characterize the energy carried by an EM wave in terms of its intensity:

$$I_{average} = \frac{\text{average power}}{\text{area}} = \frac{E_{\max} B_{\max}}{2\mu_0} .$$ (Eq. 22.3: **The average intensity in an EM wave**)

The momentum associated with EM waves is most obvious when a wave, such as that from a flashlight, is absorbed or reflected. The radiation pressure associated with the wave's momentum change is twice as large when the wave completely reflects than when it is completely absorbed.

The Doppler effect for electromagnetic waves
If a source emits EM waves with a frequency f, the observed frequency f' is given by

$$f' = f\left(1 \pm \frac{v}{c}\right),$$ (Equation 22.6: **The Doppler effect for electromagnetic waves**)

where v is the magnitude of the relative velocity between the source and the observer. As with the Doppler effect for sound, we use the top (+) sign when the source and observer are moving toward one another, and the bottom (–) sign when the source and observer are moving apart.

Polarized light
When linearly polarized light (light with all its electric field vectors in one plane) is incident on a polarizer, the intensity of the emerging light (I_1) is related to that of the incident light (I_0) by

$$I_1 = I_0 \cos^2(\Delta\theta) ,$$ (Eq. 22.7: **Malus' Law for the intensity of light emerging from a polarizer**)

where $\Delta\theta$ is the angle between the polarization direction of the light and the direction of the polarizer's transmission axis. If unpolarized light is incident on the polarizer, the intensity of the transmitted light is half of that of the incident light. In all cases, electromagnetic waves emerging from a polarizer are polarized parallel to the direction of the polarizer's transmission axis.