of the surface irregularities of the reflector are substantially less than the wavelength of the incident light. Thus the classification of the reflective properties of a surface depends on the wavelength of the radiation that strikes the surface. The bottom of a cast-iron skillet, for example, may be a good reflector for microwaves of wavelength 0.5 cm but is not a good reflector for visible light.

Maxwell's equations permit us to calculate how the incident energy is divided between the reflected and refracted beams. Figure 5 shows the theoretical prediction for (a) a light beam in air falling on a glass-air interface, and (b) a light beam in glass falling on a glass-air interface. Figure 5a shows that for angles of incidence up to about 60°, less than 10% of the light energy is reflected. At grazing incidence (that is, at angles of incidence near 90°), the surface becomes an excellent reflector. Another example of this effect is the high reflecting power of a wet road when light from automobile headlights strikes the road near grazing incidence.

Figure 5b shows clearly that at a certain critical angle (41.8° in this case), all the light is reflected. We consider this phenomenon, called total internal reflection, in Section 43-6.

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**Sample Problem 1**

Figure 6 shows an incident ray \( i \) striking a plane mirror \( MM' \) at an angle of incidence \( \theta \). Mirror \( M'M'' \) is perpendicular to \( MM' \). Trace this ray through its subsequent reflections.

**Solution** The reflected ray \( r \) makes an angle \( \theta \) with the normal at \( b \) and falls as an incident ray on mirror \( M'M'' \). Its angle of incidence \( \theta' \) on this mirror is \( \frac{\pi}{2} - \theta \). A second reflected ray \( r' \) makes an angle \( \theta' \) with the normal erected at \( b' \). Rays \( i \) and \( r' \) are antiparallel for any value of \( \theta \). To see this, note that

\[
\phi = \pi - 2\theta' = \pi - 2 \left( \frac{\pi}{2} - \theta \right) = 2\theta.
\]

Two lines are parallel if their opposite interior angles for an intersecting line (\( \phi \) and \( 2\theta \)) are equal.

Repeat the problem if the angle between the mirrors is 120° rather than 90°.

The three-dimensional analogue of Fig. 6 is the corner reflector, which consists of three perpendicular plane mirrors joined like the positive sections of the coordinate planes of an \( xyz \) system. A corner reflector has the property that, for any direction of incidence, an incident ray is reflected back in the opposite direction. Highway reflectors use this principle, so that light from the headlights of an oncoming car is reflected back toward the car, no matter when the direction of approach of the car or the angle of the headlights above the road. Corner reflectors were placed on the Moon by the Apollo astronauts; timing a reflected laser beam from Earth permits precise determination of the Earth-Moon separation.

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**Sample Problem 2**

A light beam in air is incident on the plane surface of a block of quartz and makes an angle of 30° with the normal. The beam contains two wavelengths, 400 and 500 nm. The indices of refraction for quartz at these wavelengths are 1.4702 and 1.4624, respectively. What is the angle between the two refracted beams in the quartz?