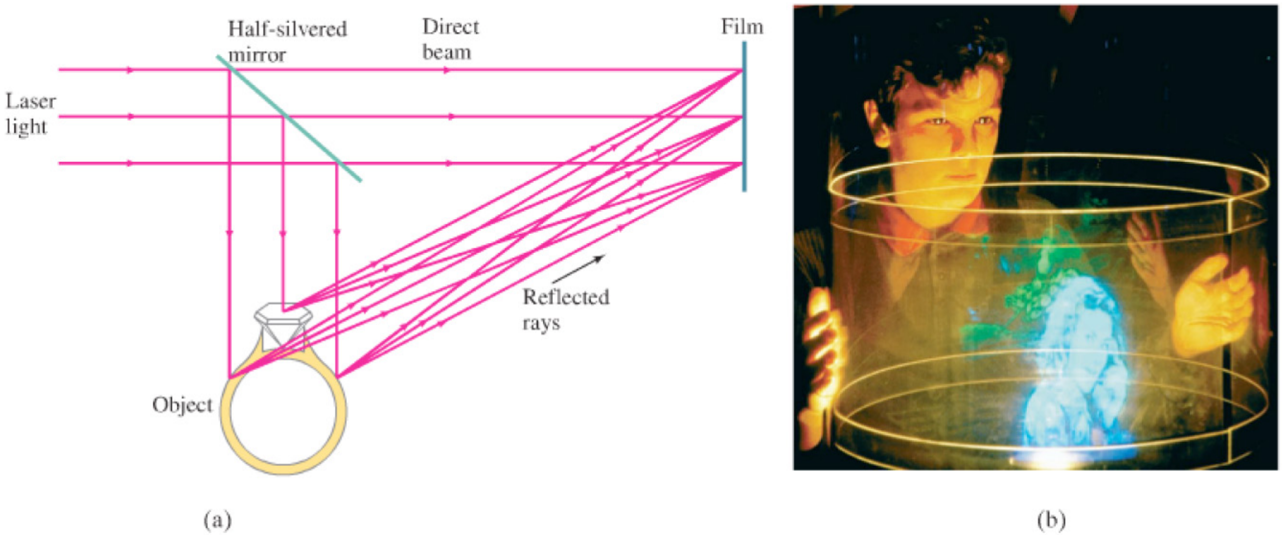

FIGURE 28–23 (a) Making a hologram. Light reflected from various points on the object interferes (at the film) with light from the direct beam. (b) A boy is looking at a hologram of two women talking on telephones.

again in a laser beam and a three-dimensional image of the object is created. You can walk around such an image and see it from different sides as if it were the original object (Fig. 28–23b). Yet, if you try to touch it with your hand, there will be nothing material there.

White-light holograms

Volume or **white-light holograms** do not require a laser to see the image, but can be viewed with ordinary white light (preferably a nearly point source, such as the Sun or a clear bulb with a small bright filament). Such holograms must be made, however, with a laser. They are made not on thin film, but on a *thick* emulsion. The interference pattern in the film emulsion can be thought of as an array of bands or ribbons where constructive interference occurred. This array, and the reconstruction of the image, can be compared to Bragg scattering of X-rays from the atoms in a crystal (see Section 25–11). White light can reconstruct the image because the Bragg condition ($m\lambda = 2d \sin\theta$) selects out the appropriate single wavelength. If the hologram is originally produced by lasers emitting the three additive primary colors (red, green, and blue), the three-dimensional image can be seen in full color when viewed with white light.

Summary

In 1925, Schrödinger and Heisenberg separately worked out a new theory, **quantum mechanics**, which is now considered to be the basic theory at the atomic level. It is a statistical theory rather than a deterministic one.

An important aspect of quantum mechanics is the Heisenberg **uncertainty principle**. It results from the wave–particle duality and the unavoidable interaction between an observed object and the observer.

One form of the uncertainty principle states that the position x and momentum p_x of an object cannot both be measured precisely at the same time. The products of the uncertainties, $(\Delta x)(\Delta p_x)$, can be no less than $\hbar\ (= h/2\pi)$:

$$(\Delta p_x)(\Delta x) \gtrsim \hbar. \qquad \textbf{(28–1)}$$

Another form of the uncertainty principle states that the energy can be uncertain by an amount ΔE for a time Δt, where

$$(\Delta E)(\Delta t) \gtrsim \hbar. \qquad \textbf{(28–2)}$$

According to quantum mechanics, the state of an electron in an atom is specified by four **quantum numbers**: n, l, m_l, and m_s:

(1) n, the **principal quantum number**, can take on any integer value $(1, 2, 3, \cdots)$ and corresponds to the quantum number of the old Bohr theory;

(2) l, the **orbital quantum number**, can take on values from 0 up to $n - 1$;

(3) m_l, the **magnetic quantum number**, can take on integer values from $-l$ to $+l$;

(4) m_s, the **spin quantum number**, can be $+\frac{1}{2}$ or $-\frac{1}{2}$.