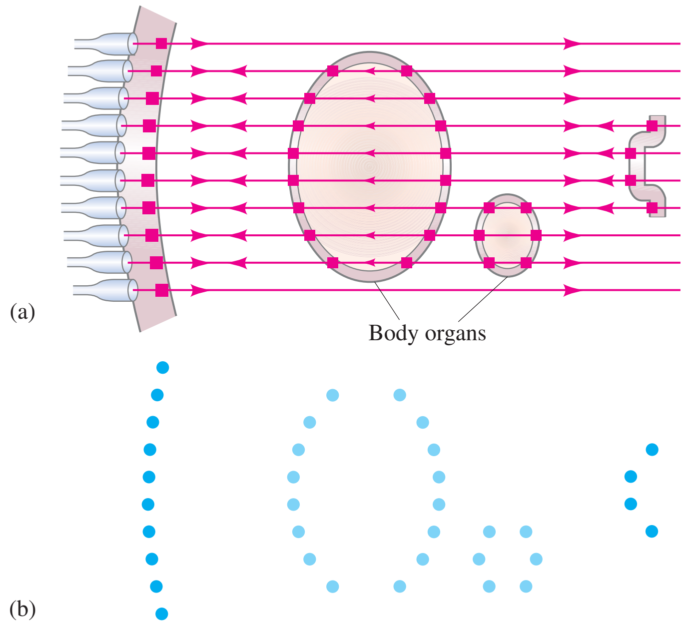

FIGURE 12–28 (a) Ten traces are made across the abdomen by moving the transducer, or by using an array of transducers. (b) The echoes from interfaces or boundaries (of organs) are plotted as dots to produce the image. More closely spaced traces would give a more detailed image.

on the strength of the echo. A two-dimensional image can then be formed out of these dots from a series of scans. The transducer is moved, or an array of transducers is used, each of which sends out a pulse at each position and receives echoes as shown in Fig. 12–28a. Each trace can be plotted, spaced appropriately one below the other, to form an image on a monitor screen as shown in Fig. 12–28b. Only 10 lines are shown in Fig. 12–28, so the image is crude. More lines give a more precise image.

Summary

Sound travels as a longitudinal wave in air and other materials. In air, the speed of sound increases with temperature. At 20°C, it is about 343 m/s.

The **pitch** of a sound is determined by the frequency; the higher the frequency, the higher the pitch.

The **audible range** of frequencies for humans is roughly 20 Hz to 20,000 Hz (1 Hz = 1 cycle per second).

The **loudness** or **intensity** of a sound is related to the amplitude squared of the wave. Because the human ear can detect sound intensities from $10^{-12}\,\mathrm{W/m^2}$ to over $1\,\mathrm{W/m^2}$, sound levels are specified on a logarithmic scale. The **sound level** β, specified in decibels, is defined in terms of intensity I as

$$\beta\,(\text{in dB}) = 10\log\left(\frac{I}{I_0}\right), \qquad \textbf{(12–1)}$$

where the reference intensity I_0 is usually taken to be $10^{-12}\,\mathrm{W/m^2}$.

Musical instruments are simple sources of sound in which *standing waves* are produced.

The strings of a stringed instrument may vibrate as a whole with nodes only at the ends; the frequency at which this standing wave occurs is called the **fundamental**. The fundamental frequency corresponds to a wavelength equal to twice the length of the string, $\lambda_1 = 2\ell$. The string can also vibrate at higher frequencies, called **overtones** or **harmonics**, in which there are one or more additional nodes. The frequency of each harmonic is a whole-number multiple of the fundamental.

In wind instruments, standing waves are set up in the column of air within the tube.

The vibrating air in an **open tube** (open at both ends) has displacement antinodes at both ends. The fundamental frequency corresponds to a wavelength equal to twice the tube length: $\lambda_1 = 2\ell$. The harmonics have frequencies that are $1, 2, 3, 4, \cdots$ times the fundamental frequency, just as for strings.

For a **closed tube** (closed at one end), the fundamental corresponds to a wavelength four times the length of the tube: $\lambda_1 = 4\ell$. Only the odd harmonics are present, equal to $1, 3, 5, 7, \cdots$ times the fundamental frequency.

Sound waves from different sources can interfere with each other. If two sounds are at slightly different frequencies, **beats** can be heard at a frequency equal to the difference in frequency of the two sources.

The **Doppler effect** refers to the change in pitch of a sound due to the motion either of the source or of the observer. If source and observer are approaching each other, the perceived pitch is higher. If they are moving apart, the perceived pitch is lower.

[*Shock waves and a sonic boom occur when an object moves at a **supersonic** speed—faster than the speed of sound. **Ultrasonic**-frequency (higher than 20 kHz) sound waves are used in many applications, including sonar and medical imaging.]