

NOTE To express our result in U.S. gallons, we see in the Table on the inside front cover that $1 \text{ liter} = 10^{-3} \text{ m}^3 \approx \frac{1}{4} \text{ gallon}$. Hence, the lake contains $(10^7 \text{ m}^3)(1 \text{ gallon}/4 \times 10^{-3} \text{ m}^3) \approx 2 \times 10^9 \text{ gallons}$ of water.

EXAMPLE 1-7 ESTIMATE Thickness of a page. Estimate the thickness of a page of this book.

APPROACH At first you might think that a special measuring device, a micrometer (Fig. 1-11), is needed to measure the thickness of one page since an ordinary ruler clearly won't do. But we can use a trick or, to put it in physics terms, make use of a *symmetry*: we can make the reasonable assumption that all the pages of this book are equal in thickness.

SOLUTION We can use a ruler to measure hundreds of pages at once. If you measure the thickness of the first 500 pages of this book (page 1 to page 500), you might get something like 1.5 cm. Note that 500 pages counted front and back is 250 separate pieces of paper. So one page must have a thickness of about

$$\frac{1.5 \text{ cm}}{250 \text{ pages}} \approx 6 \times 10^{-3} \text{ cm} = 6 \times 10^{-2} \text{ mm},$$

or less than a tenth of a millimeter (0.1 mm).

EXAMPLE 1-8 ESTIMATE Total number of heartbeats. Estimate the total number of beats a typical human heart makes in a lifetime.

APPROACH A typical resting heart rate is 70 beats/min. But during exercise it can be a lot higher. A reasonable average might be 80 beats/min.

SOLUTION If an average person lives 70 years $\approx 2 \times 10^9 \text{ s}$ (see Table 1-2),

$$\left(80 \frac{\text{beats}}{\text{min}}\right) \left(\frac{1 \text{ min}}{60 \text{ s}}\right) (2 \times 10^9 \text{ s}) \approx 3 \times 10^9,$$

or 3 trillion.

Now let's take a simple Example of how a diagram can be useful for making an estimate. It cannot be emphasized enough how important it is to draw a diagram when trying to solve a physics problem.

EXAMPLE 1-9 ESTIMATE Height by triangulation. Estimate the height of the building shown in Fig. 1-12, by "triangulation," with the help of a bus-stop pole and a friend.

APPROACH By standing your friend next to the pole, you estimate the height of the pole to be 3 m. You next step away from the pole until the top of the pole is in line with the top of the building, Fig. 1-12a. You are 5 ft 6 in. tall, so your eyes are about 1.5 m above the ground. Your friend is taller, and when she stretches out her arms, one hand touches you, and the other touches the pole, so you estimate that distance as 2 m (Fig. 1-12a). You then pace off the distance from the pole to the base of the building with big, 1-m-long, steps, and you get a total of 16 steps or 16 m.

SOLUTION Now you draw, to scale, the diagram shown in Fig. 1-12b using these measurements. You can measure, right on the diagram, the last side of the triangle to be about $x = 13 \text{ m}$. Alternatively, you can use similar triangles to obtain the height x :

$$\frac{1.5 \text{ m}}{2 \text{ m}} = \frac{x}{18 \text{ m}}, \text{ so } x \approx 13\frac{1}{2} \text{ m}.$$

Finally you add in your eye height of 1.5 m above the ground to get your final result: the building is about 15 m tall.

PROBLEM SOLVING

Use symmetry when possible



FIGURE 1-11 Example 1-7. A micrometer, which is used for measuring small thicknesses.

FIGURE 1-12 Example 1-9. Diagrams are really useful!

