Joule's result was crucial because it extended the work-energy principle to include processes involving heat. It also led to the establishment of the law of conservation of energy, which we shall discuss more fully in the next Chapter.

PHYSICS APPLIED
Working off Calories

EXAMPLE 14–1 ESTIMATE **Working off the extra Calories.** Suppose you throw caution to the wind and eat too much ice cream and cake on the order of 500 Calories. To compensate, you want to do an equivalent amount of work climbing stairs or a mountain. How much total height must you climb? For this calculation, take your mass to be about 60 kg.

APPROACH The work W you need to do in climbing stairs equals the change in gravitational potential energy: $W = \Delta PE = mgh,$ where h is the vertical height climbed.

SOLUTION 500 Calories is 500 kcal, which in joules is

$$(500\text{ kcal})(4.186 \times 10^3\text{ J/kcal}) = 2.1 \times 10^6\text{ J}.$$

The work done to climb a vertical height h is $W = mgh.$ We solve for h:

$$h = \frac{W}{mg} = \frac{2.1 \times 10^6\text{ J}}{(60\text{ kg})(9.80\text{ m/s}^2)} = 3600\text{ m}.$$

This is a huge elevation change (over 11,000 ft).

NOTE The human body does not transform energy with 100% efficiency—it is more like 20% efficient. As we'll discuss in the next Chapter, some energy is always "wasted," so you would actually have to climb only about $(0.2)(3600\text{ m}) \approx 700\text{ m},$ which is still a lot (about 2300 ft of elevation gain).

14–2 Internal Energy

Internal energy

The sum total of all the energy of all the molecules in an object is called its **internal energy**. (Sometimes **thermal energy** is used to mean the same thing.) We introduce the concept of internal energy now since it will help clarify ideas about heat.

Distinguishing Temperature, Heat, and Internal Energy

CAUTION
Distinguish heat from internal energy and from temperature

Using the kinetic theory, we can make a clear distinction between temperature, heat, and internal energy. Temperature (in kelvins) is a measure of the *average* kinetic energy of individual molecules. Internal energy refers to the *total* energy of all the molecules in the object. (Thus two equal-mass hot ingots of iron may have the same temperature, but two of them have twice as much thermal energy as one does.) Heat, finally, refers to a *transfer* of energy from one object to another because of a difference in temperature.

CAUTION
Direction of heat flow depends on temperature (not on amount of internal energy)

Notice that the direction of heat flow between two objects depends on their temperatures, not on how much internal energy each has. Thus, if 50 g of water at 30°C is placed in contact (or mixed) with 200 g of water at 25°C, heat flows *from* the water at 30°C *to* the water at 25°C even though the internal energy of the 25°C water is much greater because there is so much more of it.

Internal Energy of an Ideal Gas

Let us calculate the internal energy of n moles of an ideal monatomic (one atom per molecule) gas. The internal energy, U, is the sum of the translational kinetic energies of all the atoms. This sum is just equal to the average kinetic