The explanation for the **seasons** and the polar ice caps (see Fig. 14–13) depends on this $\cos\theta$ factor in Eq. 14–7. The seasons are *not* a result of how close the Earth is to the Sun—in fact, in the Northern Hemisphere, summer occurs when the Earth is farthest from the Sun. It is the angle (i.e., $\cos\theta$) that really matters. Furthermore, the reason the Sun heats the Earth more at midday than at sunrise or sunset is also related to this $\cos\theta$ factor.

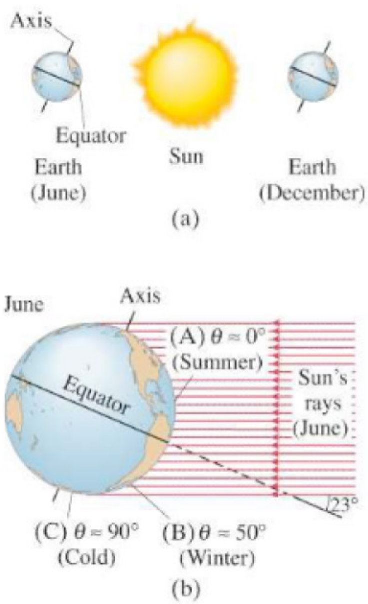

FIGURE 14–13 (a) Earth's seasons arise from the $23\frac{1}{2}°$ angle Earth's axis makes with its orbit around the Sun. (b) June sunlight makes an angle of about 23° with the equator. Thus θ in the southern United States (A) is near 0° (direct summer sunlight), whereas in the Southern Hemisphere (B), θ is 50° or 60°, and less heat can be absorbed—hence it is winter. Near the poles (C), there is never strong direct sunlight; $\cos\theta$ varies from about $\frac{1}{2}$ in summer to 0 in winter; so with little heating, ice can form.

EXAMPLE 14–13 ESTIMATE **Getting a tan—energy absorption.** What is the rate of energy absorption from the Sun by a person lying flat on the beach on a clear day if the Sun makes a 30° angle with the vertical? Assume that $e = 0.70$ and that $1000\ \mathrm{W/m^2}$ reaches the Earth's surface.

APPROACH We use Eq. 14–7 and estimate a typical human to be roughly 2 m tall by 0.4 m wide, so $A \approx (2\ \mathrm{m})(0.4\ \mathrm{m}) = 0.8\ \mathrm{m^2}$.

SOLUTION Since $\cos 30° = 0.866$, we have

$$\frac{\Delta Q}{\Delta t} = (1000\ \mathrm{W/m^2})eA\cos\theta$$
$$= (1000\ \mathrm{W/m^2})(0.70)(0.8\ \mathrm{m^2})(0.866) = 500\ \mathrm{W}.$$

NOTE If a person wears light-colored clothing, e is much smaller, so the energy absorbed is less.

An interesting application of thermal radiation to diagnostic medicine is **thermography**. A special instrument, the thermograph, scans the body, measuring the intensity of radiation from many points and forming a picture that resembles an X-ray (Fig. 14–14). Areas where metabolic activity is high, such as in tumors, can often be detected on a thermogram as a result of their higher temperature and consequent increased radiation.

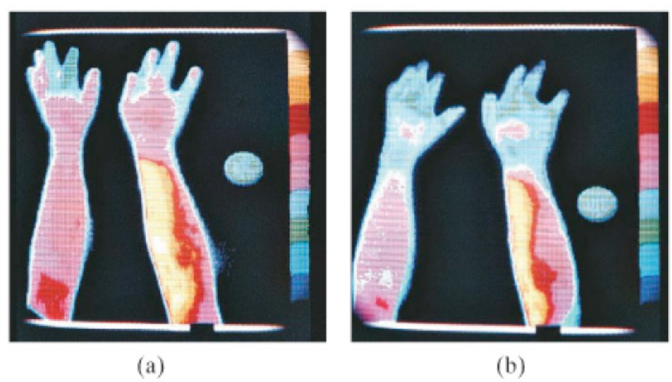

FIGURE 14–14 Thermograms of a healthy person's arms and hands (a) before and (b) after smoking a cigarette, showing a temperature decrease due to impaired blood circulation associated with smoking. The thermograms have been color-coded according to temperature; the scale on the right goes from blue (cold) to white (hot).

PHYSICS APPLIED
Astronomy—size of a star

EXAMPLE 14–14 ESTIMATE **Star radius.** The giant star Betelgeuse emits radiant energy at a rate 10^4 times greater than our Sun, whereas its surface temperature is only half (2900 K) that of our Sun. Estimate the radius of Betelgeuse, assuming $e = 1$. The Sun's radius is $r_S = 7 \times 10^8\ \mathrm{m}$.

APPROACH We assume both Betelgeuse and the Sun are spherical, with surface area $4\pi r^2$.

SOLUTION We solve Eq. 14–5 for A:

$$4\pi r^2 = A = \frac{(\Delta Q/\Delta t)}{e\sigma T^4}.$$

Then

$$\frac{r_B^2}{r_S^2} = \frac{(\Delta Q/\Delta t)_B}{(\Delta Q/\Delta t)_S}\cdot\frac{T_S^4}{T_B^4} = (10^4)(2^4) = 16 \times 10^4.$$

Hence $r_B = \sqrt{16 \times 10^4}\, r_S = (400)(7 \times 10^8\ \mathrm{m}) \approx 3 \times 10^{11}\ \mathrm{m}$. If Betelgeuse were our Sun, it would envelop us (Earth is 1.5×10^{11} m from the Sun).