It is useful to think of the energy stored in a capacitor as being stored in the electric field between the plates. As an example let us calculate the energy stored in a parallel-plate capacitor in terms of the electric field.

We have seen that the electric field $\vec{\mathbf{E}}$ between two close parallel plates is nearly uniform and its magnitude is related to the potential difference by $V = Ed$ (Eq. 17–4), where d is the separation. Also, Eq. 17–8 tells us $C = \epsilon_0 A/d$ for a parallel-plate capacitor. Thus

$$\text{PE} = \tfrac{1}{2}CV^2 = \frac{1}{2}\left(\frac{\epsilon_0 A}{d}\right)(E^2 d^2)$$
$$= \tfrac{1}{2}\epsilon_0 E^2 Ad.$$

The quantity Ad is the volume between the plates in which the electric field E exists. If we divide both sides of this equation by the volume, we obtain an expression for the energy per unit volume or **energy density**:

$$\text{energy density} = \frac{\text{PE}}{\text{volume}} = \tfrac{1}{2}\epsilon_0 E^2. \qquad \textbf{(17–11)}$$

Energy stored per unit volume in electric field

The *electric energy stored per unit volume in any region of space is proportional to the square of the electric field* in that region. We derived Eq. 17–11 for the special case of a parallel-plate capacitor. But it can be shown to be true for any region of space where there is an electric field. Indeed, we will use this result when we discuss electromagnetic radiation (Chapter 22).

Health Effects

PHYSICS APPLIED

Avoid a shock or burn

Heart defibrillator

The energy stored in a large capacitance can do harm, giving you a burn or a shock. One reason you are warned not to touch a circuit, or the inside of electronic devices, is because capacitors may still be carrying charge even if the external power has been turned off.

On the other hand, the basis of a heart *defibrillator* is a capacitor charged to a high voltage. A heart attack can be characterized by fast irregular beating of the heart, known as *ventricular* (or *cardiac*) *fibrillation*. The heart then does not pump blood to the rest of the body properly, and if it lasts for long, death results. A sudden, brief jolt of charge through the heart from a defibrillator can cause complete heart stoppage, sometimes followed by a resumption of normal beating. The defibrillator capacitor is charged to a voltage typically of a few thousand volts, and is allowed to discharge very rapidly through the heart via a pair of wide contacts known as "paddles" that spread out the current over the chest (Fig. 17–18).

FIGURE 17–18 Heart defibrillator.

* 17–10 Cathode Ray Tube: TV and Computer Monitors, Oscilloscope

An important device that makes use of voltage, and that allows us to "visualize" how a voltage changes in time, is the *cathode ray tube* (CRT). A CRT used in this way is an *oscilloscope*. The CRT has also been used for many years as the picture tube of television sets and computer monitors, although LCD and other screens are becoming popular.

The operation of a CRT depends on the phenomenon of **thermionic emission**, discovered by Thomas Edison (1847–1931). Consider two small plates (electrodes) inside an evacuated "bulb" or "tube" as shown in Fig. 17–19, to which is applied a potential difference. The negative electrode is called the **cathode**, the positive one the **anode**. If the negative cathode is heated (usually by an electric current, as in a lightbulb) so that it becomes hot and glowing, it is found that negative charge leaves the cathode and flows to the positive anode. These negative charges are now called electrons, but originally they were called **cathode rays** since they seemed to come from the cathode (see Section 27–1 on the discovery of the electron).

FIGURE 17–19 If the cathode inside the evacuated glass tube is heated to glowing (by an electric current, not shown), negatively charged "cathode rays" (electrons) are "boiled off" and flow across to the anode (+), to which they are attracted.