17–9 Storage of Electric Energy

A charged capacitor stores electric energy by separating + and − charges. The energy stored in a capacitor will be equal to the work done to charge it. The net effect of charging a capacitor is to remove charge from one plate and add it to the other plate. This is what a battery does when it is connected to a capacitor. Initially, when the capacitor is uncharged, no work is required to move the first bit of charge over. As more charge is transferred, work is needed to move charge against the increasing voltage V. The work needed to add a small amount of charge Δq, when a potential difference V is across the plates, is $\Delta W = V\,\Delta q$. The total work needed to move total charge Q is equivalent to moving all the charge Q across a voltage equal to the *average* voltage during the process. (This is just like calculating the work done to compress a spring, Section 6–4, page 147.) The average voltage is $(V_f - 0)/2 = V_f/2$, where V_f is the final voltage; so the work to move the total charge Q from one plate to the other is

$$W = Q\frac{V_f}{2}.$$

Thus we can say that the electric potential energy, PE, stored in a capacitor is

$$\text{PE} = \text{energy} = \tfrac{1}{2}QV,$$

where V is the potential difference between the plates (we have dropped the subscript), and Q is the charge on each plate. Since $Q = CV$, we can also write

Energy stored in capacitor

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C}. \qquad \textbf{(17–10)}$$

PHYSICS APPLIED

Camera flash

FIGURE 17–17 A camera flash unit.

EXAMPLE 17–11 **Energy stored in a capacitor.** A camera flash unit (Fig. 17–17) stores energy in a 150-μF capacitor at 200 V. How much electric energy can be stored?

APPROACH We use Eq. 17–10 in the form $\text{PE} = \frac{1}{2}CV^2$ because we are given C and V.

SOLUTION The energy stored is

$$\text{PE} = \tfrac{1}{2}CV^2 = \tfrac{1}{2}(150 \times 10^{-6}\,\text{F})(200\,\text{V})^2 = 3.0\,\text{J}.$$

NOTE If this energy could be released in $\frac{1}{1000}$ of a second $(10^{-3}\,\text{s})$, the power output would be equivalent to 3000 W.

EXERCISE E A capacitor stores 0.50 J of energy at 9.0 V. What is its capacitance?

CONCEPTUAL EXAMPLE 17–12 **Capacitor plate separation increased.** A parallel-plate capacitor carries charge Q and is then disconnected from a battery. The two plates are initially separated by a distance d. Suppose the plates are pulled apart until the separation is $2d$. How has the energy stored in this capacitor changed?

RESPONSE If we increase the plate separation d, we decrease the capacitance according to Eq. 17–8, $C = \epsilon_0 A/d$, by a factor of 2. The charge Q hasn't changed. So according to Eq. 17–10, where we choose the form $\text{PE} = \frac{1}{2}Q^2/C$ because we know Q is the same and C has been halved, the reduced C means the PE stored increases by a factor of 2.

NOTE We can see why the energy stored increases from a physical point of view: the two plates are charged equal and opposite, so they attract each other. If we pull them apart, we must do work, so we raise their potential energy.