* 17–11 The Electrocardiogram (ECG or EKG)

Each time the heart beats, changes in electrical potential occur on its surface that can be detected using metal contacts, called "electrodes," which are attached to the skin. The changes in potential are small, on the order of millivolts (mV), and must be amplified. They are displayed with a chart recorder on paper, or on a monitor (CRT), as in Fig. 17–22. An **electrocardiogram** (EKG or ECG) is the record of the potential changes for a given person's heart. An example is shown in Fig. 17–23. The instrument itself is called an electrocardiograph. We are not so interested now in the electronics, but in the source of these potential changes and their relation to heart activity.

PHYSICS APPLIED
Electrocardiogram

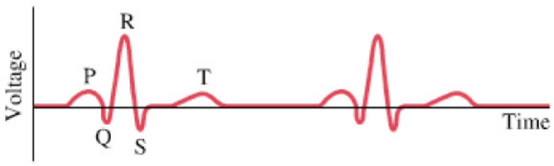

FIGURE 17–23 Typical ECG. Two heart beats are shown.

Both muscle and nerve cells have an electric dipole layer across the cell wall. That is, in the normal situation there is a net positive charge on the exterior surface and a net negative charge on the interior surface, as shown in Fig. 17–24a. The amount of charge depends on the size of the cell, but is approximately $10^{-3}\,\mathrm{C/m^2}$ of surface. For a cell whose surface area is $10^{-5}\,\mathrm{m^2}$, the total charge on either surface is thus $\approx 10^{-8}$ C. Just before the contraction of heart muscles, changes occur in the cell wall, so that positive ions on the exterior of the cell are able to pass through the wall and neutralize those on the inside, or even make the inside surface slightly positive compared to the exterior, as shown in Fig. 17–24b. This "depolarization" starts at one end of the cell and progresses toward the opposite end, as indicated by the arrow, until the whole muscle is depolarized; the muscle then repolarizes to its original state (Fig. 17–24a), all in less than a second. Figure 17–24c shows rough graphs of the potential V as a function of time at the two points P and P′ (on either side of this cell) as the depolarization moves across the cell. The path of depolarization within the heart as a whole is more complicated, and produces the complex potential difference as a function of time of Fig. 17–23.

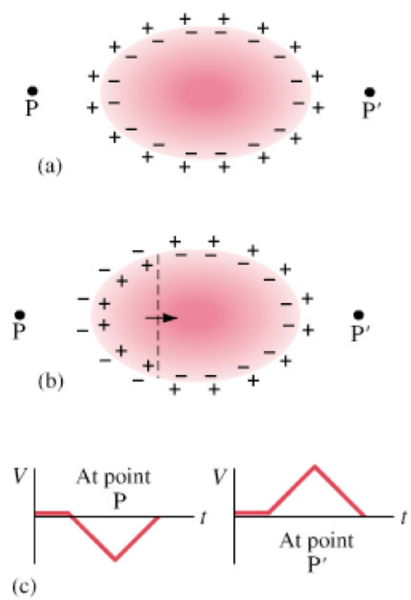

FIGURE 17–24 Heart muscle cell showing (*a*) charge dipole layer in resting state; (*b*) depolarization of cell progressing as muscle begins to contract; and (*c*) potential V at points P and P′ as a function of time.

It is standard procedure to divide a typical electrocardiogram into regions corresponding to the various deflections (or "waves"), as shown in Fig. 17–23. Each of the deflections corresponds to the activity of a particular part of the heart beat (Fig. 10–42). The P wave corresponds to contraction of the atria. The QRS group corresponds to contraction of the ventricles as the depolarization follows a very complicated path. The T wave corresponds to recovery (repolarization) of the heart in preparation for the next cycle.

Electrocardiograms make use of three basic electrodes, one placed on either side of the heart on the hands, and one on the left foot. Sometimes six additional electrodes are placed at other locations. The measurement of so many potential differences provides additional information (some of it redundant), since the heart is a three-dimensional object and depolarization takes place in all three dimensions. A complete electrocardiogram may include as many as 12 graphs.

The ECG is a powerful tool in identifying heart defects. For example, the right side of the heart enlarges if the right ventricle must push against an abnormally large load (as when blood vessels become hardened or clogged). This problem is readily observed on an ECG, since the S wave becomes very large (negatively). *Infarcts*, which are dead regions of the heart muscle that result from heart attacks, are also detected on an ECG because they reflect the depolarization wave.