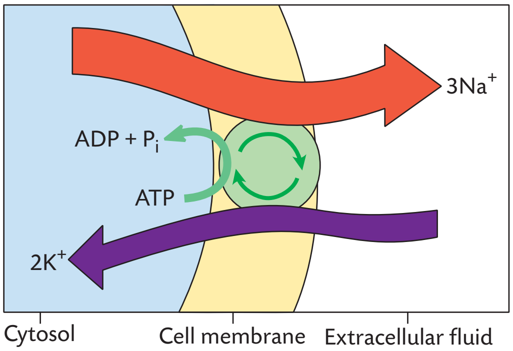

Figure 2.16 The Na$^+$-K$^+$ pump. This membrane carrier protein actively transports Na$^+$ out of the cell, while K$^+$ is simultaneously transported in. Hydrolysis of ATP provides the ion pump with the energy required for the active transport of the ions.

Cytosolic ion concentrations do not change significantly during bioelectrical events, except for Ca^{2+}

tive to the number of ions already present in the cytosol, the concentration gradients of the various ions across the cell membrane do not change significantly during such bioelectrical events. Ca^{2+} is an exception to this general rule, due to its exceedingly low cytosolic concentration (p. 75).

Ion Pumps in the Cell Membrane

Ion pumps maintain the ion concentration gradients across the cell membrane

Because the concentrations of most ions in the cytosol remain fairly constant, the cell must have mechanisms that are able to compensate for the continuous leakage of ions. For example, the low concentration of Na$^+$ in the cytosol is maintained by a specific carrier protein in the membrane that pumps Na$^+$ out of the cell (p. 64). In addition to moving Na$^+$ to a region of higher Na$^+$ concentration, the pump must also work against electrical forces. Consequently, a considerable amount of energy is needed to pump Na$^+$ out of a cell. The pump obtains the necessary energy by hydrolyzing ATP (Fig. 2.16). This ion pump consumes between 10 and 40 % of the available ATP in various cell types, and the outward pumping of Na$^+$ is the single most energy-requiring process in the body. Cells are able to maintain a high concentration of K$^+$ in the cytosol because, as Na$^+$ is being pumped out, the same pump simultaneously transports K$^+$ into the cell. Therefore, the pump is called the sodium-potassium pump (Na$^+$-K$^+$ pump or Na$^+$-K$^+$ ATPase). Due to the inside of the cell membrane being negative, the pumping of K$^+$ into the cell requires little energy input.

Outward pumping of Na$^+$ is the most energy requiring process in the body

The combined flux of Na$^+$ into the cells, via both ion channels and carrier proteins (p. 64), is larger than the efflux rate of K$^+$. However, the transmembrane gradients for these ions are still maintained, because correspondingly more Na$^+$ is pumped out by the Na$^+$-K$^+$ pump than K$^+$ is pumped in (pump ratio is 3:2). This net outward pumping of positive charge leaves a net deficit of positive ions on the inside of the membrane. Nevertheless, the Na$^+$-K$^+$ pump contributes only a few millivolts directly to the membrane potential in most cells. The main function of the Na$^+$-K$^+$ pump is to create differences in ion concentrations, which, in turn, generate the membrane potential by means of diffusion. In order to understand this point, it is useful to imagine a hypothetical cell in which the concentrations of the ions are the same on either side of the membrane, and the membrane potential is 0 mV. After the Na$^+$-K$^+$ pump in such a cell has been operating for a short while, opposite concentration gradients between the inside and the outside of the cell would be achieved for Na$^+$ and K$^+$. Therefore, both these ions would begin to diffuse across the membrane, in opposite directions. Because the membrane is more permeable to K$^+$ than to Na$^+$, the rate of outward K$^+$ diffusion would be greater than the rate of inward diffusion of Na$^+$. Thus, a deficit of positive ions would be gradually generated on the inside of the membrane, while a growing excess would be generated on the outside, as already described. This difference in charge would rise over time as the pump increased the concentration differences between the inside and outside of the cell.

Various Ca^{2+} pumps maintain the cytosolic Ca^{2+} concentration at about 1/10 000 of the extracellular concentration

There are relatively few ion channels in a cell membrane. Even if the Na$^+$-K$^+$ pumps in the membrane were blocked, several hours would elapse before the concentration differences between the two sides of the membrane would be eliminated. Cell membranes also contain other types of ion pumps, for instance an ATP-requiring pump that transports Ca^{2+} out of the cell. In addition, cell membranes contain a Ca^{2+} pump that is coupled to Na$^+$ and transports Ca^{2+} out of the cell. This pump does not derive its energy by cleavage of ATP, but instead, the necessary energy is obtained when Na$^+$ is carried along its electrochemical gradient into the cell. This is an example of an antiporter type of secondary active transport (p. 64). The membrane of the smooth endoplasmic reticulum contains a Ca^{2+} ATPase that pumps Ca^{2+} into the organelle. Together, the various Ca^{2+} pumps maintain a cytosolic Ca^{2+} concentration that is only about 1/10 000 of that outside the cell (Fig. 2.14). This is important for the function of Ca^{2+} as an intracellular signal (p. 88).

Many ions other than Ca^{2+}, and also larger molecules, are transported across the membrane