What causes the action potential to travel along the axon? The action potential occurs at the point of stimulation, as shown in Fig. 18–31a. The membrane momentarily is positive on the inside and negative on the outside at this point. Nearby charges are attracted toward this region, as shown in Fig. 18–31b. The potential in these adjacent regions then drops, causing an action potential there. Thus, as the membrane returns to normal at the original point, nearby it experiences an action potential, so the action potential moves down the axon (Figs. 18–31c and d).

You may wonder if the number of ions that pass through the membrane would significantly alter the concentrations. The answer is no; and we can show why (and again show the power and usefulness of physics) by treating the axon as a capacitor as we do in Search and Learn Problem 8 (the concentration changes by less than 1 part in 10^4).

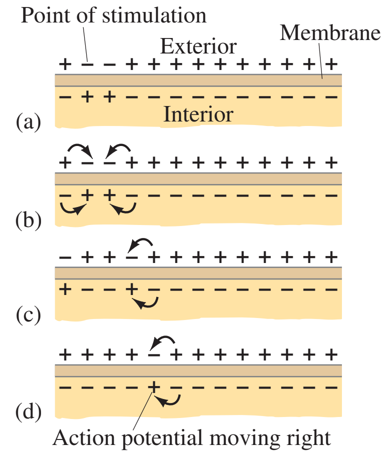

FIGURE 18–31 Propagation of action potential along axon membrane.

Summary

An electric **battery** serves as a source of nearly constant potential difference by transforming chemical energy into electric energy. A simple battery consists of two electrodes made of different metals immersed in a solution or paste known as an electrolyte.

Electric current, I, refers to the rate of flow of electric charge and is measured in **amperes** (A): 1 A equals a flow of 1 C/s past a given point.

The direction of **conventional current** is that of positive charge flow. In a wire, it is actually negatively charged electrons that move, so they flow in a direction opposite to the conventional current. A positive charge flow in one direction is almost always equivalent to a negative charge flow in the opposite direction. Positive conventional current always flows from a high potential to a low potential.

The **resistance** R of a device is defined by the relation

$$V = IR, \tag{18–2}$$

where I is the current in the device when a potential difference V is applied across it. For materials such as metals, R is a constant independent of V (thus $I \propto V$), a result known as **Ohm's law**. Thus, the current I coming from a battery of voltage V depends on the resistance R of the circuit connected to it.

Voltage is applied *across* a device or between the ends of a wire. Current passes *through* a wire or device. Resistance is a property *of* the wire or device.

The unit of resistance is the **ohm** (Ω), where $1\ \Omega = 1\ \text{V/A}$. See Table 18–3.

TABLE 18–3 Summary of Units

Current	$1\ \text{A} = 1\ \text{C/s}$
Potential difference	$1\ \text{V} = 1\ \text{J/C}$
Power	$1\ \text{W} = 1\ \text{J/s}$
Resistance	$1\ \Omega = 1\ \text{V/A}$

The resistance R of a wire is inversely proportional to its cross-sectional area A, and directly proportional to its length ℓ and to a property of the material called its resistivity:

$$R = \frac{\rho\ell}{A}. \tag{18–3}$$

The **resistivity**, ρ, increases with temperature for metals, but for semiconductors it may decrease.

The rate at which energy is transformed in a resistance R from electric to other forms of energy (such as heat and light) is equal to the product of current and voltage. That is, the **power** transformed, measured in watts, is given by

$$P = IV, \tag{18–5}$$

which for resistors can be written as

$$P = I^2R = \frac{V^2}{R}. \tag{18–6}$$

The SI unit of power is the **watt** $(1\ \text{W} = 1\ \text{J/s})$.

The total electric energy transformed in any device equals the product of the power and the time during which the device is operated. In SI units, energy is given in joules $(1\ \text{J} = 1\ \text{W}\cdot\text{s})$, but electric companies use a larger unit, the **kilowatt-hour** $(1\ \text{kWh} = 3.6 \times 10^6\ \text{J})$.

Electric current can be **direct current** (**dc**), in which the current is steady in one direction; or it can be **alternating current** (**ac**), in which the current reverses direction at a particular frequency f, typically 60 Hz. Alternating currents are typically sinusoidal in time,

$$I = I_0 \sin \omega t, \tag{18–7b}$$

where $\omega = 2\pi f$, and are produced by an alternating voltage.

The **rms** values of sinusoidally alternating currents and voltages are given by

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} \quad \text{and} \quad V_{\text{rms}} = \frac{V_0}{\sqrt{2}}, \tag{18–8}$$

respectively, where I_0 and V_0 are the **peak** values. The power relationship, $P = IV = I^2R = V^2/R$, is valid for the average power in alternating currents when the rms values of V and I are used.

[*The current in a wire, at the microscopic level, is considered to be a slow **drift velocity** of electrons, $\vec{\mathbf{v}}_{\text{d}}$. The current I is given by

$$I = neAv_{\text{d}}, \tag{18–10}$$

where n is the number of free electrons per unit volume, e is the magnitude of the charge on an electron, and A is the cross-sectional area of the wire.]

[*At very low temperatures certain materials become **superconducting**, which means their electrical resistance becomes zero.]

[*The human nervous system operates via electrical conduction: when a nerve "fires," an electrical signal travels as a voltage pulse known as an **action potential**.]