Solution

Entering the given values for B, v, and l gives

$$\begin{aligned}\varepsilon &= Blv = (0.100\ \text{T})\left(4.00\times 10^{-3}\ \text{m}\right)(0.200\ \text{m/s}) \\ &= 80.0\ \mu\text{V}\end{aligned} \tag{22.14}$$

Discussion

This is the average voltage output. Instantaneous voltage varies with pulsating blood flow. The voltage is small in this type of measurement. ε is particularly difficult to measure, because there are voltages associated with heart action (ECG voltages) that are on the order of millivolts. In practice, this difficulty is overcome by applying an AC magnetic field, so that the Hall emf is AC with the same frequency. An amplifier can be very selective in picking out only the appropriate frequency, eliminating signals and noise at other frequencies.

22.7 Magnetic Force on a Current-Carrying Conductor

Because charges ordinarily cannot escape a conductor, the magnetic force on charges moving in a conductor is transmitted to the conductor itself.

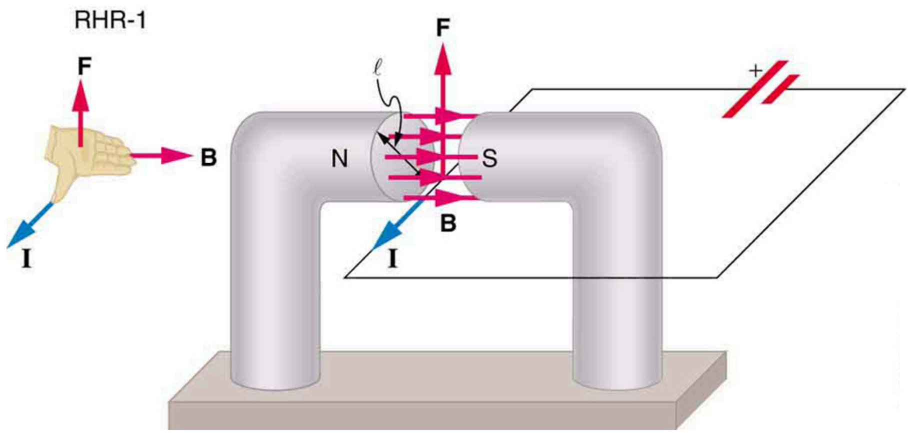

Figure 22.30 The magnetic field exerts a force on a current-carrying wire in a direction given by the right hand rule 1 (the same direction as that on the individual moving charges). This force can easily be large enough to move the wire, since typical currents consist of very large numbers of moving charges.

We can derive an expression for the magnetic force on a current by taking a sum of the magnetic forces on individual charges. (The forces add because they are in the same direction.) The force on an individual charge moving at the drift velocity v_d is given by $F = qv_\text{d}B\ \sin\ \theta$. Taking B to be uniform over a length of wire l and zero elsewhere, the total magnetic force on the wire is then $F = (qv_\text{d}B\ \sin\ \theta)(N)$, where N is the number of charge carriers in the section of wire of length l. Now, $N = nV$, where n is the number of charge carriers per unit volume and V is the volume of wire in the field. Noting that $V = Al$, where A is the cross-sectional area of the wire, then the force on the wire is $F = (qv_\text{d}B\ \sin\ \theta)(nAl)$. Gathering terms,

$$F = (nqAv_\text{d})lB\ \sin\ \theta. \tag{22.15}$$

Because $nqAv_\text{d} = I$ (see Current),

$$F = IlB\ \sin\ \theta \tag{22.16}$$

is the equation for *magnetic force on a length l of wire carrying a current I in a uniform magnetic field B*, as shown in Figure 22.31. If we divide both sides of this expression by l, we find that the magnetic force per unit length of wire in a uniform field is $\frac{F}{l} = IB\ \sin\ \theta$. The direction of this force is given by RHR-1, with the thumb in the direction of the current I. Then, with the fingers in the direction of B, a perpendicular to the palm points in the direction of F, as in Figure 22.31.

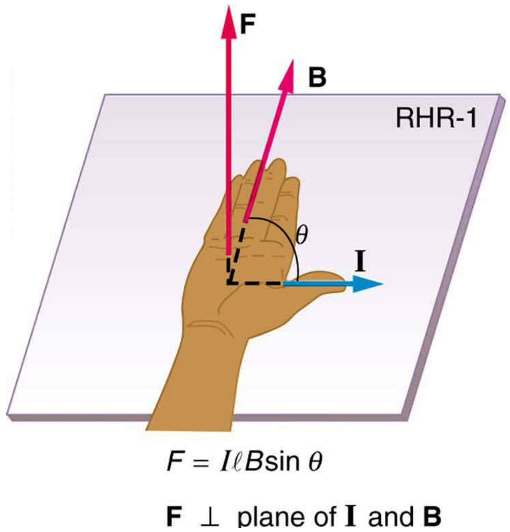

Figure 22.31 The force on a current-carrying wire in a magnetic field is $F = IlB \sin \theta$. Its direction is given by RHR-1.

EXAMPLE 22.4

Calculating Magnetic Force on a Current-Carrying Wire: A Strong Magnetic Field

Calculate the force on the wire shown in Figure 22.30, given $B = 1.50 \text{ T}$, $l = 5.00 \text{ cm}$, and $I = 20.0 \text{ A}$.

Strategy

The force can be found with the given information by using $F = IlB \sin \theta$ and noting that the angle θ between I and B is 90°, so that $\sin \theta = 1$.

Solution

Entering the given values into $F = IlB \sin \theta$ yields

$$F = IlB \sin \theta = (20.0 \text{ A}) (0.0500 \text{ m}) (1.50 \text{ T}) (1). \quad (22.17)$$

The units for tesla are $1 \text{ T} = \frac{\text{N}}{\text{A} \cdot \text{m}}$; thus,

$$F = 1.50 \text{ N}. \quad (22.18)$$

Discussion

This large magnetic field creates a significant force on a small length of wire.

Magnetic force on current-carrying conductors is used to convert electric energy to work. (Motors are a prime example—they employ loops of wire and are considered in the next section.) Magnetohydrodynamics (MHD) is the technical name given to a clever application where magnetic force pumps fluids without moving mechanical parts. (See Figure 22.32.)

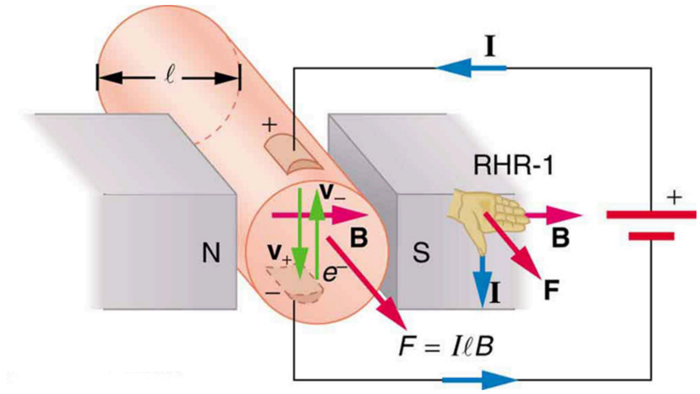

Figure 22.32 Magnetohydrodynamics. The magnetic force on the current passed through this fluid can be used as a nonmechanical pump.

A strong magnetic field is applied across a tube and a current is passed through the fluid at right angles to the field, resulting in a force on the fluid parallel to the tube axis as shown. The absence of moving parts makes this attractive for moving a hot, chemically active substance, such as the liquid sodium employed in some nuclear reactors. Experimental artificial hearts are testing with this technique for pumping blood, perhaps circumventing the adverse effects of mechanical pumps. (Cell membranes, however, are affected by the large fields needed in MHD, delaying its practical application in humans.) MHD propulsion for nuclear submarines has been proposed, because it could be considerably quieter than conventional propeller drives. The deterrent value of nuclear submarines is based on their ability to hide and survive a first or second nuclear strike. As we slowly disassemble our nuclear weapons arsenals, the submarine branch will be the last to be decommissioned because of this ability (See Figure 22.33.) Existing MHD drives are heavy and inefficient—much development work is needed.

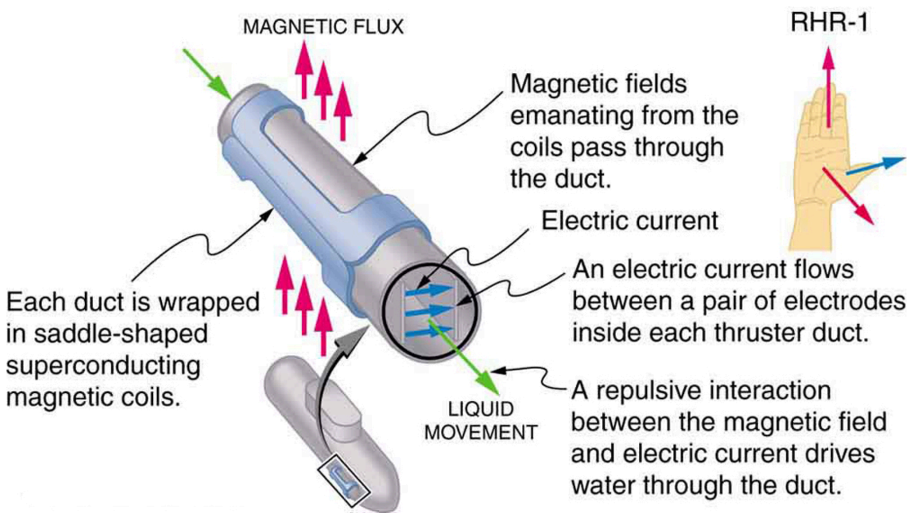

Figure 22.33 An MHD propulsion system in a nuclear submarine could produce significantly less turbulence than propellers and allow it to run more silently. The development of a silent drive submarine was dramatized in the book and the film *The Hunt for Red October*.

22.8 Torque on a Current Loop: Motors and Meters

Motors are the most common application of magnetic force on current-carrying wires. Motors have loops of wire in a magnetic field. When current is passed through the loops, the magnetic field exerts torque on the loops, which rotates a shaft. Electrical energy is converted to mechanical work in the process. (See Figure 22.34.)