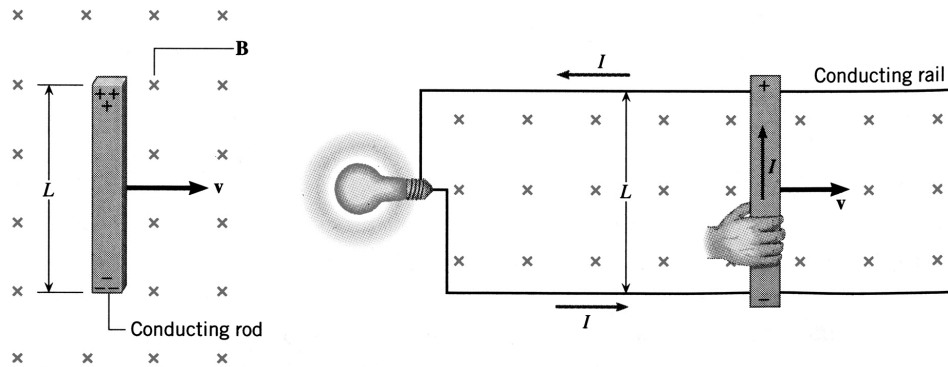


## Motional EMF

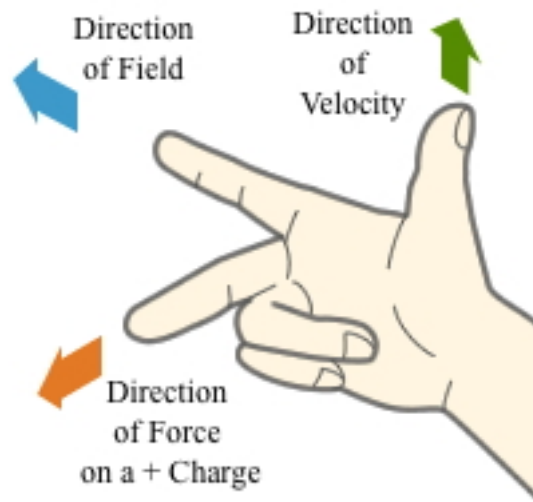
When a conducting rod moves through a constant magnetic field, a voltage is induced in the rod. This special case of electromagnetic induction arises as a result of the magnetic force that acts on a moving charge. Consider the metal rod of length  $L$  moving to the right in the diagram below.



The velocity  $v$  of the rod is constant and is perpendicular to a uniform magnetic field  $B$ . Each charge  $q$  within the rod also moves with a velocity  $v$  and experiences a force of magnitude

$$F = qvB$$

By using the right hand rule (see below), it can be seen that the electrons in the rod are driven to the bottom. This causes the top of the rod to become positively charged while the bottom becomes negatively charged.



The separated charges on the ends of the moving conductor give rise to an induced voltage, called a **motional emf**. This voltage exists as long as the rod moves. The magnitude of the voltage induced in the rod is given by

$$V = vBL$$

**Example 1**

Suppose the rod in the diagram above is moving at a speed of 5.0 m/s in a direction perpendicular to a 0.80 T magnetic field. The rod has a length of 1.6 m and a negligible electrical resistance. The light bulb, however, has a resistance of  $96 \Omega$ . Find (a) the emf produced by the rod, (b) the induced current in the circuit, (c) the electrical power delivered to the bulb, and (d) the energy used by the bulb in 60 s.

## Motional EMF and Electrical Energy

Motional emf arises because a magnetic force acts on the charges in a conductor that is moving through a magnetic field. When this voltage induces a current, a second magnetic force enters the picture. Since the current  $I$  is perpendicular to the magnetic field, it will experience a force  $F$  whose magnitude is given by

$$F = BIL$$

The direction of  $F$  is opposite to the velocity  $v$  of the rod. By itself, this force would slow down the rod. Thus, to keep the rod moving to the right with a constant velocity, a balancing force must be applied by an external agent (such as the hand in the first diagram). The balancing force must have a magnitude given by  $F = BIL$  and be directed opposite to the magnetic force  $F$ .

We can now answer an important question. Where does the 26 J of electrical energy used by the light bulb in Example 1 come from? The provider is the external agent that applies the balancing force. This agent does work, as shown in Example 2, and the work done is equal to the electrical energy used by the bulb.

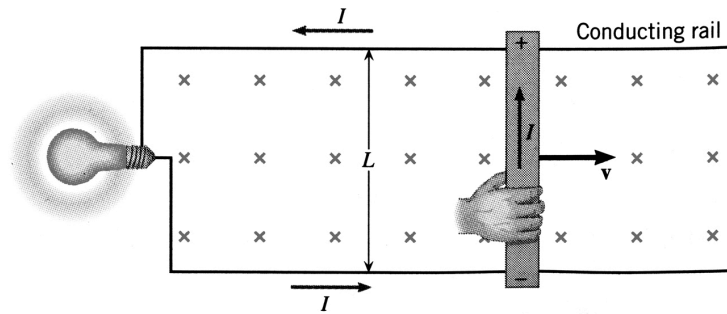
### Example 2

In Example 1, an external agent (the hand) supplies a 0.086 N force that keeps the rod moving at a constant speed of 5.0 m/s. Determine the work done in 60 s by the external agent.

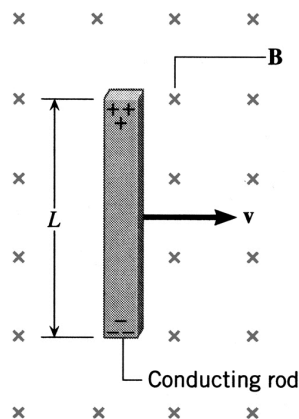


## Motional EMF

1. A spark can jump between two non-touching conductors if the potential difference between them is sufficiently large. A potential difference of approximately  $940\text{ V}$  is required to produce a spark in an air gap of  $1.0 \times 10^{-4}\text{ m}$ . Suppose the light bulb in the diagram below is replaced by such a gap. How fast would a  $1.3\text{ m}$  rod have to be moving in a magnetic field of  $4.8\text{ T}$  to cause a spark to jump across the gap? ( $150.6\text{ m/s}$ )



2. The wingspan of a Boeing 747 jetliner is  $59\text{ m}$ . The plane is flying horizontally at a speed of  $220\text{ m/s}$ . The vertical component of the earth's magnetic field is  $5.0 \times 10^{-6}\text{ T}$ . Find the emf induced between the wing tips. ( $0.0649\text{ V}$ )
3. Near San Francisco, where the vertically downward component of the earth's magnetic field is  $4.8 \times 10^{-5}\text{ T}$ , a car is traveling forward at  $25\text{ m/s}$ . An emf of  $2.4 \times 10^{-3}\text{ V}$  is induced between the sides of the car.
  - a) Which side of the car is positive, the driver's side or the passenger's side?
  - b) What is the width of the car? ( $2.0\text{ m}$ )
4. Two metal bars have the same length. Each is pushed through a magnetic field as in the diagram below. The emf generated between the ends of each bar is the same. Bar 1 moves through a field of  $0.13\text{ T}$  at a speed of  $5.8\text{ m/s}$ . Bar 2 moves through a field of  $0.33\text{ T}$ . What is the speed of Bar 2? ( $2.28\text{ m/s}$ )



5. A metal rod (length =  $0.75\text{ m}$ ) moves perpendicular to a magnetic field of  $0.15\text{ T}$ . An emf of  $0.24\text{ V}$  exists between the ends of the rod. How far does the rod move in  $7.0\text{ s}$ ? ( $14.9\text{ m}$ )
6. Suppose the light bulb in the diagram from question 1 is replaced by a  $6\ \Omega$  electric heater that consumes  $15\text{ W}$  of power. The conducting bar moves to the right at a constant speed, the field strength is  $2.4\text{ T}$ , and the length of the bar between the rails is  $1.2\text{ m}$ .
  - a) How fast is the bar moving? ( $3.29\text{ m/s}$ )
  - b) What force must be applied to the bar to keep it moving to the right at the constant speed found in (a)? ( $4.56\text{ N}$ )