Electromagnetic Induction

In 1819, Hans Christian Oersted discovered that a magnetic compass experiences a force in the vicinity of an electric current – that is, that electric currents produce magnetic fields.

Because nature is often symmetric, this led many scientists to believe that magnetic fields could also produce electric currents, a concept known as electromagnetic induction.

Why does moving a wire through a magnetic field induce a current in the wire?

Free electrons in the wire are charged particles moving through a magnetic field so there is a $qvB$ force on them causing them to move and resulting in a current.

Derivation of formula for EMF induced in a moving wire

A straight conductor is moved at constant velocity perpendicular to a uniform magnetic field.

1. Electrons in the moving conductor experience a downward magnetic force and migrate to the lower end of the conductor, leaving a net positive charge at the upper end.

2. As a result of this charge separation, an electric field is built up in the conductor.

3. Charge builds up until the downward magnetic force is balanced by the upward electric force due to the electric field. At this point, the charges stop flowing and are in equilibrium.

4. Because of this charge separation, a potential difference is set up across the conductor.

$$F_e = qvB \sin \theta$$  \((LHR \ for \ electrons)\)

$$E \quad F_e = qE$$

$$F_e = \overrightarrow{F}_e$$

$$qvB = qE$$

$$vB = E$$

$$\Delta V = E d = E l$$

$$\Delta V = vB l$$

$$E = BLv \quad E = \text{emf}$$

If the conductor is connected to a complete circuit, the induced emf will produce an induced current.

… is equivalent to …

<table>
<thead>
<tr>
<th>Amount of Current</th>
<th>Direction of Current</th>
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<tbody>
<tr>
<td>The amount of induced current in the circuit is given by</td>
<td>The direction of the induced emf and induced current can be found from the right hand rule for forces to find the force on a positive charge in the conductor.</td>
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<tr>
<td>$E = BLv$</td>
<td>$E = I R$</td>
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<tr>
<td>$I = \frac{BLv}{R}$</td>
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</table>
Two Opposing Forces

The magnetic force acts to oppose the applied force, like drag or friction.

At a constant speed,

$$F_{\text{app}} = F_B = I L B$$

The induced current now generates a magnetic field around the moving bar that causes a magnetic force ($F_B$) on itself.

Suppose a rod is moving at a constant speed of 5.0 m/s in a direction perpendicular to a 0.80-T magnetic field as shown. The rod has a length of 1.6 m and negligible electrical resistance. The rails also have negligible resistance. The light bulb, however, has a resistance of 96 Ω. Find:

a) the emf produced by the motion of the rod

$$E = BLV = (0.80 \text{T})(1.6 \text{ m})(5.0 \text{ m/s}) = 6.4 \text{ V}$$

b) the magnitude and direction of the induced current in the circuit

$$I = \frac{E}{R} = \frac{6.4 \text{ V}}{96 \Omega} = 0.067 \text{ A}$$

c) the electrical power delivered to the bulb

$$P = EI = I^2 R = 0.43 \text{ W}$$

d) the energy used by the bulb in 60.0 s.

$$P = \frac{E}{t}$$

$$E = P \times t = (0.43 \text{ W}) \times 60 \text{ s} = 26 \text{ J}$$

e) How much external force is applied to keep the rod moving at this constant speed?

$$F_{\text{app}} = F_B = I L B$$

$$= (0.067 \text{ A})(1.6 \text{ m})(0.80 \text{ T}) =$$

f) How much work is done by the applied force in 60.0 seconds?

$$W = F \cdot \Delta s = 0.086 \text{ N}$$

or $$W = \text{energy used by light bulb converted to electric energy which is then converted to EM radiation and heat}$$

... (remaining text is not fully transcribed)