Applied Physics for Engineers

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Faraday’s experiments, Faraday’s law of induction, Lenz’s Law
Induced emf

Introduction

- Experiments conducted in 1831 showed that an emf can be induced in a circuit by a changing magnetic field.
- Experiments were done by Michael Faraday and Joseph Henry.
- The results of these experiments led to *Faraday's Law of Induction.*
- An *induced current* is produced by a changing magnetic field.
- There is an *induced emf* associated with the induced current.
- A current can be produced without a battery present in the circuit.
- Faraday's law of induction describes the induced emf.

EMF Produced by a Changing Magnetic Field

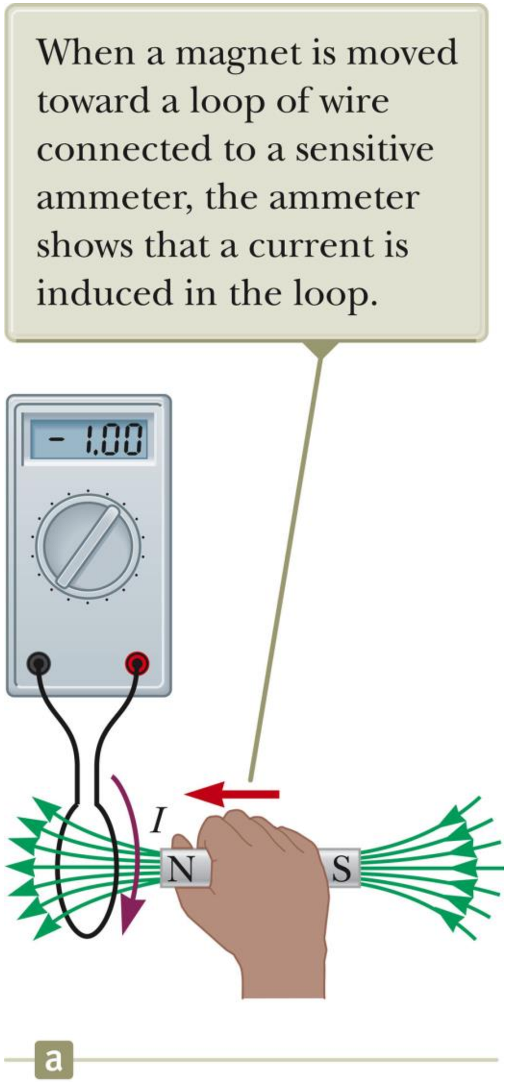
Faraday's first experiment

A loop of wire is connected to a sensitive ammeter.

1. A current appears only if there is relative motion between the loop and the magnet (one must move relative to the other); the current disappears when the relative motion between them ceases.

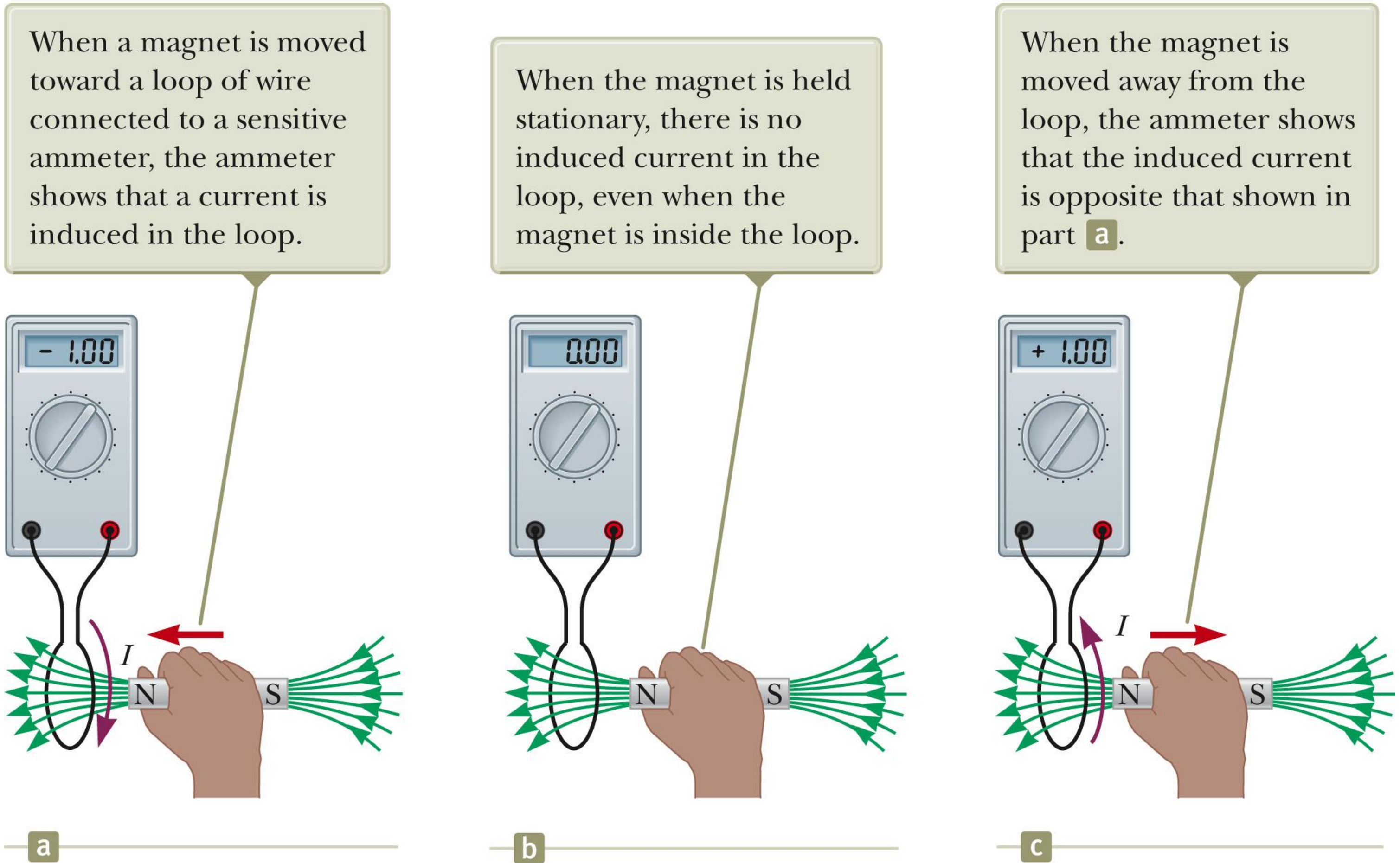
2. Faster motion produces a greater current.

3. If moving the magnet's north pole toward the loop causes, say, clockwise current, then moving the north pole away causes counterclockwise current. Moving the south pole toward or away from the loop also causes currents, but in the reversed directions.



- The current produced in the loop is called an **induced current**
- The work done per unit charge to produce that current (to move the conduction electrons that constitute the current) is called an **induced emf**
- The process of producing the current and emf is called **induction**.

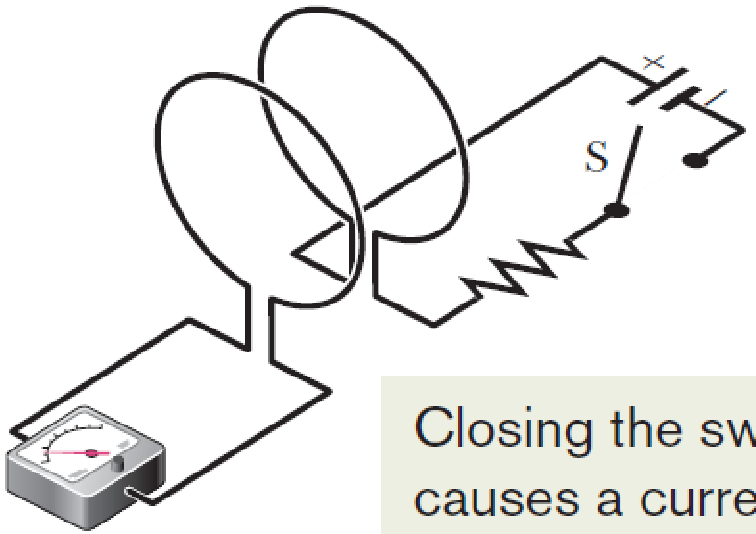
Summery of first experiment



EMF Produced by a Changing Current

Faraday's second experiment

- Two conducting loops were used that were placed near each other
- One loop was attached to the battery and the other with just a sensitive ammeter we will call it primary loop
- If switch S is closed, to turn on a current in the right-hand loop, the meter suddenly and briefly registers a current—an induced current—in the secondary loop.
- If the switch is opened, another sudden and brief induced current appears in the secondary loop, but in the opposite direction. We get an induced current (and thus an induced emf) only when the current in the primary loop is changing (either turning on or turning off) and not when it is constant (even if it is large).



Closing the switch causes a current in the left-hand loop.

Faraday's Experiment – Conclusions

An electric current can be induced in a loop by a changing magnetic field.

- This would be the current in the secondary circuit of this experimental set-up.

The induced current exists only while the magnetic field through the loop is changing.

This is generally expressed as: ***an induced emf is produced in the loop by the changing magnetic field.***

- The actual existence of the magnetic flux is not sufficient to produce the induced emf, the flux must be changing.
- The actual number of field lines passing through the loop does not matter; the values of the induced emf and induced current are determined by the *rate* at which that number changes.

Faraday's Law

"The magnitude of the emf ε induced in a conducting loop is equal to the rate at which the magnetic flux Φ_B through that loop changes with time"

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

Magnetic flux: Suppose a loop enclosing an area A is placed in a magnetic field .Then the magnetic flux through the loop is

$$\Phi_B = \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$

Unit. The SI unit for magnetic flux is the tesla–square meter, which is called the *weber* (abbreviated Wb):

$$1 \text{ weber} = 1 \text{ Wb} = 1 \text{ T. m}^2$$

- If we change the magnetic flux through a coil of N turns, an induced emf appears in every turn and the total emf induced in the coil is the sum of these individual induced emfs.
- If the coil is tightly wound (closely packed), so that the same magnetic flux Φ_B passes through all the turns, the total emf induced in the coil is

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$

- Magnetic field can be changed within the coil by using various methods

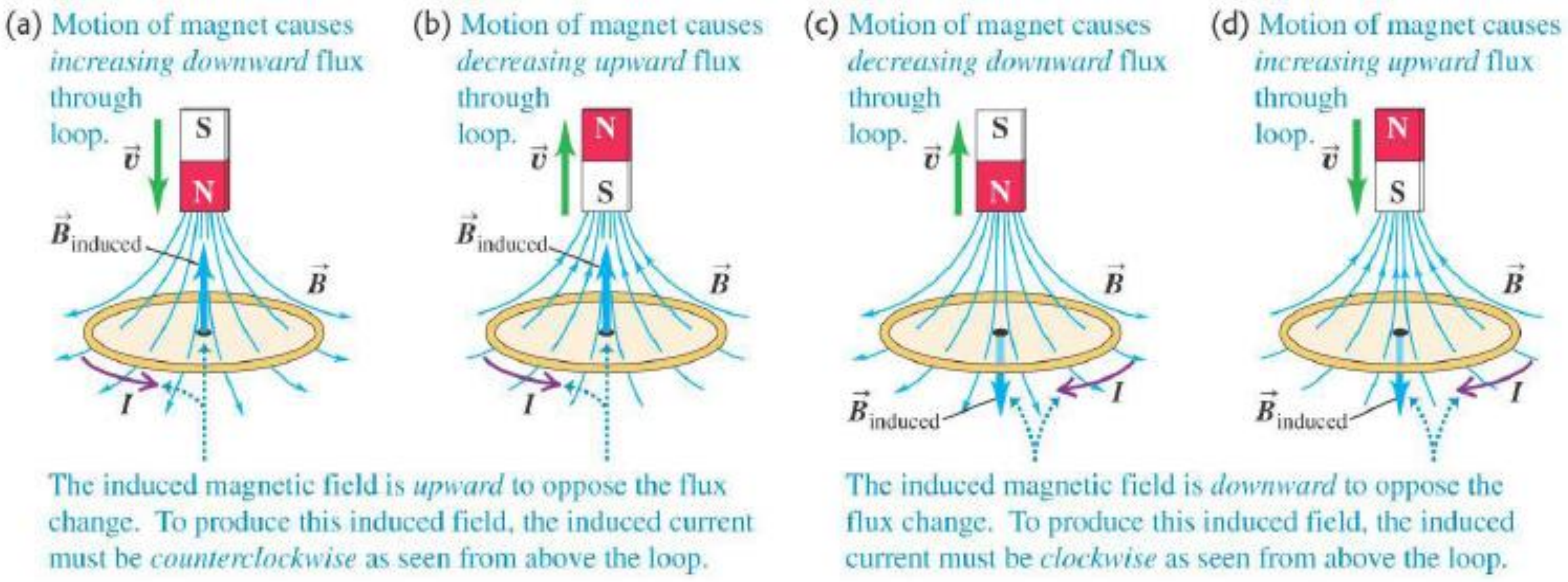
1. Change the magnitude B of the magnetic field within the coil.

2. Change either the total area of the coil or the portion of that area that lies within the magnetic field (for example, by expanding the coil or sliding it into or out of the field).

3. Change the angle between the direction of the magnetic field **B** and the plane of the coil (for example, by rotating the coil so that field **B** is first perpendicular to the plane of the coil and then is along that plane).

Lenz'z Law

"An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current."

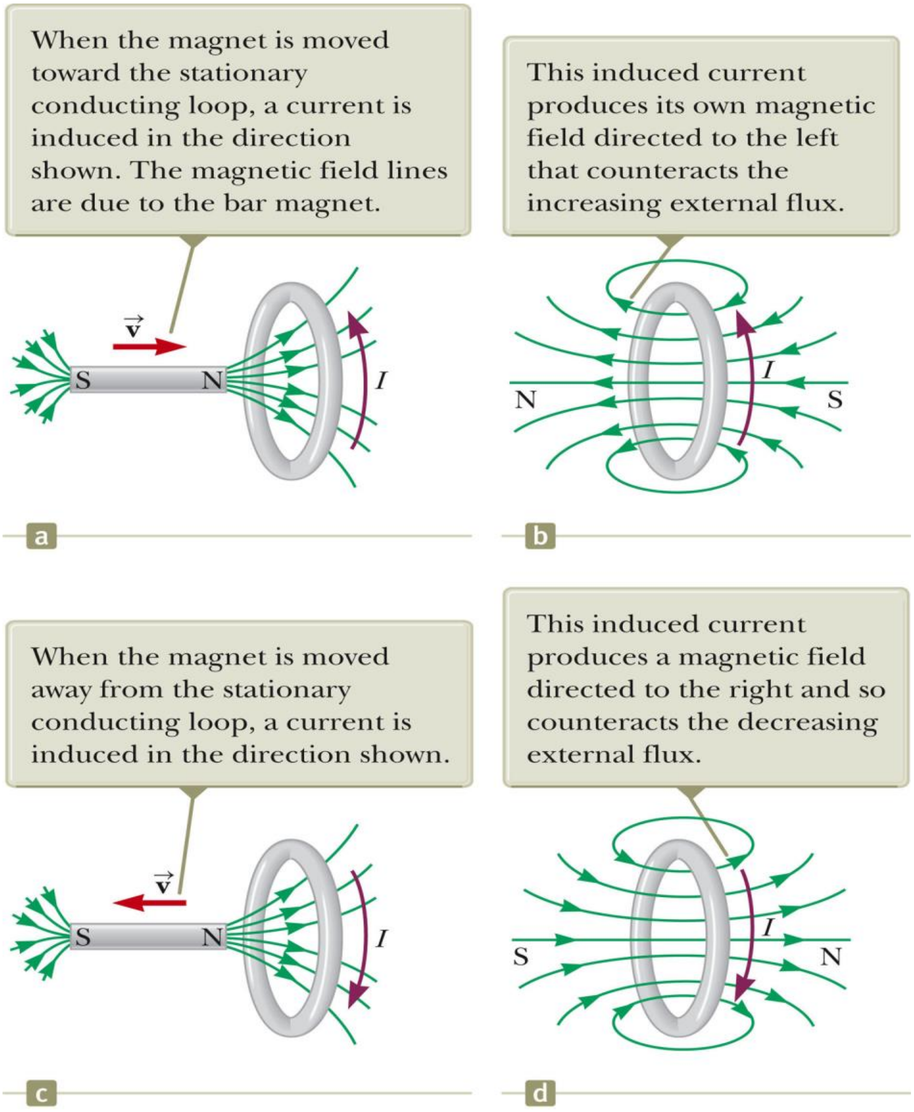


Induced Current Directions – Example

A magnet is placed near a metal loop.

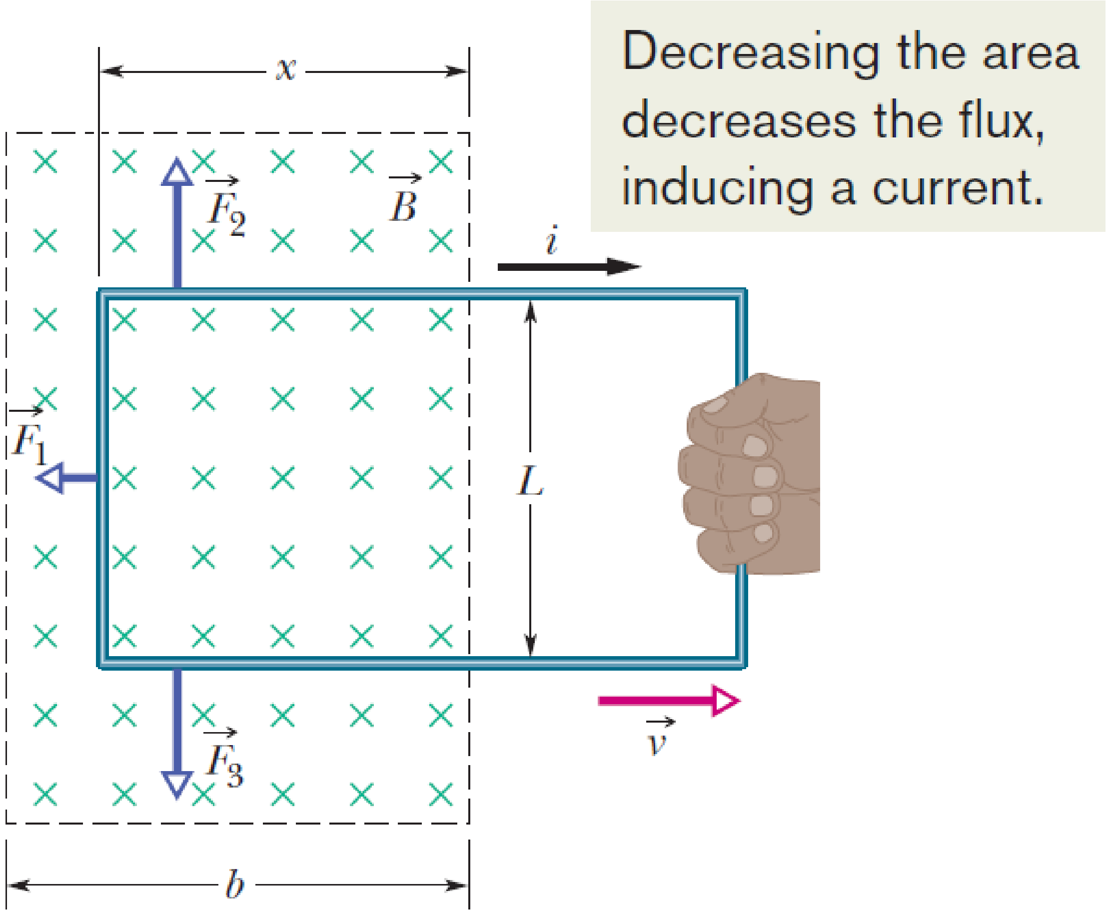
a) Find the direction of the induced current in the loop when the magnet is pushed toward the loop (a and b).

b) Find the direction of the induced current in the loop when the magnet is pulled away from the loop (c and d).



Induced emf and Current

- A rectangular loop of wire of width L has one end in a uniform external magnetic field that is directed perpendicularly into the plane of the loop.
- We are to pull this loop to the right at a constant velocity v.
- This situation is not much different from the one where we move a magnet near a closed loop In each case a magnetic field and a conducting loop are in relative motion; in each case the flux of the field through the loop is changing with time.



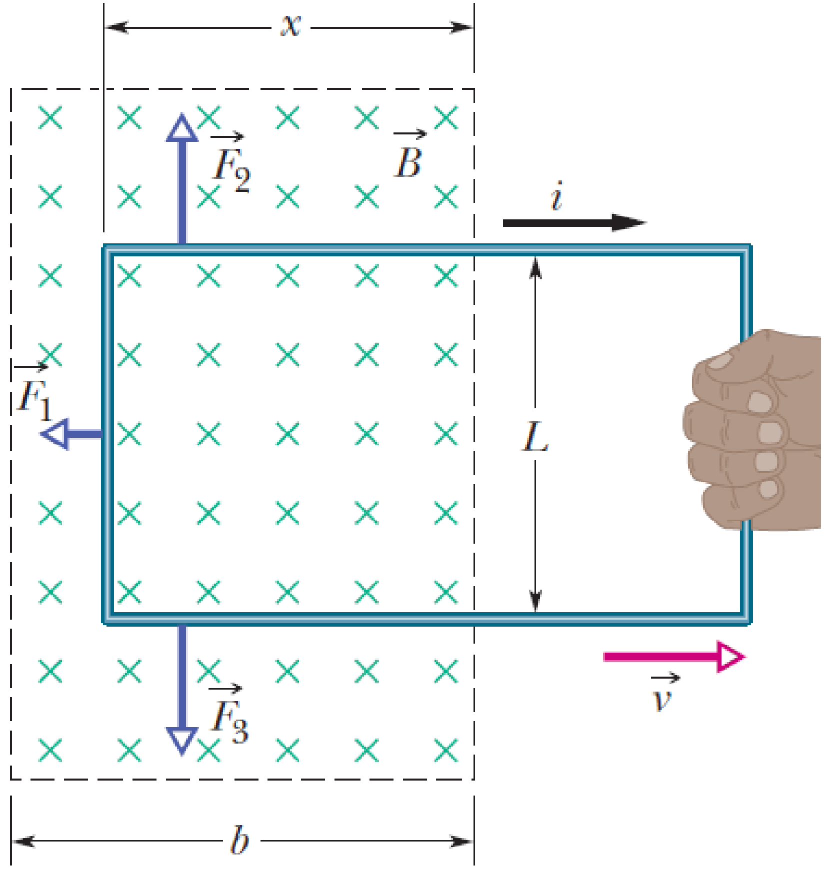
- When x is the length of the loop still in the magnetic field, the area of the loop still in the field is Lx. Then the magnitude of the flux through the loop is

$$\Phi_B = BA = BLx.$$

- As x decreases, the flux decreases. Faraday's law tells us that with this flux decrease, an emf is induced in the loop. We can write the magnitude of this emf as

$$\mathscr{E} = \frac{d\Phi_B}{dt} = \frac{d}{dt} BLx = BL\frac{dx}{dt} = BLv,$$

- In which replaced *dx*/*dt* is replaced with *v*, the speed at which the loop moves.



- To find the magnitude of the **induced current**, we can apply the equation.

$$i = \mathscr{E}/R$$

$$i = \frac{BLv}{R}$$

- Because three segments of the loop carry this current through the magnetic field sideways deflecting forces act on those segments. we know that such a deflecting force is, in general notation,

$$\vec{F}_d = i\vec{L} \times \vec{B}$$

- The deflecting forces acting on the three segments of the loop are marked $\mathbf{F_1}$, **F** and $\mathbf{F_3}$. Note, however, that from the symmetry, forces $\mathbf{F_2}$ and $\mathbf{F_3}$ are equal in magnitude and cancel. This leaves only $\mathbf{F_1}$ force , which is directed opposite you force **F** on the loop and thus is the force opposing you.

- To obtain the magnitude of $\mathbf{F_1}$ and noting that the angle between **B** and the length vector **L** for the left segment is 90^o , we write

$$F = F_1 = iLB \sin 90^\circ = iLB.$$

Putting value for i we get

$$F = \frac{B^2L^2v}{R}.$$