
بسم الله الرحمن الرحيم

Applied Physics

Course Code - PHY 124

Class: BCS-B Semester: 1st-FA23

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Lecture: 1st

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Course Contents (Theory):

Electric force and its applications and related problems, conservation of charge, charge quantization, electric fields due to point charge and lines of force, ring of charge, disk of charge, point charge in an electric field, dipole in a electric field, the flux of vector field, the flux of electric field, Gauss's law, application of Gauss's law, spherically symmetric charge distribution, a charge isolated conductor, electric potential energy, electric potentials, calculating the potential from the field and related problem, potential due to point and continuous charge distribution, potential due to dipole, equipotential surfaces, calculating the field from the potential , electric current, current density, resistance, resistivity and conductivity, Ohm's law and its applications, Hall effect, the magnetic force on a current, Biot- Savart law, Line of B, two parallel conductors, Amperes' s law, solenoid, toroids, Faraday's experiments, Faraday's law of Induction, Lenz's law, motional emf, Induced electric field, Induced electric fields, the basic equation of electromagnetism, Induced magnetic field.

Section 30.1 The Biot–Savart Law

3. Calculate the magnitude of the magnetic field at a **W** point 25.0 cm from a long, thin conductor carrying a current of 2.00 A.

P30.3 The magnetic field is given by

$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}\ \mathrm{T\cdot m/A})(2.00\ \mathrm{A})}{2\pi(0.250\ \mathrm{m})} = \boxed{1.60 \times 10^{-6}\ \mathrm{T}}$$

6. In Niels Bohr's 1913 model of the hydrogen atom, **W** an electron circles the proton at a distance of 5.29×10^{-11} m with a speed of 2.19×10^{6} m/s. Compute the magnitude of the magnetic field this motion produces at the location of the proton.

P30.6 Treat the magnetic field as that produced in the center of a ring of radius *R* carrying current *I*: from Equation 30.8, the field is $B = \frac{\mu_0 I}{2R}$.

The current due to the electron is

$$I = \frac{\Delta q}{\Delta t} = \frac{e}{2\pi R/v} = \frac{ev}{2\pi R}$$

so the magnetic field is

$$B = \frac{\mu_0 I}{2R} = \frac{\mu_0}{2R}\left(\frac{ev}{2\pi R}\right) = \frac{\mu_0}{4\pi}\frac{ev}{R^2}$$

$$= \left(\frac{4\pi \times 10^{-7}\ \mathrm{T\cdot m/A}}{4\pi}\right)\frac{(1.60 \times 10^{-19}\ \mathrm{C})(2.19 \times 10^{6}\ \mathrm{m/s})}{(5.29 \times 10^{-11}\ \mathrm{m})^2}$$

$$= \boxed{12.5\ \mathrm{T}}$$

11. A long, straight wire carries a current I. A right-angle bend is made in the middle of the wire. The bend forms an arc of a circle of radius r as shown in Figure P30.11. Determine the magnetic field at point P, the center of the arc.

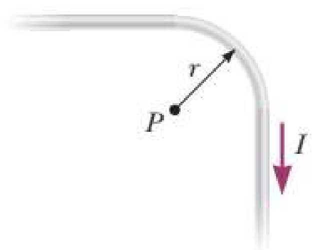

Figure P30.11

P30.11 Every element of current creates magnetic field in the same direction, into the page, at the center of the arc. The upper straight portion creates one-half of the field that an infinitely long straight wire would create. The curved portion creates one-quarter of the field that a circular loop produces at its center. The lower straight segment also creates field $\frac{1}{2}\frac{\mu_0 I}{2\pi r}$.

The total field is

$$\vec{\mathbf{B}} = \left(\frac{1}{2}\frac{\mu_0 I}{2\pi r} + \frac{1}{4}\frac{\mu_0 I}{2r} + \frac{1}{2}\frac{\mu_0 I}{2\pi r}\right) \text{ into the page}$$

$$= \boxed{\frac{\mu_0 I}{2r}\left(\frac{1}{\pi} + \frac{1}{4}\right) \text{ into the plane of the paper}}$$

$$= \left(\frac{0.284\,15\mu_0 I}{r}\right) \text{ into the page}$$

Section 30.2 The Magnetic Force Between Two Parallel Conductors

22. Two parallel wires separated by 4.00 cm repel each other with a force per unit length of 2.00×10^{-4} N/m. The current in one wire is 5.00 A. (a) Find the current in the other wire. (b) Are the currents in the same direction or in opposite directions? (c) What would happen if the direction of one current were reversed and doubled?

P30.22 (a) The force per unit length that parallel conductors exert on each other is, from Equation 30.12, $F/\ell = \mu_0 I_1 I_2 / 2\pi d$. Thus, if $F/\ell = 2.00 \times 10^{-4}$ N/m, $I_1 = 5.00$ A, and $d = 4.00$ cm, the current in the second wire must be

$$I_2 = \frac{2\pi d}{\mu_0 I_1}\left(\frac{F}{\ell}\right)$$
$$= \left[\frac{2\pi\left(4.00 \times 10^{-2}\text{ m}\right)}{\left(4\pi \times 10^{-7}\text{ T}\cdot\text{m/A}\right)\left(5.00\text{ A}\right)}\right]\left(2.00 \times 10^{-4}\text{ N/m}\right)$$
$$= \boxed{8.00\text{ A}}$$

(b) Since parallel conductors carrying currents in the same direction attract each other (see Section 30.2 in the textbook), the currents in these conductors which repel each other must be in $\boxed{\text{opposite directions.}}$

(c) From Equation 30.12, the force is directly proportional to the product of the currents. The result of reversing the direction of either of the currents and doubling the magnitude would be that the $\boxed{\text{force of interaction would be attractive and the magnitude of the force would double}}$.

Section 30.3 Ampere's Law

30. Niobium metal becomes a superconductor when cooled below 9 K. Its superconductivity is destroyed when the surface magnetic field exceeds 0.100 T. In the absence of any external magnetic field, determine the maximum current a 2.00-mm-diameter niobium wire can carry and remain superconducting.

P30.30 From $\oint \vec{\mathbf{B}} \cdot d\vec{\ell} = \mu_0 I$, $I = \dfrac{2\pi r B}{\mu_0} = \dfrac{2\pi\left(1.00 \times 10^{-3}\ \text{m}\right)(0.100\ \text{T})}{4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}} = \boxed{500\ \text{A}}$.

32. The magnetic coils of a tokamak fusion reactor are **W** in the shape of a toroid having an inner radius of 0.700 m and an outer radius of 1.30 m. The toroid has 900 turns of large-diameter wire, each of which carries a current of 14.0 kA. Find the magnitude of the magnetic field inside the toroid along (a) the inner radius and (b) the outer radius.

P30.32 (a) $B_{\text{inner}} = \dfrac{\mu_0 N I}{2\pi r} = \dfrac{\left(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}\right)(900)\left(14.0 \times 10^{3}\ \text{A}\right)}{2\pi(0.700\ \text{m})} = \boxed{3.60\ \text{T}}$

(b) $B_{\text{outer}} = \dfrac{\mu_0 N I}{2\pi r} = \dfrac{\left(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}\right)(900)\left(14.0 \times 10^{3}\ \text{A}\right)}{2\pi(1.30\ \text{m})} = \boxed{1.94\ \text{T}}$

Example 31.1 Inducing an emf in a Coil

A coil consists of 200 turns of wire. Each turn is a square of side d = 18 cm, and a uniform magnetic field directed perpendicular to the plane of the coil is turned on. If the field changes linearly from 0 to 0.50 T in 0.80 s, what is the magnitude of the induced emf in the coil while the field is changing?

SOLUTION

Conceptualize From the description in the problem, imagine magnetic field lines passing through the coil. Because the magnetic field is changing in magnitude, an emf is induced in the coil.

Categorize We will evaluate the emf using Faraday's law from this section, so we categorize this example as a substitution problem.

Evaluate Equation 31.2 for the situation described here, noting that the magnetic field changes linearly with time:

$$|\mathcal{E}| = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{\Delta(BA)}{\Delta t} = NA\frac{\Delta B}{\Delta t} = Nd^2\frac{B_f - B_i}{\Delta t}$$

$$|\mathcal{E}| = (200)(0.18 \text{ m})^2\frac{(0.50 \text{ T} - 0)}{0.80 \text{ s}} = \boxed{4.0 \text{ V}}$$

Example 31.2 An Exponentially Decaying Magnetic Field

A loop of wire enclosing an area A is placed in a region where the magnetic field is perpendicular to the plane of the loop. The magnitude of $\vec{\mathbf{B}}$ varies in time according to the expression $B = B_{max}e^{-at}$, where a is some constant. That is, at $t = 0$, the field is B_{max}, and for $t > 0$, the field decreases exponentially (Fig. 31.6). Find the induced emf in the loop as a function of time.

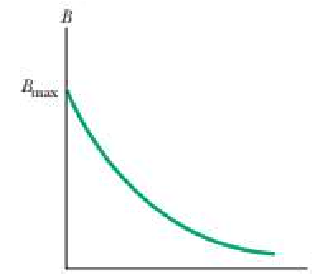

Figure 31.6 (Example 31.2) Exponential decrease in the magnitude of the magnetic field through a loop with time. The induced emf and induced current in a conducting path attached to the loop vary with time in the same way.

SOLUTION

Conceptualize The physical situation is similar to that in Example 31.1 except for two things: there is only one loop, and the field varies exponentially with time rather than linearly.

Categorize We will evaluate the emf using Faraday's law from this section, so we categorize this example as a substitution problem.

Evaluate Equation 31.1 for the situation described here:

$$\mathcal{E} = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}(AB_{max}e^{-at}) = -AB_{max}\frac{d}{dt}e^{-at} = \boxed{aAB_{max}e^{-at}}$$

This expression indicates that the induced emf decays exponentially in time. The maximum emf occurs at $t = 0$, where $\mathcal{E}_{max} = aAB_{max}$. The plot of $\mathcal{E}$ versus t is similar to the B-versus-t curve shown in Figure 31.6.

Section 31.1 Faraday's Law of Induction

1. A flat loop of wire consisting of a single turn of cross-sectional area 8.00 cm^2 is perpendicular to a magnetic field that increases uniformly in magnitude from 0.500 T to 2.50 T in 1.00 s. What is the resulting induced current if the loop has a resistance of 2.00 Ω?

***P31.1** From Equation 31.1, the induced emf is given by

$$|\mathcal{E}| = \left|\frac{\Delta\Phi_B}{\Delta t}\right| = \frac{\Delta\left(\vec{\mathbf{B}}\cdot\vec{\mathbf{A}}\right)}{\Delta t}$$

$$= \frac{(2.50\ \mathrm{T} - 0.500\ \mathrm{T})\left(8.00\times10^{-4}\ \mathrm{m}^2\right)}{1.00\ \mathrm{s}}\left(\frac{1\ \mathrm{N\cdot s}}{1\ \mathrm{T\cdot C\cdot m}}\right)\left(\frac{1\ \mathrm{V\cdot C}}{1\ \mathrm{N\cdot m}}\right)$$

$$= 1.60\ \mathrm{mV}$$

We then find the current induced in the loop from

$$I_{\mathrm{loop}} = \frac{\mathcal{E}}{R} = \frac{1.60\ \mathrm{mV}}{2.00\ \Omega} = \boxed{0.800\ \mathrm{mA}}$$

5. The flexible loop in Figure P31.5 has a radius of 12.0 cm and is in a magnetic field of magnitude 0.150 T. The loop is grasped at points *A* and *B* and stretched until its area is nearly zero. If it takes 0.200 s to close the loop, what is the magnitude of the average induced emf in it during this time interval?

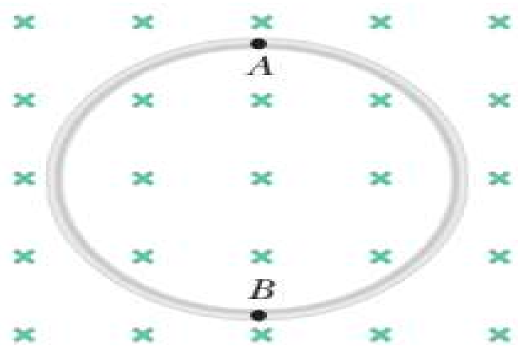

Figure P31.5 Problems 5 and 6.

P31.5 With the field directed perpendicular to the plane of the coil, the flux through the coil is $\Phi_B = BA\cos 0° = BA$. For a single loop,

$$|\mathcal{E}| = \frac{\Delta\Phi_B}{\Delta t} = \frac{B(\Delta A)}{\Delta t}$$

$$= \frac{(0.150\ \text{T})\left[\pi(0.120\ \text{m})^2 - 0\right]}{0.200\ \text{s}} = 3.39\times10^{-2}\ \text{V} = \boxed{33.9\ \text{mV}}$$

6. A circular loop of wire of radius 12.0 cm is placed in a magnetic field directed perpendicular to the plane of the loop as in Figure P31.5. If the field decreases at the rate of 0.050 0 T/s in some time interval, find the magnitude of the emf induced in the loop during this interval.

P31.6 With the field directed perpendicular to the plane of the coil, the flux through the coil is $\Phi_B = BA\cos 0° = BA$. As the magnitude of the field increases, the magnitude of the induced emf in the coil is

$$|\mathcal{E}| = \frac{|\Delta\Phi_B|}{\Delta t} = \left(\frac{\Delta B}{\Delta t}\right)A = (0.050\,0\ \text{T/s})\left[\pi(0.120\ \text{m})^2\right]$$

$$= 2.26\times10^{-3}\ \text{V} = \boxed{2.26\ \text{mV}}$$

So far, our studies in electricity and magnetism have focused on the electric fields produced by stationary charges and the magnetic fields produced by moving charges.

This chapter explores the effects produced by magnetic fields that vary in time.

Experiments conducted by Michael Faraday in England in 1831 and independently by Joseph Henry in the United States that same year showed that an emf can be induced in a circuit by a changing magnetic field.

The results of these experiments led to a very basic and important law of electromagnetism known as *Faraday's law of induction.*

An emf (and therefore a current as well) can be induced in various processes that involve a change in a magnetic flux.

Faraday's Law of Induction

To see how an emf can be induced by a changing magnetic field, consider the experimental results obtained when a loop of wire is connected to a sensitive ammeter as illustrated in Figure 31.1 (page 936). When a magnet is moved toward the loop, the reading on the ammeter changes from zero to a nonzero value, arbitrarily shown as negative in Figure 31.1a. When the magnet is brought to rest and held stationary relative to the loop (Fig. 31.1b), a reading of zero is observed. When the magnet is moved away from the loop, the reading on the ammeter changes to a positive value as shown in Figure 31.1c.

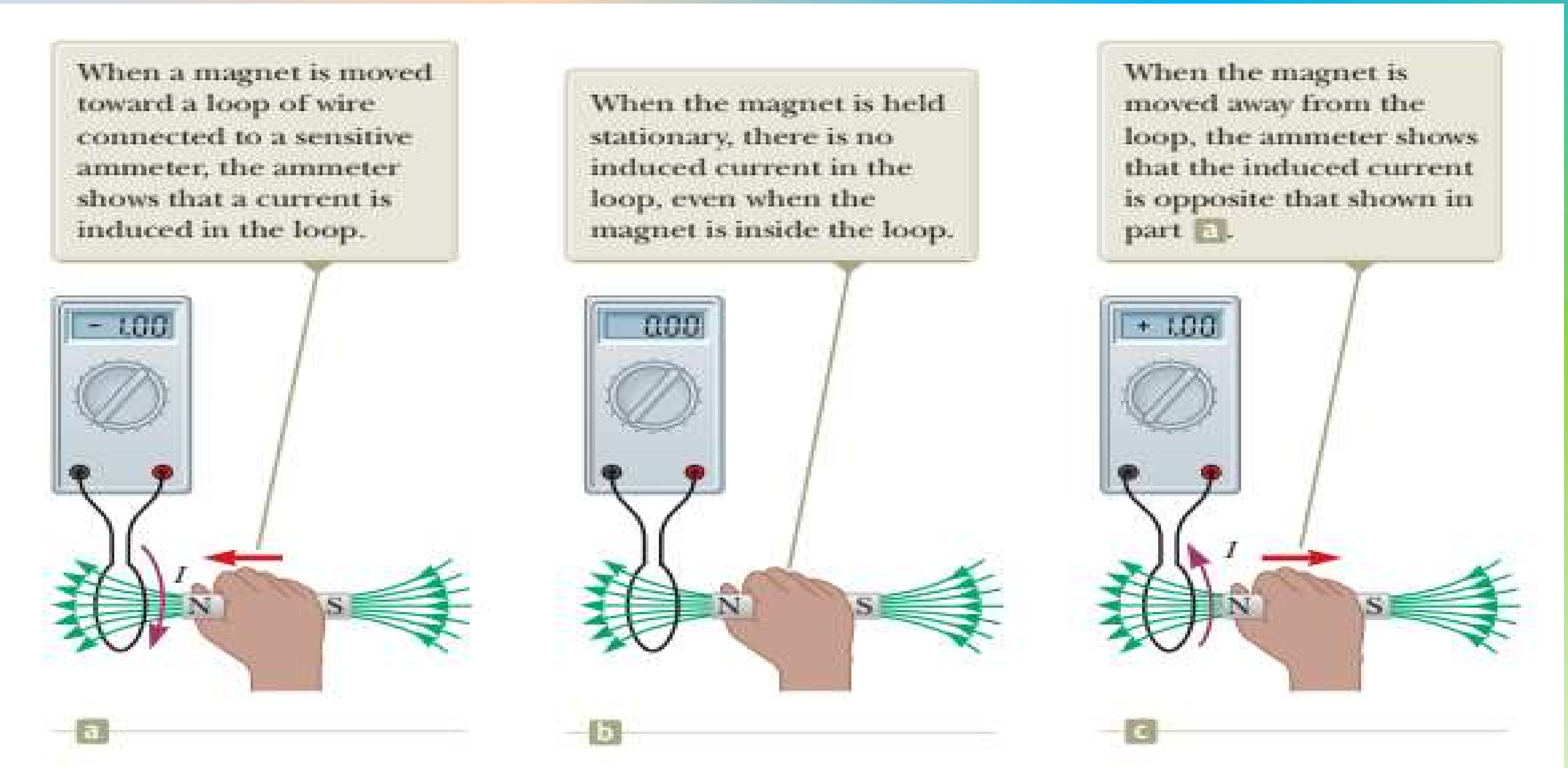

Figure 31.1 A simple experiment showing that a current is induced in a loop when a magnet is moved toward or away from the loop.

Finally, when the magnet is held stationary and the loop is moved either toward or away from it, the reading changes from zero.
From these observations, we conclude that the loop detects that the magnet is moving relative to it and we relate this detection to a change in magnetic field. ***Therefore, it seems that a relationship exists between a current and a changing magnetic field.***

These results are quite remarkable because a current is set up even though no batteries are present in the circuit!
We call such a current an *induced current* and say that it is produced by an *induced emf.*

Now let's describe an experiment conducted by Faraday and illustrated in Figure 31.2. A primary coil is wrapped around an iron ring and connected to a switch and a battery. A current in the coil produces a magnetic field when the switch is closed. A secondary coil also is wrapped around the ring and is connected to a sensitive ammeter. No battery is present in the secondary circuit, and the secondary coil is not electrically connected to the primary coil. Any current detected in the secondary circuit must be induced by some external agent.

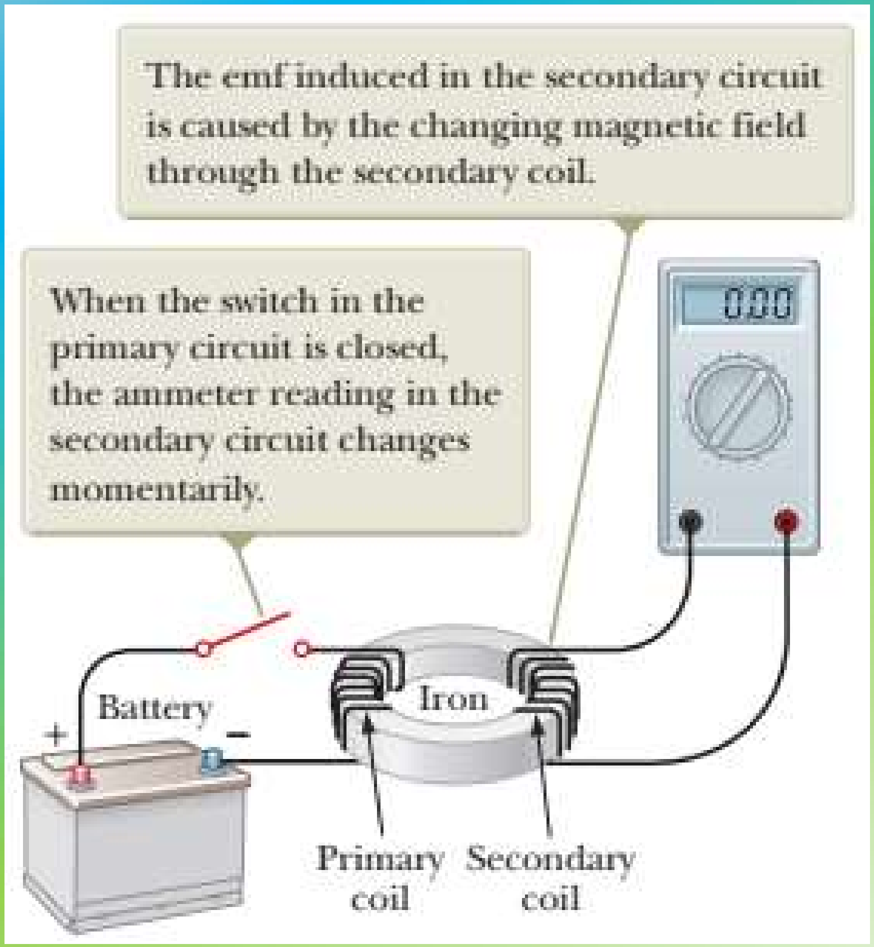

Figure 31.2 Faraday's experiment.

Initially, you might guess that no current is ever detected in the secondary circuit. Something quite amazing happens when the switch in the primary circuit is either opened or thrown closed, however.

At the instant the switch is closed, the ammeter reading changes from zero momentarily and then returns to zero.

At the instant the switch is opened, the ammeter changes to a reading with the opposite sign and again returns to zero.

Finally, the ammeter reads zero when there is either a steady current or no current in the primary circuit.

To understand what happens in this experiment, note that when the switch is closed, the current in the primary circuit produces a magnetic field that penetrates the secondary circuit. Furthermore, when the switch is thrown closed, the magnetic field produced by the current in the primary circuit changes from zero to some value over some finite time, and this changing field induces a current in the secondary circuit. Notice that no current is induced in the secondary coil even when a steady current exists in the primary coil.

It is a *change* in the current in the primary coil that induces a current in the secondary coil, not just the *existence* of a current.

As a result of these observations, Faraday concluded that an electric current can be induced in a loop by a changing magnetic field.
The induced current exists only while the magnetic field through the loop is changing.
Once the magnetic field reaches a steady value, the current in the loop disappears.
In effect, the loop behaves as though a ***source of emf*** were connected to it for a short time.
It is customary to say that an induced emf is produced in the loop by the changing magnetic field.

The experiments shown in Figures 31.1 and 31.2 have one thing in common: in each case, an ***emf is induced in a loop*** when the magnetic flux through the loop changes with time.
In general, this emf is directly proportional to the time rate of change of the magnetic flux through the loop.

This statement can be written mathematically as
Faraday's law of induction:

$$\varepsilon = -\frac{d\varphi_B}{dt} \qquad (31.1)$$

where $\Phi_B = \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$ is the magnetic flux through the loop.

If a coil consists of N loops with the same area and Φ_B is the magnetic flux through one loop, an emf is induced in every loop. The loops are in series, so their emfs add; therefore, the total induced emf in the coil is given by

$$\boxed{\mathcal{E} = -N\frac{d\varphi_B}{dt} \qquad (31.2)}$$

Suppose a loop enclosing an area A lies in a uniform magnetic field $\vec{\mathbf{B}}$ as in Figure 31.3. The magnetic flux through the loop is equal to $BA\cos\theta$, where θ is the angle between the magnetic field and the normal to the loop; hence, the induced emf can be expressed as

$$\mathcal{E} = -\frac{d}{dt}(BA\cos\theta) \qquad (31.3)$$

From this expression, we see that an emf can be induced in the circuit in several ways:

- The magnitude of $\vec{\mathbf{B}}$ can change with time.
- The area enclosed by the loop can change with time.
- The angle θ between $\vec{\mathbf{B}}$ and the normal to the loop can change with time.
- Any combination of the above can occur.

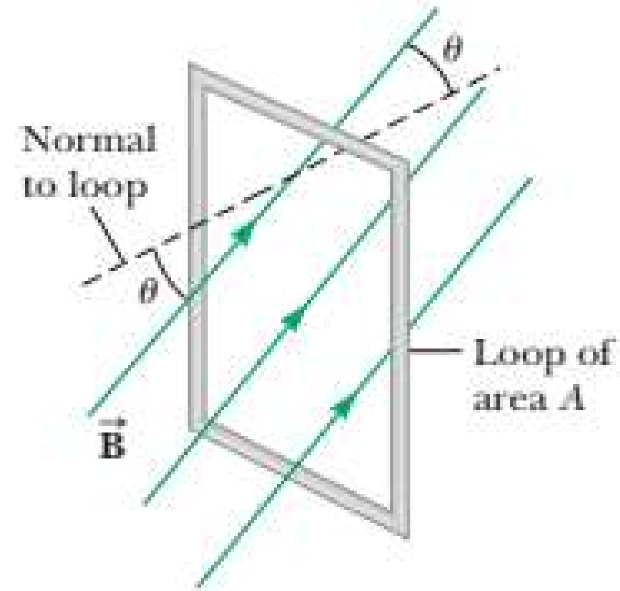

Figure 31.3 A conducting loop that encloses an area A in the presence of a uniform magnetic field $\vec{\mathbf{B}}$. The angle between $\vec{\mathbf{B}}$ and the normal to the loop is θ.