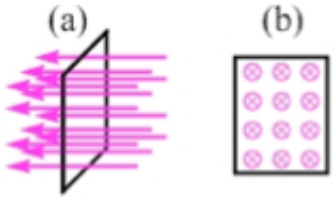
CH 20-1 – Faraday's Law

Important Ideas

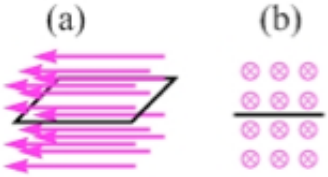
- Magnetic flux is a measure of the number of magnetic field lines that pass through a given area, A. The magnetic flux is

$$\Phi_{mag} = BA\cos(\theta)$$

where θ is the angle between the magnetic field and the area vector $\vec{A}$. The area vector has a magnitude equal to the area of a surface and a direction perpendicular to the plane of the surface. The SI unit for magnetic flux is the weber (Wb). 1 Wb = 1 T $\cdot$ m^2. In the example below, $\theta = 0$ and the flux through the area is a maximum.



In the example below, $\theta = 90°$ and the magnetic flux through the area is zero.



- If the magnetic flux through a loop of wire changes, then a voltage across the loop is induced and current flows through the loop. If it is a coil of N loops, then the induced voltage across the coil will be N times the induced voltage across a single loop. (The coil is like having many loops connected in series.) This induced voltage is called an *induced emf*. According to Faraday's Law, the magnitude of the induced emf is

$$|\varepsilon| = N\frac{\Delta\Phi}{\Delta t} = N\frac{\Delta(BA\cos\theta)}{\Delta t}$$

The induced current in a loop or coil of resistance R is given by Ohm's law.

$$I = \frac{emf}{R}$$

- Note that there are three ways to change the magnetic flux and thus induce current in a coil.

1. Change B
2. Change A (or usually the percentage of A in which B is non-zero, such as pulling a loop into or out of a region of uniform magnetic field)
3. Change θ by rotating the loop in the magnetic field or change the direction of B while the loop remains stationary.

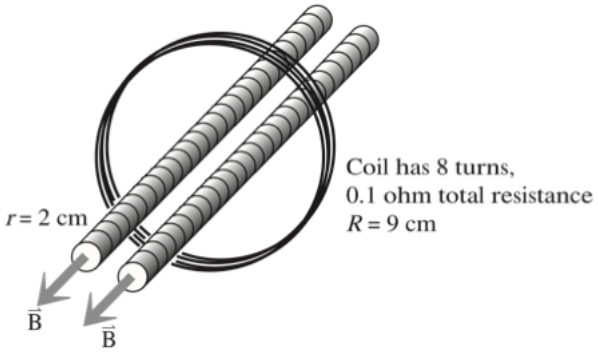
If the magnetic flux is constant, then no emf is induced around the coil.

- The direction of the induced current in the coil (and the induced electric field in space if no coil is present) is given by Lenz's Law. Here is a right hand rule for applying Lenz's law.

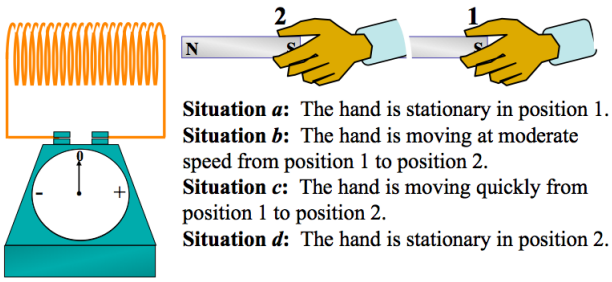
    1. Identify whether the magnetic flux is increasing or decreasing.
    2. If increasing, point your thumb in the opposite direction of $\vec{B}$. If decreasing, point your thumb in the same direction of $\vec{B}$.
    3. Your fingers curl in the direction of induced current in a coil.

Examples

1. A current-carrying solenoid creates a uniform magnetic field inside the solenoid and zero magnetic field outside the solenoid. Two solenoids, each producing a magnetic field of 0.8 T, pass through a coil with 8 turns. What is the total magnetic flux through one turn of the coil?



2. Which of the following correctly compares how far the voltmeter needle deflects during each of these situations?



Situation *a*: The hand is stationary in position 1.
Situation *b*: The hand is moving at moderate speed from position 1 to position 2.
Situation *c*: The hand is moving quickly from position 1 to position 2.
Situation *d*: The hand is stationary in position 2.

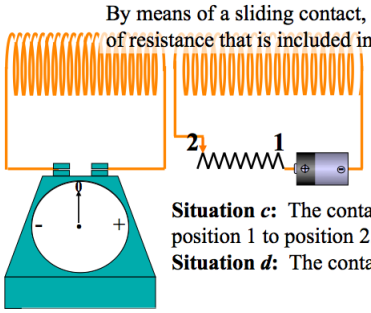
(a) Most in d, least in a, same in-between value in b and c

(b) Most in d, less in c, still less in b, least in a

(c) Most in c, less in b, a and d tied for least

(d) Most in c, less in b, still less in d, least in a

3. Which of the following correctly compares how far the voltmeter needle deflects during each of these situations?



Situation *a*: The contact is stationary in position 1.
Situation *b*: The contact is slid at moderate speed from position 1 to position 2.
Situation *c*: The contact is slid quickly from position 1 to position 2.
Situation *d*: The contact is stationary in position 2.

(a) Most in d, least in a, same in-between value in b and c.

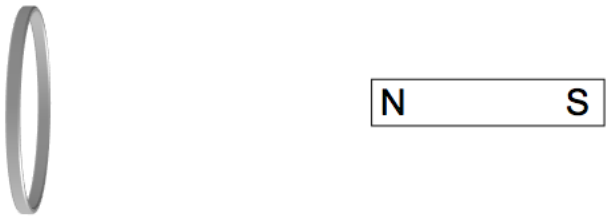
(b) Most in d, less in c, still less in b, least in a.

(c) Most in c, less in b, a and d tied for least.

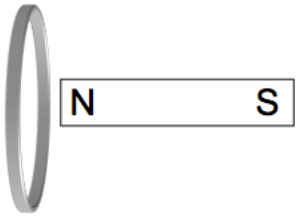
(d) Most in c, less in b, still less in d, least in a.

4. A primary coil has a current of 0.5 A, radius 0.02 m, and 20 loops of wire. It creates a magnetic field in the plane of a pickup coil of 0.001 T. If the current in the primary coil decreases to zero in 0.1 s, what is the magnitude of the emf induced in the pickup coil if its radius is 0.01 m and it is made of 100 loops of wire? (Assume that the two coils are aligned along the same axis.)

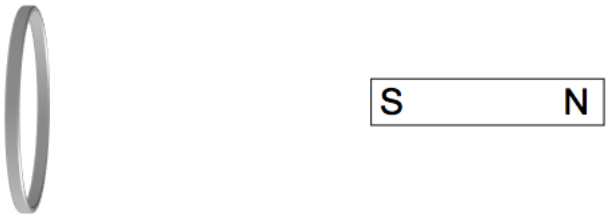
5. If you move the magnet toward the coil, in what direction is the induced current in the coil?



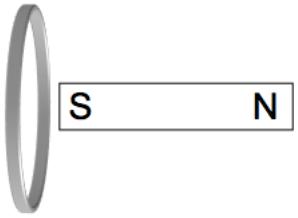
6. If you move the magnet away from the coil, in what direction is the induced current in the coil?



7. If you move the magnet toward the coil, in what direction is the induced current in the coil?



8. If you move the magnet away from the coil, in what direction is the induced current in the coil?



9. If current increases in the primary coil, what is the direction of the induced current in the secondary coil?

10. If current decreases in the primary coil, what is the direction of the induced current in the secondary coil?