Faraday's Law

Recall that the amount of voltage induced in a coil of wire depends on the following factors:

1. How quickly the magnetic field changes.
   - a very slow change results in a very small induced current
   - a quicker change results in a larger induced current
2. The area of the loop.
3. The orientation (angle) of the loop relative to the magnetic field lines.
4. The number of loops in the coil of wire.
   - the greater the number of loops, the greater the induced voltage
   - pushing a magnet into twice as many loops will induce twice as much voltage, pushing it into ten times as many loops will induce ten times as much voltage, and so on

Three of these four factors (magnetic field strength, area, and angle) are often combined into a single quantity. This quantity, known as the **magnetic flux**, is equal to the product of the magnetic field strength (B), the area of the loop (A), and the cosine of the angle between the magnetic field and a line perpendicular to the face of the loop.

$$\Phi = BA\cos\theta$$

The unit of magnetic flux is the **weber** (Wb).

Example 1
A square loop of wire $10\ cm$ on a side is in a $1.25\ T$ magnetic field that is perpendicular to the loop. What is the magnetic flux passing through the loop?

With this definition of flux, the results of Faraday's investigations can be expressed as:

> The induced voltage in a coil is equal to the product of the number of loops times the rate at which the magnetic flux changes within those loops.

$$V = -N\frac{\Delta\Phi}{\Delta t}$$

This is known as **Faraday's law** of electromagnetic induction. The minus sign is there to remind us of the direction in which the induced voltage acts. We will discuss this further in a later lesson.

Example 2
A square coil $5\ cm$ on a side contains 100 loops and is positioned perpendicular to a uniform $0.6\ T$ magnetic field. The coil is removed from the field in $0.1\ s$. Determine the voltage induced in the coil.

Worksheet

1. A 15 cm diameter circular loop of wire is placed in a 0.5 T magnetic field. When the loop is perpendicular to the field lines, what is the magnetic flux through the loop? (0.0088 Wb)

2. The magnetic flux through a coil of wire containing two loops changes from $-50\ Wb$ to $+38\ Wb$ in 0.42 s. What is the voltage induced in the coil? ($-419\ V$)

3. A 9.6 cm diameter circular loop of wire is in a 1.1 T magnetic field. The loop is removed from the field in 0.15 s. What is the voltage induced in the loop? ($+0.053\ V$)

4. A 12 cm diameter loop of wire is initially oriented perpendicular to a 1.5 T magnetic field. The loop is rotated so that its lane is parallel to the field in 0.2 s. What is the voltage induced in the loop? ($+0.085\ V$)

5. A 10.2 cm diameter wire coil is initially oriented so that it is perpendicular to a magnetic field of 0.63 T pointing up. During the course of 0.15 s, the field is changed to one of 0.25 T pointing down. What is the voltage induced in the coil? ($+0.048\ V$)

6. A 15 cm diameter circular loop of wire is placed in a 0.5 T magnetic field.

   a) When the loop is perpendicular to the magnetic field lines, what is the magnetic flux through the loop? (0.0088 Wb)

   b) When the loop makes a $35°$ angle with the field lines, what is the magnetic flux through the loop? (0.0051 Wb)

7. The magnetic field perpendicular to a circular wire loop 12 cm in diameter is changed from $+0.52\ T$ to $-0.45\ T$ in 180 ms. Calculate the induced voltage. ($+0.061\ V$)