

10.10: Faraday's Law of Induction- Lenz's Law

Learning Objectives

- Calculate voltage, current, and magnetic fields using Faraday's Law.
- Explain the physical results of Lenz's Law

Faraday's and Lenz's Law

Faraday's experiments showed that the voltage induced by a change in magnetic flux depends on only a few factors. First, voltage is directly proportional to the change in flux $\Delta\Phi$. Second, voltage is greatest when the change in time Δt is smallest—that is, voltage is inversely proportional to Δt . Finally, if a coil has N turns, a voltage will be produced that is N times greater than for a single coil, so that voltage is directly proportional to N . The equation for the voltage induced by a change in magnetic flux is

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

This relationship is known as **Faraday's law of induction**.

The minus sign in Faraday's law of induction is very important. The minus means that *the induced voltage creates a current I and magnetic field B that oppose the change in flux $\Delta\Phi$ —this is known as Lenz's law*. Faraday was aware of the direction, but Lenz stated it so clearly that he is credited for its discovery. (See Figure 10.10.1)

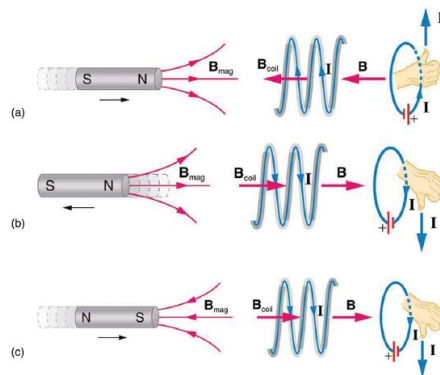


Figure 10.10.1: (a) When this bar magnet is thrust into the coil, the strength of the magnetic field increases in the coil. The current induced in the coil creates another field, in the opposite direction of the bar magnet's to oppose the increase. This is one aspect of *Lenz's law—induction opposes any change in flux*. (b) and (c) are two other situations. Verify for yourself that the direction of the induced B_{coil} shown indeed opposes the change in flux and that the current direction shown is consistent with RHR-2.

Applications of Electromagnetic Induction

There are many applications of Faraday's Law of induction, as we will explore in this chapter and others. At this juncture, let us mention several that have to do with data storage and magnetic fields. A very important application has to do with audio and video *recording tapes*. A plastic tape, coated with iron oxide, moves past a recording head. This recording head is basically a round iron ring about which is wrapped a coil of wire—an electromagnet (Figure 10.10.2). A signal in the form of a varying input current from a microphone or camera goes to the recording head. These signals (which are a function of the signal amplitude and frequency) produce varying magnetic fields at the recording head. As the tape moves past the recording head, the magnetic field orientations of the iron oxide molecules on the tape are changed thus recording the signal. In the playback mode, the magnetized tape is run past another head, similar in structure to the recording head. The different magnetic field orientations of the iron oxide molecules on the tape induces a voltage in the coil of wire in the playback head. This signal then is sent to a loudspeaker or video player.



Figure 10.10.2: Recording and playback heads used with audio and video magnetic tapes. (credit: Steve Jurvetson)

Similar principles apply to computer hard drives, except at a much faster rate. Here recordings are on a coated, spinning disk. Read heads historically were made to work on the principle of induction. However, the input information is carried in digital rather than analog form – a series of 0's or 1's are written upon the spinning hard drive. Today, most hard drive readout devices do not work on the principle of induction, but use a technique known as *giant magnetoresistance*. (The discovery that weak changes in a magnetic field in a thin film of iron and chromium could bring about much larger changes in electrical resistance was one of the first large successes of nanotechnology.) Another application of induction is found on the magnetic stripe on the back of your personal credit card as used at the grocery store or the ATM machine. This works on the same principle as the audio or video tape mentioned in the last paragraph in which a head reads personal information from your card.

Another application of electromagnetic induction is when electrical signals need to be transmitted across a barrier. Consider the *cochlear implant* shown below. Sound is picked up by a microphone on the outside of the skull and is used to set up a varying magnetic field. A current is induced in a receiver secured in the bone beneath the skin and transmitted to electrodes in the inner ear. Electromagnetic induction can be used in other instances where electric signals need to be conveyed across various media.

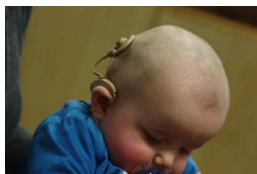


Figure 10.10.3: Electromagnetic induction used in transmitting electric currents across mediums. The device on the baby's head induces an electrical current in a receiver secured in the bone beneath the skin. (credit: Bjorn Knetsch)

Another contemporary area of research in which electromagnetic induction is being successfully implemented (and with substantial potential) is transcranial magnetic stimulation. A host of disorders, including depression and hallucinations can be traced to irregular localized electrical activity in the brain. In *transcranial magnetic stimulation*, a rapidly varying and very localized magnetic field is placed close to certain sites identified in the brain. Weak electric currents are induced in the identified sites and can result in recovery of electrical functioning in the brain tissue.

Sleep apnea ("the cessation of breath") affects both adults and infants (especially premature babies and it may be a cause of sudden infant deaths [SID]). In such individuals, breath can stop repeatedly during their sleep. A cessation of more than 20 seconds can be very dangerous. Stroke, heart failure, and tiredness are just some of the possible consequences for a person having sleep apnea. The concern in infants is the stopping of breath for these longer times. One type of monitor to alert parents when a child is not breathing uses electromagnetic induction. A wire wrapped around the infant's chest has an alternating current running through it. The expansion and contraction of the infant's chest as the infant breathes changes the area through the coil. A pickup coil located nearby has an alternating current induced in it due to the changing magnetic field of the initial wire. If the child stops breathing, there will be a change in the induced current, and so a parent can be alerted.

MAKING CONNECTIONS: CONSERVATION OF ENERGY

Lenz's law is a manifestation of the conservation of energy. The induced voltage produces a current that opposes the change in flux, because a change in flux means a change in energy. Energy can enter or leave, but not instantaneously. Lenz's law is a consequence. As the change begins, the law says induction opposes and, thus, slows the change. In fact, if the induced voltage were in the same direction as the change in flux, there would be a positive feedback that would give us free energy from no apparent source—conservation of energy would be violated.

Section Summary

- Faraday's law of induction states that the voltage induced by a change in magnetic flux is

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

when flux changes by $\Delta \Phi$ in a time Δt .

- If voltage is induced in a coil, N is its number of turns.
- The minus sign means that the induced voltage creates a current I and magnetic field B that *oppose the change in flux* $\Delta \Phi$ — this opposition is known as Lenz's law.

Glossary

Faraday's law of induction

the means of calculating the voltage in a coil due to changing magnetic flux, given by $V = -N \frac{\Delta\Phi}{\Delta t}$

Lenz's law

the minus sign in Faraday's law, signifying that the voltage induced in a coil opposes the change in magnetic flux

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