Chapter 20: Electromagnetic Induction
A high voltage power line 20 m above the ground carries a current of 2 000 A. What is the magnetic field due to the current directly underneath the power line? ($\mu_0 = 4\pi \times 10^{-7} \text{T} \cdot \text{m/A}$)

a. 20 $\mu$T  
b. 35 $\mu$T  
c. 14 mT  
d. 0.30 T
Topics

Electromagnetic Induction

- Magnetic flux
- Induced emf
  - Faraday’s Law
  - Lenz’s Law
  - Motional emf
- Magnetic energy
- Inductance
- RL circuits
- Generators and transformers
Reading Quiz 1

Magnetic flux through a wire loop depends on:

1) thickness of the wire
2) resistivity of the wire
3) geometrical layout of the wire
4) material that the wire is made of
5) none of the above

\[ \Phi_B = BA \cos \theta \]  
Flux depends only on geometrical properties
Magnetic Flux

Define magnetic flux $\Phi_B$

$$\Phi_B = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$$

- $\theta$ is angle between $\mathbf{B}$ and the normal to the plane
- Flux units are T-m$^2$ = “webers”

When $\mathbf{B}$ field is not constant or area is not flat
- Integrate over area
  $$\Phi_B = \int_A \mathbf{B} \cdot d\mathbf{A}$$
- Won’t cover this case here
\[ \Phi_B = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta \]

\[ \Phi_B = 0 \quad \Phi_B = \frac{1}{\sqrt{2}} BA \quad \Phi_B = BA \]
Experimental Observation of Induction

This effect can be quantified by Faraday's Law
An induced emf produced in a motionless circuit is due to

1) a static (steady) magnetic field
2) a changing magnetic field
3) a strong magnetic field
4) the Earth’s magnetic field
5) a zero magnetic field

Faraday’s law
Reading Quiz 3

Motional emf relates to an induced emf in a conductor which is:

- 1) long
- 2) sad
- 3) stationary
- 4) insulated
- 5) moving

Potential difference proportional to velocity
Faraday’s Law of Induction

\[ \mathcal{E} = -N \frac{\Delta \Phi_B}{\Delta t} \]

- The faster the change, the larger the induced emf
- Flux change caused by changes in either B, area, orientation
- Minus sign explained next slide
Faraday’s Law of Induction

\[ \mathcal{E} = -N \frac{\Delta \Phi_B}{\Delta t} \]

- Minus sign from Lenz’s Law:
- Induced current produces a magnetic field which \textit{opposes} the original change in flux
Comment on Lenz’s Law

Why does the induced current oppose the change in flux?

Consider the alternative

- If the induced current reinforced the change
- ... then the change would get bigger
- ... which would then induce a larger current
- ... and then the change would get even bigger
- ... and so on . . .

A clear violation of conservation of energy!!
Direction of Induced Current

Bar magnet moves through coil
- Current induced in coil

Reverse pole
- Induced current changes sign

Coil moves past fixed bar magnet
- Current induced in coil as in (A)

Bar magnet stationary inside coil
- No current induced in coil
Question

An incredible amount of electrical energy passes down the funnel of a large tornado every second. Measurements taken in Oklahoma at a distance of 9.00 km from a large tornado showed an almost constant magnetic field of $1.50 \times 10^{-8}$ T associated with the tornado. What was the average current going down the funnel? ($\mu_0 = 4\pi \times 10^{-7}$ T·m/A)

a. 450 A
b. 675 A
b. 675 A
b. 675 A
c. 950 A
d. 1 500 A

\[
B = \frac{\mu_0 i}{2\pi d}
\]