Physics 202
Chapter 31
Oct 23, 2007

Faraday's Law

Faraday's Law

- The final step to ignite the industrial use of electromagnetism on a large scale.
- Light, toasters, cars, TVs, telephones, iPods, industrial production, …

Faraday's Law

- "the emf induced in a circuit is directly proportional to the time rate of change of the magnetic flux through the circuit"

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

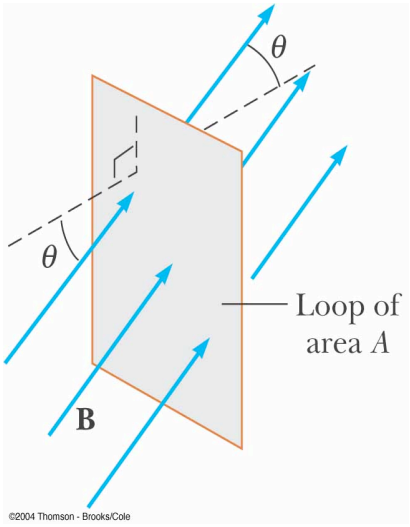
$\mathcal{E}$ = induced emf,
= induced potential difference

$$\Phi_B = \int \mathbf{B} \cdot d\mathbf{A}$$

- In practice often: $\Phi_B = BA \cos\theta$
- The induced emf is then: $\varepsilon = -d/dt\,(BA\cos\theta)$

Faraday's Law – Example

- Assume a loop enclosing an area A lies in a uniform magnetic field $\mathbf{B}$
- The magnetic flux through the loop is $\Phi_B = BA\cos\theta$
- The induced emf is $\varepsilon = -d/dt\,(BA\cos\theta)$



Ways of Inducing an emf

- The magnitude of **B** can change with time
- The area enclosed by the loop can change with time
- The angle θ between **B** and the normal to the loop can change with time
- Any combination of the above can occur

Lenz's Law

- Faraday's law indicates that the induced emf and the change in flux have opposite algebraic signs

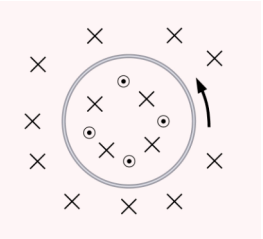
$$\varepsilon = -\frac{d\Phi_B}{dt}$$

- **Lenz's law:** *the induced current in a loop is in the direction that creates a magnetic field that opposes the change in magnetic flux through the area enclosed by the loop*

Induced emf by changing B-field – a closer look

- An increasing B-field generates a current.
- That means electrons in the wire "see" a (circular) electric field. The E-field is not caused by a static electric charge distribution.
- That means (in presence of a changing magnetic field):

$$\oint \vec{E} \cdot \vec{ds} \neq 0$$

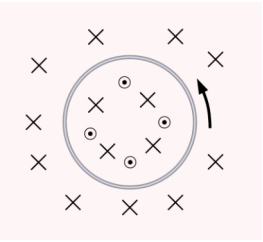


- Faraday's law can be written in a general form:

$$\oint \vec{E} \cdot \vec{ds} = -\frac{d\Phi_B}{dt}$$

Examples on the whiteboard

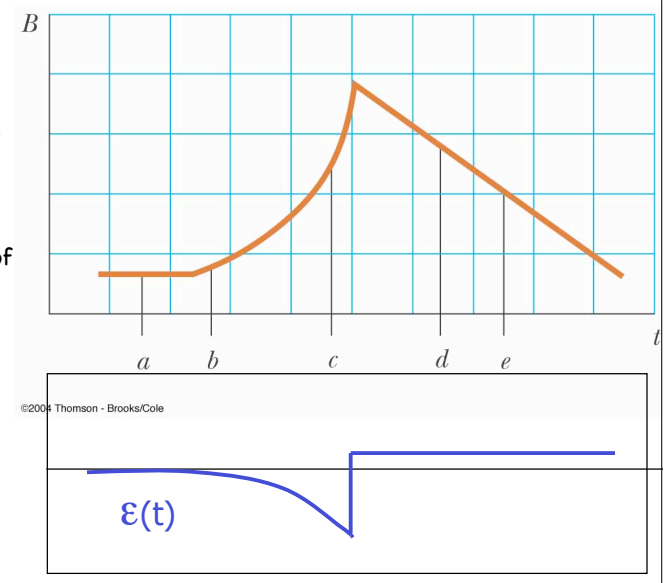
- Changing B-field
- Motional emf
- Demonstration: The soda can crusher



Quick Quiz 31.2

The figure shows the time dependence of a uniform fiel B(t) that passes through a fixed loop and is oriented perpendicular to the plane of the loop.

Rank the magnitudes of the emf generated in the loop at the five instants indicated, from largest to smallest.



Quick Quiz 31.8

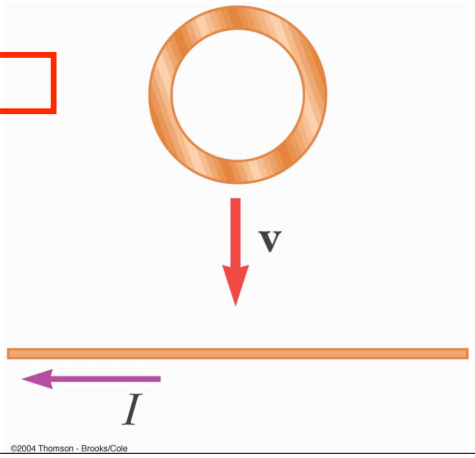
The figure below shows a circular loop of wire being dropped toward a wire carrying a current to the left. The direction of the induced current in the loop of wire is

(a) clockwise

(b) counterclockwise

(c) zero

(d) impossible to determine



QUICK QUIZ 31.3

A square loop of wire is being pulled at a constant velocity through a region of uniform magnetic field pointing into the screen.

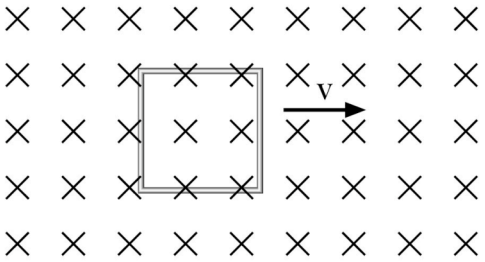
In the loop of wire

a) there will be a current induced,

b) charge separation will occur,

c) a and b, or

d) neither a nor b.

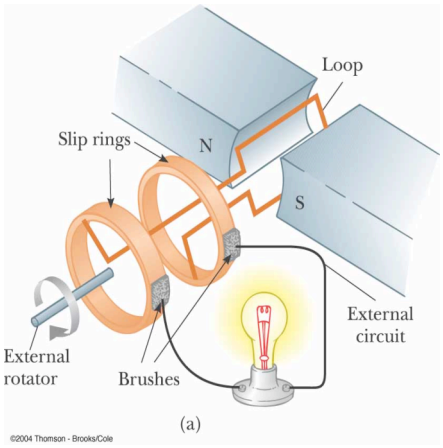


No Flux change!
No induced field!
No current!
No force!

Animation here

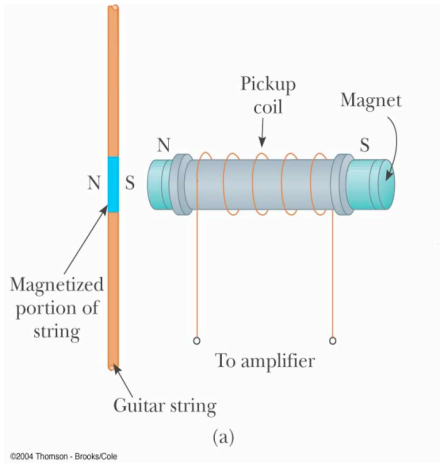
Generators

- Electric generators take in energy by work and transfer it out by electrical transmission
- The AC generator consists of a loop of wire rotated by some external means in a magnetic field



Applications of Faraday's Law – Pickup Coil in electric guitar

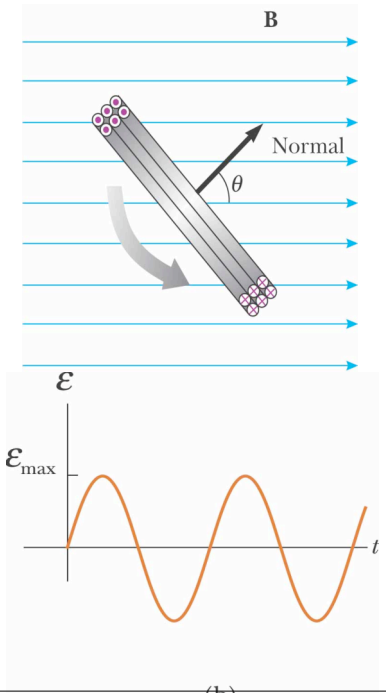
- A permanent magnet is placed near the string of the guitar and causes a portion of the string to become magnetized
- When the string vibrates at some frequency, the magnetized segment produces a changing flux through the coil.
- The induced emf is fed to an amplifier.



Rotating Loop

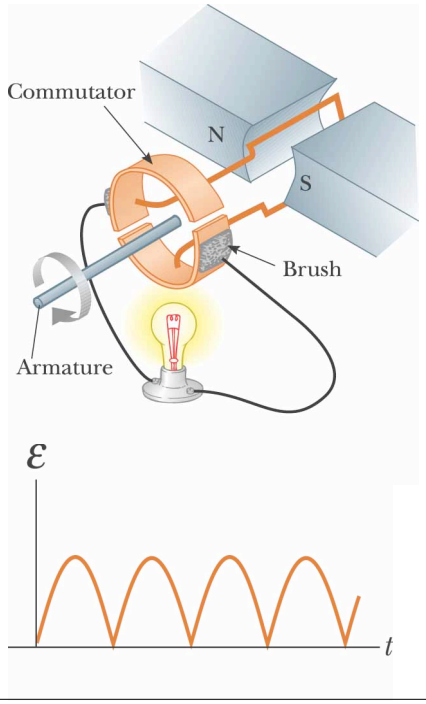
- Assume a loop with N turns,
- The flux through the loop at any time t is $\Phi_B = BA \cos \theta = BA \cos \omega t$
- *Resulting emf:*

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$
$$= NAB\omega \sin \omega t$$



DC Generators

- The DC (direct current) generator has essentially the same components as the AC generator
- The main difference is that the contacts to the rotating loop are made using a split ring called a *commutator*

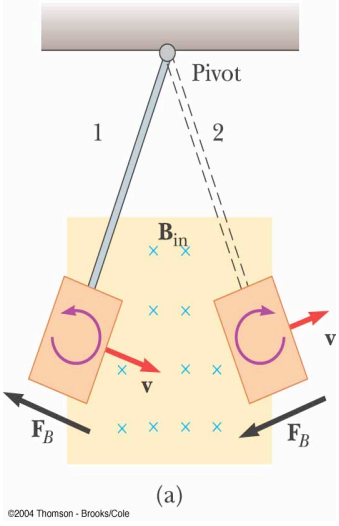


Motors

- A motor is a generator operating in reverse

Eddy Currents

- Circulating currents called **eddy currents** are induced in bulk pieces of metal moving through a magnetic field
- The eddy currents are in opposite directions as the plate enters or leaves the field
- Eddy currents are often undesirable because they represent a transformation of mechanical energy into internal energy



Maxwell's Equations, Introduction

- Maxwell's equations are regarded as the basis of all electrical and magnetic phenomena
- Maxwell's equations represent the laws of electricity and magnetism that have already been discussed, but they have additional important consequences

Maxwell's Equations

$$\oint_S \vec{E} \cdot \overrightarrow{dA} = \frac{q}{\varepsilon_0}$$

- Gauss's law (electric)

$$\oint_S \vec{B} \cdot \overrightarrow{dA} = 0$$

- Gauss's law in Magnetism

$$\oint \vec{E} \cdot \overrightarrow{ds} = -\frac{d\Phi_B}{dt}$$

- Faraday's Law

$$\oint \vec{B} \cdot \overrightarrow{ds} = \mu_0 I + \varepsilon_0 \mu_0 \frac{d\Phi_E}{dt}$$

- Ampere-Maxwell Law