Lecture 36

PHYC 161 Fall 2015

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Maxwell's equations of electromagnetism

- All the relationships between electric and magnetic fields and their sources are summarized by four equations, called **Maxwell's equations**.
- The first Maxwell equation is Gauss's law for electric fields from Chapter 22:

Gauss's law for $\vec{E}$:

Flux of electric field through a closed surface

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\epsilon_0}$$

Charge enclosed by surface (Q_{encl})

Electric constant (ϵ_0)

- The second Maxwell equation is Gauss's law for magnetic fields from Chapter 27:

Gauss's law for $\vec{B}$:

Flux of magnetic field through any closed surface ...

$$\oint \vec{B} \cdot d\vec{A} = 0$$

... equals zero.

Maxwell's equations of electromagnetism

- The third Maxwell equation is this chapter's formulation of Faraday's law:

Faraday's law for a stationary integration path:

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

Line integral of electric field around path

Negative of the time rate of change of magnetic flux through path

- The fourth Maxwell equation is Ampere's law, including displacement current:

Ampere's law for a stationary integration path:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(i_C + \epsilon_0 \frac{d\Phi_E}{dt} \right)_{\text{encl}}$$

Line integral of magnetic field around path

Electric constant

Time rate of change of electric flux through path

Magnetic constant

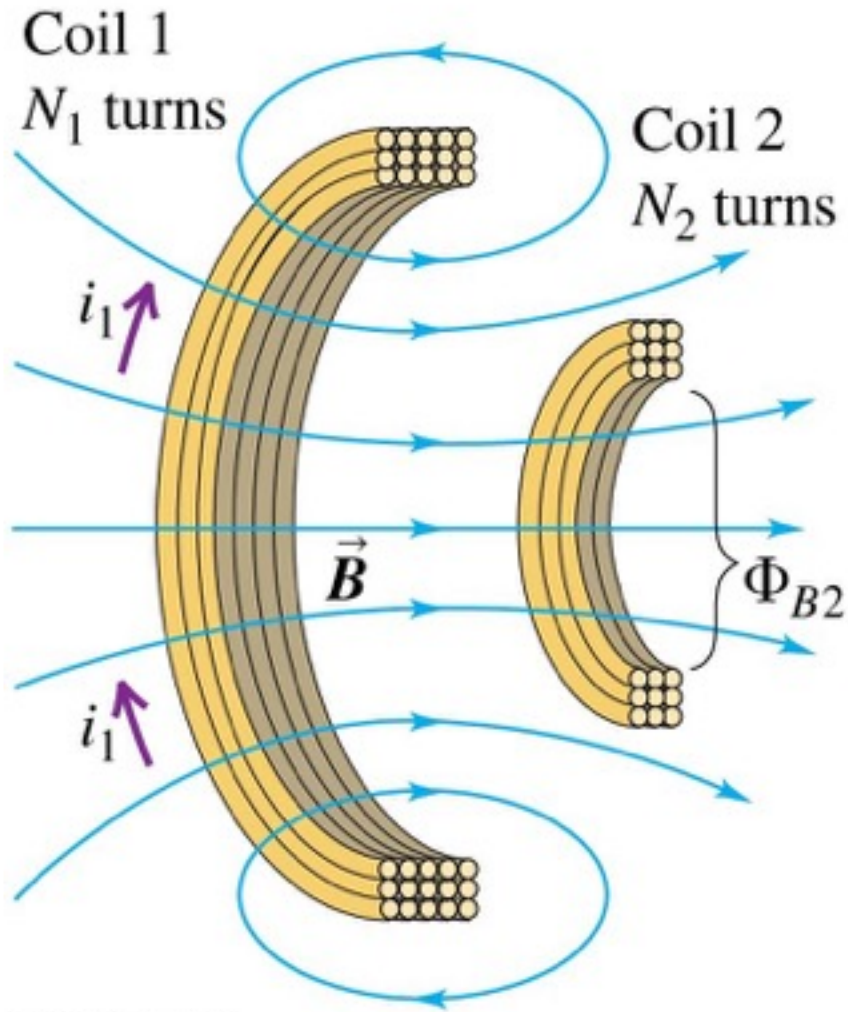
Conduction current through path

Displacement current through path

Mutual inductance

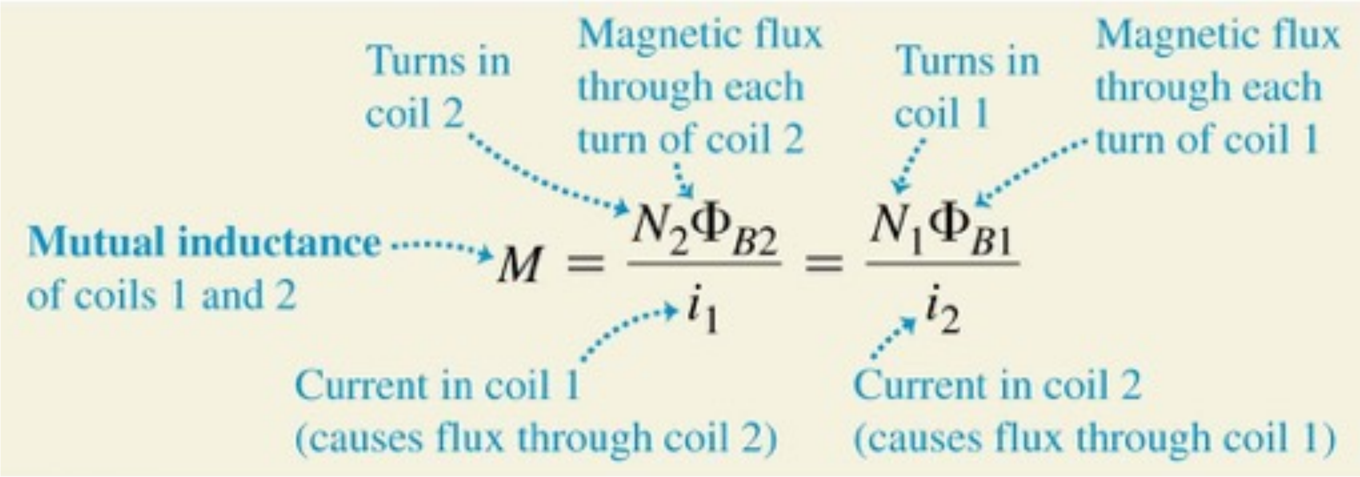
- Consider two neighboring coils of wire, as shown.
- If the current in coil 1 changes, this induces an emf in coil 2, and vice versa.
- The proportionality constant for this pair of coils is called the **mutual inductance**, *M*.

$$\mathcal{E}_2 = -N_2 \frac{d\Phi_{B2}}{dt}$$



Mutual inductance

- The mutual inductance M is:



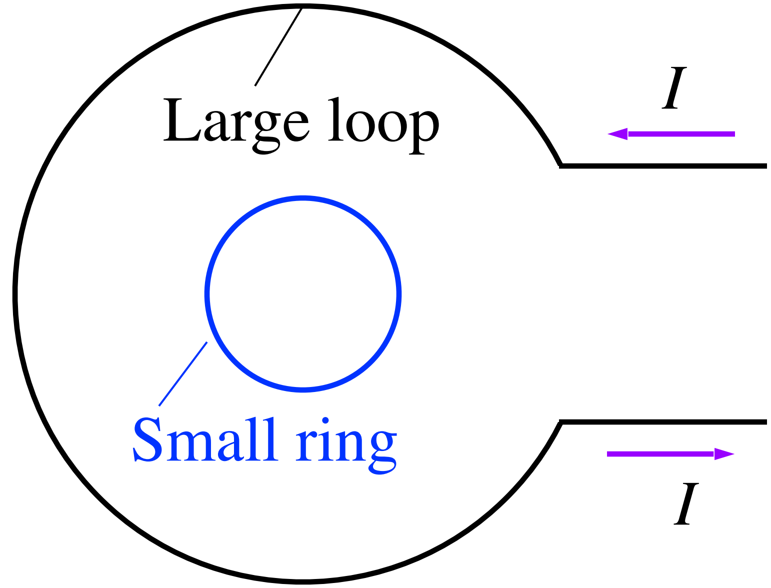
$$M = \frac{N_2 \Phi_{B2}}{i_1} = \frac{N_1 \Phi_{B1}}{i_2}$$

- The SI unit of mutual inductance is called the henry (1 H), in honor of the American physicist Joseph Henry.

$$1\ \text{H} = 1\ \text{Wb/A} = 1\ \text{V} \cdot \text{s/A} = 1\ \Omega \cdot \text{s} = 1\ \text{J/A}^2$$

Q30.1

A small, circular ring of wire (shown in blue) is inside a larger loop of wire that carries a current I as shown. The small ring and the larger loop both lie in the same plane. If I increases, the current that flows in the small ring



A. is clockwise and caused by self-inductance.

B. is counterclockwise and caused by self-inductance.

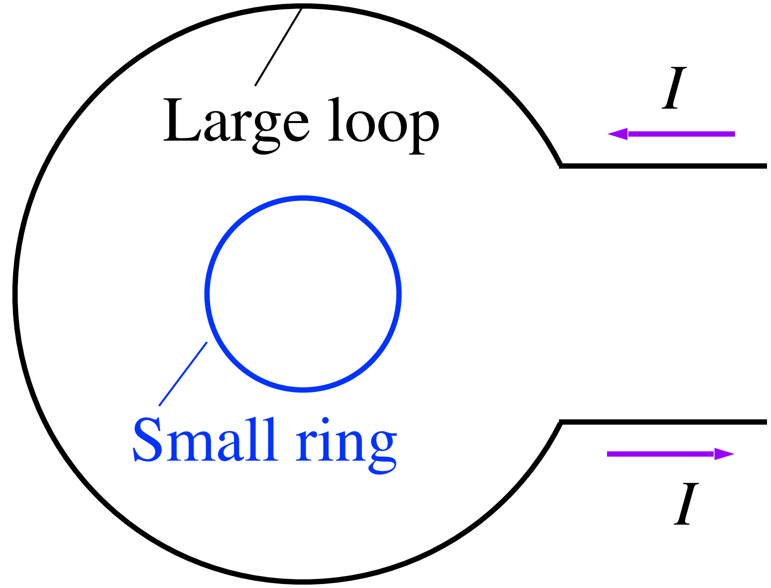
C. is clockwise and caused by mutual inductance.

D. is counterclockwise and caused by mutual inductance.

E. is zero, since the two rings of wire are not connected.

A30.1

A small, circular ring of wire (shown in blue) is inside a larger loop of wire that carries a current *I* as shown. The small ring and the larger loop both lie in the same plane. If *I* increases, the current that flows in the small ring



A. is clockwise and caused by self-inductance.

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✔ C. is clockwise and caused by mutual inductance.

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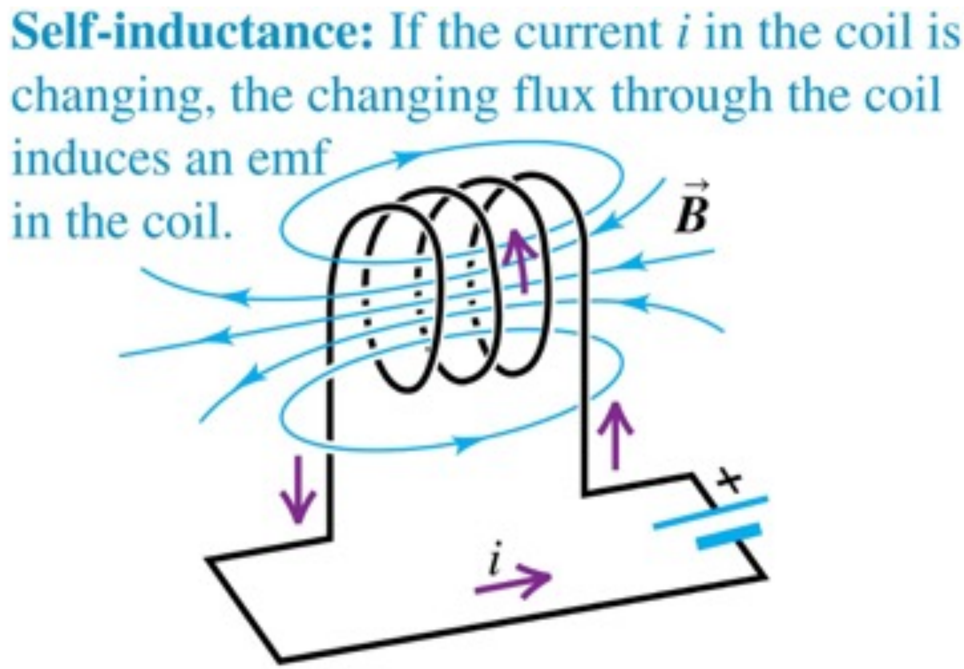
Self-inductance

- Any circuit with a coil that carries a varying current has a **self-induced emf**.
- We define the self-inductance L of the circuit as:



Self-inductance (or **inductance**) of a coil

$$L = \frac{N\Phi_B}{i}$$

- N: Number of turns in coil
- Φ_B: Flux due to current through each turn of coil
- i: Current in coil

Inductors and lightning strikes

- If lightning strikes part of an electrical power transmission system, it causes a sudden spike in voltage that can damage the components of the system.
- To minimize these effects, large **inductors** are incorporated into the transmission system.
- These use the principle that an inductor opposes and suppresses any rapid changes in the current.

Inductors as circuit elements

- In the circuit shown, the box enables us to control the current i in the circuit.
- The potential difference between the terminals of the inductor L is:

$$V_{ab} = V_a - V_b = L\frac{di}{dt}$$