SUNDAY Nov 17: SECOND HOUR EXAM
6:10-7:30 PM in SEC 111 (Ch. 25-29) -- no
recitations the previous Friday and following
Monday

Includes material on homework due next Tuesday
Exam review in class next week Thursday

COME DOWN AND HAVE FUN WITH THE
changing MAGNETIC FIELDS and their surprising
effects!
New law that shows how CHANGES in magnetic field create this new kind of electric field

**FARADAY’S LAW**

\[ \int_C \vec{E} \cdot d\vec{s} = -\frac{d}{dt} \int_S \vec{B} \cdot d\vec{A} \]

line integral surface integral (magnetic flux)

Loop C is the boundary of the surface S
\[ \int_c \vec{E} \cdot d\vec{s} = -\frac{d}{dt} \int_s \vec{B} \cdot d\vec{A} \]

The math is enough to figure out which way the E field is pointing around the loop

OR

Use “Lenz’s law” to find direction of induced current: “Any induced current would create an additional magnetic flux that OPPOSES \( \frac{d\Phi}{dt} \)”

To use Lenz’s law, need to know the magnetic flux created by a current in the loop!
To use Lenz’s law, need to know the magnetic flux created by a current in the loop!

Magnetic field inside the loop due to clockwise $i$ is into the page

$\hat{n}$ points out of page

Magnetic flux due to current in loop is negative
To use Lenz’s law, need to know the magnetic flux created by a current in the loop!

Magnetic field inside the loop due to counterclockwise i is \( \text{out of the page} \)

Magnetic flux due to current in loop is \( \text{positive} \)
\[ \Phi = B(t)A \]

Current flows in loop as if a battery were included

\[ \mathcal{E} = -\frac{d\Phi}{dt} \]

wire of resistance \( R \) made into a loop

\( \hat{n} \) points out of page
\[ \Phi = B(t)A \]

Current flows in loop as if a battery were included

\[ \mathcal{E} = -\frac{d\Phi}{dt} \]

“induced emf”

- \( B(t) \) out of page increasing with time
- Wire of resistance \( R \) made into a loop
- Point out of page
- Point \( \hat{n} \) points out of page
$\Phi = B(t)A$ increasing

Current flows in loop as if a battery were included

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

“induced emf”

direction of induced current: current flowing in loop creates a negative flux

This OPPOSITES $\frac{d\Phi}{dt}$

LENZ’S LAW
B(t) out of page and increasing with time.
Which direction does the induced current flow?
(A) Clockwise
(B) Counterclockwise
(C) The current is zero

The induced current produces a magnetic flux that OPPOSES THE CHANGE.
B(t) out of page and increasing with time. Which direction does the induced current flow?
(A) Clockwise  
(B) Counterclockwise  
(C) The current is zero

The induced current produces a magnetic flux that OPPOSES THE CHANGE.
wire of resistance R made into a loop
\( \hat{n} \) points out of page

CHECKPOINT 1

The graph gives the magnitude \( B(t) \) of a uniform magnetic field that exists throughout a conducting loop, with the direction of the field perpendicular to the plane of the loop. Rank the five regions of the graph according to the magnitude of the emf induced in the loop, greatest first.
New law that shows how CHANGES in magnetic field create this new kind of electric field

**FARADAY’S LAW**

\[
\oint_C \mathbf{E} \cdot d\mathbf{s} = -\frac{d}{dt} \int_S \mathbf{B} \cdot d\mathbf{A}
\]

line integral surface integral (magnetic flux)

Loop C is the boundary of the surface S
Computing flux for a given magnetic field and given surface $S$

\[ \Phi_B = \int \vec{B} \cdot d\vec{A} \]

when magnetic field is not uniform or surface is not flat
\( \mathbf{B}(r) \), surface \( S \)

Magnetic flux through a surface

\[
\Phi_B = \int \mathbf{B} \cdot d\mathbf{A}
\]

Flat surface, \( B \) uniform on each part:

\[
\Phi = (\mathbf{B}_1 \cdot \hat{n})A_1 + (\mathbf{B}_2 \cdot \hat{n})A_2
\]
What can we say about the flux through the green wire loop?
What can we say about the flux through the green wire loop?
If \( i \) is increasing with time, what can we say about the current through the green wire loop?
If \( i \) is increasing, is there an electric field at point \( P \)?
\[ \int_c \vec{E} \cdot d\vec{s} = -\frac{d}{dt} \int_s \vec{B} \cdot d\vec{A} \]

Current in wire loop is induced by electric field created by the changing magnetic flux

Electric field is created whether a wire loop is there or not
If $B(t) = a \ t$, what is $E(r)$?

$E(r) \ 2\pi r = - \frac{d}{dt} (a \ t \ \pi \ r^2) = -a \ \pi \ r^2$

$E(r) = -a \ r / 2$

(negative means pointing clockwise)
Simplest way to change the flux:
Change the magnetic field, keeping the loop fixed

Example: pass a bar magnet through the loop
OTHER WAYS TO CHANGE THE MAGNETIC FLUX THROUGH A LOOP

Move the loop into or out of a region with B field

Rotate the loop in a uniform field:
angle between B and n changes, so $\Phi$ changes

Change the size of the loop in a uniform field
Examples:
pull the loop closed
a moving metal rod on U-shaped wire
Move the loop into or out of a region with B field
With the normal vector out of the page, the flux is negative and increasing (becoming less negative). The induced current flows clockwise to produce a negative flux, opposing this change.
OTHER WAYS TO CHANGE THE MAGNETIC FLUX THROUGH A LOOP

Move the loop into or out of a region with B field

Rotate the loop in a uniform field:
angle between B and n changes, so $\Phi$ changes
https://www.youtube.com/watch?v=wchiNm1CgC4

Change the size of the loop in a uniform field
Examples:
pull the loop closed
a moving metal rod on U-shaped wire
Figure 30-24 shows two circuits in which a conducting bar is slid at the same speed $v$ through the same uniform magnetic field and along a U-shaped wire. The parallel lengths of the wire are separated by $2L$ in circuit 1 and by $L$ in circuit 2. The current induced in circuit 1 is counterclockwise. (a) Is the magnetic field into or out of the page? (b) Is the current induced in circuit 2 clockwise or counterclockwise? (c) Is the emf induced in circuit 1 larger than, smaller than, or the same as that in circuit 2?
In Fig. 30-50, a metal rod is forced to move with constant velocity \( \vec{v} \) along two parallel metal rails, connected with a strip of metal at one end. A magnetic field of magnitude \( B = 0.350 \) T points out of the page. (a) If the rails are separated by \( L = 25.0 \) cm and the speed of the rod is 55.0 cm/s, what emf is generated? (b) If the rod has a resistance of 18.0 \( \Omega \) and the rails and connector have negligible resistance, what is the current in the rod? (c) At what rate is energy being transferred to thermal energy?
If you have a wire loop, there is induced current.

Induced current feels a force from the magnetic field.
Move the loop into or out of a region with B field

$\Phi$ Negative increasing (less negative)

Induced current is clockwise

Magnetic force on induced current in loop opposite to direction of motion