PHY294H

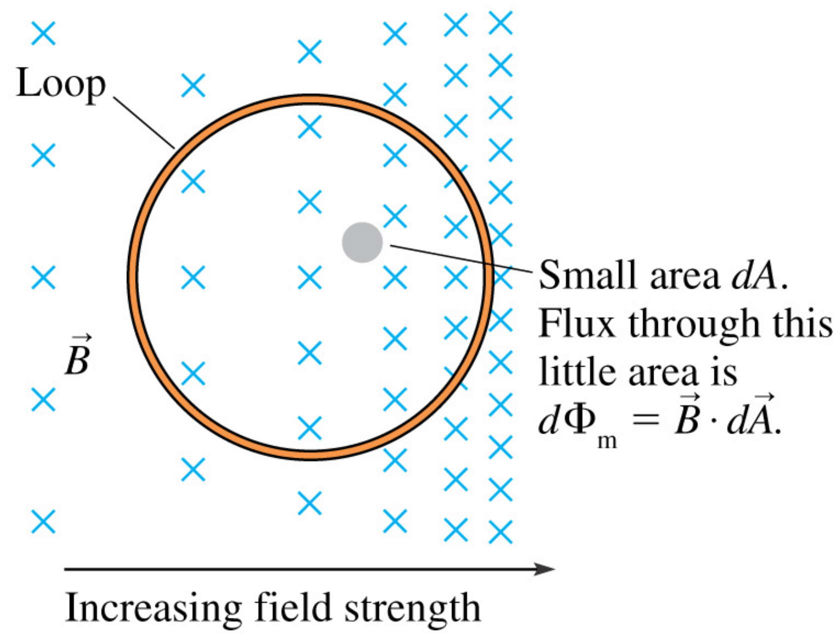
- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **Help-room hours: 12:40-2:40 Monday (note change); 3:00-4:00 PM Friday**
  - **hand-in problem for Wed Mar. 16: 33.54**
- Quizzes by iclicker (sometimes hand-written)
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so
- **Have a great Spring Break!**

Flux in non-uniform field

- The situations we've been considering so far have had a uniform field, so it's easy to calculate the flux
- But we may encounter situations where the field is not uniform, and we can still calculate the flux

$$d\Phi_B = \vec{B} \bullet d\vec{A}$$

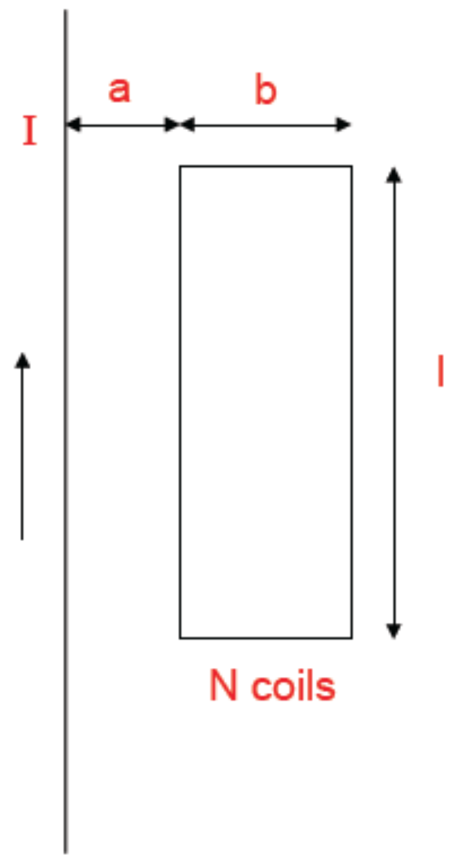
$$\Phi_B = \int \vec{B} \bullet d\vec{A}$$



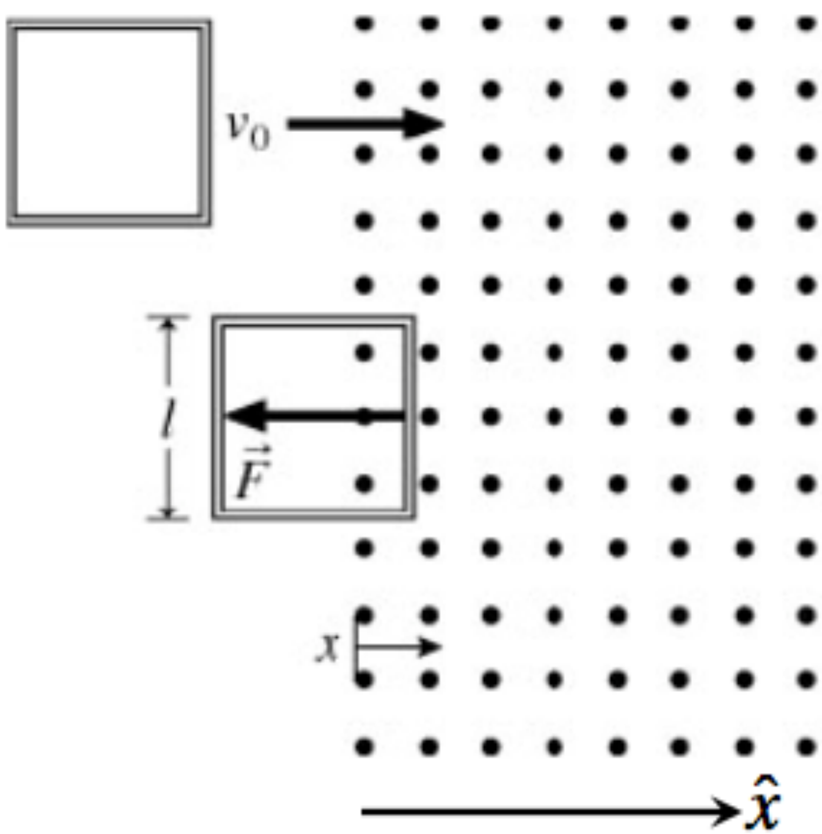
Example

- N=100
- a=b=5 cm
- l=20 cm
- I=50 A

What if I=(50A)*t, i.e. the current changes with time. The magnetic flux will change with time and there will be an emf induced.



An example of eddy current braking: A square loop with length l is shot with velocity v_0 into a uniform B field that is perpendicular to the plane of the loop. The loop has mass m, resistance R and enters the B field at time t = 0 s. Assume that the loop is moving to the right along the x-axis and that the B field begins at x = 0 m.



1) Find an expression for the loop's velocity as a function of time as it enters the B field. Ignore gravity and assume that the back edge of the loop doesn't enter the B field.

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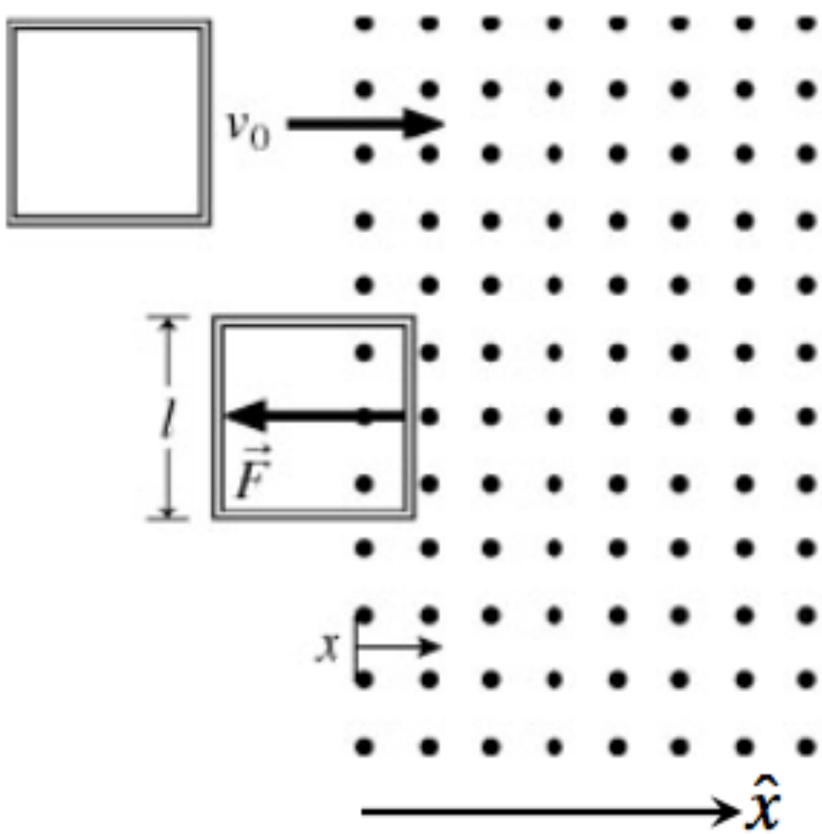

1) Find an expression for the loop's velocity as a function of time as it enters the B field. Ignore gravity and assume that the back edge of the loop doesn't enter the B field.

$$v = v_0 e^{-\frac{l^2 B^2}{mR} t}$$

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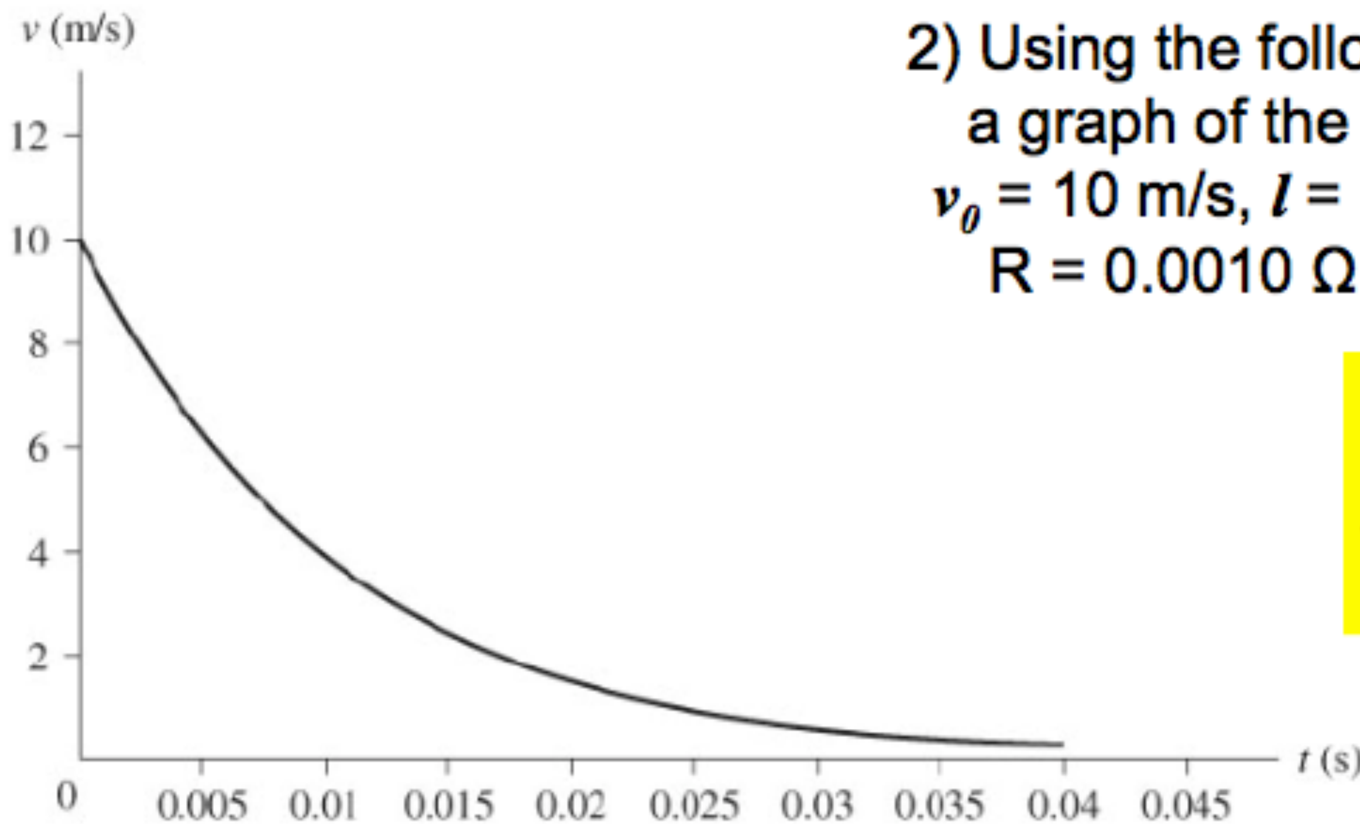


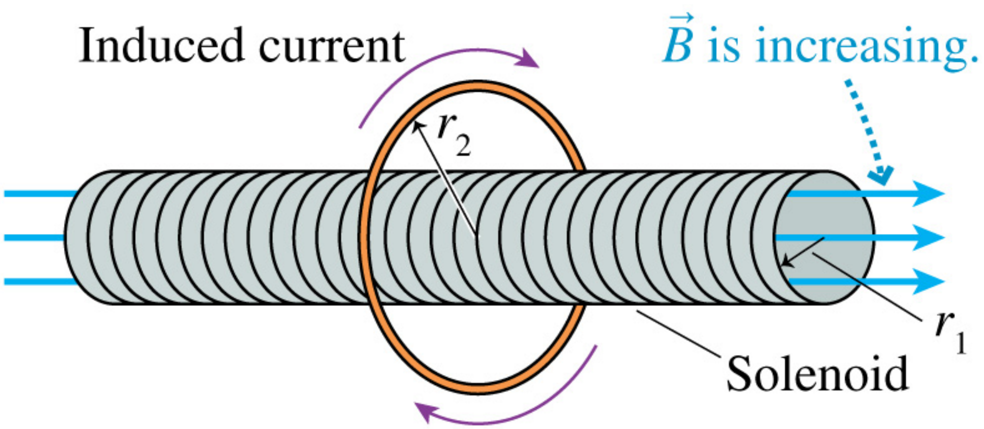
2) Using the following values make a graph of the velocity vs time:
v_0 = 10 m/s, ***l*** = 10 cm, m = 1.0 g,
R = 0.0010 Ω and B = 0.10 T

$$v = v_0 e^{-\frac{l^2 B^2}{mR} t}$$

Note that the loop stops in less than 0.05 seconds

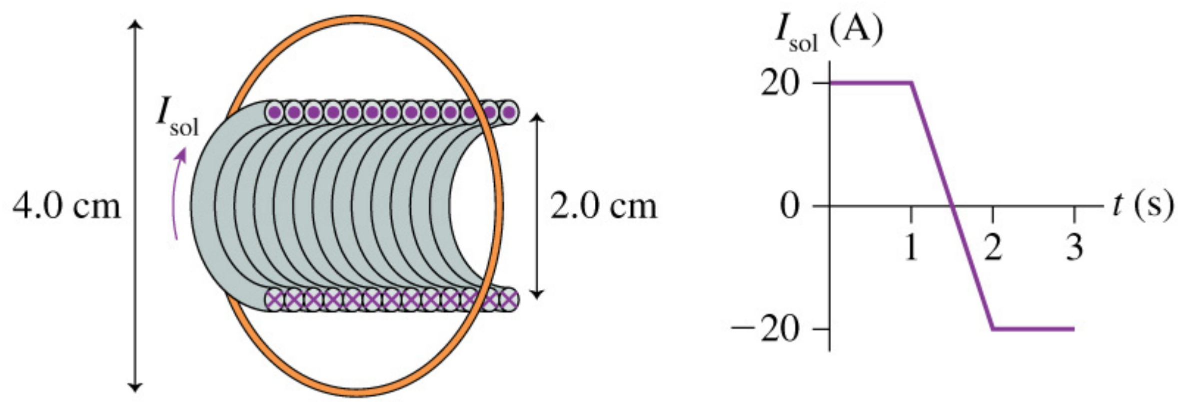
Now to a puzzle

- Suppose I have a conducting coil outside a perfect solenoid
- The current inside the solenoid is increasing with time resulting in an increasing magnetic field inside the solenoid
- There is no field outside the solenoid
- Is there a current induced in the coil?
- If so, how does the coil know the magnetic field inside the solenoid is changing?



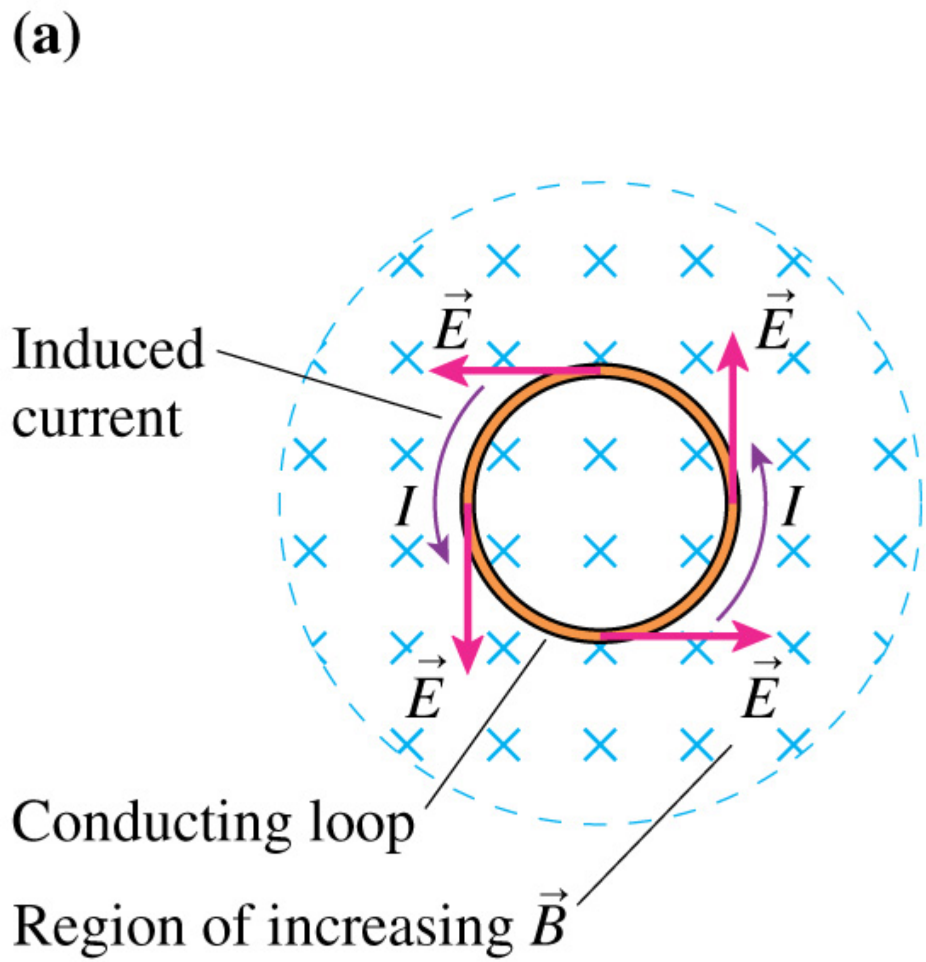
Example

- A 4.0 cm diameter loop with resistance 0.01 Ω surrounds a 2.0 cm diameter solenoid. The solenoid is 10 cm long, has 100 turns, and carries the current shown in the graph. A positive current is CCW when seen from the left. Determine the current in the loop as a function of time.



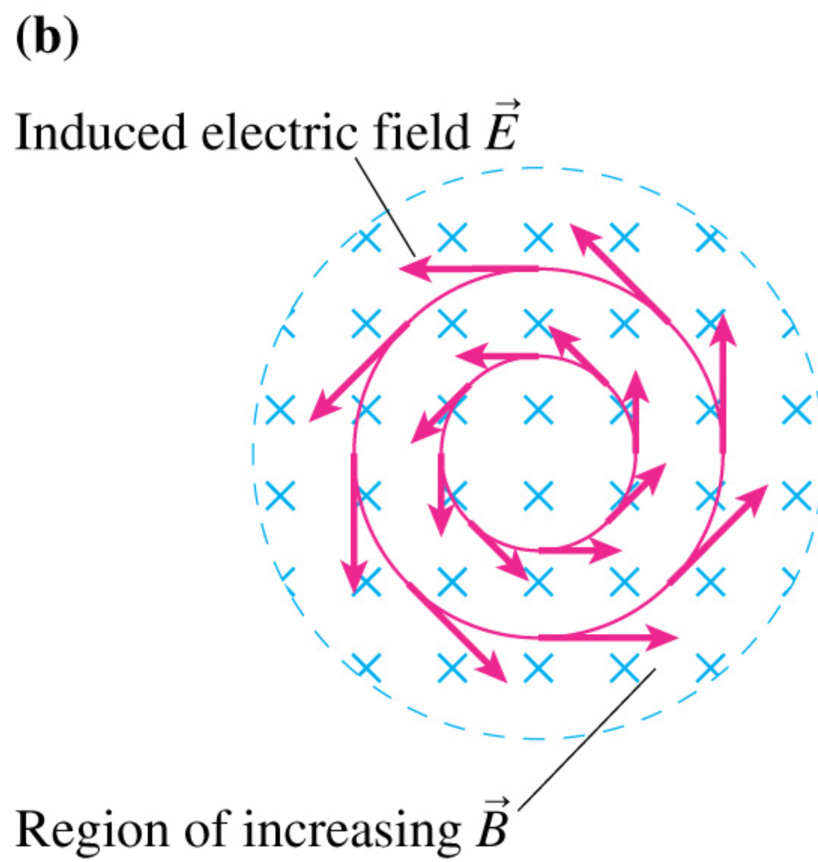
Induced electric field

- Suppose I have a conducting loop in a region of increasing magnetic field
- There’s a current induced in a direction to oppose the increase in magnetic field
- But if there’s a current flowing, there must be an electric field responsible, an electric field tangent to the loop
- This electric field is caused by the changing magnetic field and is called an induced electric field

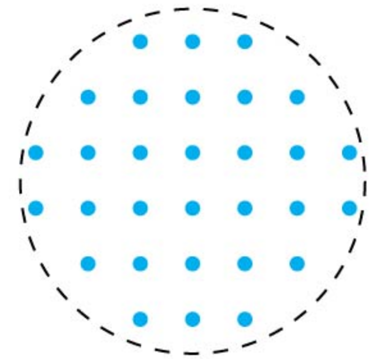


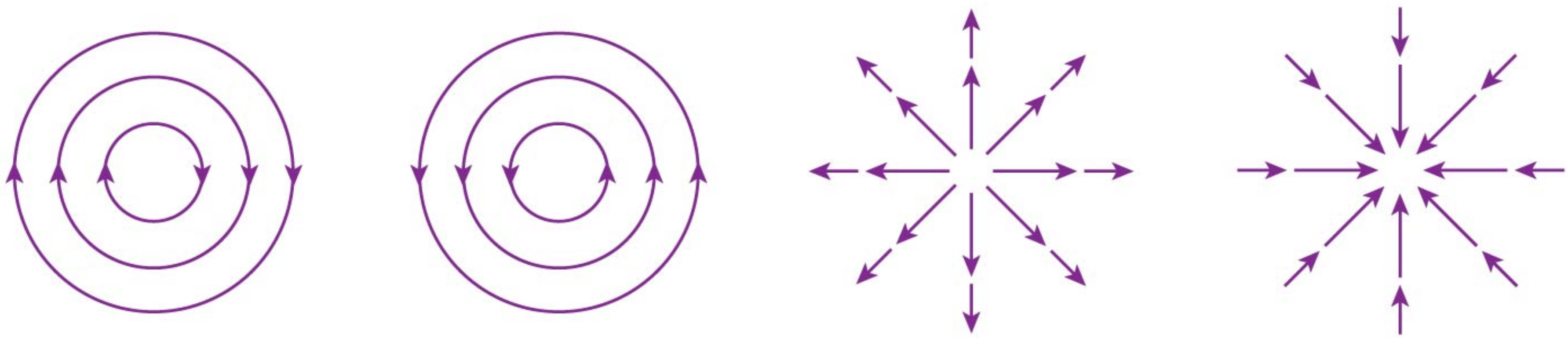
Induced electric field

- Suppose I lose the conductor but otherwise keep the situation the same
- There's still an induced electric field (pinwheel pattern) caused by the changing magnetic field
  - changing magnetic fields create electric fields
- Note that the electric field lines do not originate on positive charges nor terminate on negative charges
- It's a *non-Coulomb* electric field
  - as opposed to a Coulomb electric field
  - both exert a force on electric charges



The magnetic field is decreasing. Which is the induced electric field?





A. B. C. D.

E. There’s no induced field in this case.

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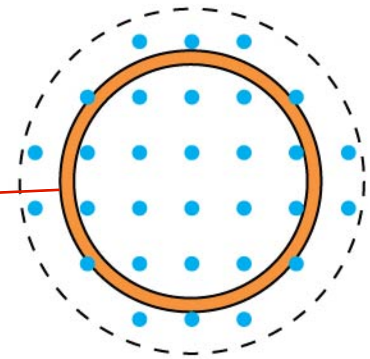
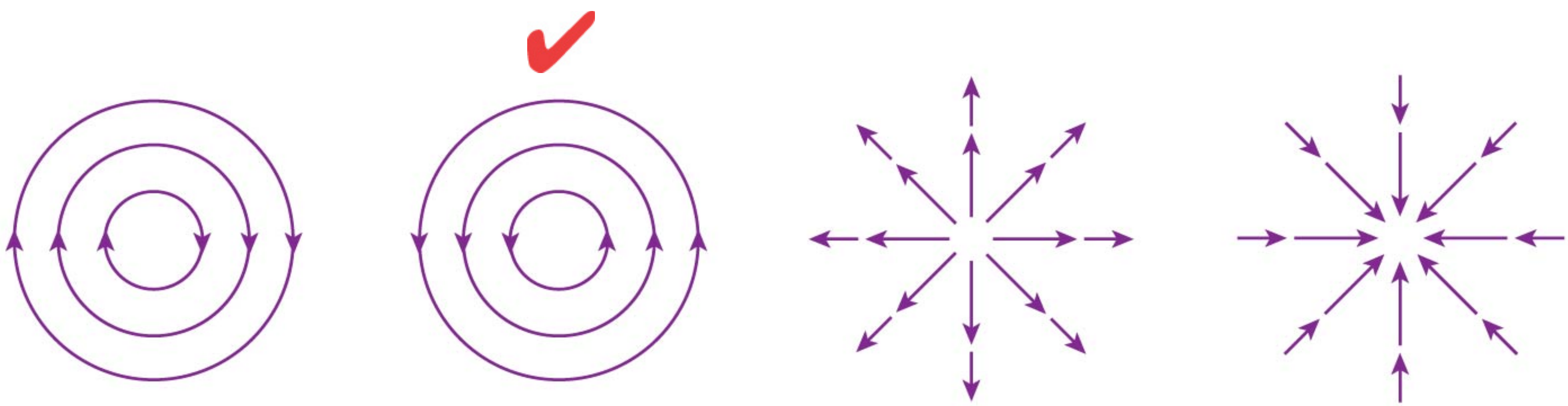


The field is the same direction as induced current would flow if there were a loop in the field.



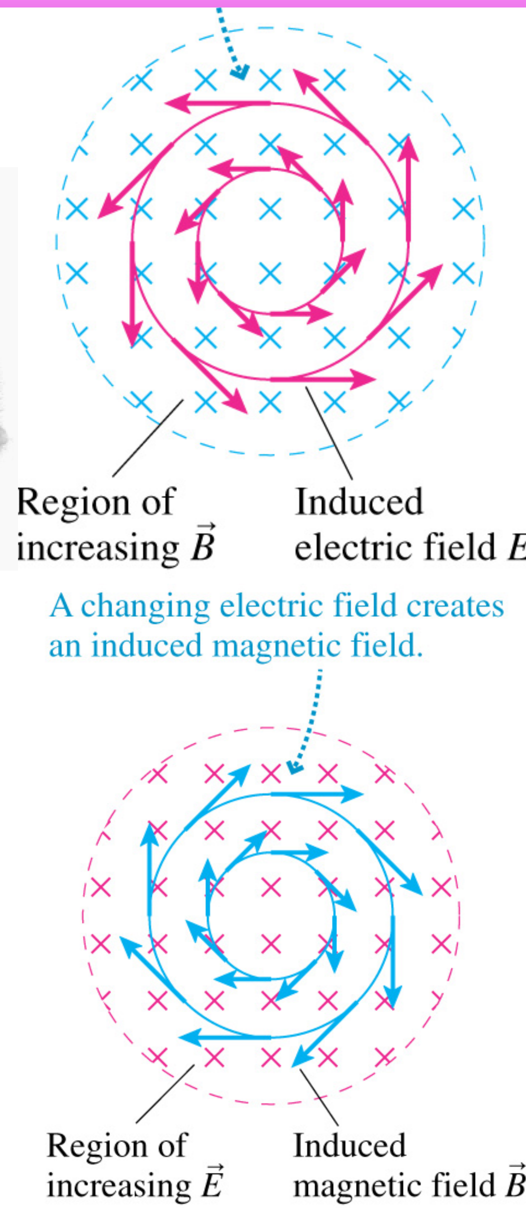
A. B. C. D.

E. There's no induced field in this case.

Hmm

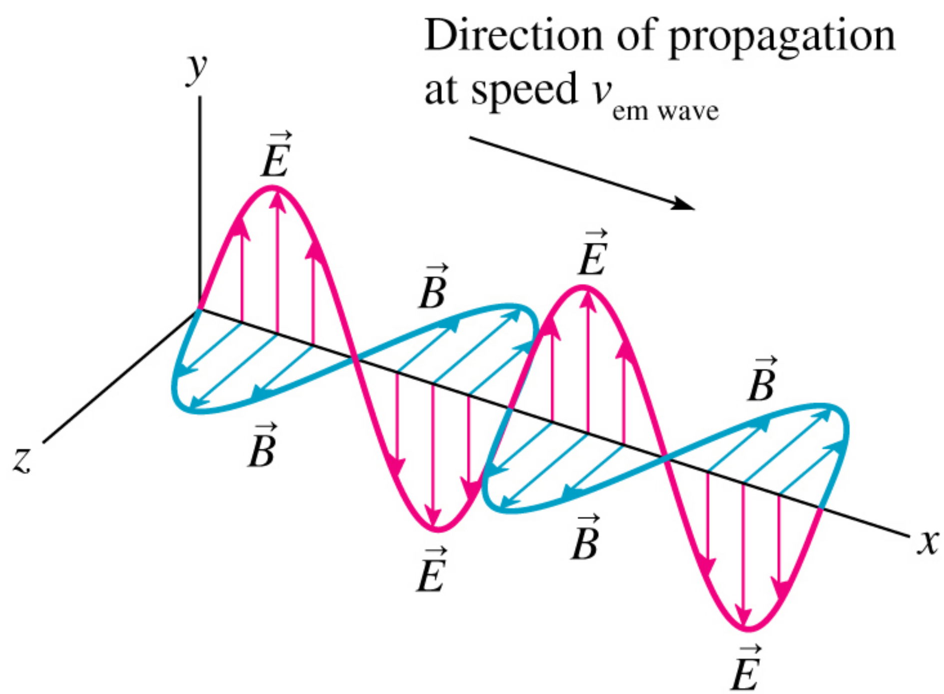
- A changing magnetic field creates an electric field

- To complete the symmetry, Maxwell hypothesized that a changing electric field also creates a magnetic field
  - an induced magnetic field not tied to currents
  - oriented in the opposite direction as the induced electric field
  - still just an inspired hypothesis by Maxwell



Electromagnetic waves

- Maxwell: Could self-sustaining electric and magnetic fields be established?
  - changing magnetic fields creating electric fields
  - changing electric fields creating magnetic fields
  - fields continually created through induction without any reliance on charges or currents
- Maxwell predicted that the waves would travel with a speed



$$v_{emwave} = \frac{1}{\sqrt{\mu_o e_o}} = 3X10^8 \, m/s$$

- Mathematics in the next chapter

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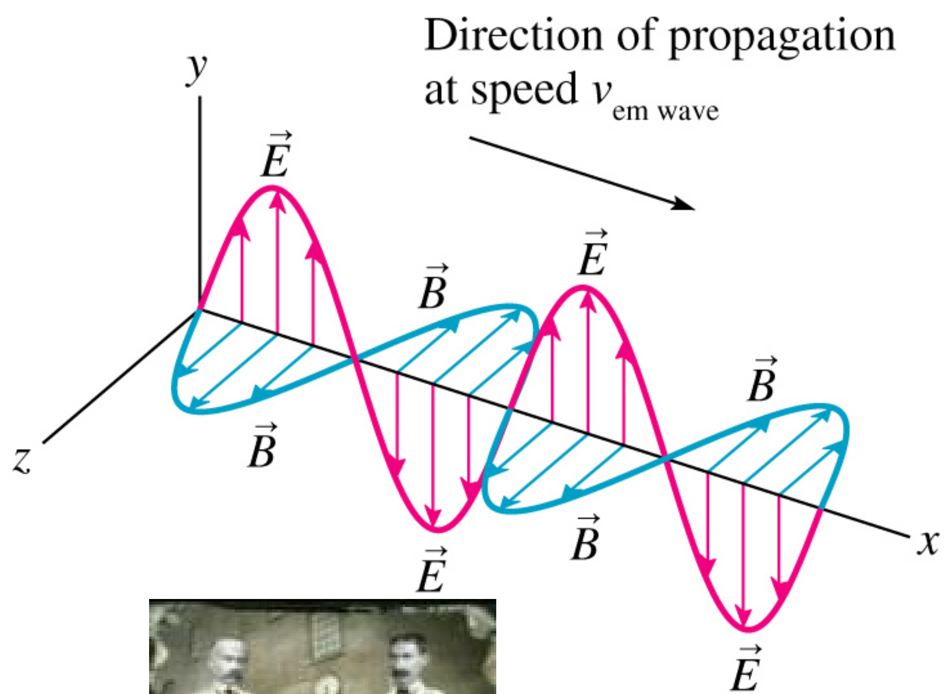


Brilliant!

$$v_{emwave} = \frac{1}{\sqrt{\mu_o e_o}} = 3X10^8 \, m/s$$

Maxwell’s chair

Me sitting in Maxwell's chair

Me sitting in Sheldon's chair

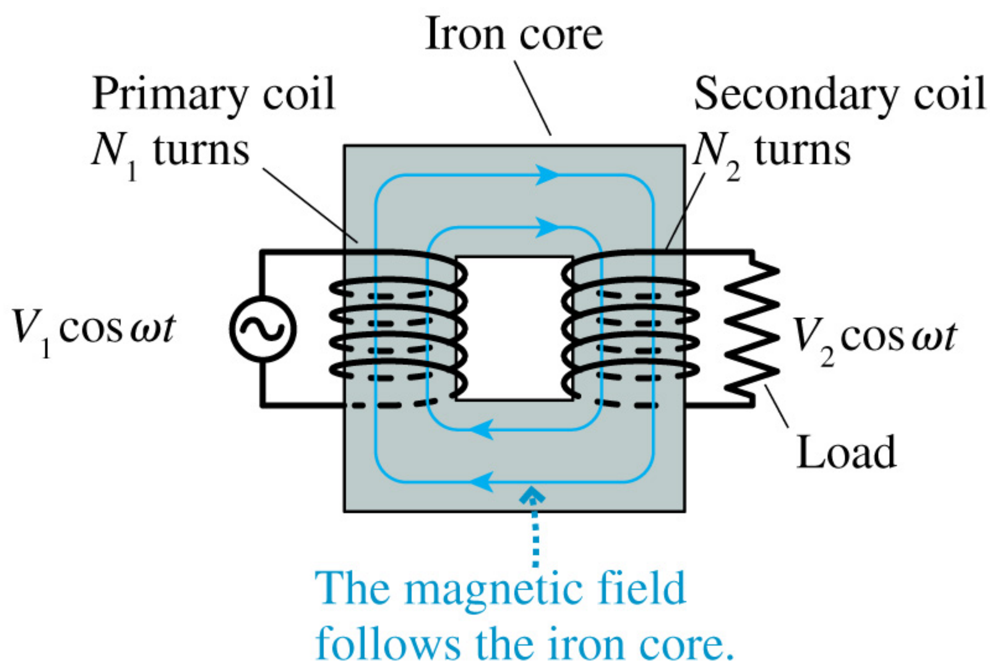
Brilliant!

Transformer

- Two coils are wrapped around an iron core
  - left coil is called the primary coil; has an incident voltage $V_1\cos\omega t$
  - right coil is called the secondary coil
- An alternating current through the first coil causes an oscillating flux through the second coil and thus an induced emf $V_2\cos\omega t$
  - total flux through each coil depends on the number of turns

$$V_2 = \frac{N_2}{N_1} V_1$$

- Depending on the ratio of N_2/N_1, V_2 can be transformed to a higher voltage than V_1, or to a lower voltage



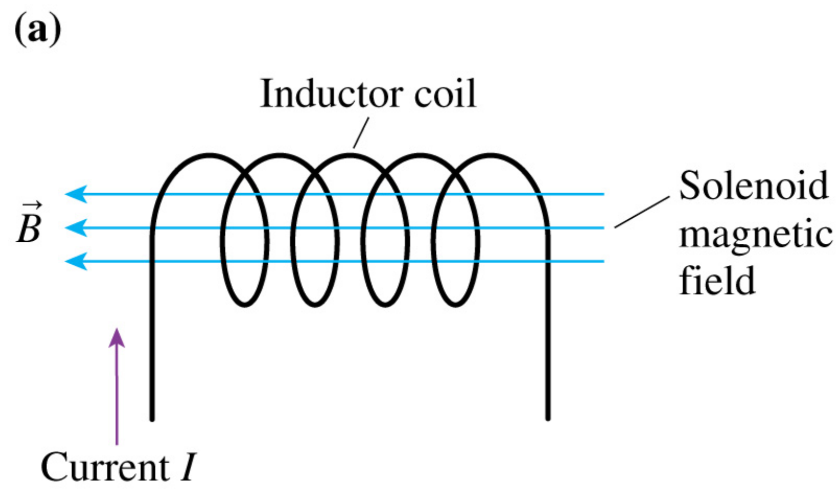
Higher voltages are usually used for long distance power transmission. Why?


SCIENCESOURCE

Inductors

- A capacitor is a good way of producing a uniform electric field
  - it also stores energy in the form of the electric field
- A solenoid is a useful way of producing a uniform magnetic field
  - and we'll find can also store energy in the form of the magnetic field
- Define the inductance L of a circuit element as the ratio of the magnetic flux it holds to the current flowing through it

$$L = \frac{N\phi_m}{I}$$



The larger the inductance, the larger flux can be held for a given current. Remember, the larger the capacitance, the larger charge that can be held for a a given voltage.

Unit of inductance is the Henry
1H = 1 Tm^2/A

Inductors in circuits

- We'll encounter inductors in circuits in the future
- The voltage drop across an inductor is proportional to the rate of change of current though it (and can be large)