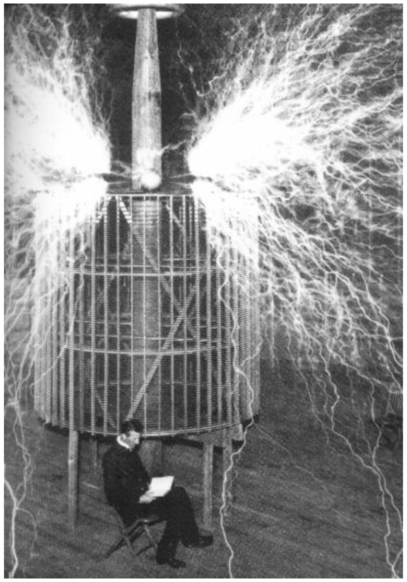
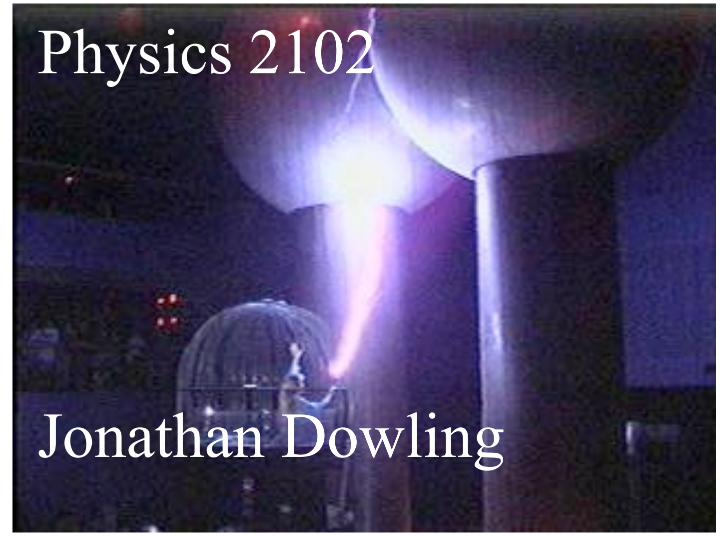





# Physics 2102
# Lecture 19

## Ch 30:
## Inductors and RL Circuits

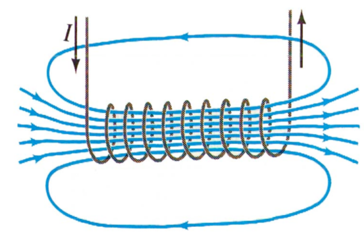
Nikolai Tesla

# What are we going to learn?
# A road map

- Electric *charge*
  ➔ Electric *force* on other electric charges
  ➔ Electric *field*, and electric *potential*
- Moving electric charges : current
- Electronic circuit components: batteries, resistors, capacitors
- Electric currents ➔ Magnetic field
  ➔ Magnetic force on moving charges
- Time-varying magnetic field ➔ Electric Field
- More circuit components: inductors.
- Electromagnetic waves ➔ light waves
- Geometrical Optics (light rays).
- Physical optics (light waves)

# Inductors: Solenoids

Inductors are with respect to the magnetic field what capacitors are with respect to the electric field. They "pack a lot of field in a small region". Also, the higher the current, the higher the magnetic field they produce.



Capacitance → how much **potential** for a given charge: **Q=CV**

Inductance → how much **magnetic flux** for a given current: **Φ=L*i***

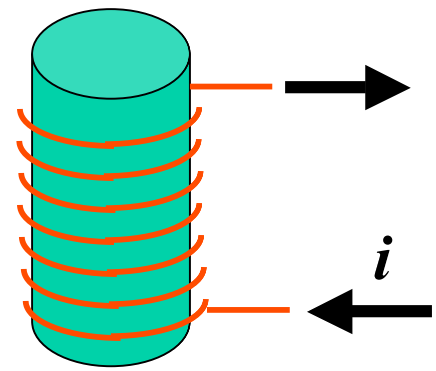
Using Faraday's law: $$EMF = -L\frac{di}{dt}$$

Units: $$[L] = \frac{\mathrm{Tesla}\cdot \mathrm{m}^2}{\mathrm{Ampere}} \equiv \mathrm{H}\ \ (\mathrm{Henry})$$

Joseph Henry
(1799-1878)

# "Self"-Inductance of a solenoid

- Solenoid of cross-sectional area ***A***, length ***l***, total number of turns ***N***, turns per unit length ***n***
- Field inside solenoid = $\mu_0 n i$
- Field outside ~ 0



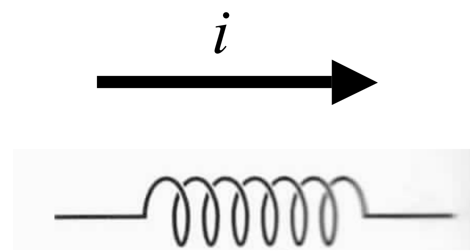

$$\Phi_B = NAB = NA\mu_0 ni = Li$$

L = "inductance" $= \mu_0 NAn = \mu_0 \dfrac{N^2}{l} A$

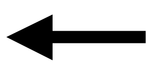
$$EMF = -L\frac{di}{dt}$$

# Example

- The current in a 10 H inductor is decreasing at a steady rate of 5 A/s.
- If the current is as shown at some instant in time, what is the magnitude and direction of the induced EMF?



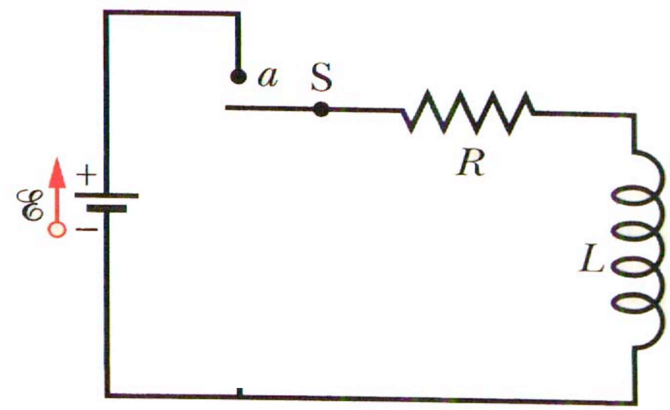

(a) 50 V 

(b) 50 V 

- Magnitude = (10 H)(5 A/s) = 50 V
- Current is <u>decreasing</u>
- Induced emf must be in a direction that OPPOSES this change.
- So, induced emf must be in same direction as current

# The RL circuit

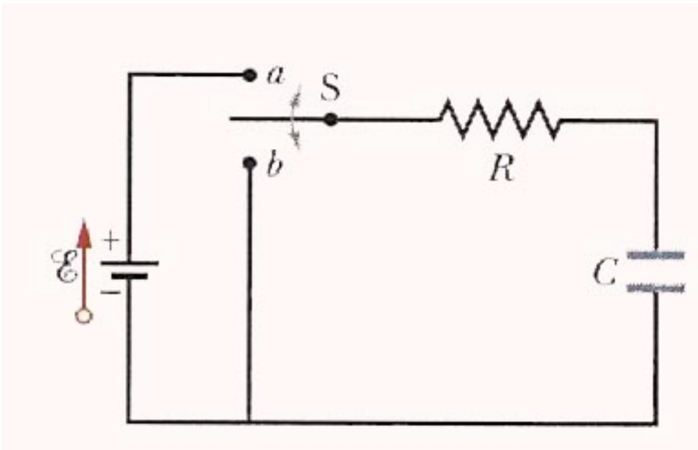
- Set up a single loop series circuit with a battery, a resistor, a solenoid and a switch.
- Describe what happens when the switch is closed.
- Key processes to understand:
  - What happens JUST AFTER the switch is closed?
  - What happens a LONG TIME after switch has been closed?
  - What happens in between?

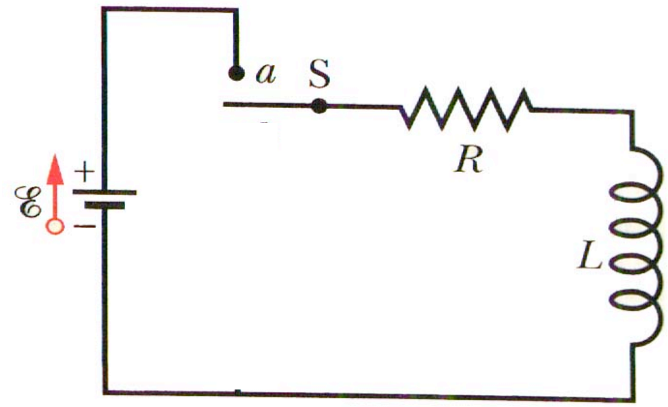



<u>Key insights:</u>
- If a circuit is not broken, one cannot change the CURRENT in an inductor instantaneously!
- If you wait long enough, the current in an RL circuit stops changing!

**At t=0, a capacitor acts like a wire; an inductor acts like a broken wire.**
**After a long time, a capacitor acts like a broken wire, and inductor acts like a wire.**

# RL circuits




In an RC circuit, while charging, Q = CV and the loop rule mean:

- charge increases from 0 to CE
- current decreases from E/R to 0
- voltage across capacitor increases from 0 to E

In an RL circuit, while "charging" (rising current), emf = Ld*i*/dt and the loop rule mean:

- magnetic field increases from 0 to B
- current increases from 0 to E/R
- voltage across inductor decreases from –E to 0

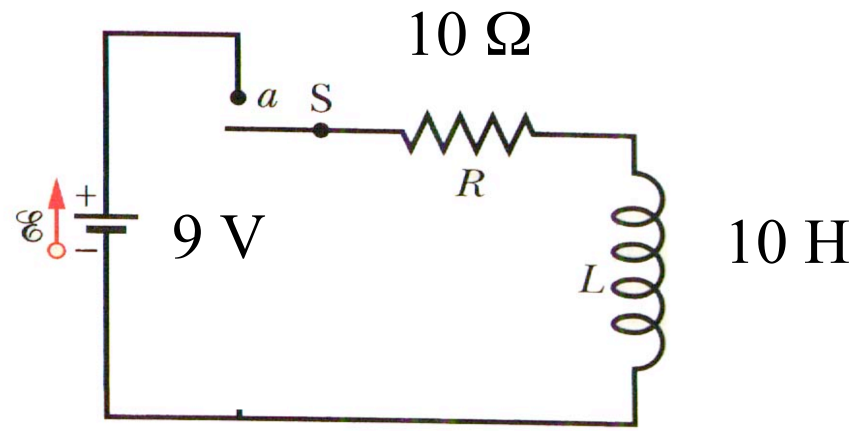
# Example

<u>Immediately</u> after the switch is closed, what is the potential difference across the inductor?

(a) 0 V

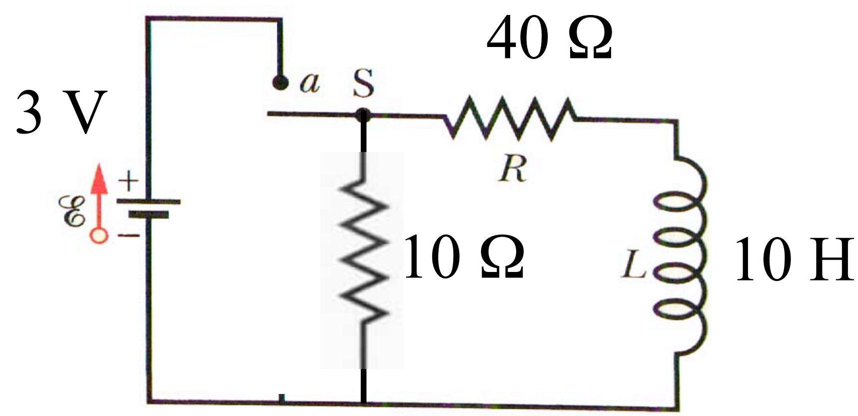
(b) 9 V

(c) 0.9 V




- Immediately after the switch, current in circuit = 0.
- So, potential difference across the resistor = 0!
- So, the potential difference across the inductor = **E** = 9 V!

# Example




- Immediately after the switch is closed, what is the current ***i*** through the 10 Ω resistor?

(a) 0.375 A

(b) 0.3 A

(c) 0

• Immediately after switch is closed, current through inductor = ***0*.**
• Hence, current trhough battery and through 10 Ω resistor is
***i* = (3 V)/(10Ω) = 0.3 A**

- Long after the switch has been closed, what is the current in the 40Ω resistor?

(a) 0.375 A

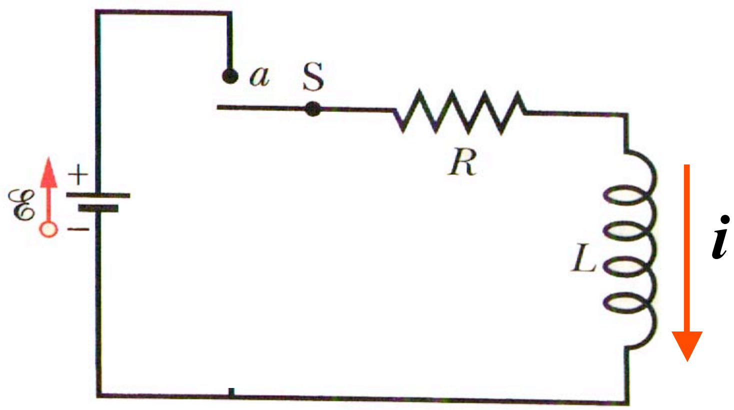
(b) 0.3 A

(c) 0.075 A

- Long after switch is closed, potential across inductor = 0.
- Hence, current through 40**Ω** resistor = (3 V)/(40Ω) = 0.075 A

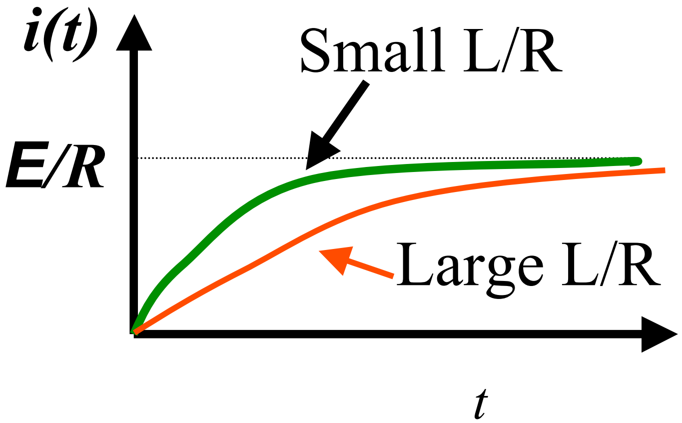
# "Charging" an inductor

- How does the current in the circuit change with time?




$$-iR + \mathcal{E} - L\frac{di}{dt} = 0$$

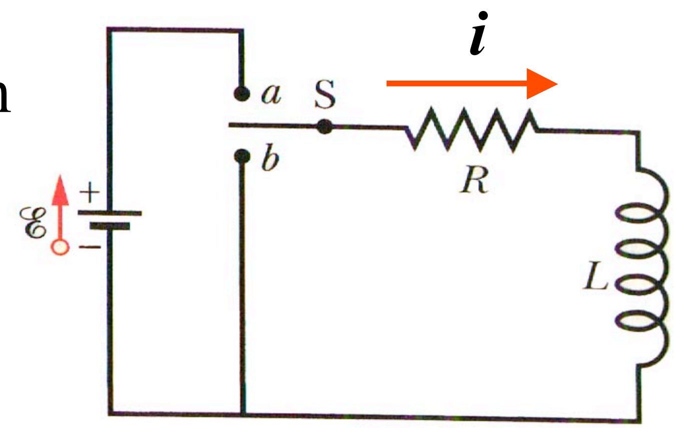
$$i = \frac{\mathcal{E}}{R}\left(1 - e^{-\frac{Rt}{L}}\right)$$




"Time constant" of RL circuit = L/R

# “Discharging” an inductor

The switch is in a for a long time, until the inductor is charged. Then, the switch is closed to b.

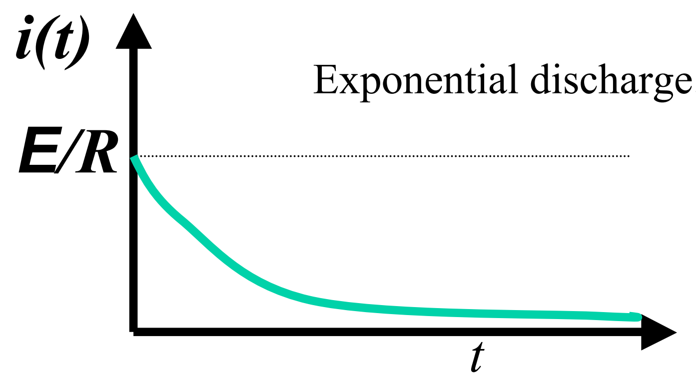



What is the current in the circuit?

Loop rule around the new circuit:

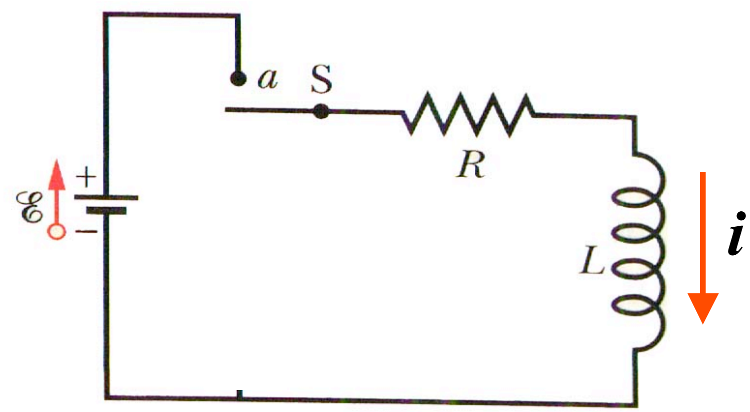
$$iR + L\frac{di}{dt} = 0$$

$$i = \frac{\mathrm{E}}{R} e^{-\frac{Rt}{L}}$$



# Inductors & Energy

- Recall that **capacitors** store energy in an **electric** field
- **Inductors** store energy in a **magnetic** field.




$$\mathcal{E} = iR + L\frac{di}{dt}$$

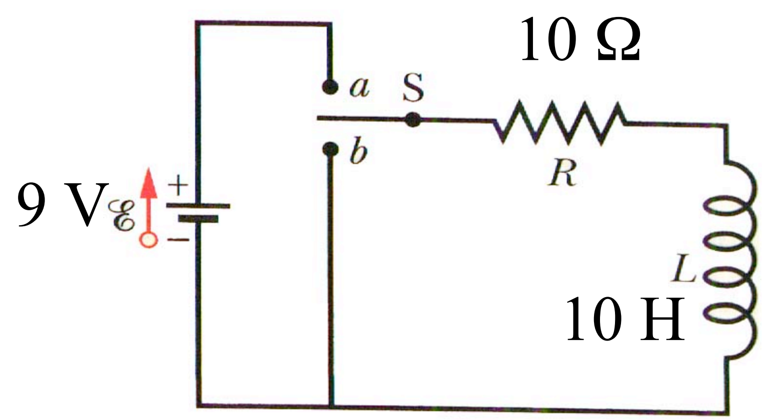
$$(i\mathcal{E}) = (i^2R) + Li\frac{di}{dt} \Rightarrow (i\mathcal{E}) = (i^2R) + \frac{d}{dt}\left(\frac{Li^2}{2}\right)$$

Power delivered by battery = power dissipated by R

+ (d/dt) energy stored in L

# Example

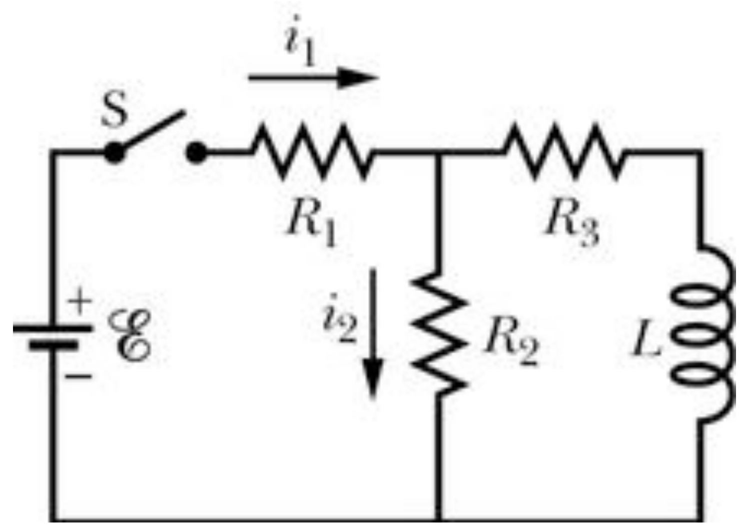
- The switch has been in position "a" for a long time.
- It is now moved to position "b" without breaking the circuit.
- What is the total energy dissipated by the resistor until the circuit reaches equilibrium?

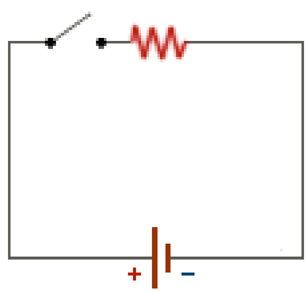



- When switch has been in position "a" for long time, current through inductor = (9V)/(10Ω) = 0.9A.
- Energy stored in inductor = $(0.5)(10\text{H})(0.9\text{A})^2 = 4.05$ J
- When inductor "discharges" through the resistor, all this stored energy is dissipated as heat = 4.05 J.

E=120V, $R_1$=10Ω, $R_2$=20Ω, $R_3$=30Ω, L=3H.

1. What are $i_1$ and $i_2$ immediately after closing the switch?
2. What are $i_1$ and $i_2$ a long time after closing the switch?
3. What are $i_1$ and $i_2$ 1 second after closing the switch?
4. What are $i_1$ and $i_2$ immediaately after reopening the switch?
5. What are $i_1$ and $i_2$ a long time after reopening the switch?

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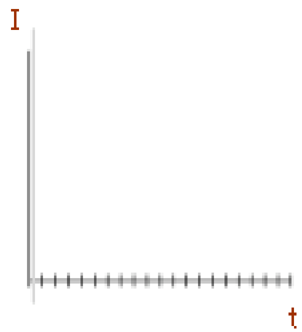
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