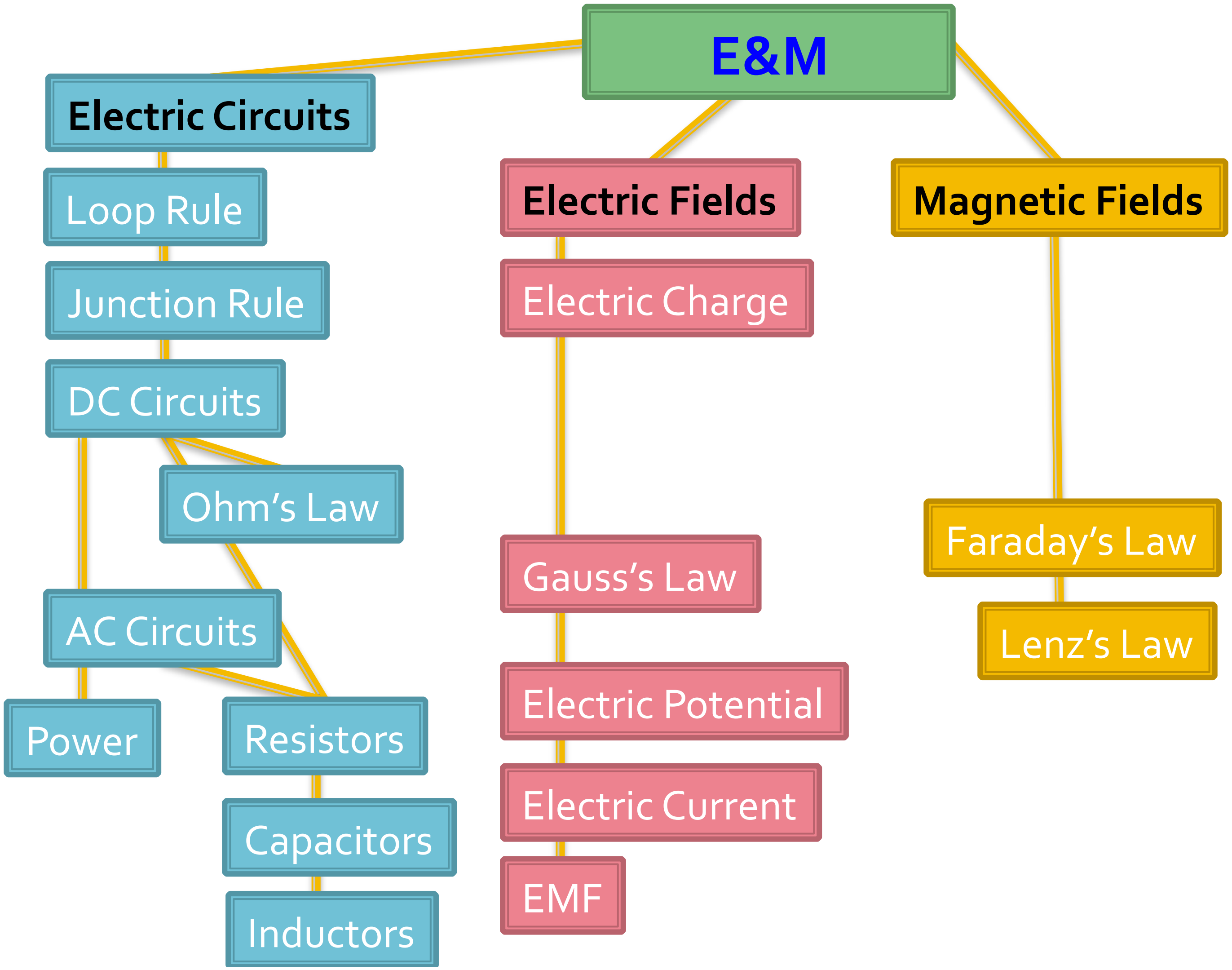
Physics II: 1702
Gravity, Electricity, & Magnetism

Professor Jasper Halekas
Van Allen 70 [Clicker Channel #18]
MWF 11:30-12:30 Lecture, Th 12:30-1:30 Discussion

Circuits



E&M
Electric Circuits
Loop Rule
Junction Rule
DC Circuits
Ohm's Law
AC Circuits
Power
Resistors
Capacitors
Inductors
Electric Fields
Electric Charge
Gauss's Law
Electric Potential
Electric Current
EMF
Magnetic Fields
Faraday's Law
Lenz's Law

Junction Rule

- The sum of currents entering and departing from any junction is **always** zero
- If this were not true, charge would **very** quickly build up that would oppose the non-equilibrium current

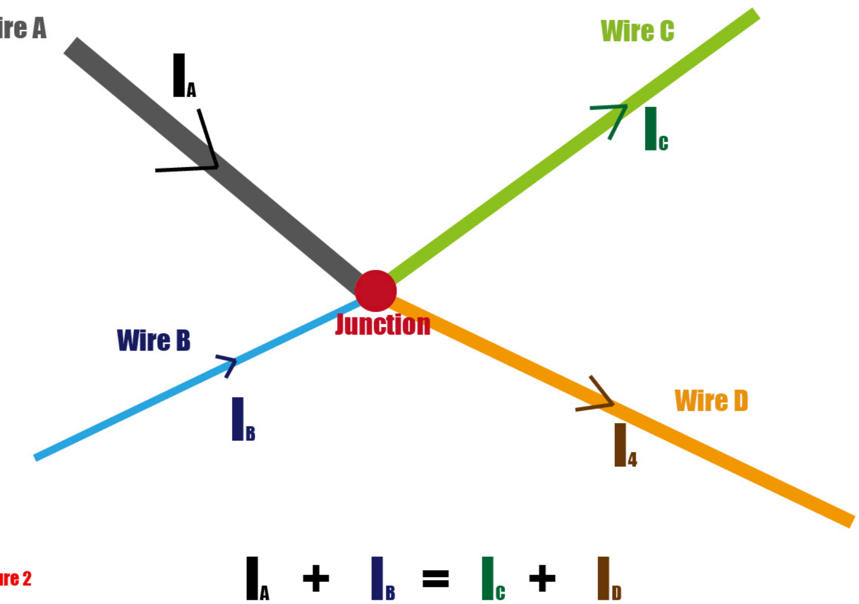
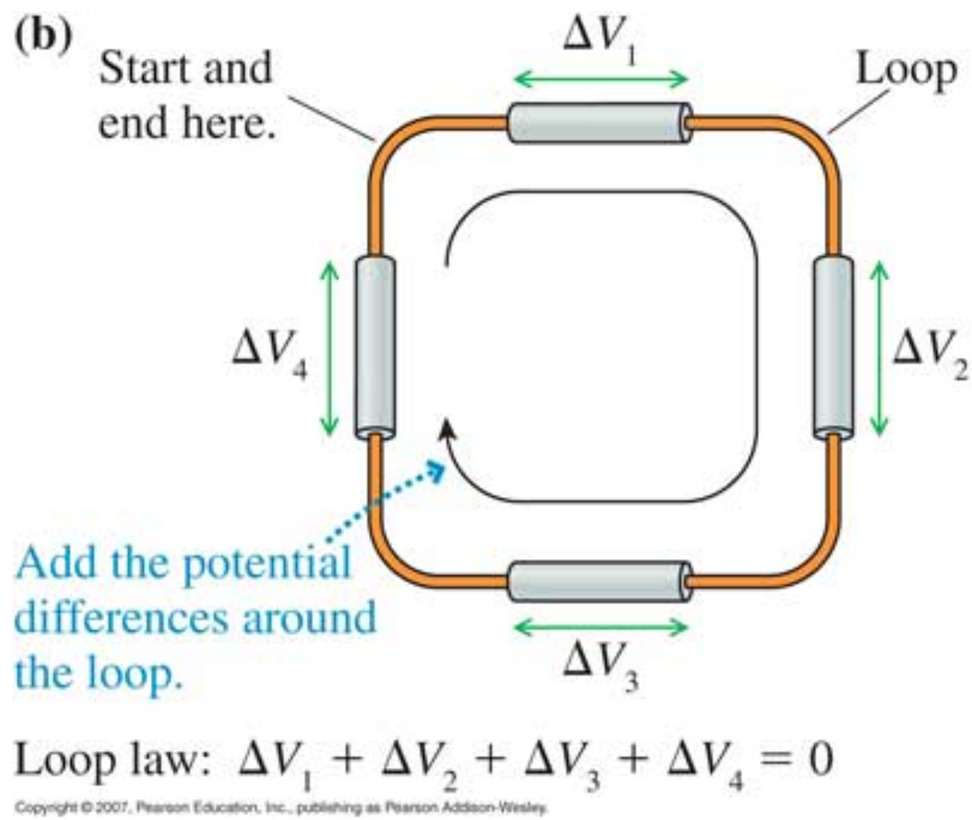


Figure 2

Loop Rule

- The sum of the voltage drops around a loop (excluding any induced EMF from externally applied magnetic field variations) is equal to zero
- Since $\Delta V = \Delta U/q$, this statement is equivalent to conservation of energy

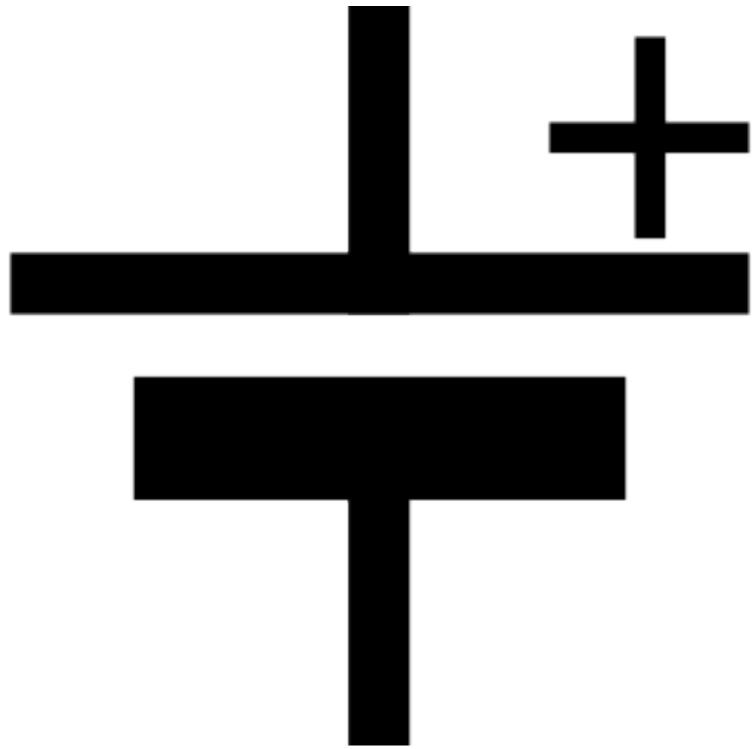


Loop Rule Special Case

- A changing magnetic field can produce an external EMF which may not be apparent from the circuit itself
  - The energy for this comes from the magnetic field and it does not contradict conservation of energy
- As long as this extra EMF is added properly to any battery EMF the loop rule can still be applied

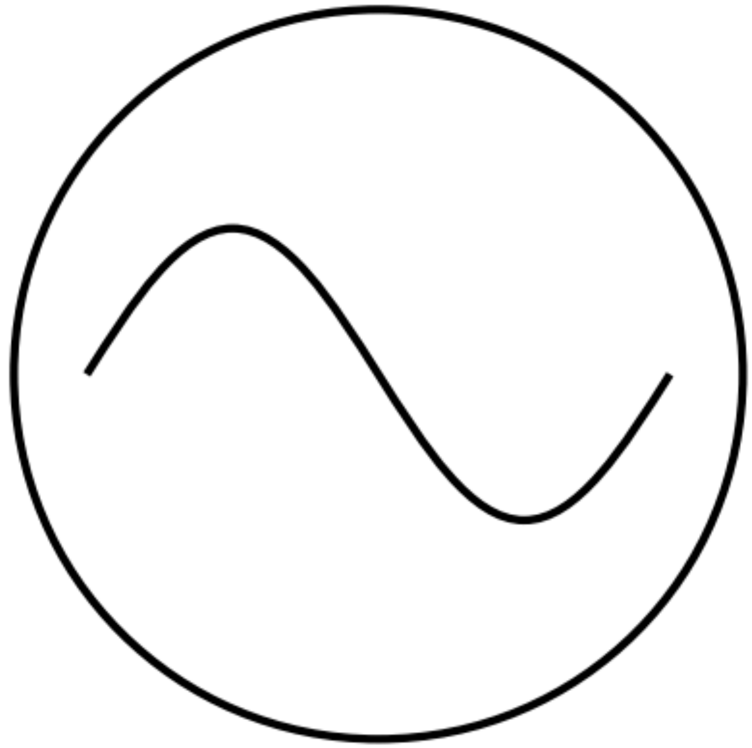
Batteries

- A battery (neglecting any losses) provides a fixed EMF to a circuit
- Traversing a battery from minus to plus terminals gives a positive ΔV for the loop rule



AC Voltage Source

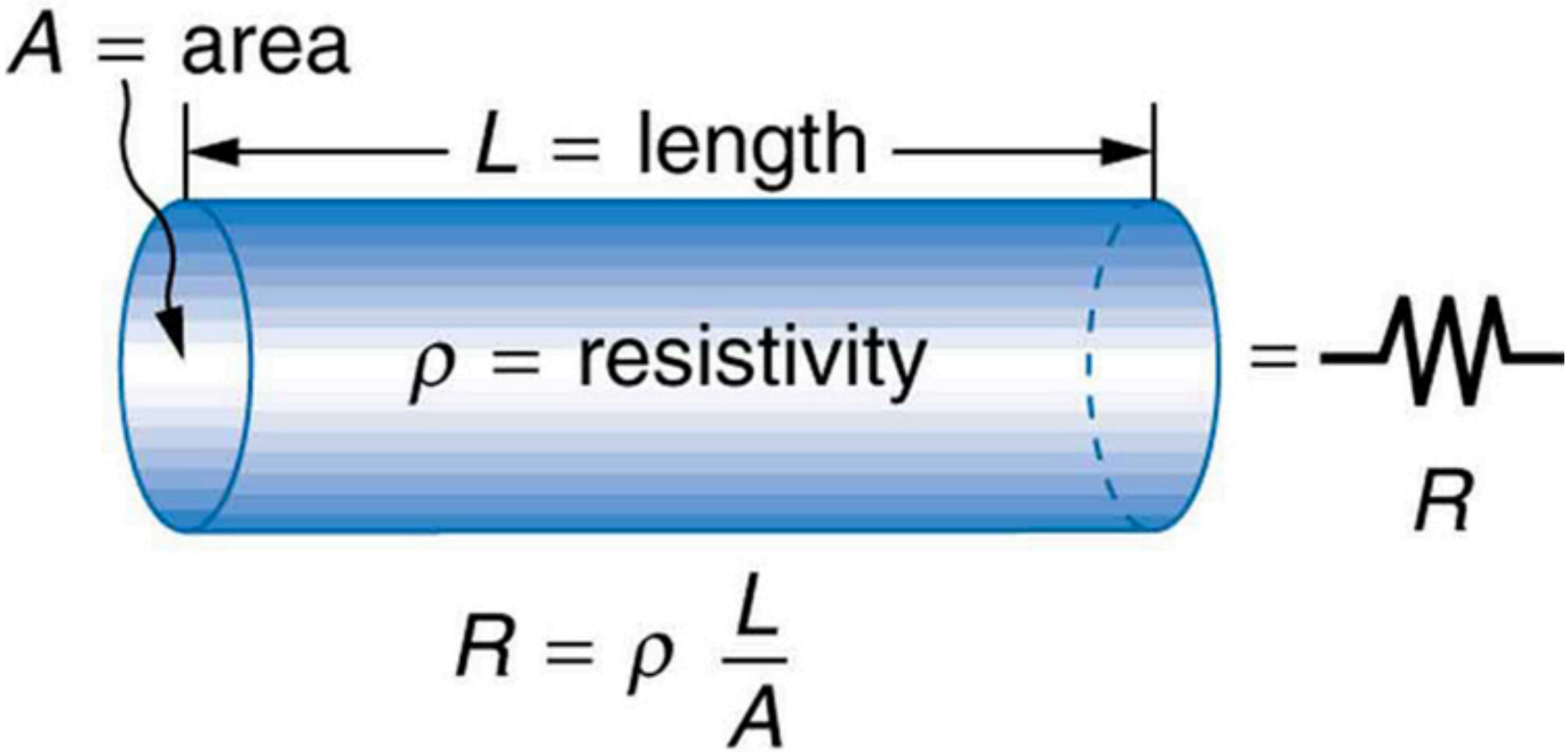
- An alternating voltage source provides a voltage of the form $\varepsilon_m \sin(\omega t)$ to a circuit



Resistor

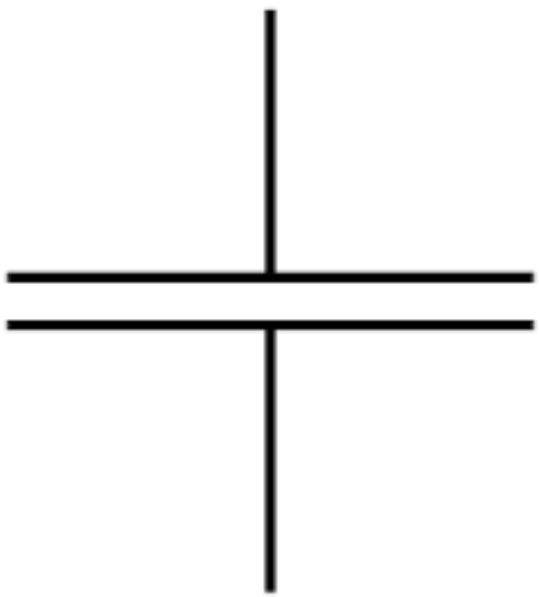
- A resistor dissipates energy in the form of heat due to collisions between current-carrying electrons and molecules in the resistor
  - Ohm's Law states $\Delta V = IR$
- Traversing a resistor in the direction of current flow gives a negative ΔV for the loop rule

Resistor Properties



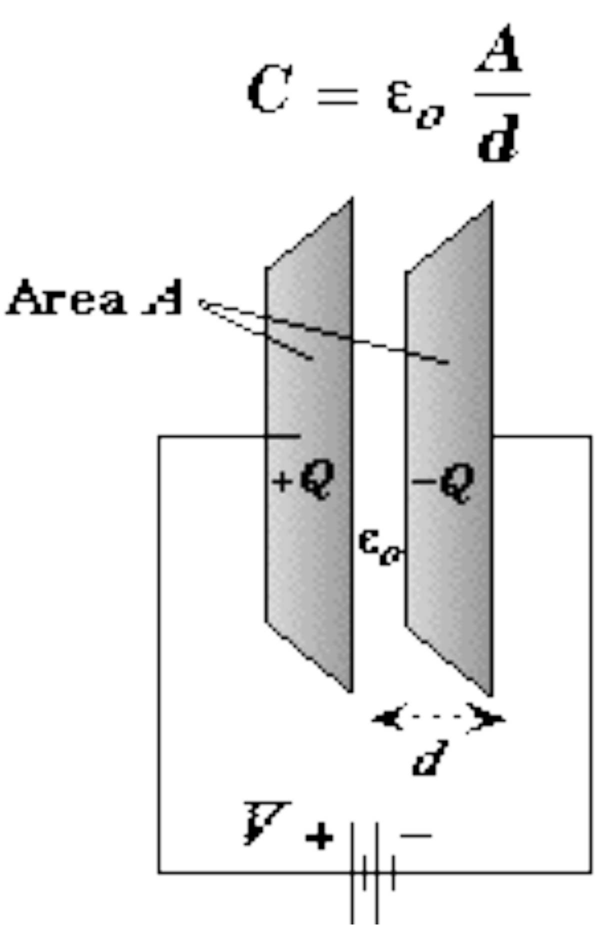
Capacitor

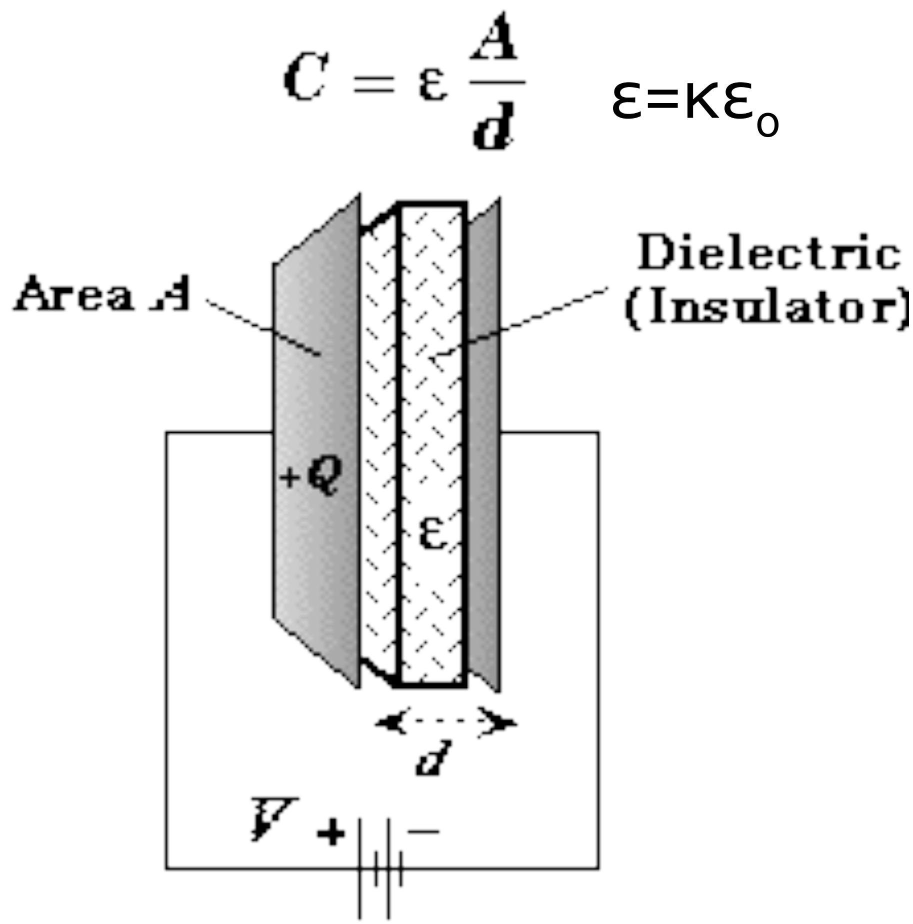
- A capacitor stores charge built up by the flow of current
  - By the definition of capacitance $\Delta V = Q/C$



- Traversing a capacitor in the direction of current flow gives a negative ΔV for the loop rule

Capacitor Properties



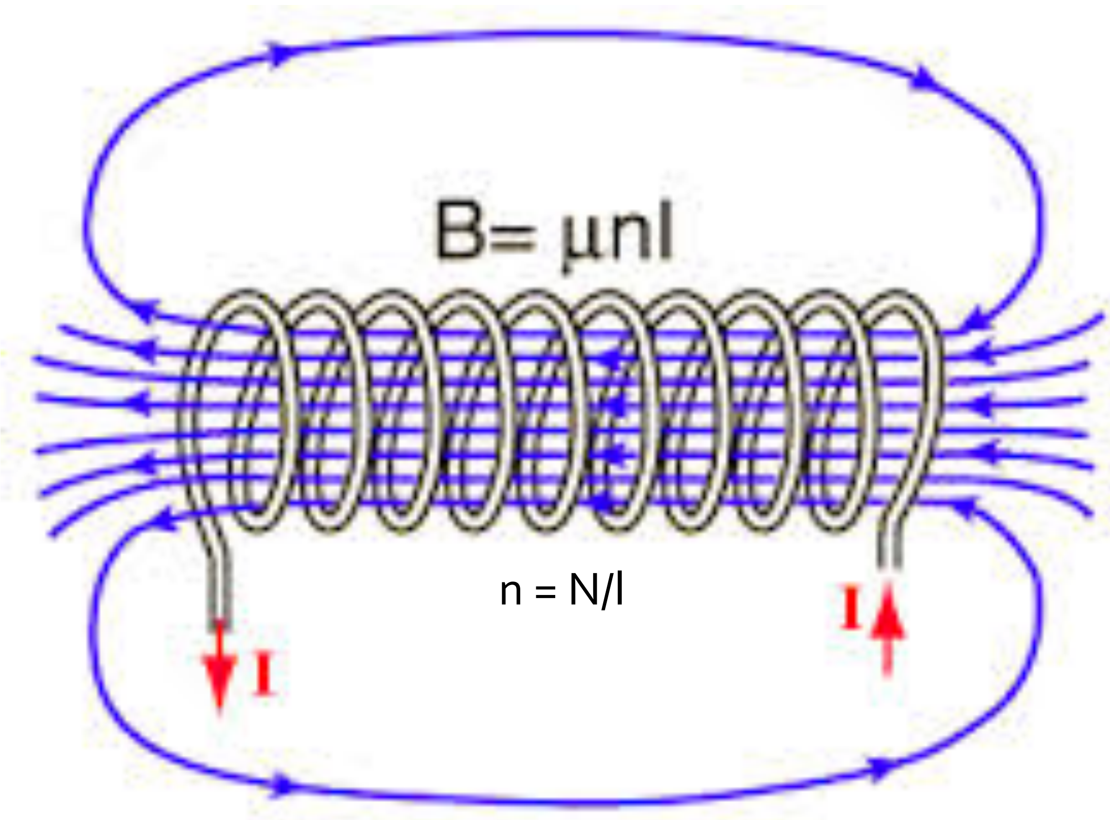


$\varepsilon = \kappa \varepsilon_o$

Inductor

- An inductor produces a voltage drop that opposes the change in current
  - By the definition of inductance $\Delta V = -L dI/dt$
- Traversing an inductor in the direction of the change in the current gives a negative ΔV for the loop rule

Inductor Properties



$$\phi = BA = \frac{\mu_0 N^2 A I}{l}$$

but , $\phi = LI$

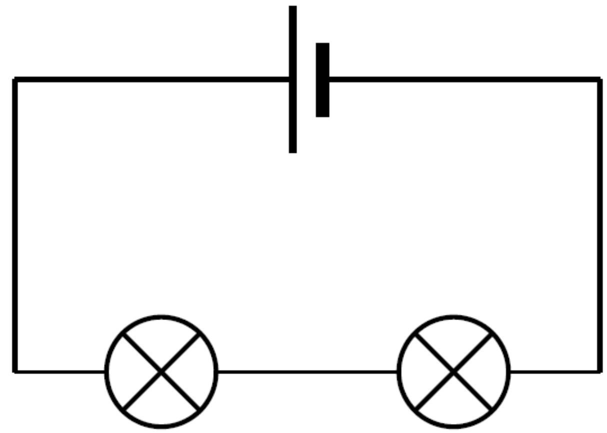
So, $LI = \frac{\mu_0 N^2 A I}{l}$

or, coefficent of self induction

$$L = \frac{\mu_0 N^2 A}{l}$$

Series Combinations

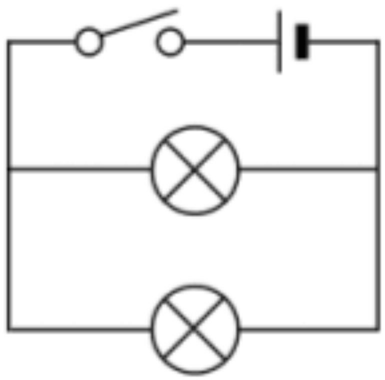
- Components in series share the same current
- The voltage drops add



- Thus resistances and inductances in series add, and inverse capacitances add

Parallel Combinations

- Components in parallel share the same voltage drop

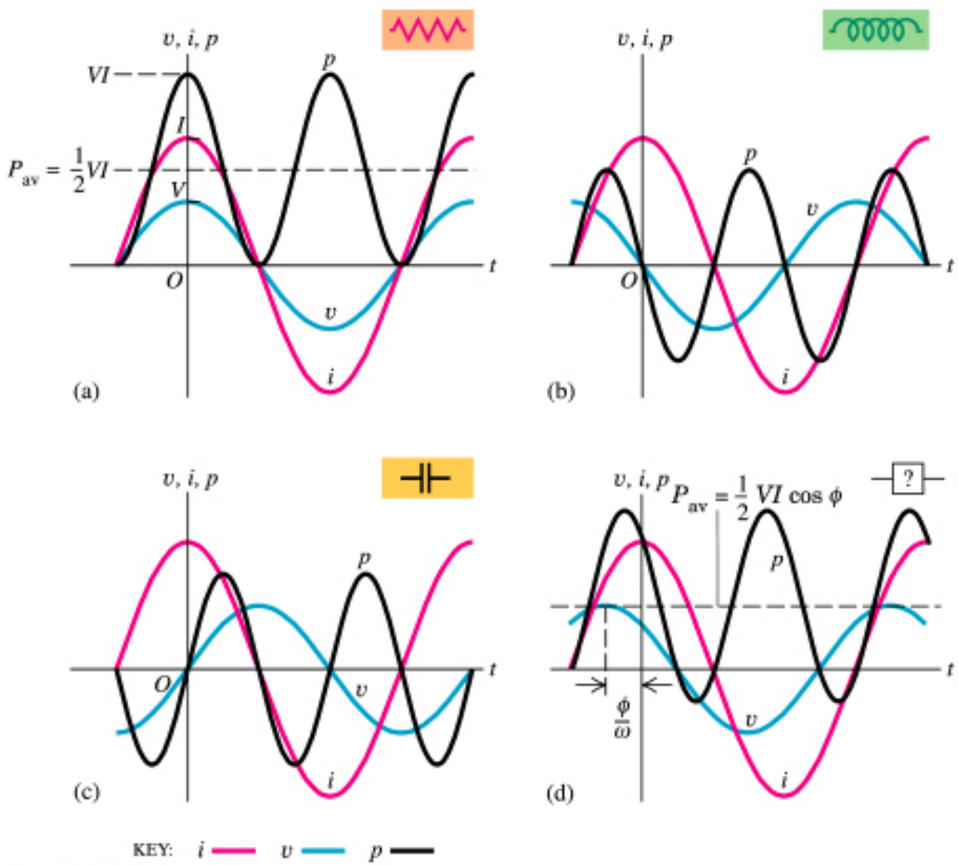


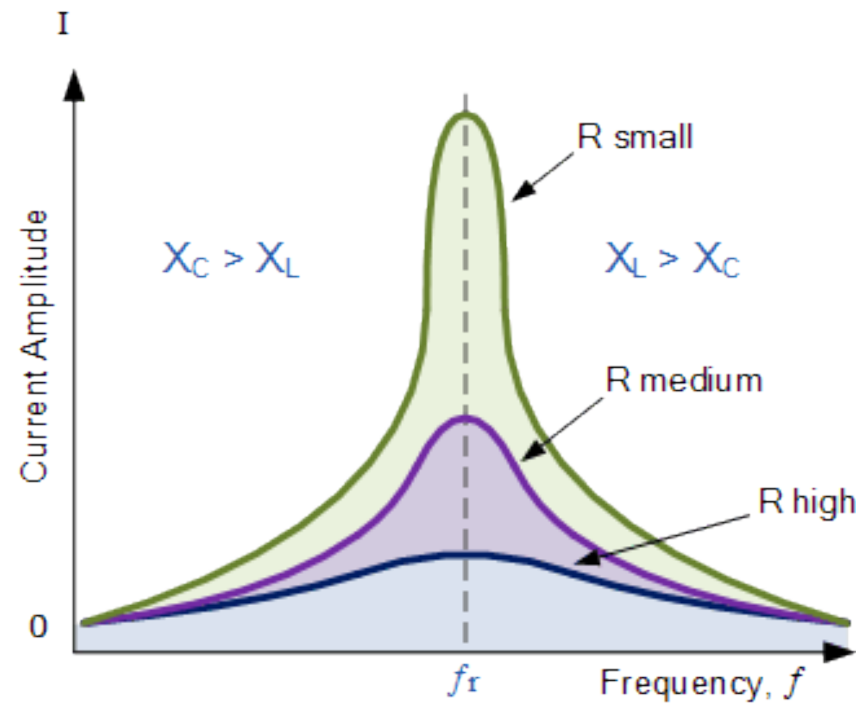
- The currents add
- Thus capacitances in parallel add, and inverse resistances and inverse inductances in parallel add

Power Dissipation

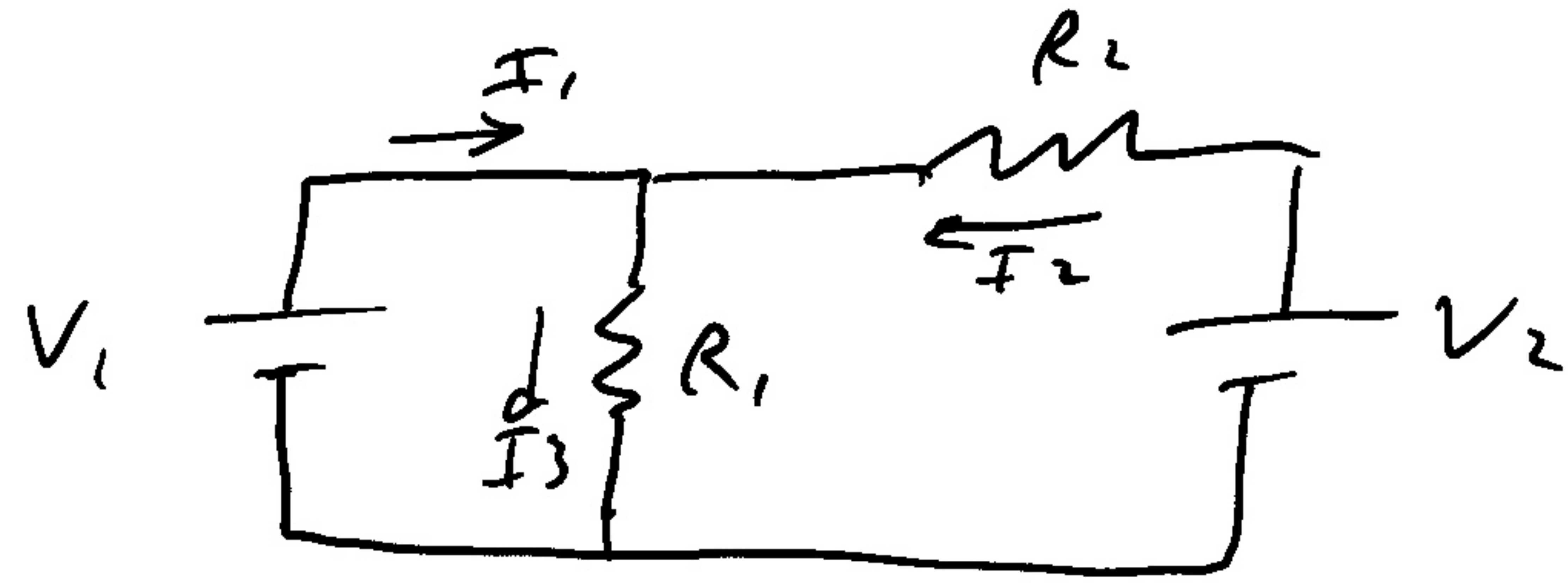
- $P = dU/dt = Vdq/dt = VI$ for circuit element
- For Ohmic component (resistor)
  - $P = I^2R = V^2/R$
- For inductor or capacitor, power dissipation can be positive or negative (energy can be stored!)

AC Power Dissipation & Lead/Lag





R-circuits



$$I_3 = I_2 + I_1$$
$$V_1 - I_3 R_1 = 0$$
$$V_2 - I_2 R_2 - I_3 R_1 = 0$$

$$\Rightarrow V_2 - V_1 - I_2 R_2 = 0$$

$$\Rightarrow I_2 = \frac{V_2 - V_1}{R_2}$$

$$I_3 = V_1/R_1$$

$$I_1 = I_3 - I_2 = \frac{V_1}{R_1} + \frac{V_1 - V_2}{R_2}$$

RC

$$V - IR - Q/C = 0$$
$$V - R\,dQ/dt - 1/C\,Q = 0$$

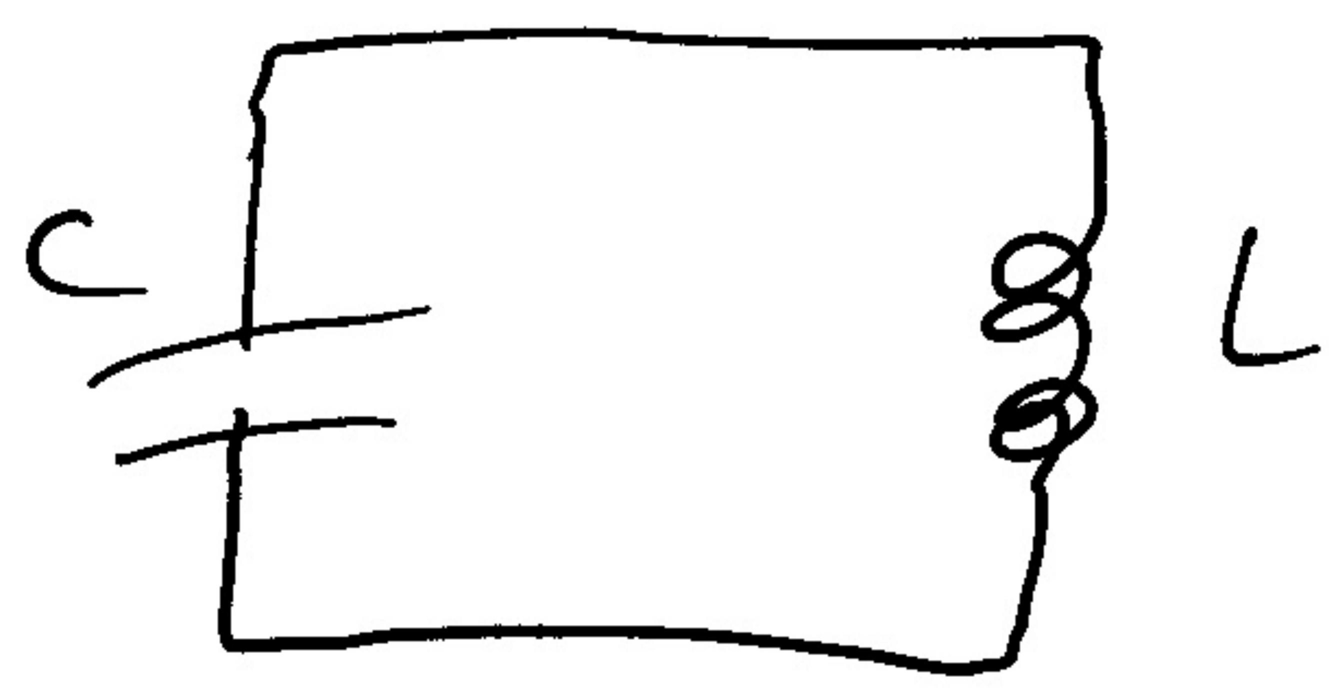
exponential w/ time constant RC

RL

$V - IR - L\, dI/dt = 0$

exponential w/ time constant L/R

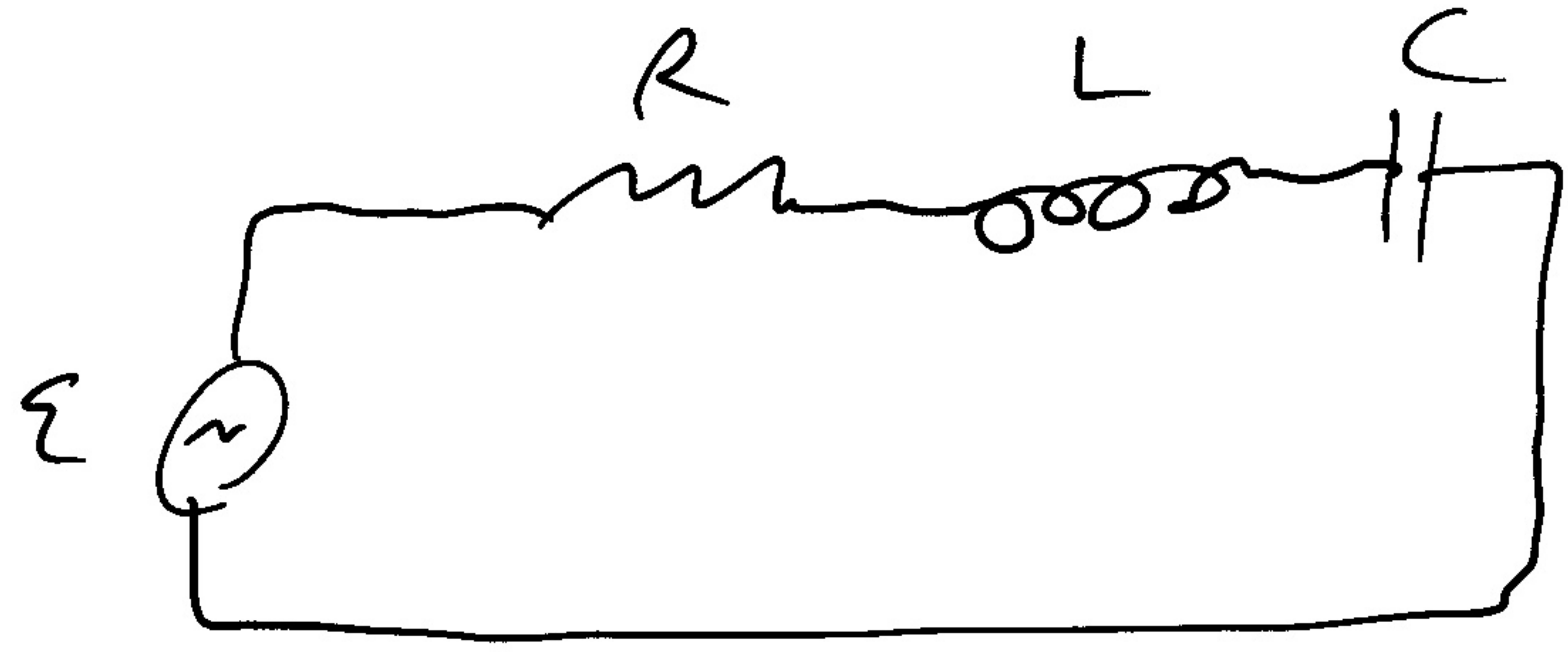
LC



$Q/C + L\, d^2Q/dt^2 = 0$

$\sin(\omega t - \varphi)$ w/ $\omega = 1/\sqrt{LC}$

RLC



$$\mathcal{E} = \mathcal{E}_m \sin(\omega_d t)$$

$$\mathcal{E} - iR - L\,di/dt - q/C = 0$$

magnitudes:

$$\mathcal{E}_m - IZ = 0$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$X_L = \omega L$

$X_C = 1/\omega C$

$$i = I \sin(\omega_d t - \varphi)$$

$$\varphi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

$$\langle P \rangle = \langle \mathcal{E} i \rangle = \mathcal{E}_m^2/2Z \cos\varphi$$

$$\cos\varphi = R/Z = \text{"power factor"}$$