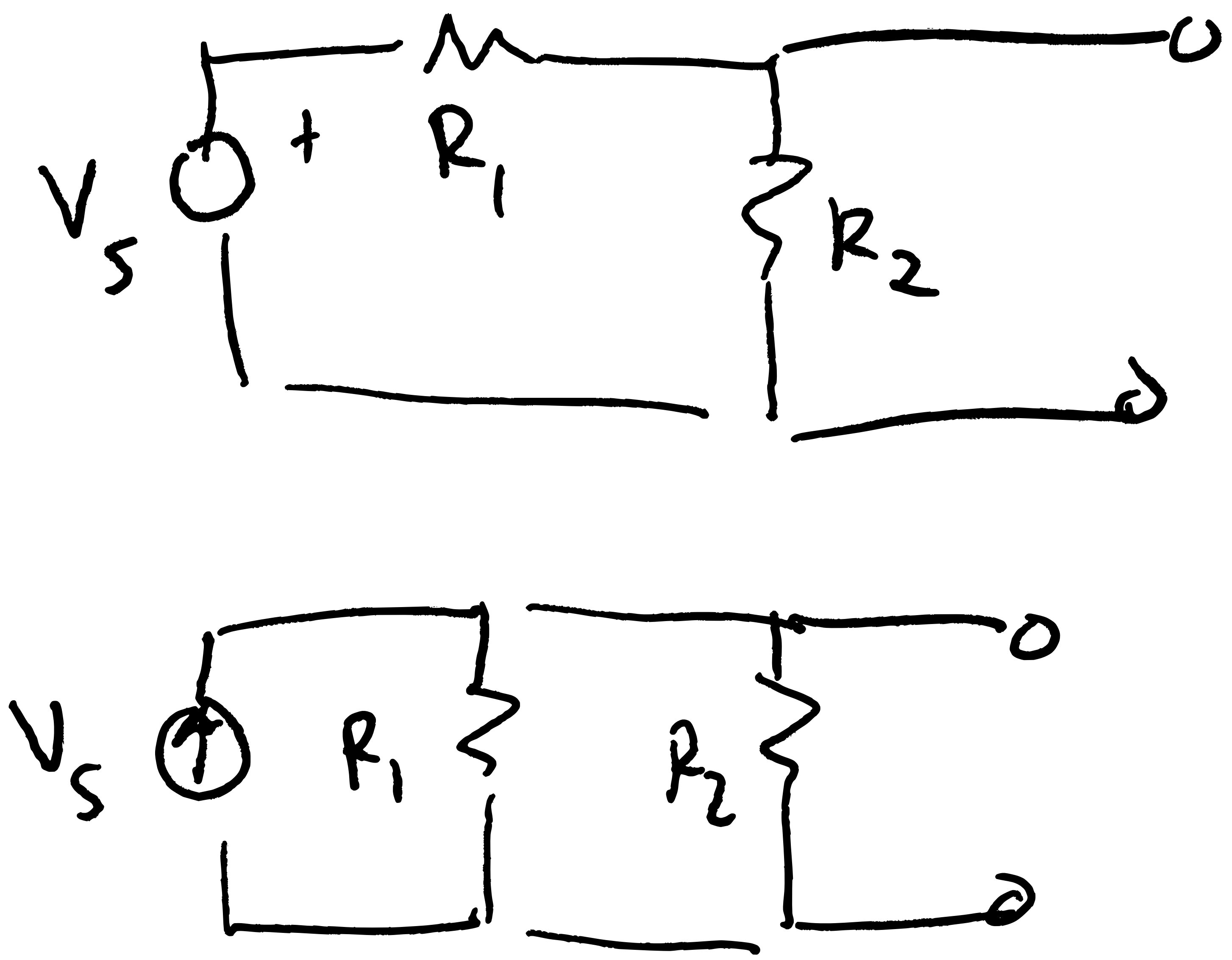
# ME133 Lecture 4

1/19/23

## Last time:

- series & parallel equivalent circuits
- source & meters
  - → loading effect
- output/input impedance
- Power.




translate to the Norton ($I_{sc}$) & Thevenin ($V_{oc}$) Eq.

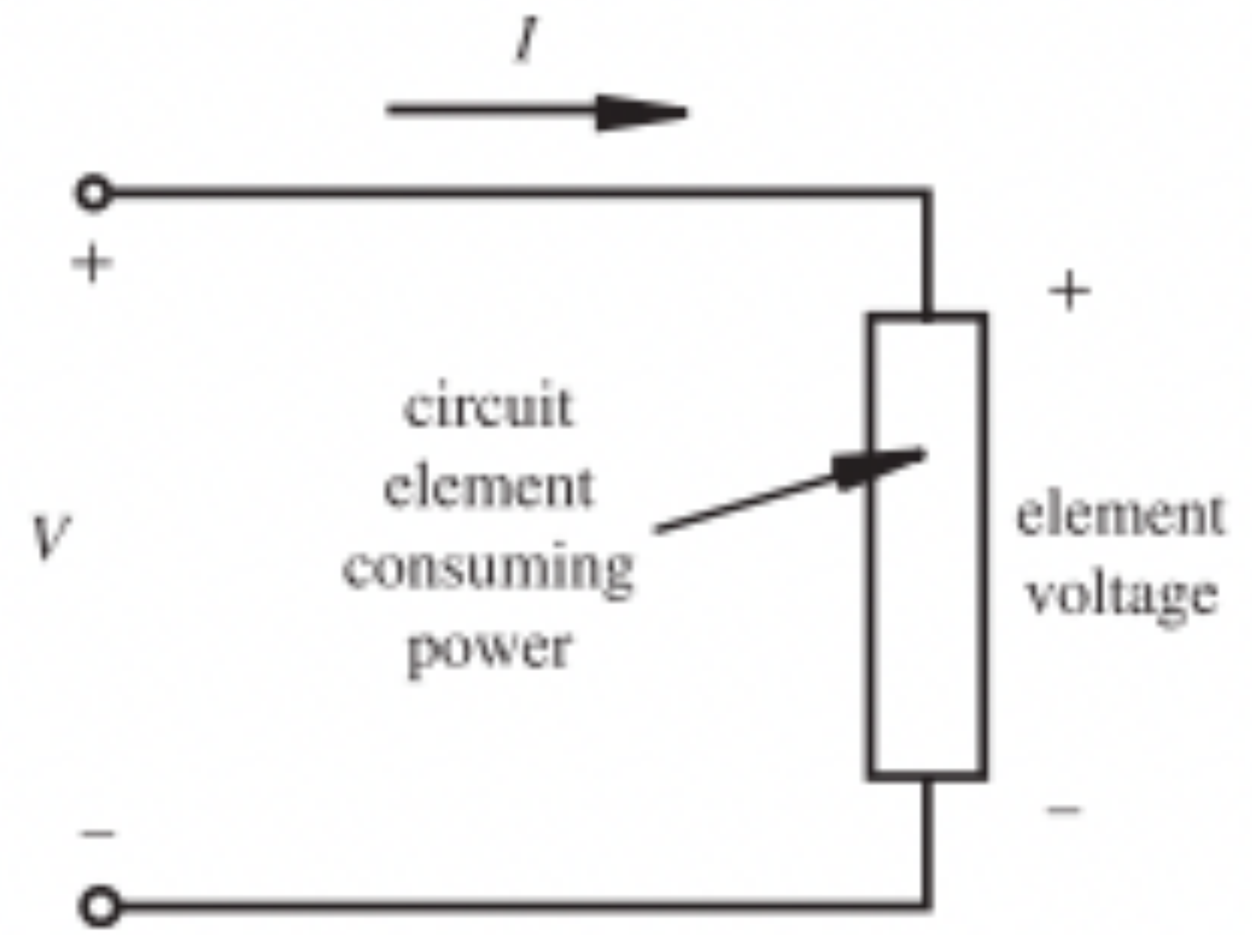
both $R_{TH}$

Electrical Power

All circuit elements either dissipate, store, or deliver power

> physical interactions between charge and electromagnetic fields

The amount of infinitesimal work done on/by an element by infinitesimal charge moving:




$$dW = V\,dq$$

Power is the rate of work:

$$P = \frac{dW}{dt} = V\frac{dq}{dt} = \boxed{VI = I^2R = \frac{V^2}{R}}$$

# Electrical Power

Power in Circuits

$$\boxed{P = VI}$$

- for any element power consumed or generated is the product of voltage across & current through that element

P negative: dissipation / storage

P positive: generation

Today:

- AC circuits CH1.2
- Transformers

- Intro to Semiconductors CH.3

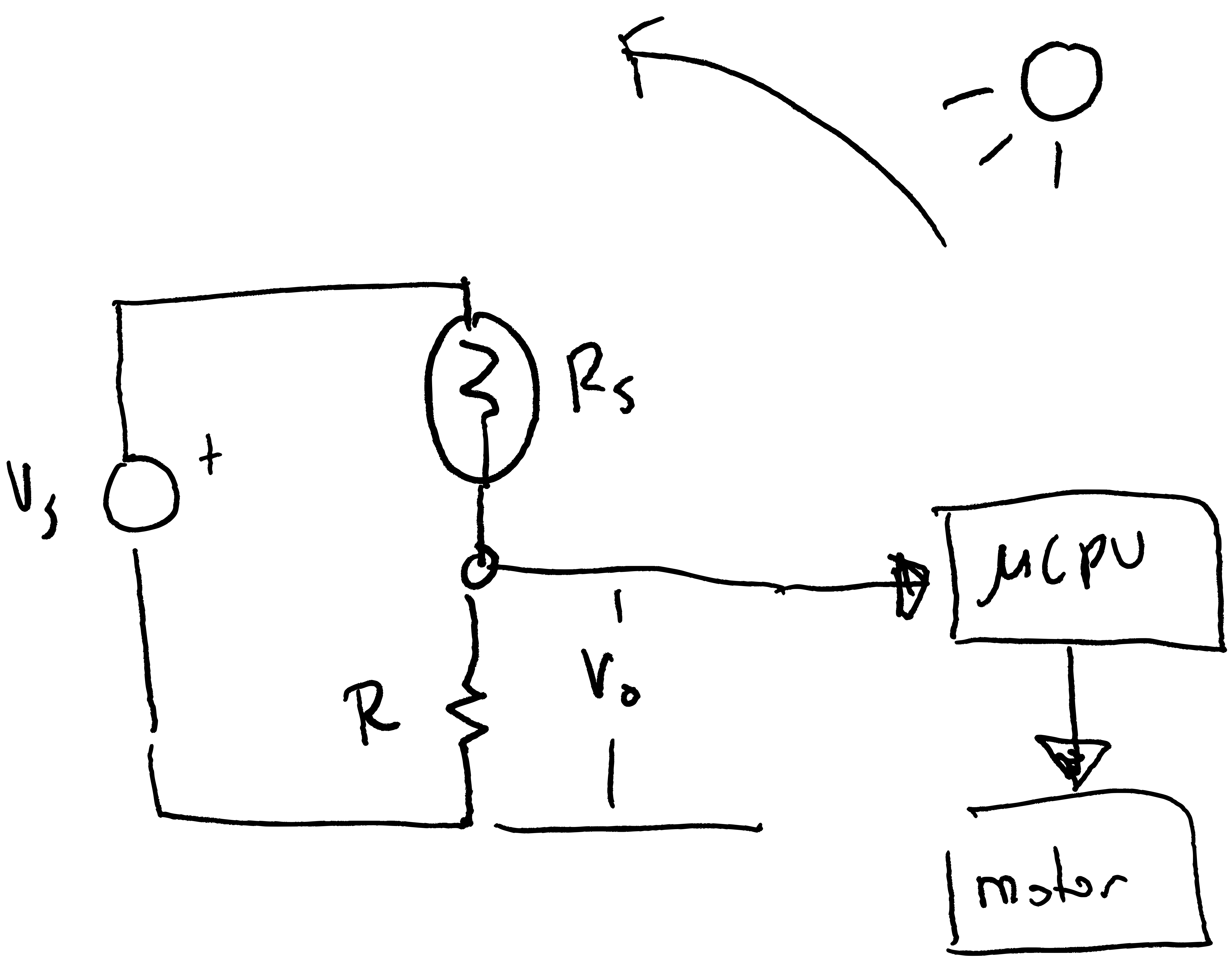
# AC circuits

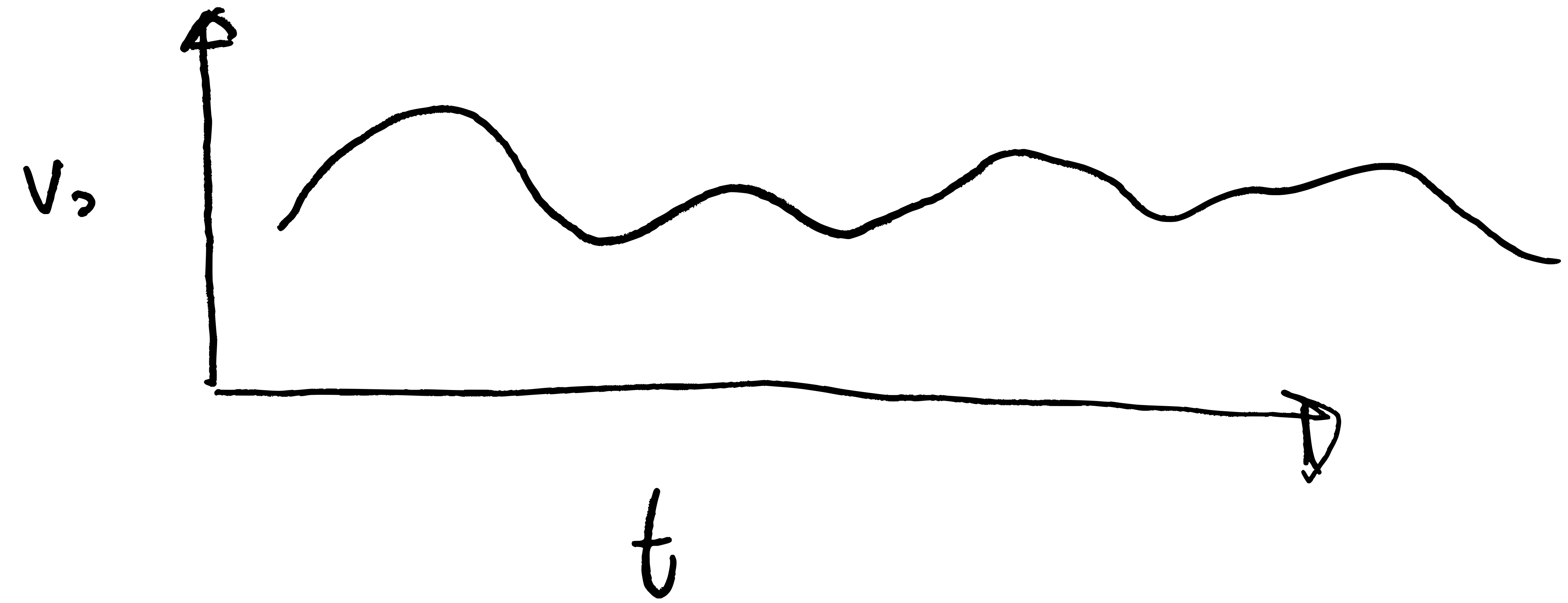
## Why?

- most electrical signals are not pure DC ($V = c$)

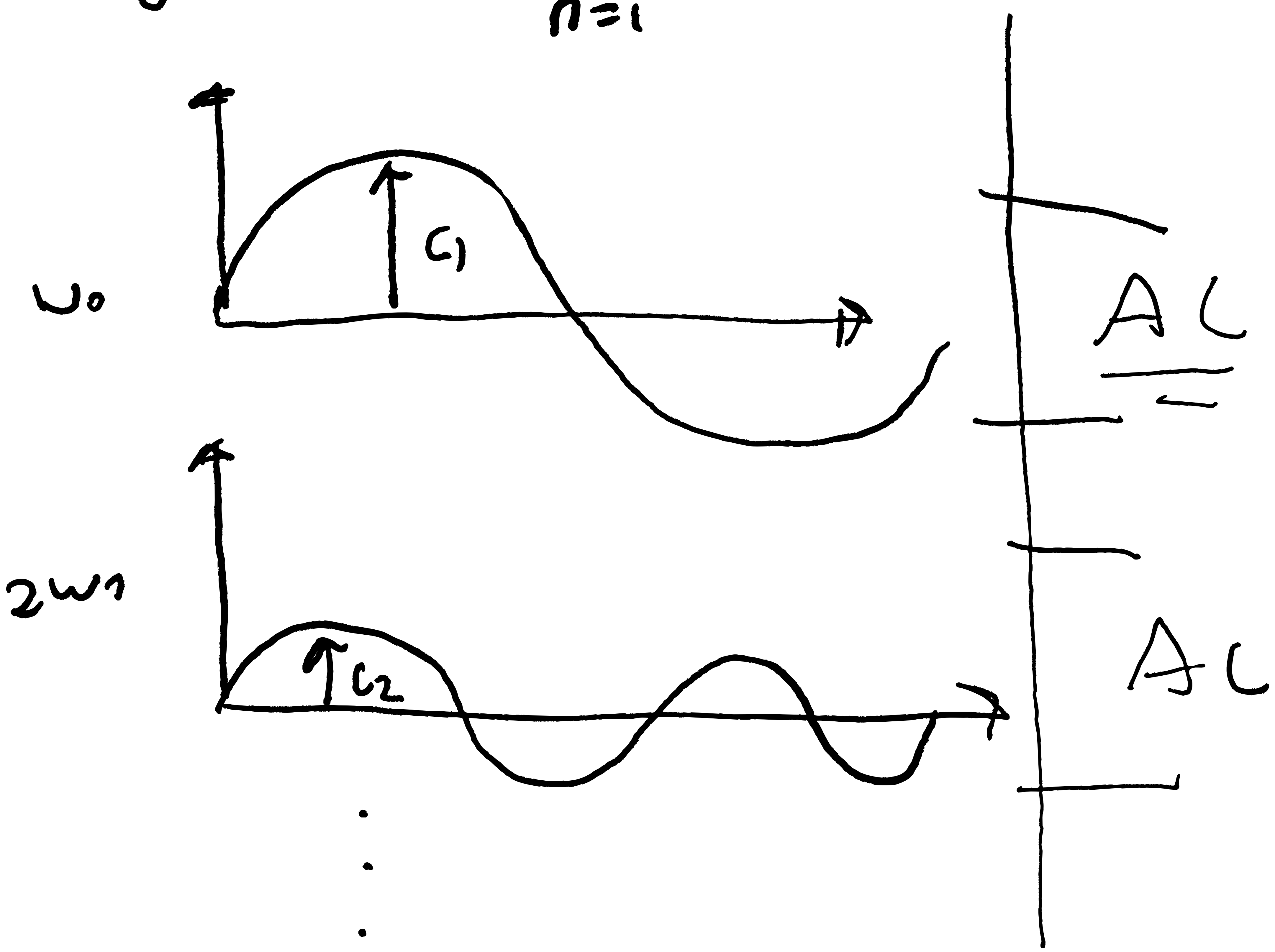
→ even when your system is powered by DC.

# Example: Photoresistor controls a motor




$$V_o(t) = C_0 + \sum_{n=1}^{\infty} C_n \cos(n\omega_0 t + \phi_n)$$



# AC Signal Definition (for a single freq.)

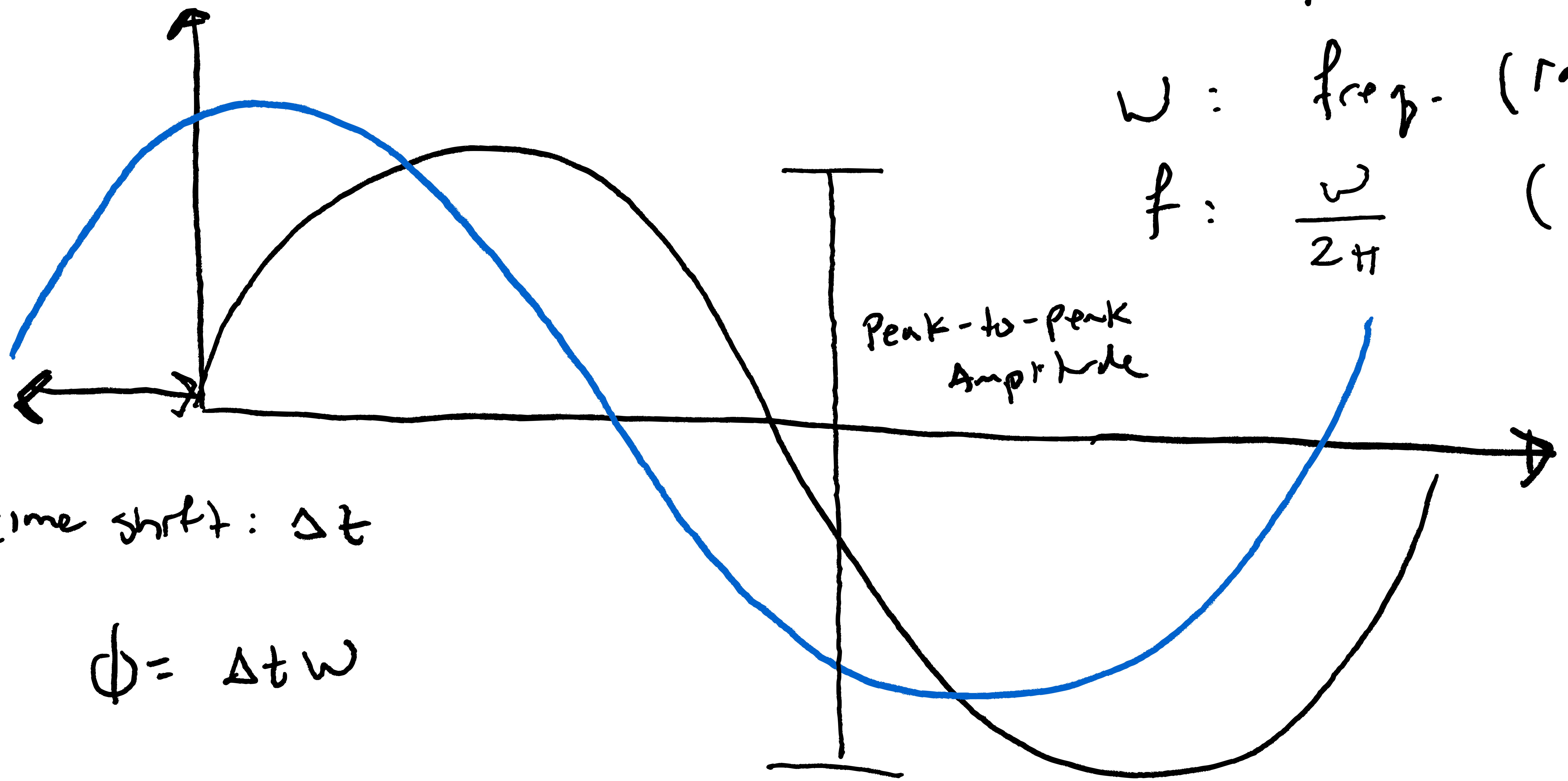
$$V(t) = V_m \sin(\omega t + \phi)$$

$V_m$ : amplitude

$\phi$ : phase

$\omega$ : freq. (rad/s)

$f$ : $\frac{\omega}{2\pi}$ (Hz)




time shift : $\Delta t$

$\phi = \Delta t\, \omega$

# Steady State Analysis

current & voltage of
every element are AC signals
with same freq. as
excitation freq.

# Euler's Formula

$$\underbrace{e^{j(wt+\phi)}}_{\text{exponential form}} = \underbrace{\cos(wt+\phi) + j\sin(wt+\phi)}_{\text{rectangular form}}$$

fundamental relationship between trig.

functions & the complex exponential

# Phasors

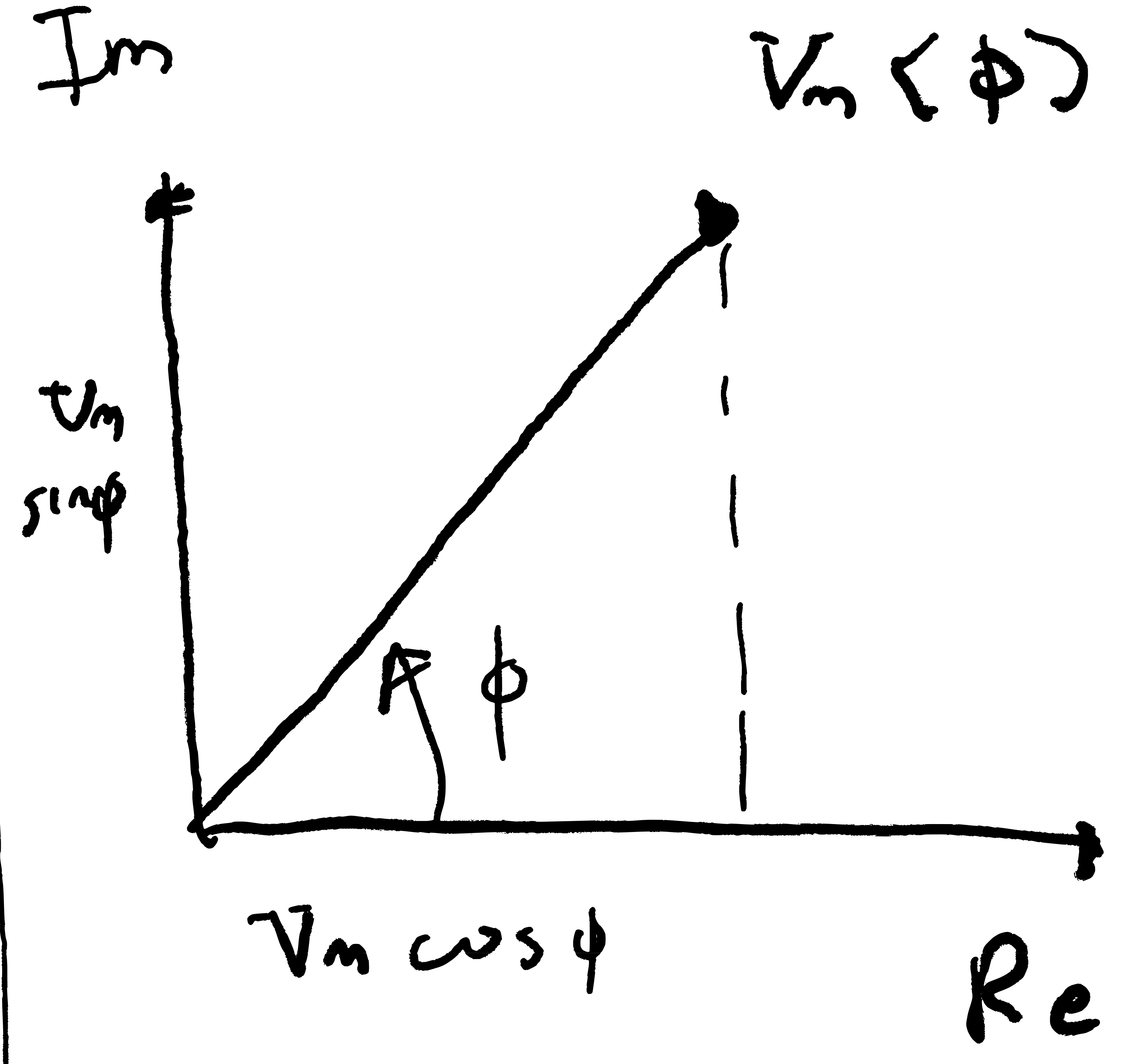
We can treat V, I in AC

as phasors:

$$V = V_m e^{j(\omega t + \phi)} \qquad \text{exp. form}$$

$$= V_m \angle \phi \qquad \text{phasor form}$$

$$= V_m [\cos(\omega t + \phi) + j \sin(\omega t + \phi)$$




Complex number = $x + jy$

Example 2.6

$$V(t) = 5.00 \sin(t - 1) \text{ V}$$

Find amplitude, frequency, and phase

$V_m = 5 \text{ V}$

$f = \frac{1}{2\pi} \text{ Hz}$

$\phi = -1$

## ■ CLASS DISCUSSION ITEM 2.7

### *Reasons for AC*

Justify and fully explain the reasons why AC power is used in virtually all commercial and public utility systems. Refer to the reasons just listed.

* AC power is easy to generate with rotating machinery.

* AC can power rotating machinery

* AC power is more efficient

  → step up to high voltage

# Generalized Ohm's Law

$$V = RI$$

$$V = Z\, I$$

$$Z = f(\omega)$$

* In general impedance is a function of frequency.

# Generalized Ohm's Law

What is the impedance of a resistor?

$$V = RI$$

$$Z_R = R$$ (no freq. dependence)

What is the impedance of an Inductor?

$$V = L\dot{I}$$

$$I = I_m e^{j(\omega t + \phi)}$$

$$\dot{I} = j\omega I_m e^{j(\omega t + \phi)}$$

$$V = Lj\omega I_m e^{j(\omega t + \phi)}$$

$$V = L\dot{I}$$

$$= \underbrace{Lj\omega}_{Z_L} \underbrace{I_m e^{j(\omega t + \phi)}}_{I}$$

$$Z_L(\omega) = j\omega L$$

$$e^{j\phi} = \cos(\phi) + j\sin\phi$$

$$\phi = 90^\circ$$

$$e^{j90^\circ} = 0 + j$$

$$\therefore Z_L = \omega L \angle 90^\circ$$

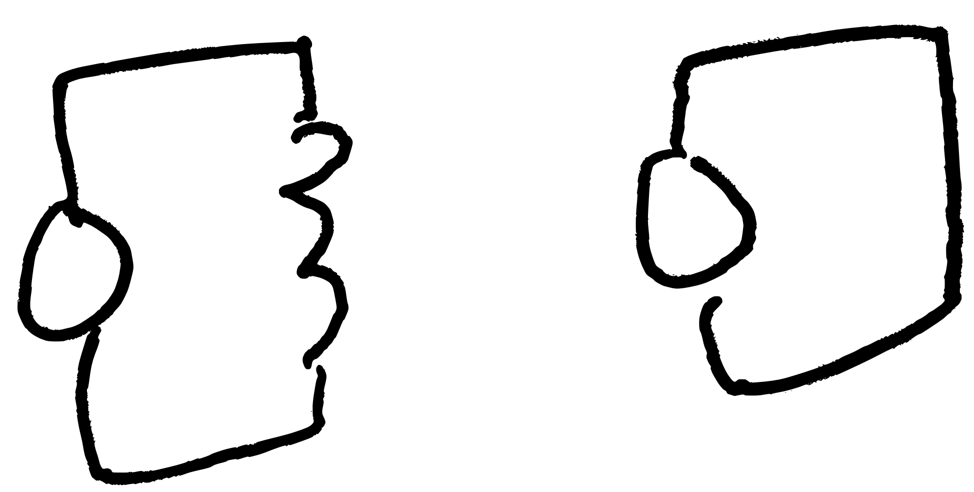
$$\boxed{\text{voltage } \underline{\text{leads}} \text{ current by } 90^\circ}$$

# Generalized Ohm's Law

$Z_{x_L} = \omega L \angle 90^\circ$

$\omega \to 0 \quad Z_L = 0$

inductor acts like a short circuit at low freq.



$\omega \to \infty \quad Z_L = \infty$ open circuit

What is the impedance of a Capacitor?

$\underline{I} = C\dot{\underline{V}}$

$\underline{V} = V_m e^{j(\omega t + \phi)}$

$\dot{\underline{V}} = j\omega V_m e^{j(\omega t + \phi)}$

$\underline{I} = j\omega C \underline{V}$

$\underline{V} = \underbrace{\frac{1}{j\omega C}}\underline{I}$

$Z_C = \frac{1}{\omega C} \angle -90^\circ$

Voltage lags current by $90^\circ$

$\omega \to 0$

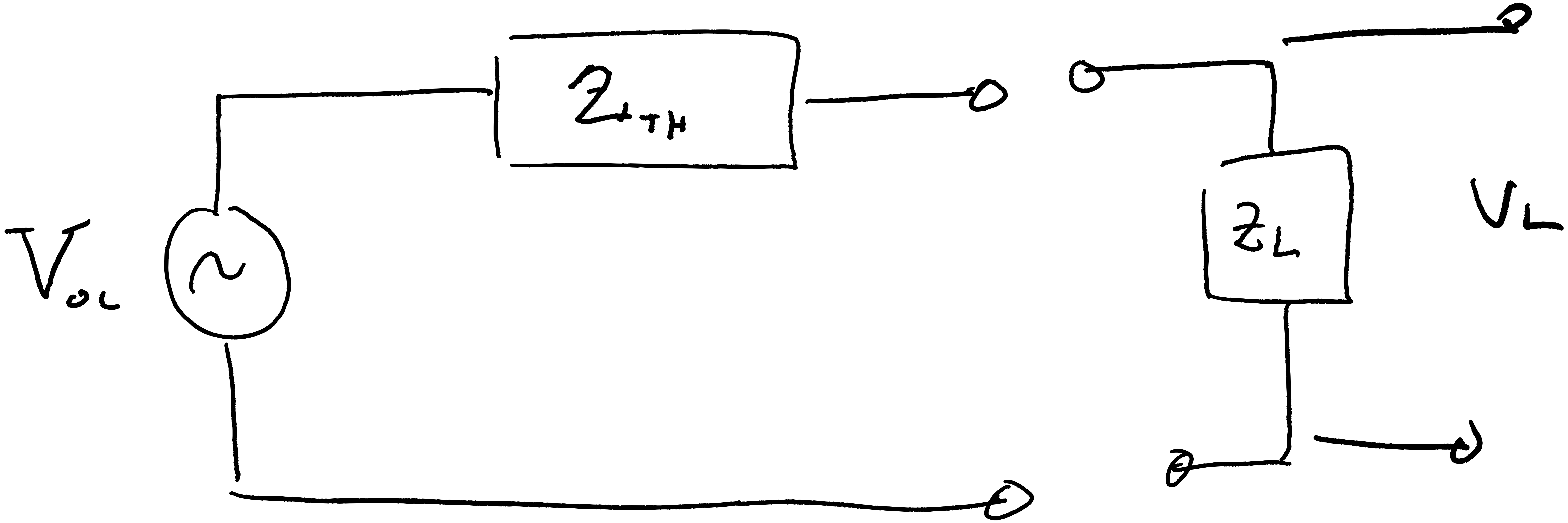
$Z_{x_C} = \infty$

$\omega \to \infty$

$Z_{x_C} = 0$

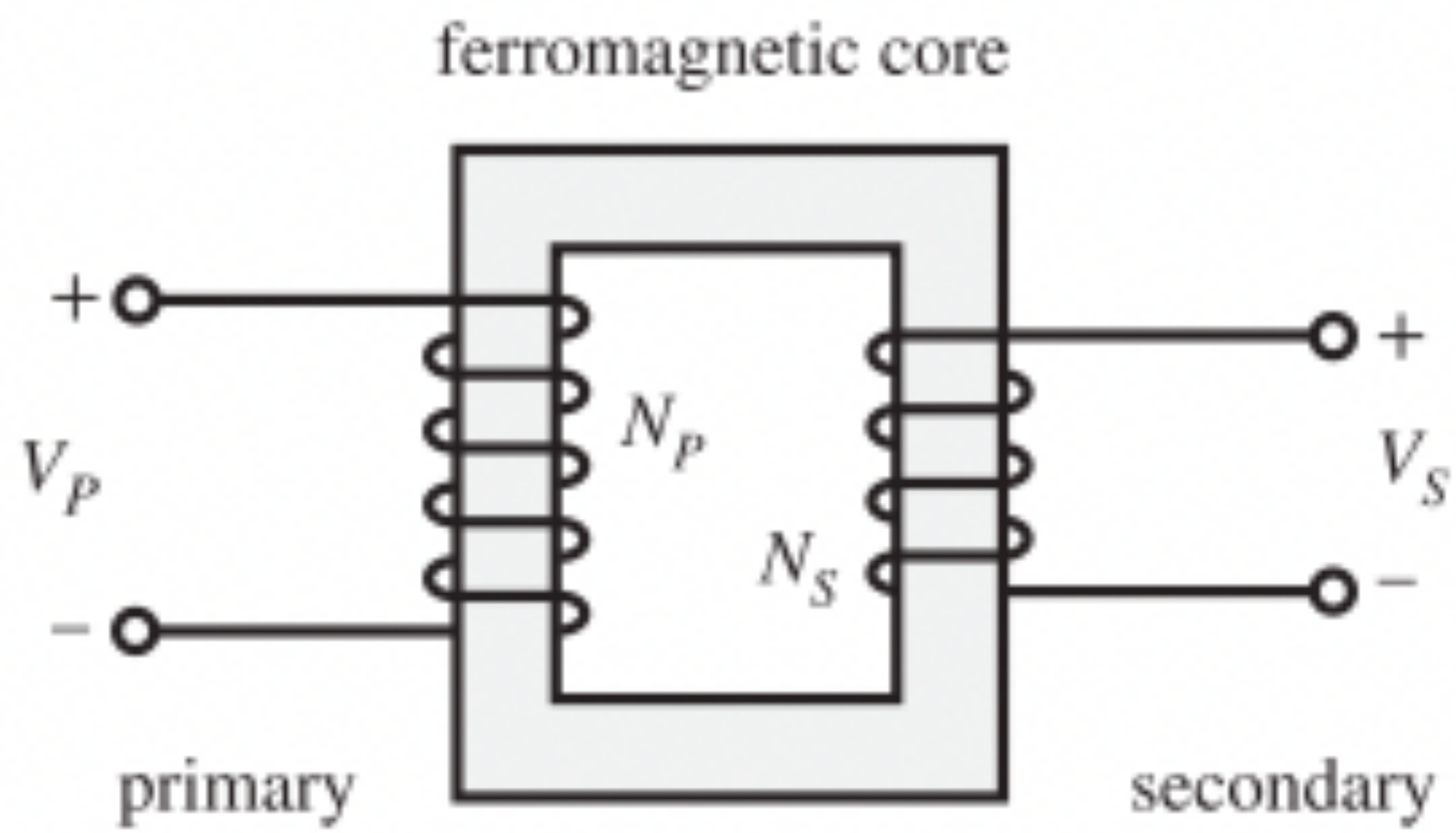
# How to analyze AC circuits?

→ same way as DC, except use $\underline{\underline{Z}}$




$$\boxed{V_L = \left(\frac{Z_L}{Z_{TH} + Z_L}\right) V_{oc}}$$

Transformers : only for $\underline{\underline{AC}}$.




. Change the relative amplitude of voltage / current in an AC circuit

$N_p$ : # of coils

$N_s$ : # of coils

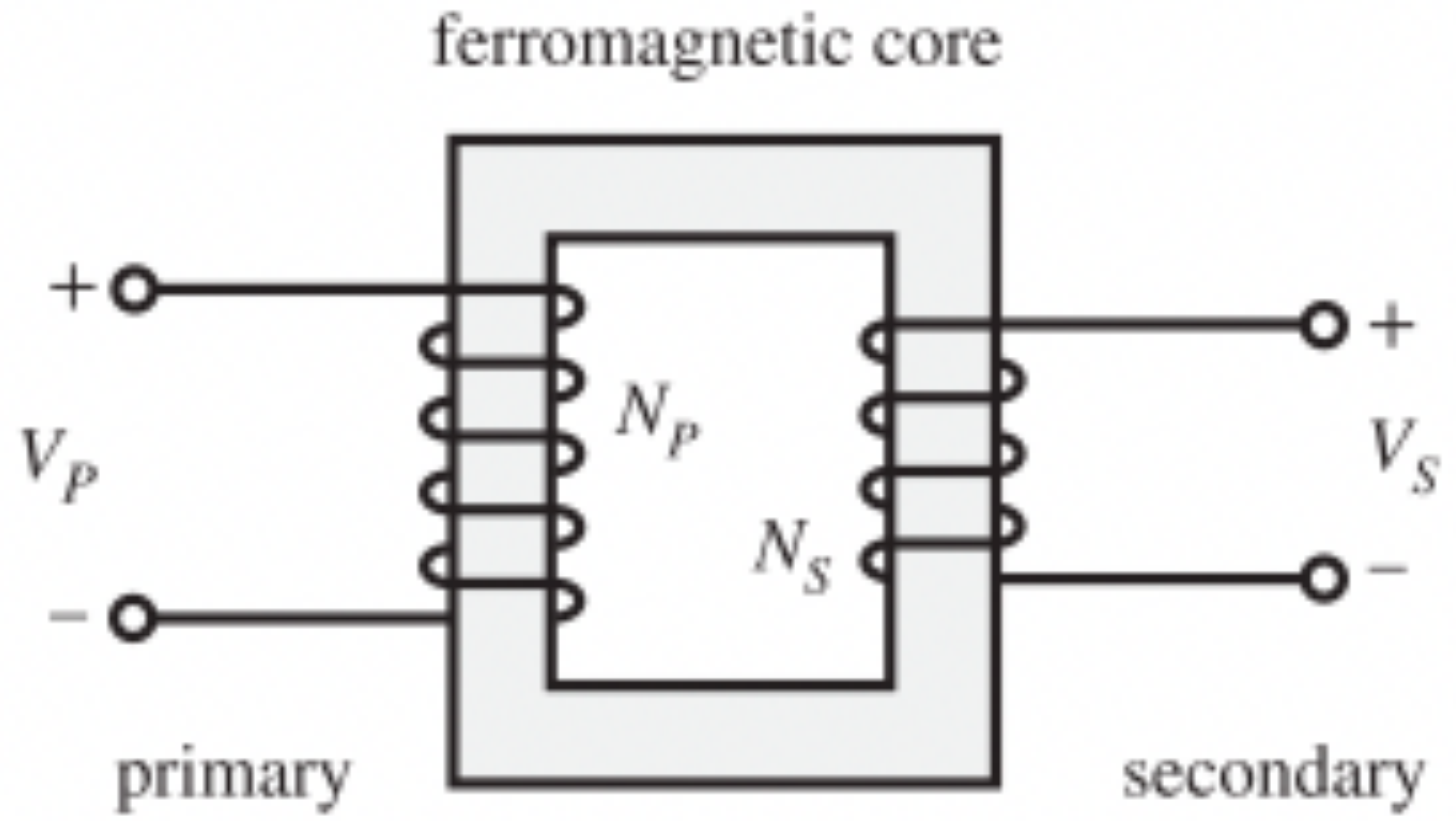
$$\frac{V_p}{N_p} = \frac{V_s}{N_s} = \frac{-d\phi}{dt} \leftarrow \text{flux}$$

$$\therefore V_s = \underbrace{\frac{N_s}{N_p}}_{\text{like gears}} V_p$$

$N_s > N_p \rightarrow \frac{N_s}{N_p} > 1$ step-up

$N_s < N_p \rightarrow \frac{N_s}{N_p} < 1$ step down

# Transformers




$$P_{in} = P_{out}$$

$$\eta \quad P_{in} = P_{out}$$

$$\boxed{V_p I_p = V_s I_s}$$ ideal

$$I_s = \frac{V_p}{V_s} I_p$$

$$\boxed{I_s = \frac{N_p}{N_s} I_p}$$

$$V \uparrow \; I \downarrow$$

# Semiconductors — Ch.3

Sensors
signal processing
display (UI)

Focus: diodes
transistor

# Semiconductor Physics

- metal (e.g. conductors) have a large number of weakly bound electrons

# Semiconductor Physics

- under an electric potential
  voltage

  these electrons flow
  current

- other materials (insulators) have valence electrons which tightly bound

- no flow, under potential for insulator.

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- semiconductor have properties somewhere in between
  ex: silicon, germanium

- current-carrying characteristics depend on environment: temperature or light

* properties of semiconductors can be significantly changed by **doping**: insert other elements into lattice

# Semiconductor Physics: Types of dopants

- **donor**: enhances electron conductivity

n-type (negative)

- **acceptor**: reduces electron conductivity

p-type (positive)

The whole point of doping to control # of charge carriers

- n-type: charge carrier $e^-$
- p-type: charge carrier $\oplus$

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The interaction of p- & n-type areas within a singul device is Basis for semiconductors

# Junction Diode: pn-junction

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# Junction Diode: pn-junction

# Diode water analogy

# Semiconductor Intro Summary