

# Welcome to EECS 16A!

## Designing Information Devices and Systems I

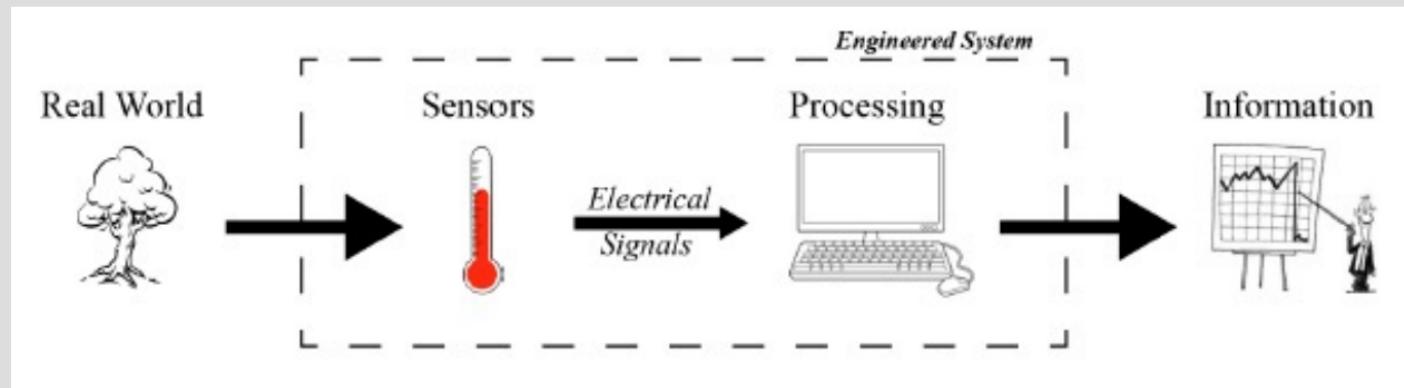


**Ana Claudia Arias and Miki Lustig**  
**Spring 2022**

Module 2  
Lecture 1  
Introduction to Circuit Analysis  
(Note 11)



# Designing Information Devices and Systems



# Module 2 – More tools to build systems

Analog World

Sensor

Processing

Actuation

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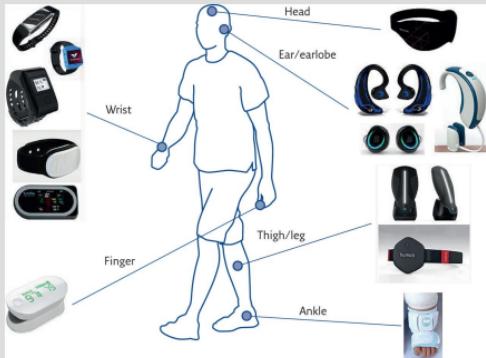
# Module 2 – More tools to build systems

Analog World

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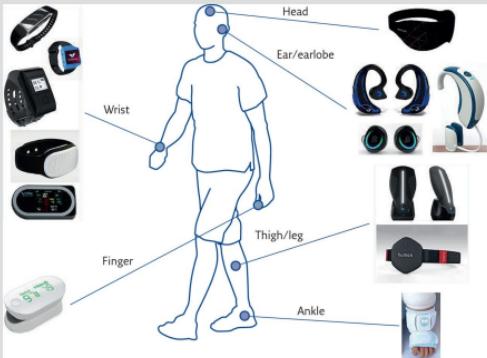
# Module 2 – More tools to build systems

16B

## Analog World



## Sensor



## Processing

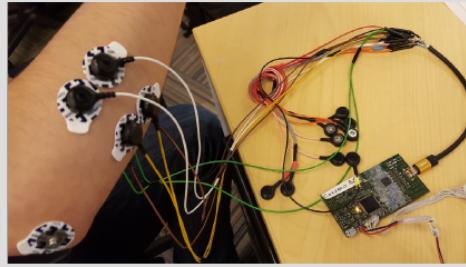


## Actuation



# System Example - Electromyography

- ✓ Monitors muscle activity
  - ✓ Used in gesture recognition
  - ✓ Impact in rehabilitation
- 
- ✗ Bulky electrodes
  - ✗ Poor accuracy – low resolution
  - ✗ Computation performed on external devices

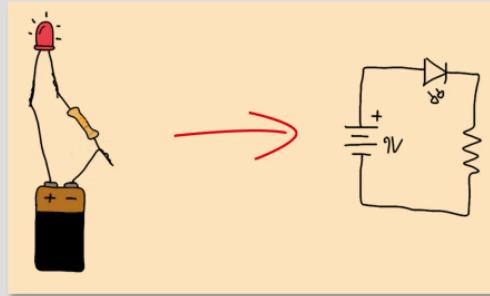


# System Example - Electromyography



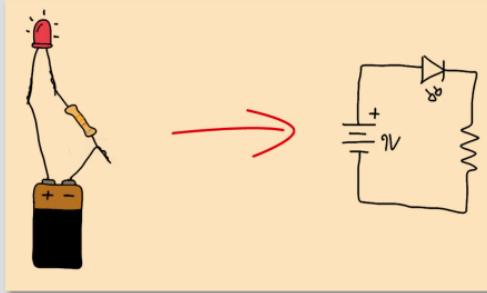
# In Module 2 we will learn how to analyze circuits

We need to be able to go from a real-world circuit, to a circuit model, and vice versa.



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We need to be able to go from a real-world circuit, to a circuit model, and vice versa.

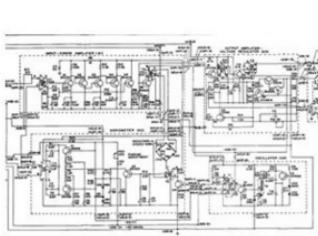


**CLASS**

**HOPES**

**REALITY**

Introduction to Electrical Engineering



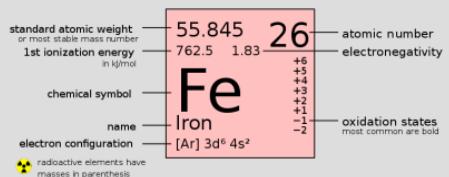
Then we need to know how to solve the model...

**Note:** the tool used by computers to analyze circuits is linear algebra!

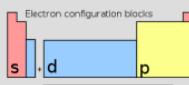
# First: Science Review

## Periodic Table of the Elements

Group 1	
Period 1	1 H Hydrogen [He] 1s <sup>1</sup>
2	6.94 520.2 0.98 3 Li Lithium [He] 2s <sup>1</sup>
3	24.990 593.9 0.95 11 Be Beryllium [He] 2s <sup>2</sup>
4	24.305 593.9 1.31 12 Mg Magnesium [Ne] 3s <sup>2</sup>
5	39.098 413.0 0.82 19 K Potassium [Ar] 4s <sup>1</sup>
6	85.468 409.0 0.82 37 Ca Calcium [Ar] 4s <sup>2</sup>
7	132.91 373.7 0.79 55 Rb Rubidium [Kr] 5s <sup>1</sup>
8	137.33 502.9 0.89 56 Sr Strontium [Kr] 5s <sup>2</sup>
9	138.91 503.1 1.10 57 Ba Barium [Kr] 5s <sup>2</sup>
10	(223) 100.0 0.70 87 Cs Cesium [Kr] 6s <sup>1</sup>
11	(226) 509.9 0.90 88 Fr Francium [Rn] 7s <sup>1</sup>
12	(227) 499.0 1.10 89 Ra Radium [Rn] 7s <sup>2</sup>
13	(227) 499.0 1.10 89 Ac Actinium [Rn] 6d <sup>1</sup> 7s <sup>1</sup>



13	14	15	16	17	18
10.81 800.6 2.04 B Boron [He] 2s <sup>2</sup> 2p <sup>1</sup>	12.011 1086.5 2.55 C Carbon [He] 2s <sup>2</sup> 2p <sup>2</sup>	14.007 1402.3 3.04 N Nitrogen [He] 2s <sup>2</sup> 2p <sup>3</sup>	15.999 1313.9 3.44 O Oxygen [He] 2s <sup>2</sup> 2p <sup>4</sup>	18.998 1481.0 3.98 F Fluorine [He] 2s <sup>2</sup> 2p <sup>5</sup>	20.180 2080.7 4.00 He Helium [He]
26.982 577.5 1.81 Al Aluminum [Ne] 3s <sup>2</sup> 3p <sup>1</sup>	32.06 999.8 2.58 Si Silicon [Ne] 3s <sup>2</sup> 3p <sup>2</sup>	34.45 1521.2 3.18 P Phosphorus [Ne] 3s <sup>2</sup> 3p <sup>3</sup>	35.45 1520.6 3.48 S Sulfur [Ne] 3s <sup>2</sup> 3p <sup>4</sup>	39.948 1520.6 3.48 Cl Chlorine [Ne] 3s <sup>2</sup> 3p <sup>5</sup>	40.0026 2373.3 1.91 Ne Neon [Ne] 3s <sup>2</sup> 3p <sup>6</sup>
47.867 583.0 1.54 Ti Titanium [Ar] 3d <sup>2</sup> 4s <sup>2</sup>	50.942 583.0 1.63 V Vanadium [Ar] 3d <sup>3</sup> 4s <sup>2</sup>	51.996 583.0 1.66 Cr Chromium [Ar] 3d <sup>5</sup> 4s <sup>1</sup>	54.938 577.5 1.55 Mn Manganese [Ar] 3d <sup>5</sup> 4s <sup>1</sup>	55.845 575.5 1.83 Fe Iron [Ar] 3d <sup>6</sup> 4s <sup>2</sup>	58.933 577.5 1.81 Co Cobalt [Ar] 3d <sup>7</sup> 4s <sup>1</sup>
91.224 640.1 1.33 Zr Zirconium [Ar] 4d <sup>2</sup> 5s <sup>2</sup>	92.909 652.1 1.60 Nb Niobium [Ar] 4d <sup>3</sup> 5s <sup>1</sup>	95.95 683.1 2.16 Mo Molybdenum [Ar] 4d <sup>4</sup> 5s <sup>1</sup>	101.07 702.0 1.90 Tc Technetium [Ar] 4d <sup>5</sup> 5s <sup>1</sup>	101.91 702.0 1.90 Ru Ruthenium [Ar] 4d <sup>7</sup> 5s <sup>1</sup>	106.42 804.4 2.20 Rh Rhodium [Ar] 4d <sup>8</sup> 5s <sup>1</sup>
178.49 595.5 1.30 Hf Hafnium [Ar] 4f <sup>14</sup> 5d <sup>2</sup> 6s <sup>2</sup>	180.95 761.0 1.50 Ta Tantalum [Ar] 4f <sup>14</sup> 5d <sup>3</sup> 6s <sup>2</sup>	183.84 770.0 2.36 W Tungsten [Ar] 4f <sup>14</sup> 5d <sup>4</sup> 6s <sup>2</sup>	186.21 790.0 1.90 Re Rhenium [Ar] 4f <sup>14</sup> 5d <sup>5</sup> 6s <sup>2</sup>	190.23 800.0 2.20 Os Osmium [Ar] 4f <sup>14</sup> 5d <sup>6</sup> 6s <sup>2</sup>	192.22 807.0 2.28 Ir Iridium [Ar] 4f <sup>14</sup> 5d <sup>7</sup> 6s <sup>2</sup>
(261) 104 Rf Rutherfordium [Rn] 5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>1</sup>	(262) 105 Db Dubnium [Rn] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>1</sup>	(266) 106 Sg Seaborgium [Rn] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>1</sup>	(264) 107 Bh Bohrium [Rn] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>1</sup>	(277) 108 Hs Hassium [Rn] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>1</sup>	(268) 109 Mt Meitnerium [Rn] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>1</sup>
*	*	*	*	*	*
230.42 587.0 1.30 Ce Cerium [Ce] 4f <sup>9</sup> 5d <sup>1</sup> 6s <sup>2</sup>	231.04 568.0 1.19 Pr Praseodymium [Ce] 4f <sup>9</sup> 5d <sup>1</sup> 6s <sup>2</sup>	238.03 597.6 1.38 Nd Neodymium [Ce] 4f <sup>9</sup> 5d <sup>1</sup> 6s <sup>2</sup>	237.91 604.5 1.36 Pm Promethium [Ce] 4f <sup>9</sup> 5d <sup>1</sup> 6s <sup>2</sup>	240.4 584.7 1.28 Sm Samarium [Ce] 4f <sup>9</sup> 5d <sup>1</sup> 6s <sup>2</sup>	245.7 578.0 1.30 Eu Europium [Ce] 4f <sup>9</sup> 5d <sup>1</sup> 6s <sup>2</sup>
*	*	*	*	*	*
232.04 587.0 1.30 Th Thorium [Th] 5f <sup>1</sup> 6d <sup>1</sup> 7s <sup>2</sup>	231.04 568.0 1.19 Pa Protactinium [Th] 5f <sup>1</sup> 6d <sup>1</sup> 7s <sup>2</sup>	238.03 597.6 1.38 U Uranium [Th] 5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>	237.91 604.5 1.36 Np Neptunium [Th] 5f <sup>2</sup> 6d <sup>1</sup> 7s <sup>2</sup>	244.0 584.7 1.28 Am Americium [Th] 5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>	243.0 581.0 1.30 Cm Curium [Th] 5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup>
*	*	*	*	*	*
234.0 587.0 1.30 Bk Berkelium [Bk] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>2</sup>	234.0 568.0 1.19 Cf Californium [Bk] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>2</sup>	238.03 597.6 1.38 Es Einsteinium [Cf] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>2</sup>	237.91 604.5 1.36 Fm Fermium [Cf] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>2</sup>	240.4 584.7 1.28 Ts Tennessine [Fm] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>2</sup>	245.7 578.0 1.30 Og Oganesson [Ts] 5f <sup>5</sup> 6d <sup>1</sup> 7s <sup>2</sup>
*	*	*	*	*	*



### Notes

- 1 eV/mJ = 96.485 eV
- all elements are implied to have an oxidation state of zero.

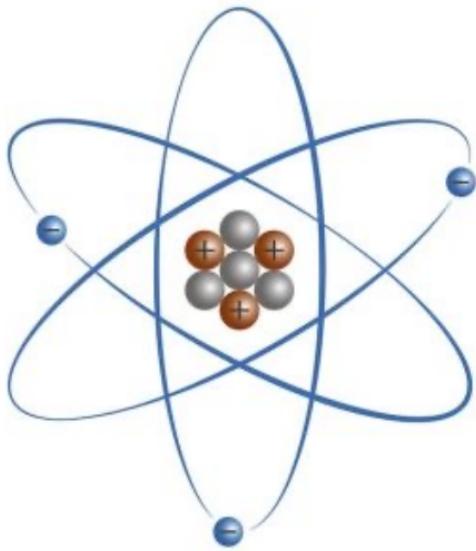
by Adam Lampton - updated 2016.2018



# First: Science Review

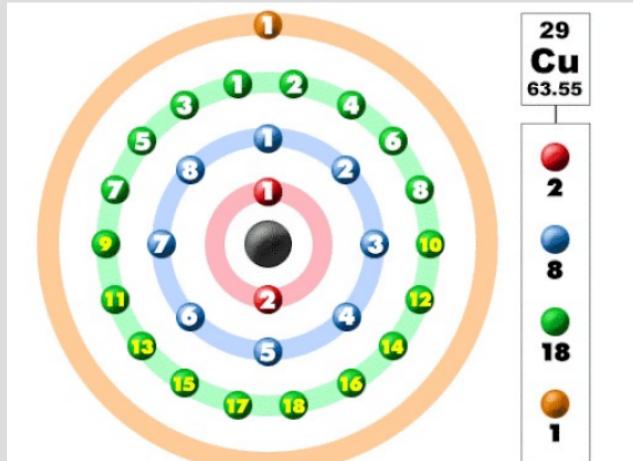


# First: Science Review



Atom structure

- Proton
- Neutron
- Electron



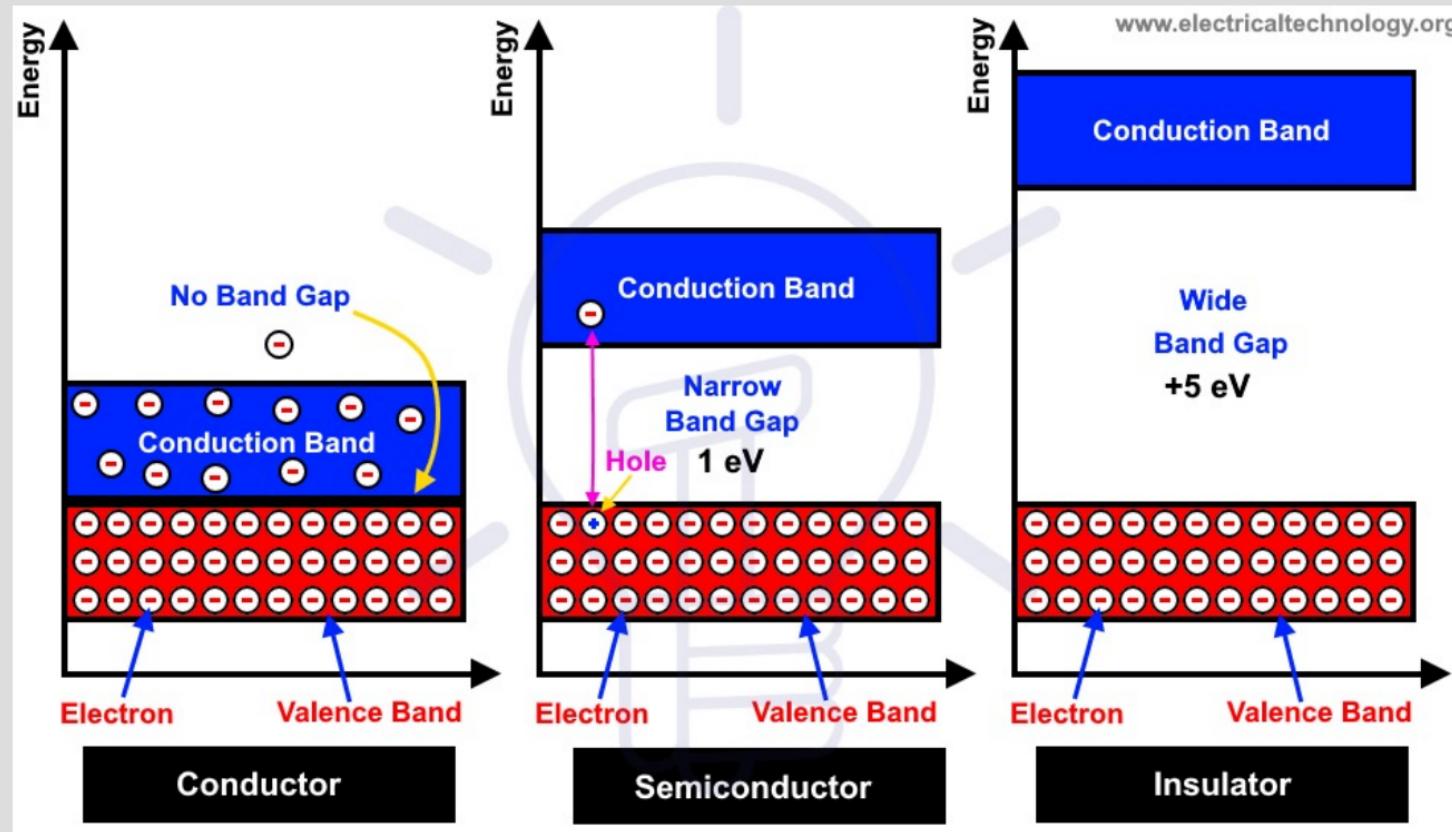
29  
**Cu**  
63.55

2  
8  
18  
1

			4s	3d	
Calcium	Ca	20	[Ar] $4s^2$	$\uparrow\downarrow$	$\square\square\square\square\square$
Iron	Fe	26	[Ar] $4s^2 3d^6$	$\uparrow\downarrow$	$\uparrow\downarrow \uparrow \uparrow \uparrow \uparrow$
Copper	Cu	29	[Ar] $4s^1 3d^{10}$	$\uparrow$	$\uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow \uparrow\downarrow$

Element	Symbol	Electronic Configuration
Scandium	Sc	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^1 4s^2$
Titanium	Ti	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$
Vanadium	V	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^2$
Chromium	Cr	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$
Manganese	Mn	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^2$
Iron	Fe	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$
Cobalt	Co	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 4s^2$
Nickel	Ni	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^2$
Copper	Cu	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$
Zinc	Zn	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2$

## Second: a tiny bit of Solid-State Physics



Electronic Devices depend on movement of charges

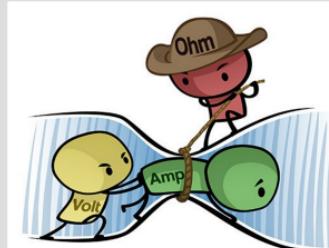
# Electrical Quantities

Quantities	Analytical Symbol	Units
Current	I	Amperes (A)
Voltage	V	Volts (V)
Resistance	R	Ohms ( $\Omega$ )

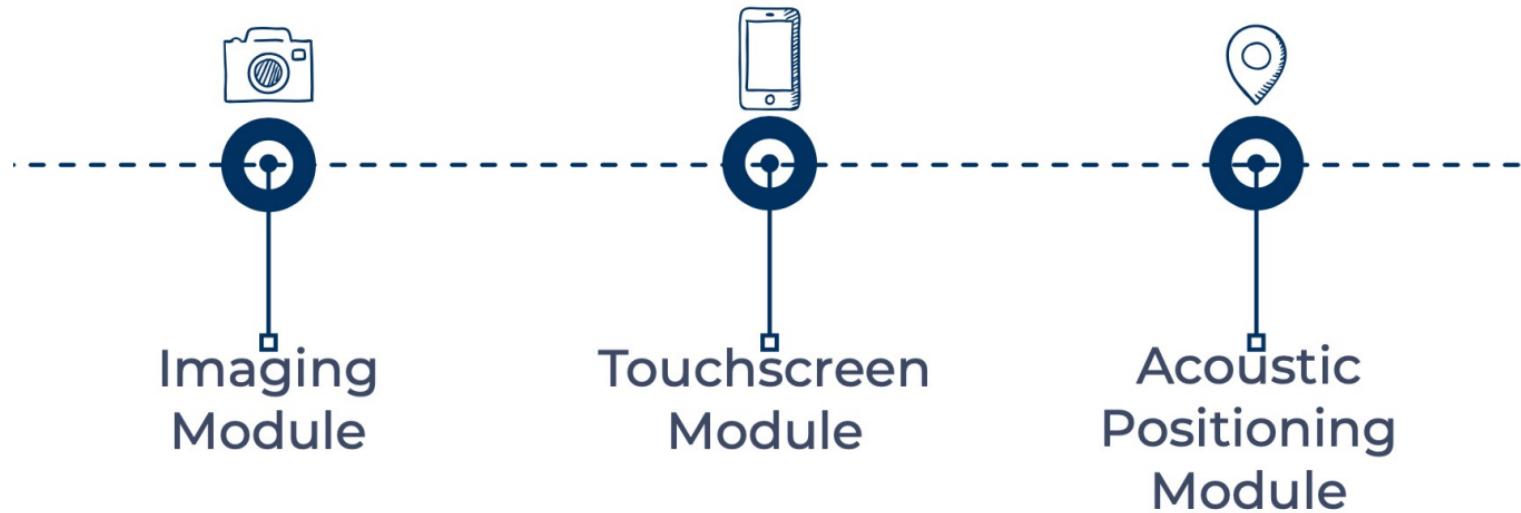
$I \Rightarrow$  flows through an element

$V \Rightarrow$  applied across an element

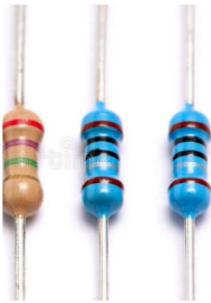
$R \Rightarrow$  opposition to current flow



# In the lab

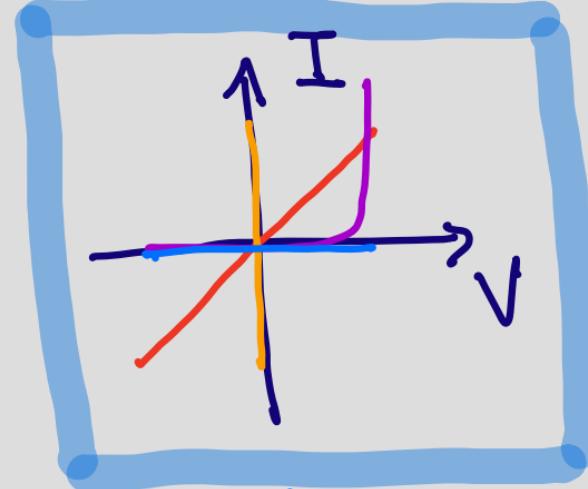
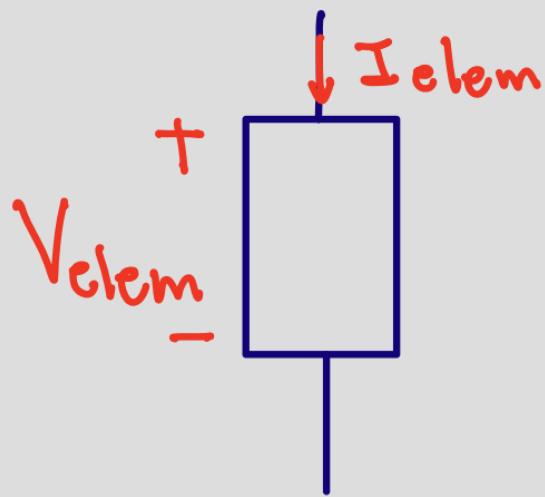


# In the lab



# Definitions needed to analyze a circuit : Circuit Diagram

Collection of elements, where each element has some voltage across it and some current through it



$V_{\text{elem}}$  : Voltage across the element  
 $I_{\text{elem}}$  : Current across the element

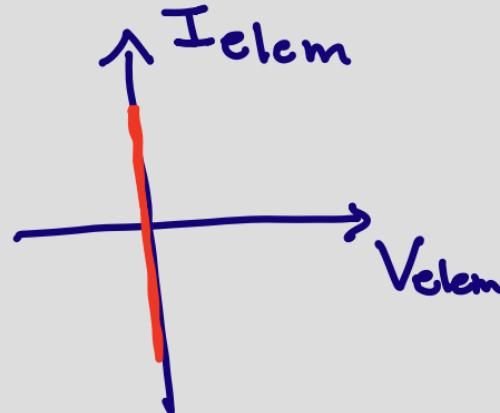
## Key circuit elements: Wire



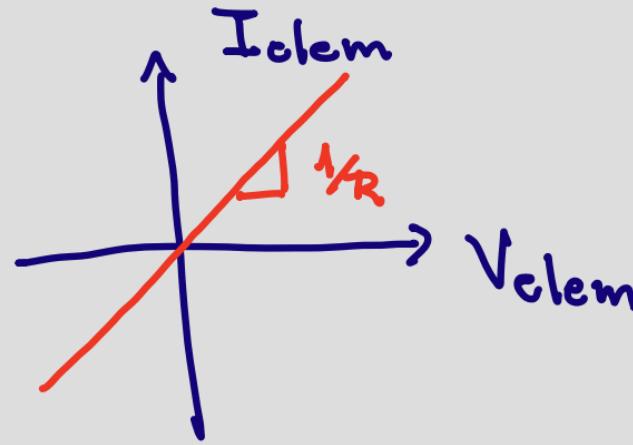
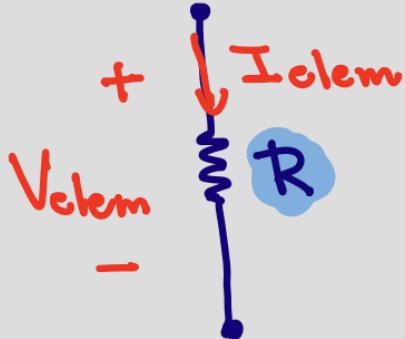
$$V_{\text{clem}} = 0$$

$$I_{\text{clem}} = ?$$

(set by the external circuit)



# Key circuit elements: Resistor

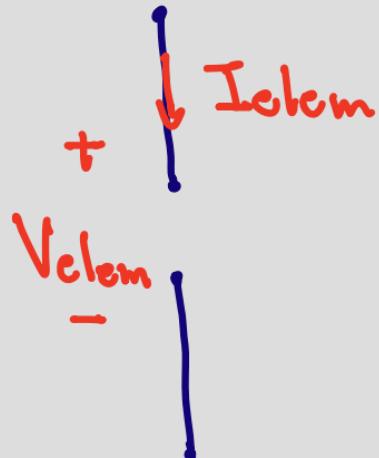


$$V_{clem} = R \cdot I_{clem}$$

Ohm's Law



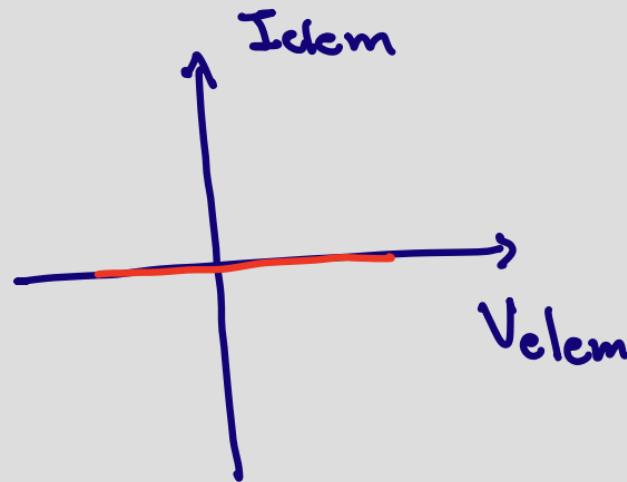
# Key circuit elements: Open circuit



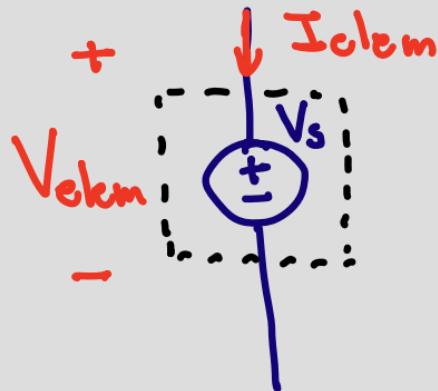
$$I_{elem} = 0$$

$$V_{elem} = ?$$

( $V$  is set by  
the external  
circuit)



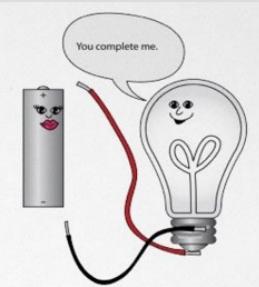
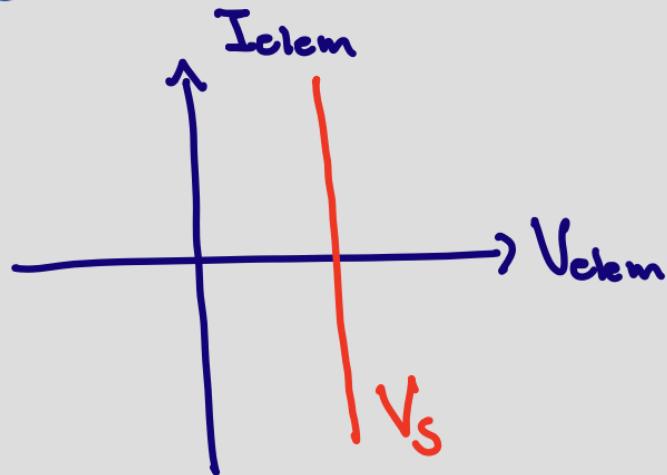
# Key circuit elements: Voltage Source



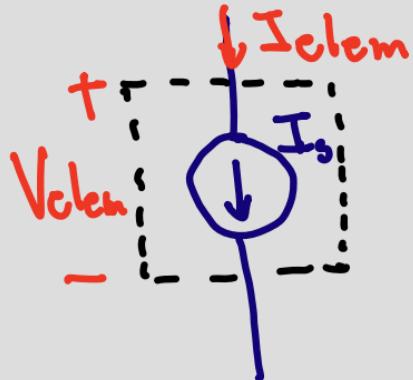
$$V_{clem} = V_s$$

$$I_{clem} = ?$$

( $I$  set by  
external  
circuit)



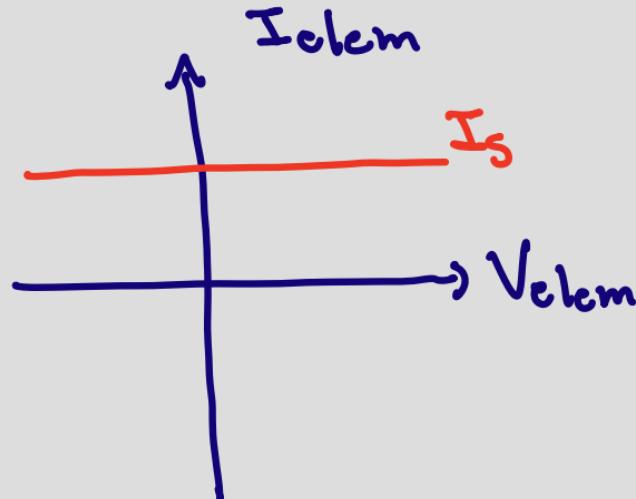
# Key circuit elements: Current Source



$$I_{\text{clm}} = I_s$$

$$V_{\text{clm}} = ?$$

( $V$  is set by  
external  
circuit)

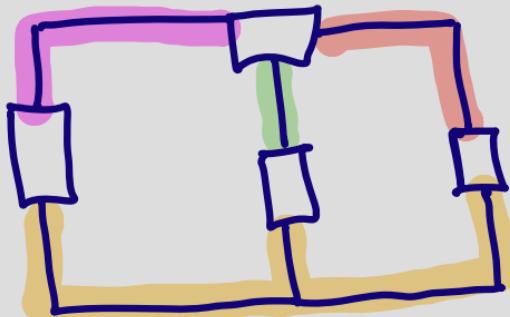


$V_{\text{clm}}$  and  $I_{\text{clm}}$  can be positive or negative

# Definitions needed to analyze a circuit : Circuit Diagram

Collection of elements, where each element has some voltage across it and some current through it

## Example



4 nodes

many junctions

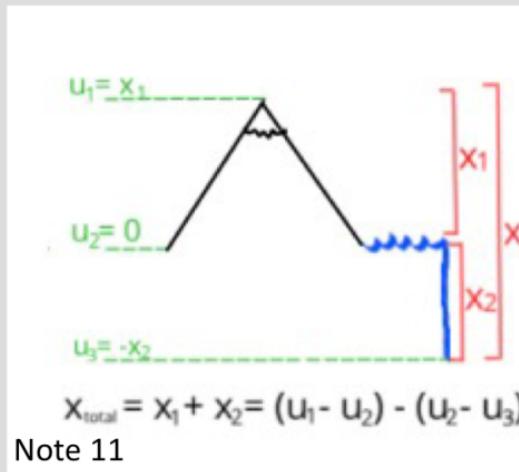
Nodes : point where  
elements meet

Junction : point where  
different materials meet

# Circuit Analysis Algorithm

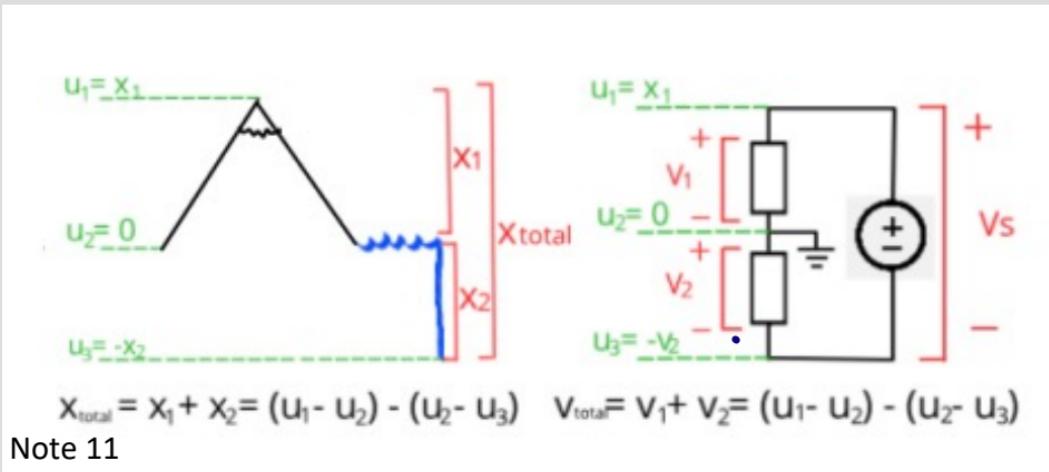
Voltage = difference of two potential

Find: currents through elements and potentials of inputs/outputs of each element (junctions)



Note 11

# Electronic Devices depend on movement of charges



Note 11

We always need to define a reference for potentials.

Ground = 0

$U_1, U_2, U_3$   
potentials

$$V_1 = U_1 - U_2$$

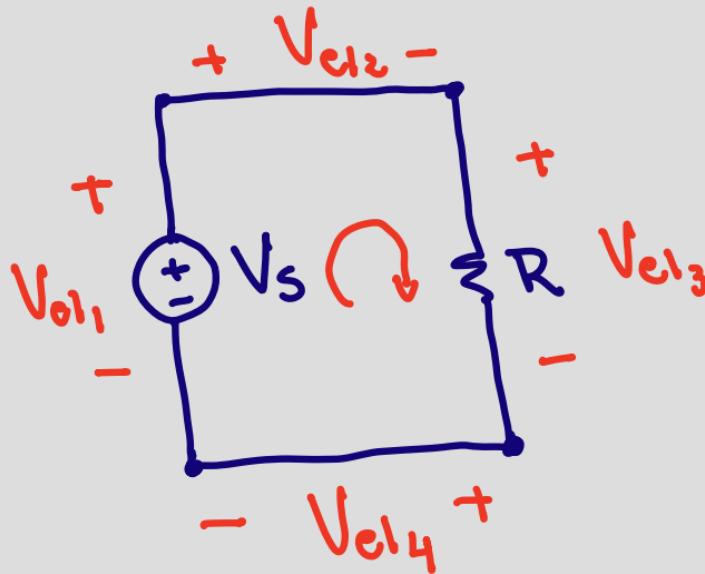
$$V_2 = U_2 - U_3$$

$$V_{\text{total}} = V_1 + V_2$$

$$V_{\text{total}} = V_s$$

# Rules for circuit analysis: Kirchoff's Voltage Law (KVL)

Sum of Voltages across the elements in a loop equal zero



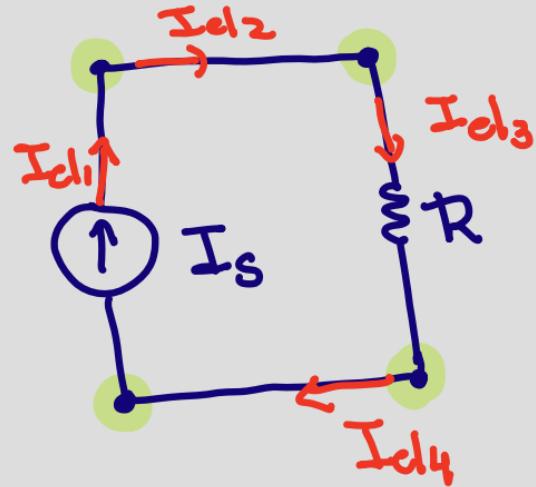
$$V_{el1} - V_{el2} - V_{el3} - V_{el4} = 0$$

$$\begin{array}{rcl} + & \pm V_{el2} \\ V_{el1} & \pm V_{el3} \\ - & \pm V_{el4} \end{array}$$

$$V_{el1} = V_s$$

# Rules for circuit analysis: Kirchoff's Current Law (KCL)

The current flowing into any junction must equal the current flowing out



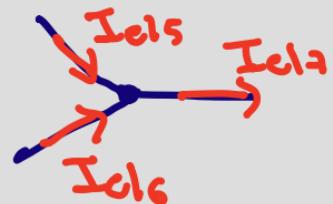
$$I_{cl1} = I_{cl2}$$

$$I_{cl2} = I_{cl3}$$

$$I_{cl3} = I_{cl4}$$

$$I_{cl4} = I_{cl1}$$

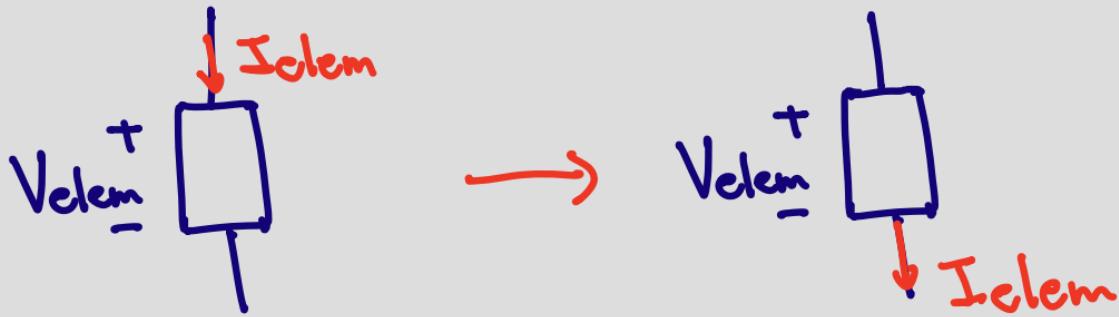
Example 2:



$$I_{cl5} + I_{cl6} = I_{cl2}$$

# Rules for circuit analysis: KCL within the element

The current flowing into any junction must equal the current flowing out



Same current!

Both are allowed.

$I_{elem}$  goes  
into a  $+$   
or out of  
a  $-$  terminal



Passive sign  
convention