

# Welcome to EECS 16A!

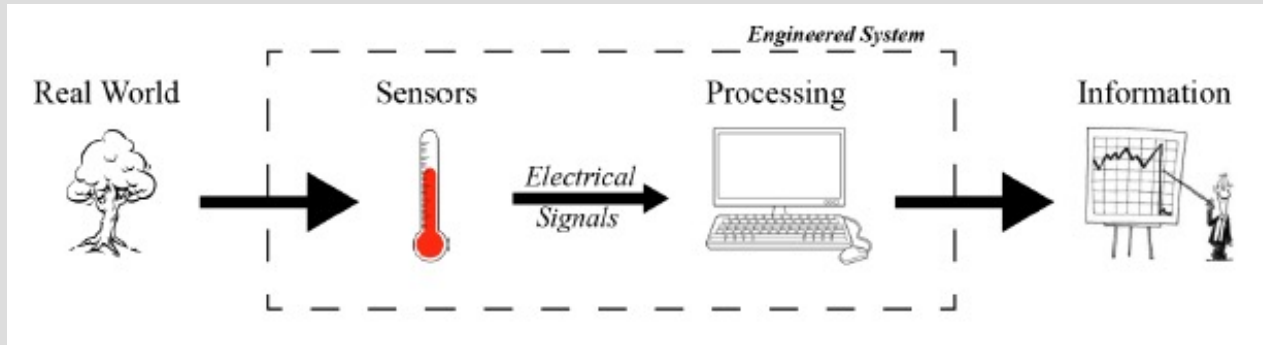
## Designing Information Devices and Systems I

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

# Module 2 – More tools to build systems

Analog World

Sensor

Processing

Actuation



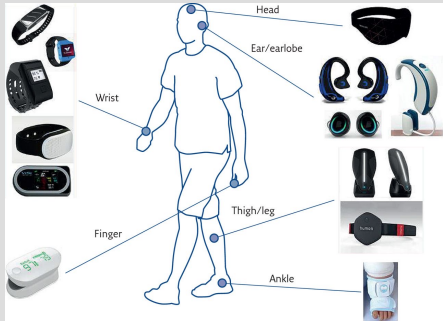
# Module 2 – More tools to build systems

Analog World

Sensor

Processing

Actuation



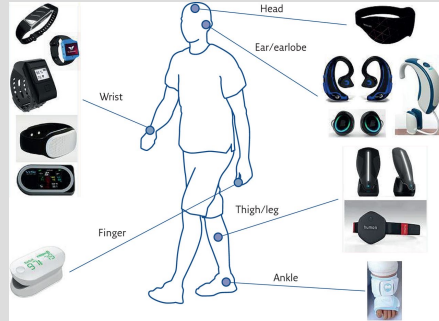
# Module 2 – More tools to build systems

16B

Analog World

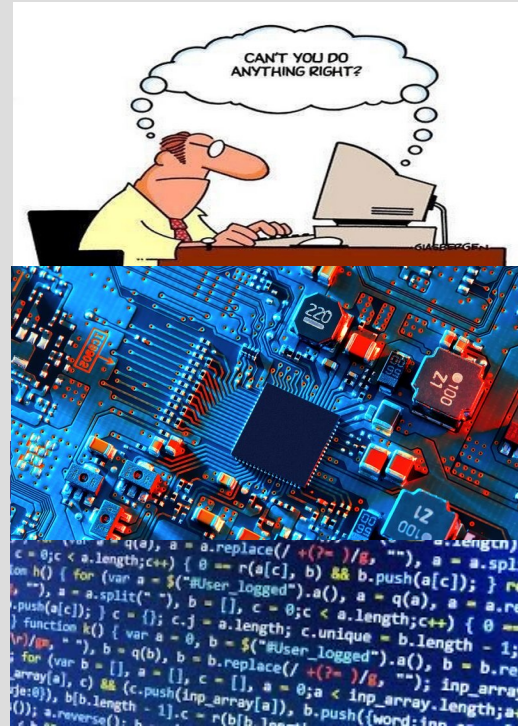


Sensor



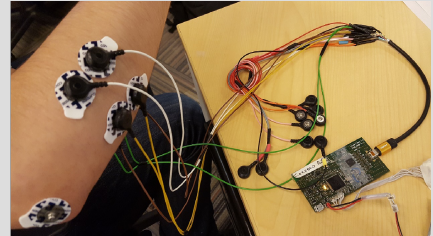
Processing

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



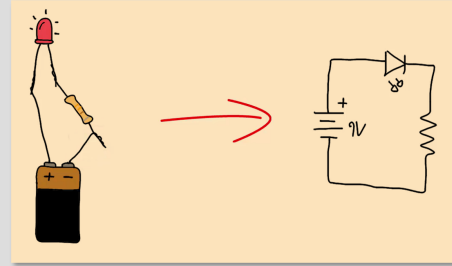
# System Example - Electromyography





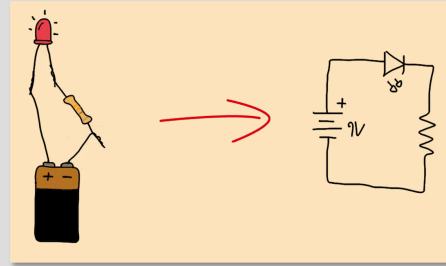
# In Module 2 we will learn how to analyze circuits

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



# 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.



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																2										13										14										15										16										17										18																																																																																																													
Period 1	1.008 1.125 2.20 <sup>+</sup> <b>H</b> Hydrogen [1] <sup>1</sup>																2										13										14										15										16										17										18																																																																																																													
Period 2	6.94 520.2 0.98 <sup>+</sup> <b>Li</b> Lithium [2] <sup>1</sup>																9.0122 895.5 1.57 <sup>+</sup> <b>Be</b> Beryllium [2] <sup>2</sup>										26.9815 147.24 <sup>+</sup> <b>B</b> Boron [2] <sup>1,2</sup>										12.011 1086.5 2.55 <sup>+</sup> <b>C</b> Carbon [2] <sup>2,4</sup>										14.007 1402.3 3.04 <sup>+</sup> <b>N</b> Nitrogen [2] <sup>3,5</sup>										15.999 1313.9 3.44 <sup>+</sup> <b>O</b> Oxygen [2] <sup>2,4</sup>										18.998 1468.0 3.98 <sup>+</sup> <b>F</b> Fluorine [2] <sup>3,5</sup>										20.180 1681.0 3.98 <sup>+</sup> <b>Ne</b> Neon [2] <sup>1,4</sup>																																																																																																													
Period 3	22.990 875.8 0.97 <sup>+</sup> <b>Na</b> Sodium [3] <sup>1</sup>																24.305 737.7 1.31 <sup>+</sup> <b>Mg</b> Magnesium [3] <sup>2</sup>										26.9815 147.24 <sup>+</sup> <b>Al</b> Aluminium [3] <sup>3</sup>										28.085 786.5 1.90 <sup>+</sup> <b>Si</b> Silicon [3] <sup>3,4</sup>										30.974 1011.8 <b>P</b> Phosphorus [3] <sup>3,5</sup>										32.06 999.6 2.58 <sup>+</sup> <b>S</b> Sulfur [3] <sup>2,4,6</sup>										35.45 1051.2 3.16 <sup>+</sup> <b>Cl</b> Chlorine [3] <sup>3,5,7</sup>										39.948 1520.6 <b>Ar</b> Argon [3] <sup>1,4,6</sup>																																																																																																													
Period 4	39.098 438.8 0.84 <sup>+</sup> <b>K</b> Potassium [4] <sup>1</sup>																40.078 589.5 1.00 <sup>+</sup> <b>Ca</b> Calcium [4] <sup>2</sup>										44.956 653.1 1.36 <sup>+</sup> <b>Sc</b> Scandium [4] <sup>3</sup>										47.867 503.8 1.54 <sup>+</sup> <b>Ti</b> Titanium [4] <sup>2,3,4</sup>										50.942 558.9 1.63 <sup>+</sup> <b>V</b> Vanadium [4] <sup>3,4,5</sup>										51.996 568.9 1.66 <sup>+</sup> <b>Cr</b> Chromium [4] <sup>3,4,6</sup>										54.938 578.7 1.59 <sup>+</sup> <b>Mn</b> Manganese [4] <sup>3,4,6,7</sup>										55.845 762.5 1.83 <sup>+</sup> <b>Fe</b> Iron [4] <sup>2,3,6,7</sup>										58.933 589.4 1.93 <sup>+</sup> <b>Co</b> Cobalt [4] <sup>3,4,5,6</sup>										58.933 589.4 1.93 <sup>+</sup> <b>Ni</b> Nickel [4] <sup>3,4,5,6</sup>										63.546 746.5 1.90 <sup>+</sup> <b>Cu</b> Copper [4] <sup>3,4,5,6</sup>										65.38 746.5 1.90 <sup>+</sup> <b>Zn</b> Zinc [4] <sup>3,4,5,6</sup>										69.723 578.8 1.89 <sup>+</sup> <b>Ga</b> Gallium [4] <sup>3,4,5,6</sup>										72.630 762.0 2.01 <sup>+</sup> <b>Ge</b> Germanium [4] <sup>3,4,5,6</sup>										74.922 847.7 2.19 <sup>+</sup> <b>As</b> Arsenic [4] <sup>3,4,5,6</sup>										78.971 846.0 2.30 <sup>+</sup> <b>Se</b> Selenium [4] <sup>3,4,5,6</sup>										79.904 1159.4 2.36 <sup>+</sup> <b>Br</b> Bromine [4] <sup>3,4,5,6</sup>										83.798 1329.8 3.00 <sup>+</sup> <b>Kr</b> Krypton [4] <sup>1,4,6</sup>									
Period 5	85.468 403.0 0.82 <sup>+</sup> <b>Rb</b> Rubidium [5] <sup>1</sup>																87.62 549.5 0.95 <sup>+</sup> <b>Sr</b> Strontium [5] <sup>2</sup>										88.906 600.0 1.32 <sup>+</sup> <b>Y</b> Yttrium [5] <sup>3</sup>										91.224 650.1 1.33 <sup>+</sup> <b>Zr</b> Zirconium [5] <sup>2,3,4</sup>										92.906 652.1 1.60 <sup>+</sup> <b>Nb</b> Niobium [5] <sup>3,4,5</sup>										95.95 684.3 2.16 <sup>+</sup> <b>Mo</b> Molybdenum [5] <sup>4,5,6</sup>										(98) 702.0 1.99 <sup>+</sup> <b>Tc</b> Technetium [5] <sup>4,5,6,7</sup>										101.07 710.2 2.20 <sup>+</sup> <b>Ru</b> Ruthenium [5] <sup>4,5,6,7</sup>										102.91 715.7 2.28 <sup>+</sup> <b>Rh</b> Rhodium [5] <sup>4,5,6,7</sup>										106.42 884.4 2.20 <sup>+</sup> <b>Pd</b> Palladium [5] <sup>4,5,6,7</sup>										107.87 731.0 1.93 <sup>+</sup> <b>Ag</b> Silver [5] <sup>4,5,6,7</sup>										112.41 867.8 1.69 <sup>+</sup> <b>Cd</b> Cadmium [5] <sup>4,5,6,7</sup>										114.82 558.3 1.78 <sup>+</sup> <b>In</b> Indium [5] <sup>4,5,6,7</sup>										118.71 706.6 1.96 <sup>+</sup> <b>Sn</b> Tin [5] <sup>4,5,6,7</sup>										121.76 834.0 2.05 <sup>+</sup> <b>Sb</b> Antimony [5] <sup>4,5,6,7</sup>										127.60 869.3 2.10 <sup>+</sup> <b>Te</b> Tellurium [5] <sup>4,5,6,7</sup>										126.90 1008.4 2.66 <sup>+</sup> <b>I</b> Iodine [5] <sup>4,5,6,7</sup>										131.29 1170.4 2.60 <sup>+</sup> <b>Xe</b> Xenon [5] <sup>1,4,6</sup>									
Period 6	132.91 375.7 0.79 <sup>+</sup> <b>Cs</b> Cesium [6] <sup>1</sup>																137.33 502.9 0.89 <sup>+</sup> <b>Ba</b> Barium [6] <sup>2</sup>										138.91 589.3 1.10 <sup>+</sup> <b>La</b> Lanthanum [6] <sup>3</sup>										178.49 658.1 1.30 <sup>+</sup> <b>Hf</b> Hafnium [6] <sup>2,3,4,5,6</sup>										180.95 761.0 1.50 <sup>+</sup> <b>Ta</b> Tantalum [6] <sup>2,3,4,5,6</sup>										183.84 761.0 2.36 <sup>+</sup> <b>W</b> Tungsten [6] <sup>4,5,6,7</sup>										186.21 705.0 1.90 <sup>+</sup> <b>Re</b> Rhenium [6] <sup>4,5,6,7</sup>										187.20 844.0 2.20 <sup>+</sup> <b>Os</b> Osmium [6] <sup>4,5,6,7</sup>										192.22 880.0 2.20 <sup>+</sup> <b>Ir</b> Iridium [6] <sup>4,5,6,7</sup>										195.08 891.2 2.28 <sup>+</sup> <b>Pt</b> Platinum [6] <sup>4,5,6,7</sup>										196.97 890.1 2.54 <sup>+</sup> <b>Au</b> Gold [6] <sup>4,5,6,7</sup>										200.59 1007.1 2.00 <sup>+</sup> <b>Hg</b> Mercury [6] <sup>4,5,6,7</sup>										204.38 589.4 1.62 <sup>+</sup> <b>Tl</b> Thallium [6] <sup>4,5,6,7</sup>										207.2 715.8 2.33 <sup>+</sup> <b>Pb</b> Lead [6] <sup>4,5,6,7</sup>										208.98 843.1 2.02 <sup>+</sup> <b>Bi</b> Bismuth [6] <sup>4,5,6,7</sup>										(210) 832.1 2.60 <sup>+</sup> <b>Po</b> Polonium [6] <sup>4,5,6,7</sup>										(210) 853.8 2.20 <sup>+</sup> <b>At</b> Astatine [6] <sup>4,5,6,7</sup>										(220) 1370.7 <b>Rn</b> Radon [6] <sup>1,4,6</sup>									
Period 7	(223) 769.1 0.79 <sup>+</sup> <b>Fr</b> Francium [7] <sup>1</sup>																(226) 589.3 0.80 <sup>+</sup> <b>Ra</b> Radium [7] <sup>2</sup>										(227) 589.3 1.10 <sup>+</sup> <b>Ac</b> Actinium [7] <sup>3</sup>										(261) 589.3 1.10 <sup>+</sup> <b>Rf</b> Rutherfordium [7] <sup>3,4,5,6,7</sup>										(262) 589.3 1.10 <sup>+</sup> <b>Db</b> Dubnium [7] <sup>3,4,5,6,7</sup>										(266) 589.3 1.10 <sup>+</sup> <b>Sg</b> Seaborgium [7] <sup>3,4,5,6,7</sup>										(264) 589.3 1.10 <sup>+</sup> <b>Bh</b> Bohrium [7] <sup>3,4,5,6,7</sup>										(277) 589.3 1.10 <sup>+</sup> <b>Hs</b> Hassium [7] <sup>3,4,5,6,7</sup>										(268) 589.3 1.10 <sup>+</sup> <b>Mt</b> Meitnerium [7] <sup>3,4,5,6,7</sup>										(271) 589.3 1.10 <sup>+</sup> <b>Ds</b> Darmstadtium [7] <sup>3,4,5,6,7</sup>										(272) 589.3 1.10 <sup>+</sup> <b>Rg</b> Roentgenium [7] <sup>3,4,5,6,7</sup>										(285) 589.3 1.10 <sup>+</sup> <b>Cn</b> Copernicium [7] <sup>3,4,5,6,7</sup>										(284) 589.3 1.10 <sup>+</sup> <b>Nh</b> Nihonium [7] <sup>3,4,5,6,7</sup>										(289) 589.3 1.10 <sup>+</sup> <b>Fl</b> Flerovium [7] <sup>3,4,5,6,7</sup>										(288) 589.3 1.10 <sup>+</sup> <b>Mc</b> Moscovium [7] <sup>3,4,5,6,7</sup>										(292) 589.3 1.10 <sup>+</sup> <b>Lv</b> Livermorium [7] <sup>3,4,5,6,7</sup>										(294) 589.3 1.10 <sup>+</sup> <b>Ts</b> Tennessine [7] <sup>3,4,5,6,7</sup>										(294) 589.3 1.10 <sup>+</sup> <b>Og</b> Oganesson [7] <sup>3,4,5,6,7</sup>									

standard atomic weight  
or most stable mass number  
1st ionization energy  
in kJ/mol

55.845 26

762.5 1.83

+6  
+3  
+2  
-1  
-2

atomic number

electronegativity

oxidation states  
most common are bold

chemical symbol

**Fe**

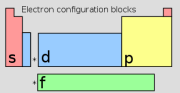
name

Iron

electron configuration

[Ar] 3d<sup>6</sup> 4s<sup>2</sup>

radioactive elements have  
masses in parenthesis



Notes

- 1 kJ/mol = 96.485 eV
- \* elements are implied to have an oxidation state of zero.

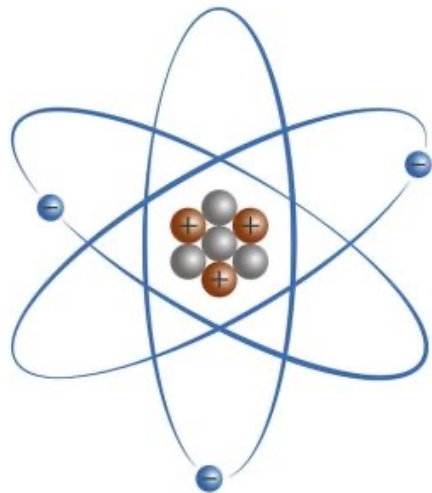
by Robert Campion / updated 2016, 2018

- alkali metals
- alkaline earth metals
- lanthanides
- actinides
- transition metals
- unknown properties
- post-transition metals
- metalloids
- reactive nonmetals
- noble gases

# First: Science Review



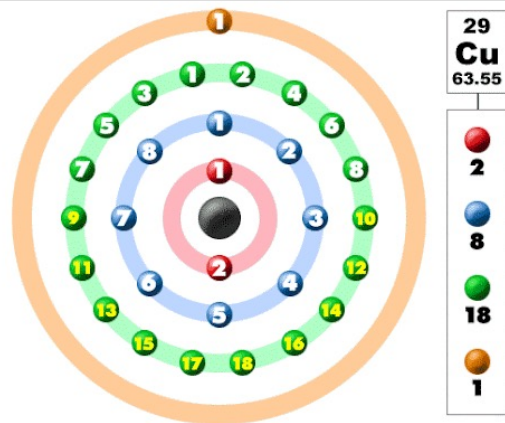
# First: Science Review



Atom structure

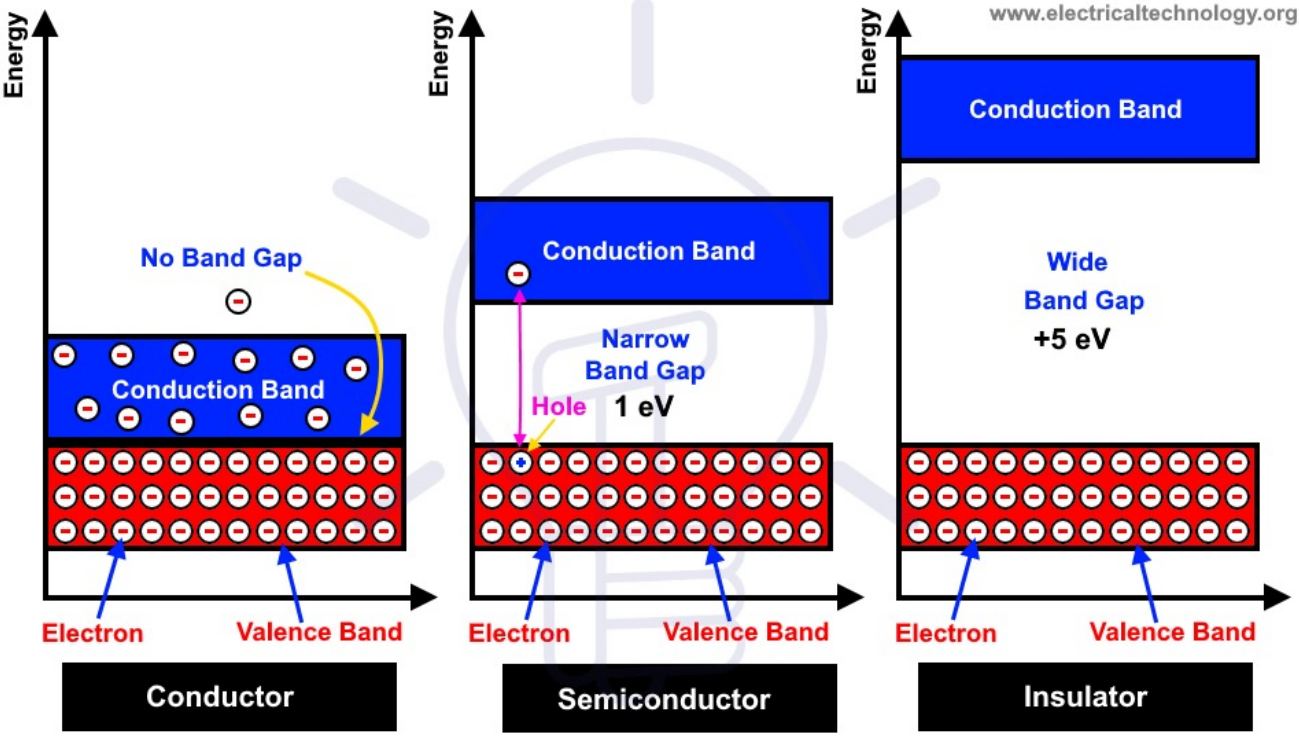
- Proton
- Neutron
- Electron

				4s	3d						
Calcium	Ca	20	[Ar]	4s <sup>2</sup>	<table border="1" style="display: inline-table;"><tr><td>↑↓</td><td></td><td></td><td></td><td></td><td></td></tr></table>	↑↓					
↑↓											
Iron	Fe	26	[Ar]	4s <sup>2</sup>	3d <sup>6</sup>						
				<table border="1" style="display: inline-table;"><tr><td>↑↓</td></tr></table>	↑↓	<table border="1" style="display: inline-table;"><tr><td>↑↓</td><td>↑</td><td>↑</td><td>↑</td><td>↑</td></tr></table>	↑↓	↑	↑	↑	↑
↑↓											
↑↓	↑	↑	↑	↑							
Copper	Cu	29	[Ar]	4s <sup>1</sup>	3d <sup>10</sup>						
				<table border="1" style="display: inline-table;"><tr><td>↑</td></tr></table>	↑	<table border="1" style="display: inline-table;"><tr><td>↑↓</td><td>↑↓</td><td>↑↓</td><td>↑↓</td><td>↑↓</td></tr></table>	↑↓	↑↓	↑↓	↑↓	↑↓
↑											
↑↓	↑↓	↑↓	↑↓	↑↓							



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

# Second: a tiny bit of Solid-State Physics



Electronic Devices depend on movement of charges

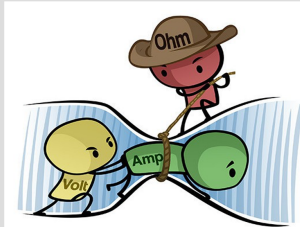
# Electrical Quantities

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

$I \Rightarrow$  flows through an element

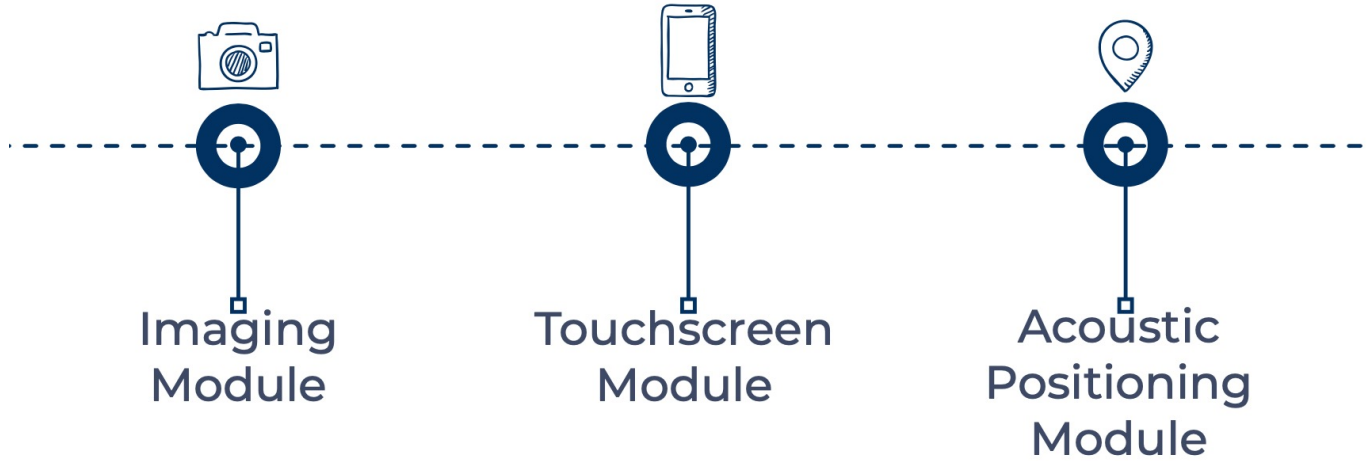
$V \Rightarrow$  applied across an element

$R \Rightarrow$  opposition to current flow

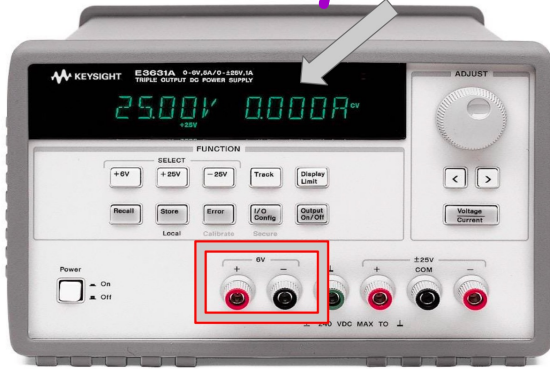




# In the lab

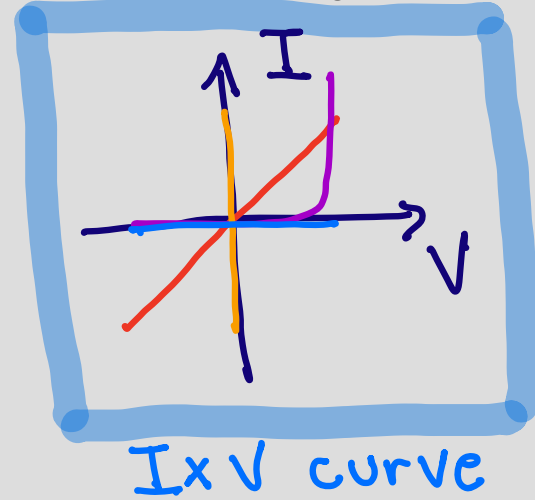
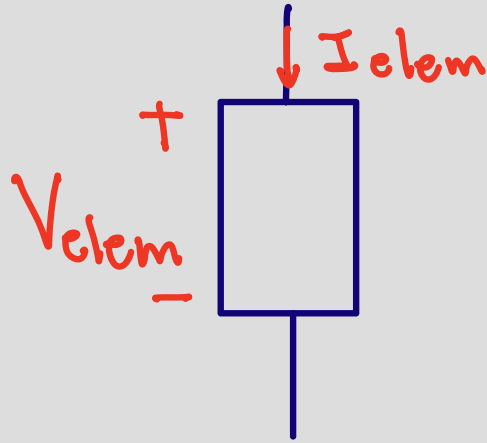


# In the lab



# Definitions needed to analyze a circuit : Circuit Diagram

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



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

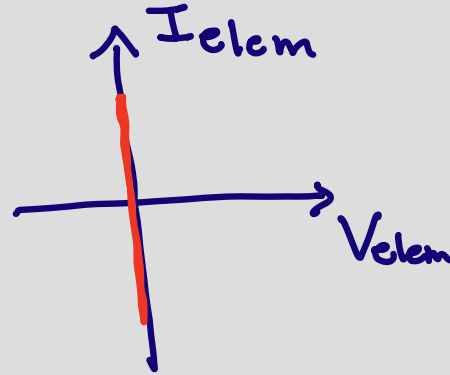
# Key circuit elements: Wire



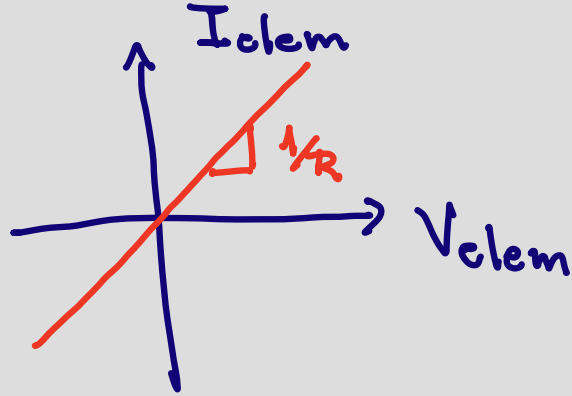
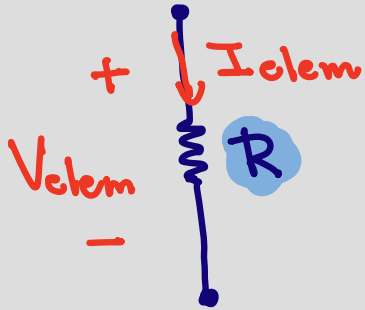
$$V_{elem} = 0$$

$$I_{elem} = ?$$

(set by the external circuit)



# Key circuit elements: Resistor

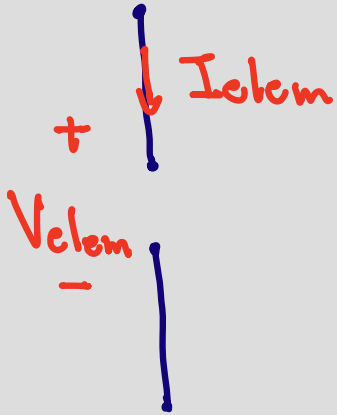


$$V_{elem} = R \cdot I_{elem}$$

Ohm's Law



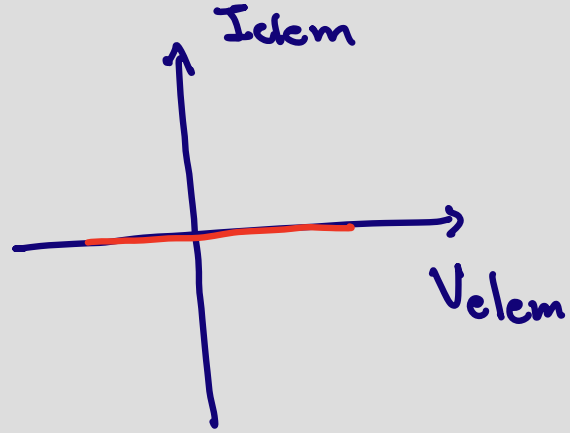
# Key circuit elements: Open circuit



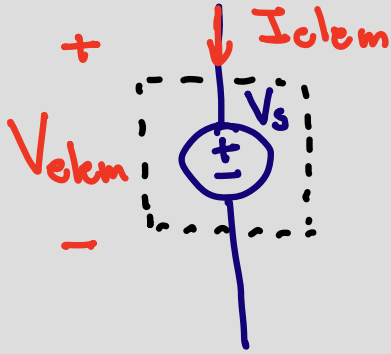
$$I_{elem} = 0$$

$$V_{elem} = ?$$

( $V$  is set by  
the external  
circuit)



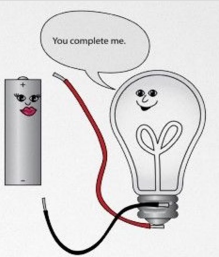
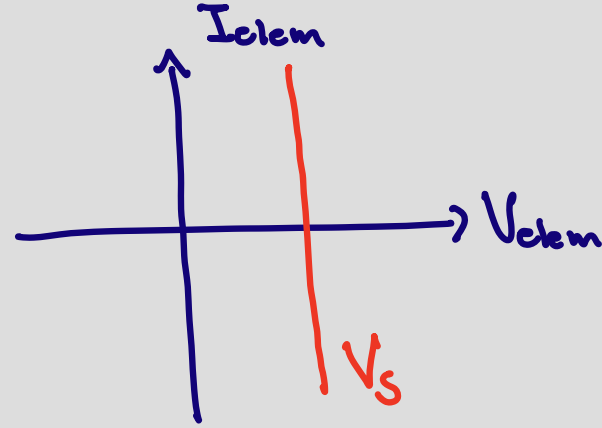
# Key circuit elements: Voltage Source



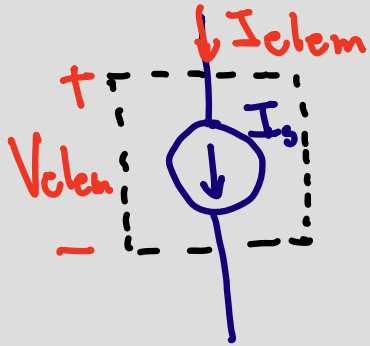
$$V_{elem} = V_s$$

$$I_{elem} = ?$$

(**I** set by external circuit)



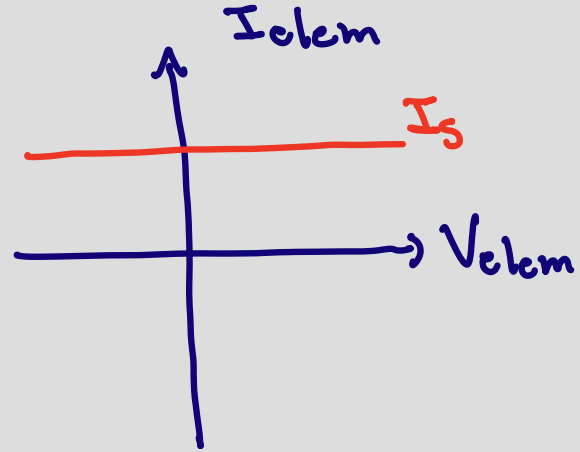
# Key circuit elements: Current Source



$$I_{elem} = I_s$$

$$V_{elem} = ?$$

( $V$  is set by external circuit)



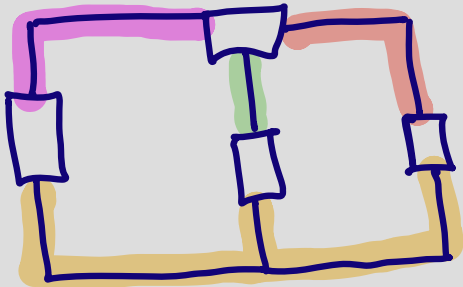
$V_{elem}$  and  $I_{elem}$  can be positive or negative



# 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

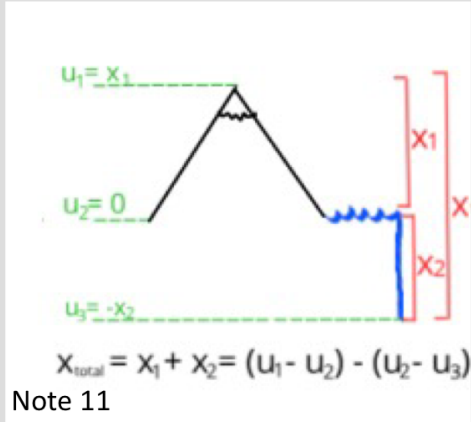
Nodes : point where elements meet

Junction : point where different materials meet

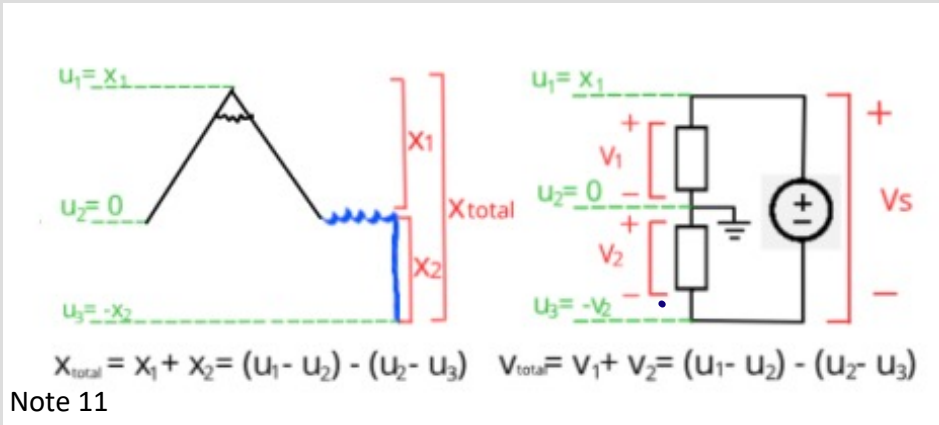
# Circuit Analysis Algorithm

Voltage = difference of two potential

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



# 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

$$V_1 = U_1 - U_2$$

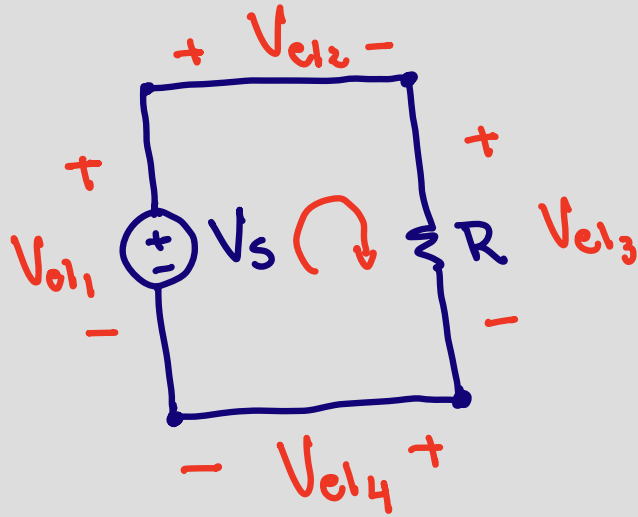
$$V_2 = U_2 - U_3$$

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

$$V_{total} = V_s$$

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

Sum of Voltages across the elements in a loop equal zero



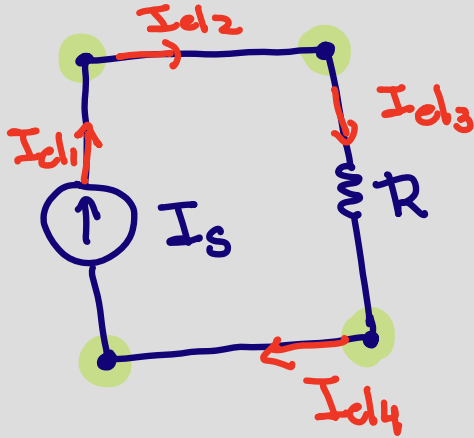
$$V_{cl1} - V_{cl2} - V_{cl3} - V_{cl4} = 0$$

$$+ \quad \uparrow V_{cl2}$$
$$V_{cl1} \quad \uparrow V_{cl3}$$
$$- \quad \uparrow V_{cl4}$$

$$V_{cl1} = V_s$$

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

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



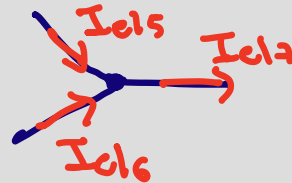
$$I_{e1} = I_{e2}$$

$$I_{e2} = I_{e3}$$

$$I_{e3} = I_{e4}$$

$$I_{e4} = I_{e1}$$

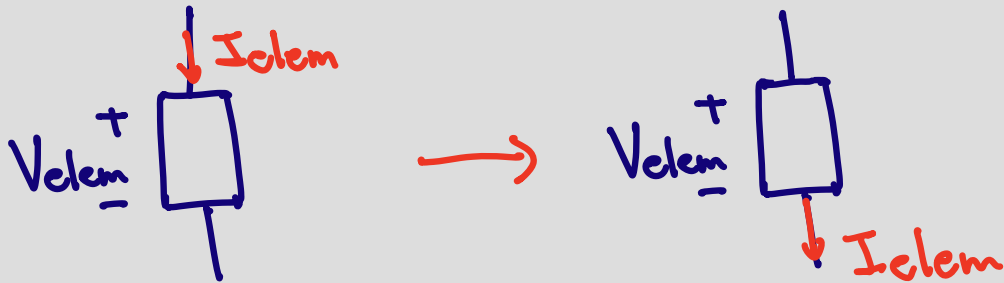
Example 2:



$$I_{e5} + I_{e6} = I_{e7}$$

# 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  $\oplus$  or out of a  $\ominus$  terminal

Passive sign convention