

# Welcome to EECS 16A!

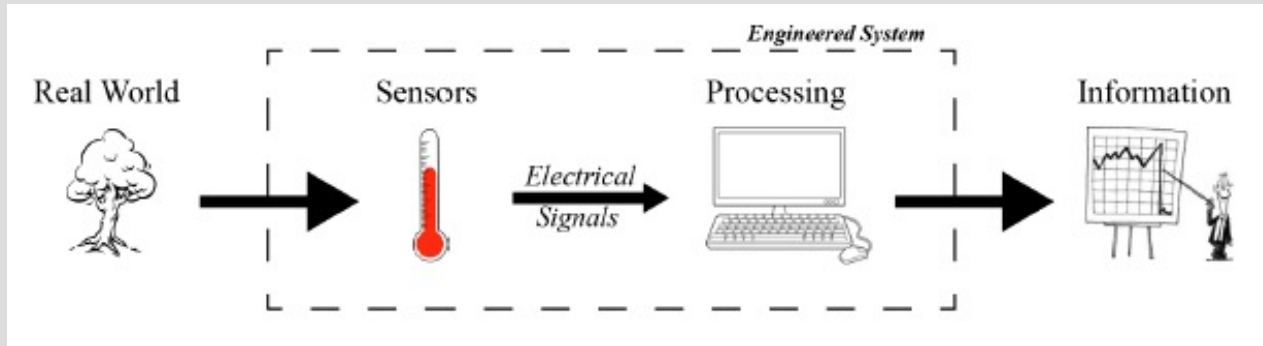
## Designing Information Devices and Systems I

Ana Claudia Arias and Miki Lustig  
Fall 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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Analog World

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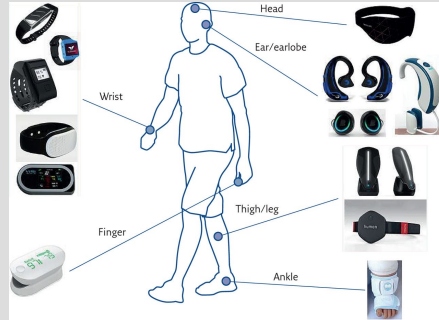
# Module 2 – More tools to build systems

Analog World

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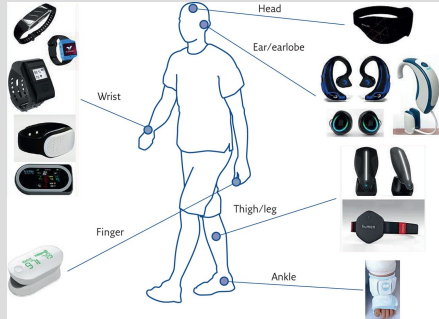
# Module 2 – More tools to build systems

16B

Analog World

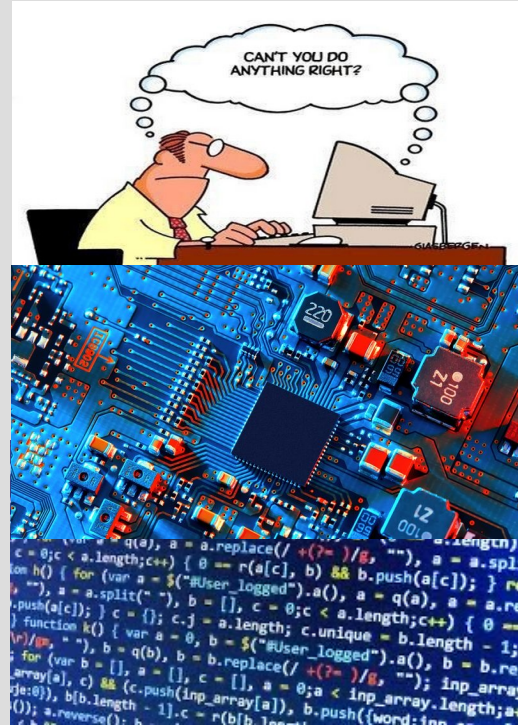


Sensor



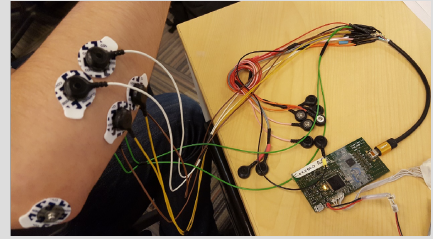
Processing

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



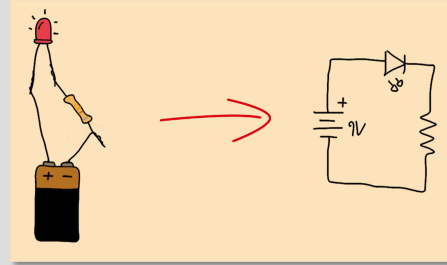
# System Example - Electromyography





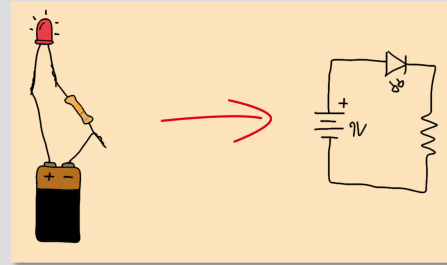
# In Module 2 we will learn how to analyze circuits


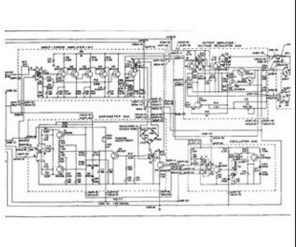
We need to be able to go from a real-world circuit, to a circuit model, and vice versa.



# 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																		Group 2																		Group 13										Group 14										Group 15										Group 16										Group 17										Group 18																																																																																																					
Period 1																		Period 2																		Period 3										Period 4										Period 5										Period 6										Period 7										Period 8																																																																																																					
1																		2																		3										4										5										6										7										8																																																																																																					
1.008 1.112 0 2.016 1 H Hydrogen (1) <sup>1</sup> 1H																		6.94 7.024 0.938 3 Li Lithium (3) <sup>3</sup> Li																		9.0122 9.009 5 1.9 2.2 4 Be Beryllium (4) <sup>4</sup> Be																		10.81 10.811 2.04 5 B Boron (5) <sup>5</sup> B										12.011 12.011 2.5 2.04 6 C Carbon (6) <sup>6</sup> C										14.007 14.007 2.04 7 N Nitrogen (7) <sup>7</sup> N										15.999 15.999 3.44 8 O Oxygen (8) <sup>8</sup> O										18.998 18.998 3.98 9 F Fluorine (9) <sup>9</sup> F										20.180 20.180 10 Ne Neon (10) <sup>10</sup> Ne																																																																																			
22.990 22.990 0.931 11 Na Sodium (11) <sup>11</sup> Na																		24.305 24.305 1.31 12 Mg Magnesium (12) <sup>12</sup> Mg																		26.982 26.982 1.41 13 Al Aluminium (13) <sup>13</sup> Al										28.085 28.085 1.90 14 Si Silicon (14) <sup>14</sup> Si										30.974 30.974 2.58 15 P Phosphorus (15) <sup>15</sup> P										32.06 32.06 2.58 16 S Sulfur (16) <sup>16</sup> S										35.45 35.45 3.16 17 Cl Chlorine (17) <sup>17</sup> Cl										39.948 39.948 3.84 18 Ar Argon (18) <sup>18</sup> Ar																																																																																																					
39.098 39.098 0.82 19 K Potassium (19) <sup>19</sup> K																		40.078 40.078 1.00 20 Ca Calcium (20) <sup>20</sup> Ca																		44.956 44.956 1.39 21 Sc Scandium (21) <sup>21</sup> Sc										47.867 47.867 1.54 22 Ti Titanium (22) <sup>22</sup> Ti										50.942 50.942 1.63 23 V Vanadium (23) <sup>23</sup> V										51.996 51.996 1.66 24 Cr Chromium (24) <sup>24</sup> Cr										54.938 54.938 1.83 25 Mn Manganese (25) <sup>25</sup> Mn										55.845 55.845 1.83 26 Fe Iron (26) <sup>26</sup> Fe										58.933 58.933 1.83 27 Co Cobalt (27) <sup>27</sup> Co										58.693 58.693 1.83 28 Ni Nickel (28) <sup>28</sup> Ni										63.546 63.546 1.90 29 Cu Copper (29) <sup>29</sup> Cu										65.38 65.38 1.83 30 Zn Zinc (30) <sup>30</sup> Zn										69.723 69.723 1.93 31 Ga Gallium (31) <sup>31</sup> Ga										72.630 72.630 2.03 32 Ge Germanium (32) <sup>32</sup> Ge										74.922 74.922 2.03 33 As Arsenic (33) <sup>33</sup> As										78.971 78.971 2.03 34 Se Selenium (34) <sup>34</sup> Se										79.904 79.904 2.06 35 Br Bromine (35) <sup>35</sup> Br										83.798 83.798 2.00 36 Kr Krypton (36) <sup>36</sup> Kr	
85.468 85.468 0.82 37 Rb Rubidium (37) <sup>37</sup> Rb																		87.62 87.62 0.95 38 Sr Strontium (38) <sup>38</sup> Sr																		88.906 88.906 1.22 39 Y Yttrium (39) <sup>39</sup> Y										91.224 91.224 1.30 40 Zr Zirconium (40) <sup>40</sup> Zr										92.906 92.906 1.60 41 Nb Niobium (41) <sup>41</sup> Nb										95.95 95.95 2.16 42 Mo Molybdenum (42) <sup>42</sup> Mo										(98) 98 2.16 43 Tc Technetium (43) <sup>43</sup> Tc										101.07 101.07 2.20 44 Ru Ruthenium (44) <sup>44</sup> Ru										102.91 102.91 2.28 45 Rh Rhodium (45) <sup>45</sup> Rh										106.42 106.42 2.23 46 Pd Palladium (46) <sup>46</sup> Pd										107.87 107.87 2.28 47 Ag Silver (47) <sup>47</sup> Ag										112.41 112.41 2.4 48 Cd Cadmium (48) <sup>48</sup> Cd										114.82 114.82 2.4 49 In Indium (49) <sup>49</sup> In										118.71 118.71 2.4 50 Sn Tin (50) <sup>50</sup> Sn										121.76 121.76 2.51 51 Sb Antimony (51) <sup>51</sup> Sb										127.60 127.60 2.52 52 Te Tellurium (52) <sup>52</sup> Te										129.50 129.50 2.56 53 I Iodine (53) <sup>53</sup> I										131.29 131.29 2.60 54 Xe Xenon (54) <sup>54</sup> Xe	
132.91 132.91 0.79 55 Cs Cesium (55) <sup>55</sup> Cs																		137.33 137.33 0.89 56 Ba Barium (56) <sup>56</sup> Ba																		138.91 138.91 1.10 57 La Lanthanum (57) <sup>57</sup> La										178.49 178.49 1.30 72 Hf Hafnium (72) <sup>72</sup> Hf										180.95 180.95 1.50 73 Ta Tantalum (73) <sup>73</sup> Ta										186.21 186.21 2.36 74 W Tungsten (74) <sup>74</sup> W										187.21 187.21 1.90 75 Re Rhenium (75) <sup>75</sup> Re										195.08 195.08 2.28 76 Os Osmium (76) <sup>76</sup> Os										197.22 197.22 2.77 77 Ir Iridium (77) <sup>77</sup> Ir										195.08 195.08 2.28 78 Pt Platinum (78) <sup>78</sup> Pt										200.59 200.59 2.54 79 Au Gold (79) <sup>79</sup> Au										200.59 200.59 2.63 80 Hg Mercury (80) <sup>80</sup> Hg										204.38 204.38 2.60 81 Tl Thallium (81) <sup>81</sup> Tl										207.2 207.2 2.33 82 Pb Lead (82) <sup>82</sup> Pb										208.98 208.98 2.02 83 Bi Bismuth (83) <sup>83</sup> Bi										(210) 210 2.02 84 Po Polonium (84) <sup>84</sup> Po										(210) 210 2.20 85 At Astatine (85) <sup>85</sup> At										(220) 220 2.60 86 Rn Radon (86) <sup>86</sup> Rn	
(223) 223 0.76 87 Fr Francium (87) <sup>87</sup> Fr																		(226) 226 0.90 88 Ra Radium (88) <sup>88</sup> Ra																		(227) 227 1.10 89 Ac Actinium (89) <sup>89</sup> Ac										(261) 261 1.04 104 Rf Rutherfordium (104) <sup>104</sup> Rf										(262) 262 1.05 105 Db Dubnium (105) <sup>105</sup> Db										(266) 266 1.06 106 Sg Seaborgium (106) <sup>106</sup> Sg										(264) 264 1.07 107 Bh Bohrium (107) <sup>107</sup> Bh										(277) 277 1.08 108 Hs Hassium (108) <sup>108</sup> Hs										(268) 268 1.09 109 Mt Meitnerium (109) <sup>109</sup> Mt										(271) 271 1.10 110 Ds Darmstadtium (110) <sup>110</sup> Ds										(272) 272 1.11 111 Rg Roentgenium (111) <sup>111</sup> Rg										(285) 285 1.12 112 Cn Copernicium (112) <sup>112</sup> Cn										(284) 284 1.13 113 Nh Nihonium (113) <sup>113</sup> Nh										(289) 289 1.14 114 Fl Flerovium (114) <sup>114</sup> Fl										(288) 288 1.15 115 Mc Moscovium (115) <sup>115</sup> Mc										(292) 292 1.16 116 Lv Livermorium (116) <sup>116</sup> Lv										(294) 294 1.17 117 Ts Tennessine (117) <sup>117</sup> Ts										(294) 294 1.17 118 Og Oganesson (118) <sup>118</sup> Og	

standard atomic weight or most stable mass number: 55.845

1st ionization energy in kJ/mol: 762.5

chemical symbol: Fe

name: Iron

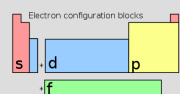
electron configuration: [Ar] 3d<sup>6</sup> 4s<sup>2</sup>

atomic number: 26

electronegativity: +6, +5, +4, +3, +2, +1, -1, -2

oxidation states most common are bold

radioactive elements have masses in parenthesis



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

by Robert Campion / updated 2016, 2018

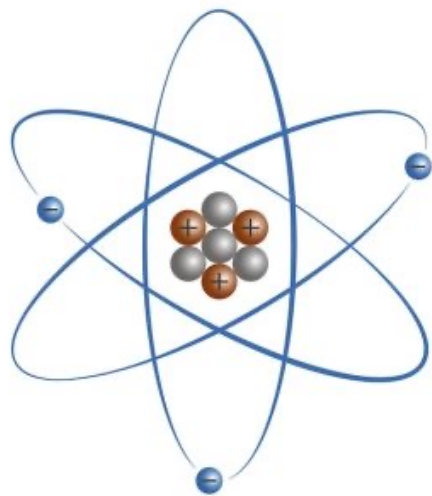
Legend for element categories:

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

# First: Science Review



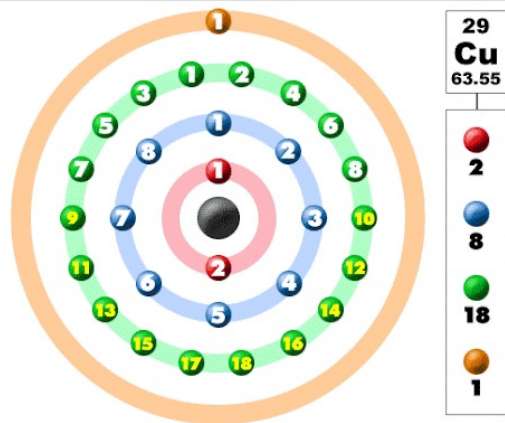
# First: Science Review



Atom structure

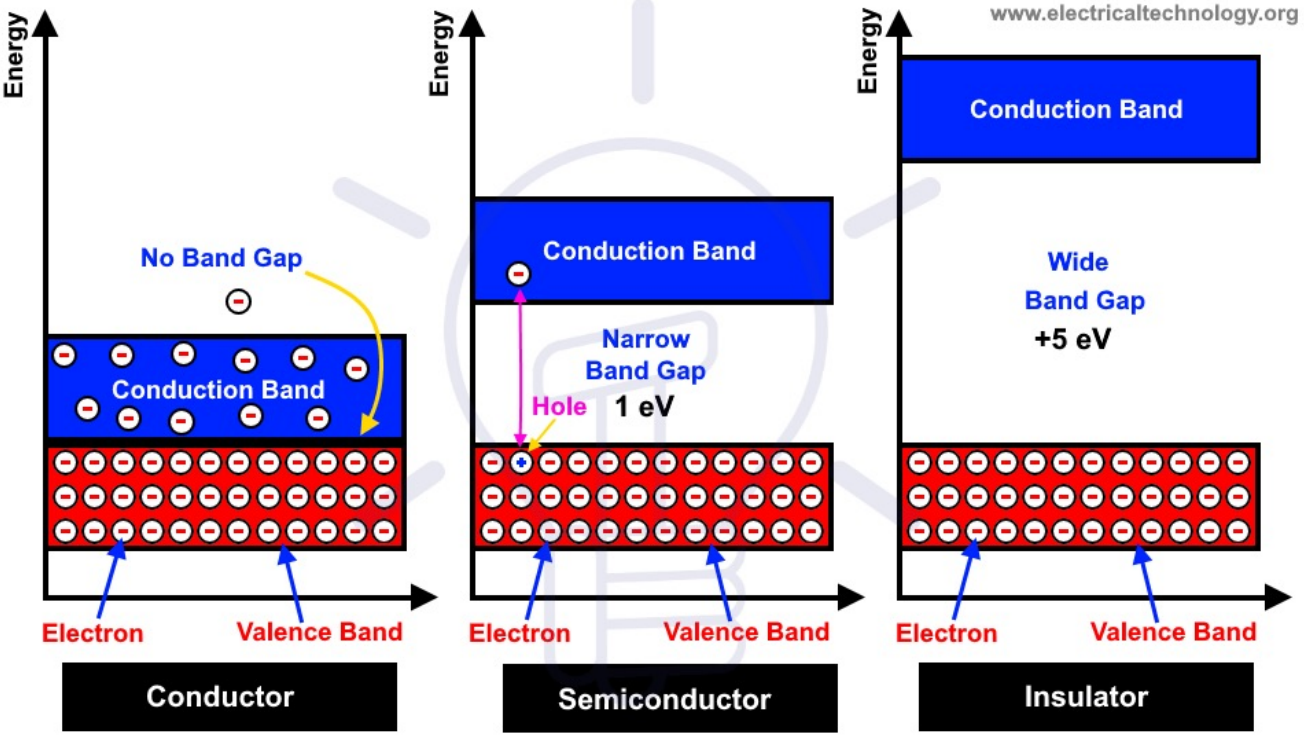
- Proton
- Neutron
- Electron

				4s	3d
Calcium	Ca	20	[Ar]	$4s^2$	$\uparrow\downarrow$ <span style="border: 1px solid black; display: inline-block; width: 20px; height: 20px;"></span> <span style="border: 1px solid black; display: inline-block; width: 20px; height: 20px;"></span> <span style="border: 1px solid black; display: inline-block; width: 20px; height: 20px;"></span> <span style="border: 1px solid black; display: inline-block; width: 20px; height: 20px;"></span> <span style="border: 1px solid black; display: inline-block; width: 20px; height: 20px;"></span>
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

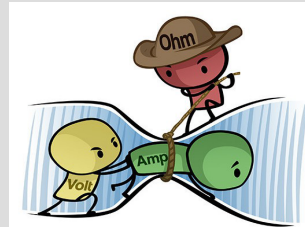


Electronic Devices depend on movement of charges

# Electrical Quantities

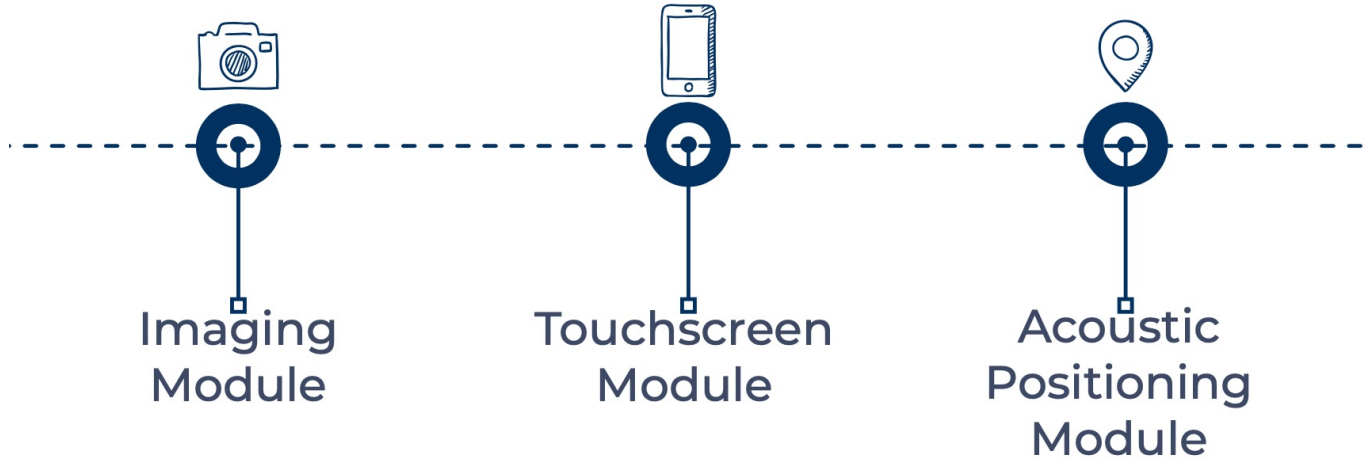
Quantities	Analytical Symbol	Units
Current	$I$	Amperes (A)
Voltage	$V$	Volts (V)
Resistance	$R$	Ohms ( $\Omega$ )

$I \Rightarrow$  flows through an element  
 $V \Rightarrow$  applied across an element  
 $R \Rightarrow$  opposition to current flow

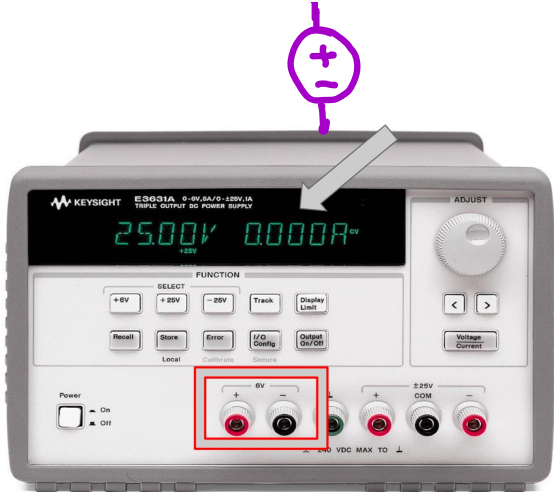




# In the lab

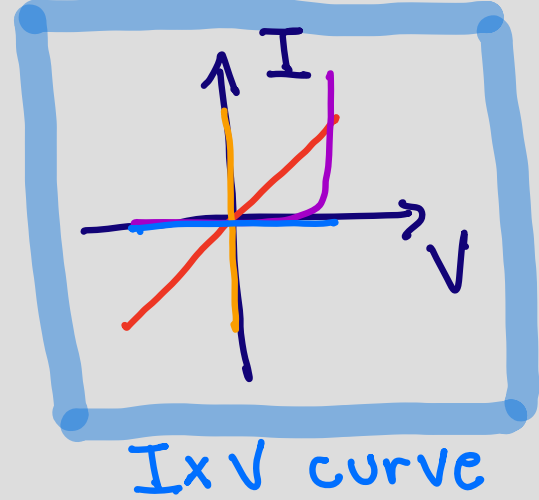
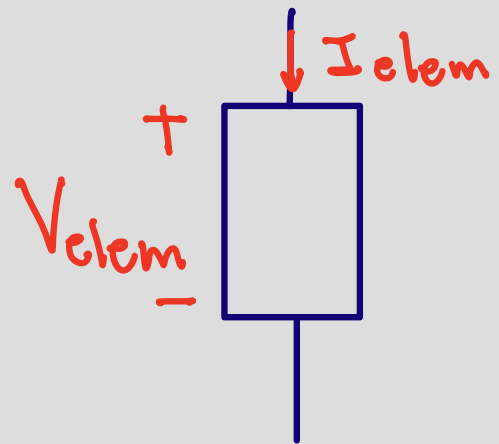


# In the lab



# Definitions needed to analyze a circuit : Circuit Diagram

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



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

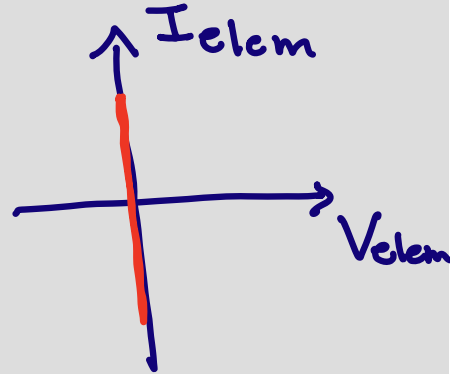
# Key circuit elements: Wire



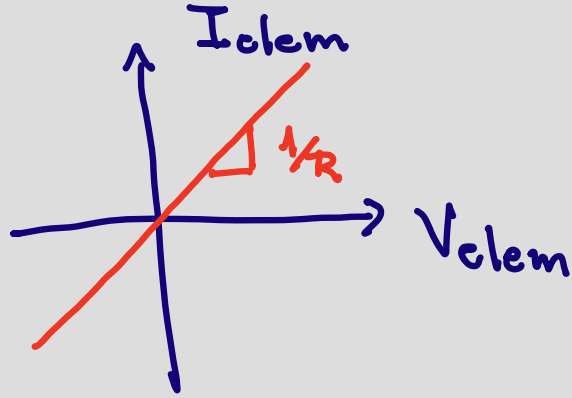
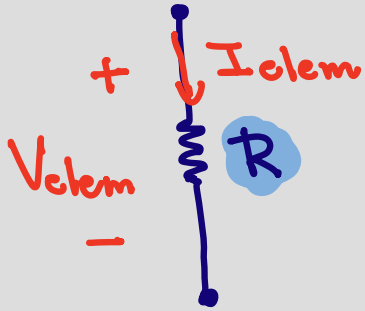
$$V_{elem} = 0$$

$$I_{elem} = ?$$

(set by the external circuit)



# Key circuit elements: Resistor

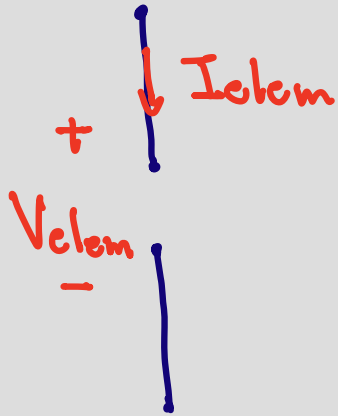


$$V_{elem} = R \cdot I_{elem}$$

Ohm's Law



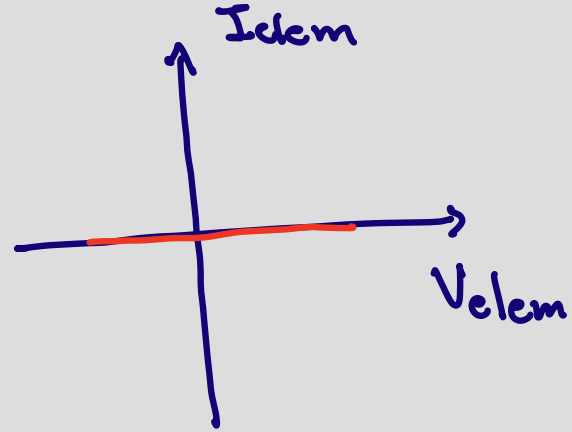
# Key circuit elements: Open circuit



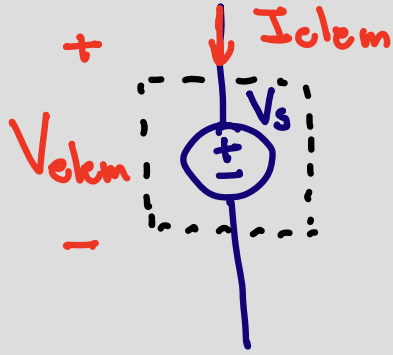
$$I_{elem} = 0$$

$$V_{elem} = ?$$

( $V$  is set by  
the external  
circuit)



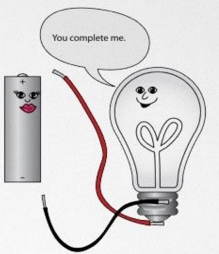
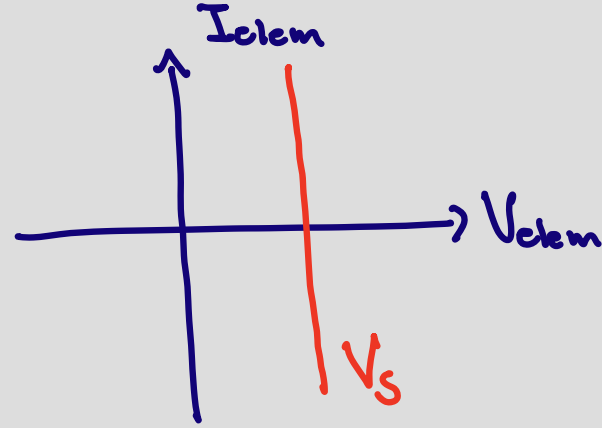
# Key circuit elements: Voltage Source



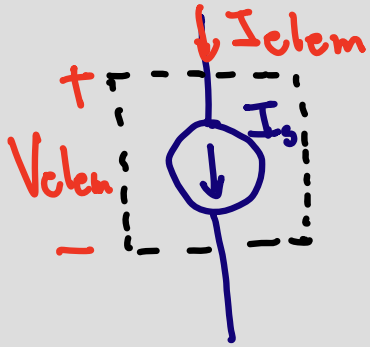
$$V_{\text{elem}} = V_s$$

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

(**I** set by external circuit)



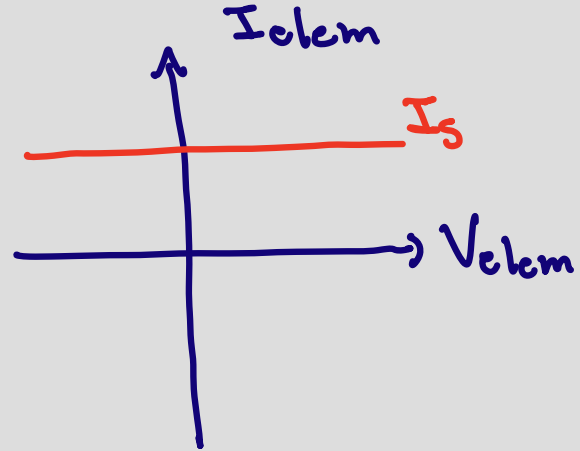
# Key circuit elements: Current Source



$$I_{elem} = I_s$$

$$V_{elem} = ?$$

( $V$  is set by external circuit)



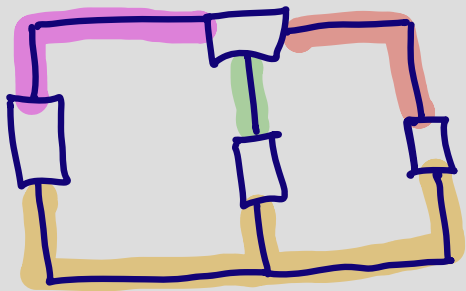
$V_{elem}$  and  $I_{elem}$  can be positive or negative



# 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

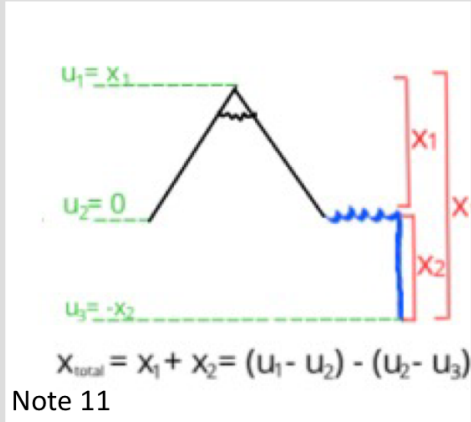
Nodes : point where elements meet

Junction : point where different materials meet

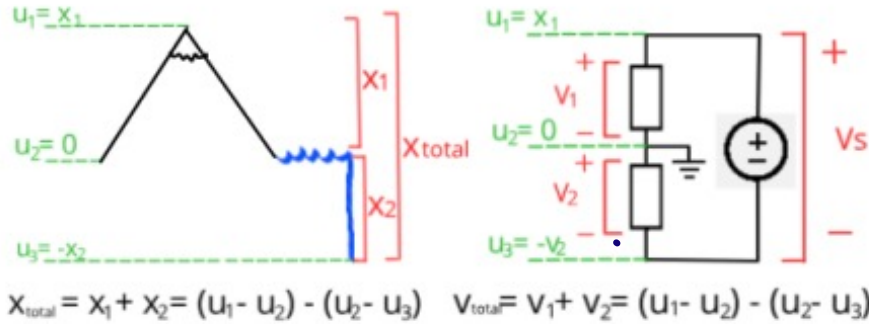
# Circuit Analysis Algorithm

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

$$V_1 = U_1 - U_2$$

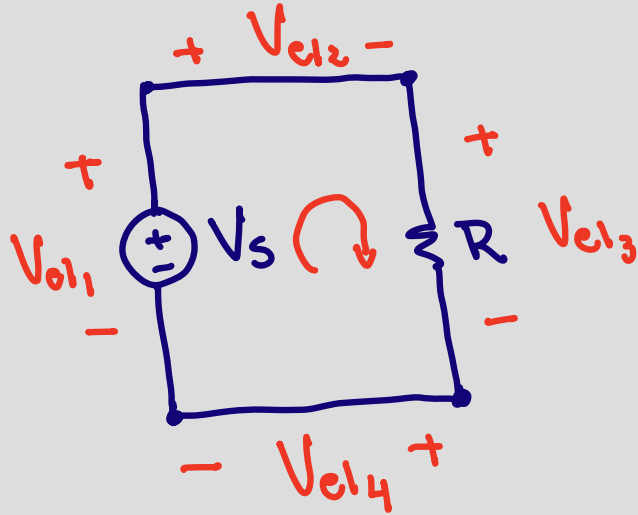
$$V_2 = U_2 - U_3$$

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

$$V_{total} = V_s$$

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

Sum of Voltages across the elements in a loop equal zero



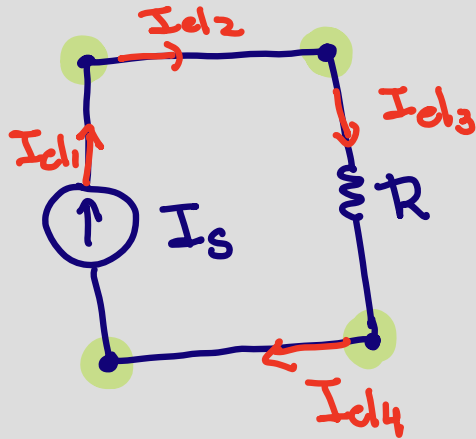
$$V_{vol1} - V_{vol2} - V_{vol3} - V_{vol4} = 0$$

$$+ \quad \underline{+} \quad V_{vol2}$$
$$V_{vol1} \quad \underline{+} \quad V_{vol3}$$
$$- \quad \underline{+} \quad V_{vol4}$$

$$V_{vol1} = V_s$$

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

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



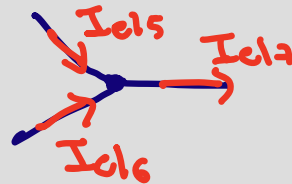
$$I_{e1} = I_{e2}$$

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

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

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

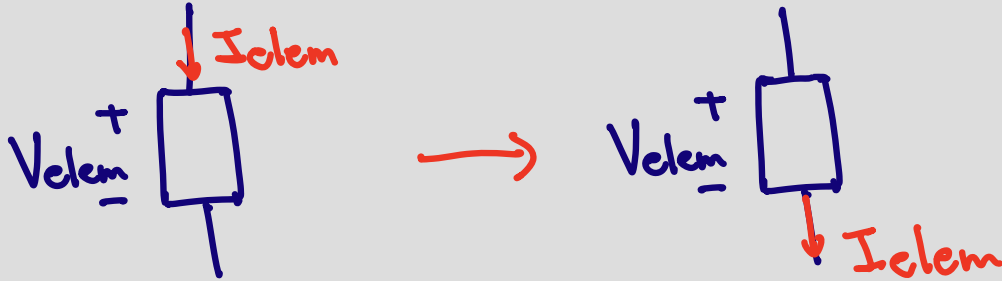
Example 2:



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

# 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