

Welcome to EECS 16A!

Designing Information Devices and Systems I

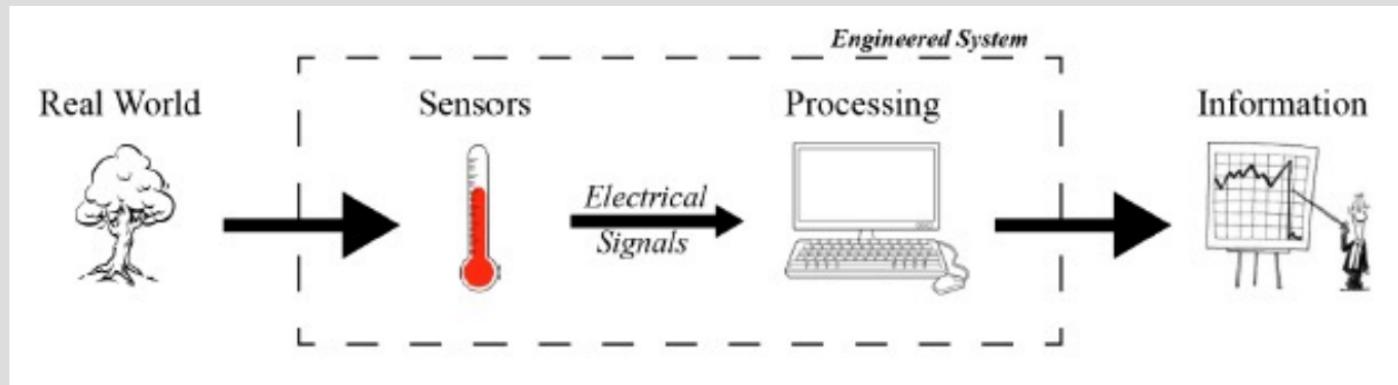


Ana Claudia Arias and Miki Lustig
Fall 2022

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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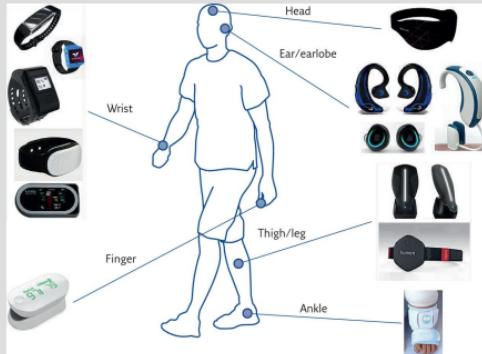
Module 2 – More tools to build systems

Analog World

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Module 2 – More tools to build systems

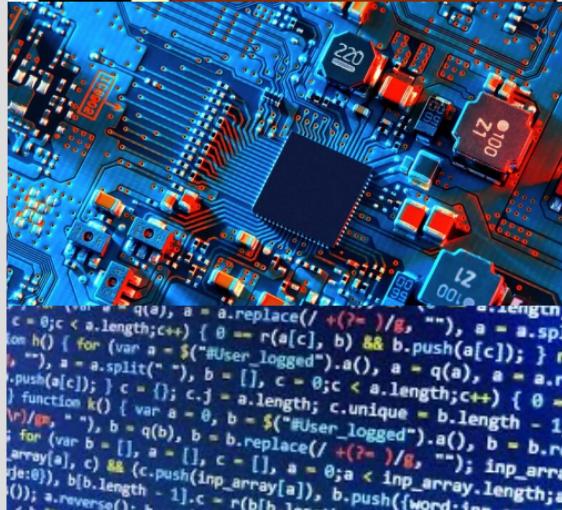
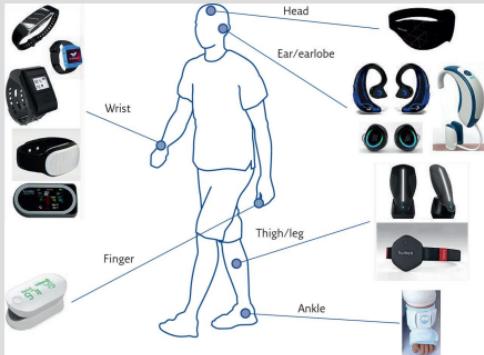
16B

Analog World

Sensor

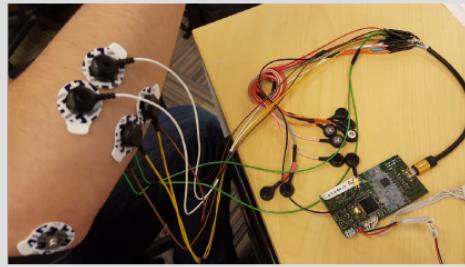
Processing

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

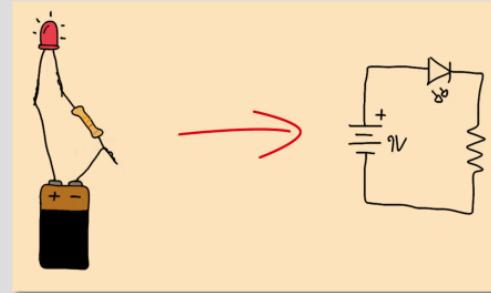


System Example - Electromyography



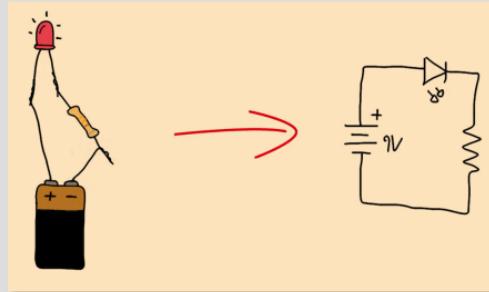
In Module 2 we will learn how to analyze circuits

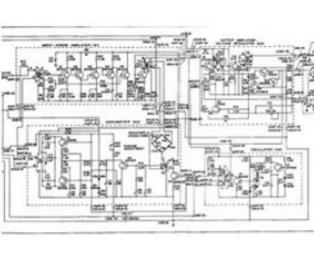
We need to be able to go from a real-world circuit, to a circuit model, and vice versa.



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		18																																																																																																																																																																										
1	H Hydrogen [He] 1s ¹	55.845	26	atomic number electronegativity	Boron [He] 2s ² 2p ¹	C Carbon [He] 2s ² 2p ²	N Nitrogen [He] 2s ² 2p ³	O Oxygen [He] 2s ² 2p ⁴	F Fluorine [He] 2s ² 2p ⁵	Neon [He] 2s ² 2p ⁶	He Helium [He]	4.0026 2372.3	4.0026 2372.3	2	He Helium [He]	20.180 2086.7	10	Ne Neon [He] 2s ² 2p ⁶	18																																																																																																																																																									
2	Li Lithium [He] 2s ¹	6.94 320.2 0.98	3	9.0122 899.5 1.57	Be Boronium [He] 2s ² 2p ⁰	13	14	15	16	17	18	13.011	14.007	15.999	18.998	19.99	20.180	2086.7	10																																																																																																																																																									
3	Na Sodium [Ne] 3s ¹	22.990 403.0 0.93	11	24.305 77.7 1.31	Mg Magnesium [Ne] 3s ²	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18																																																																																																																																																								
4	K Potassium [Ar] 4s ¹	39.098 418.8 0.82	19	40.078 588.8 1.00	Ca Calcium [Ar] 4s ²	20	44.956 589.8 1.36	21	51.996 635.9 1.66	Sc Scandium [Ar] 3d ¹ 4s ²	23	54.938 747.3 1.55	24	55.845 762.5 1.83	25	56.939 760.4 1.91	26	57.546 771.5 1.89	27	58.933 780.4 1.87	28	59.805 795.4 1.90	29	60.538 804.4 1.85	30	60.720 818.8 1.81	31	60.920 820.2 2.01	32	61.206 821.0 2.11	33	61.922 821.8 1.99	34	62.911 840.0 2.15	35	63.799 858.0 3.00	36	78.971 918.0 2.55	37	79.904 919.2 2.96	38	83.799 1386.8 3.00	39	84.002 1396.4 2.66	40	84.300 1397.2 2.10	41	84.600 1397.4 2.66	42	84.900 1397.6 2.10	43	85.200 1397.8 2.66	44	85.500 1398.0 2.10	45	85.800 1398.2 2.66	46	86.100 1398.4 2.10	47	86.400 1398.6 2.66	48	86.700 1398.8 2.10	49	87.000 1399.0 2.66	50	87.300 1399.2 2.10	51	87.600 1399.4 2.66	52	87.900 1399.6 2.10	53	88.200 1399.8 2.66	54	131.29 1179.4 2.66	55	126.90 1008.4 2.66	56	127.60 889.3 2.10	57	128.30 834.0 2.05	58	128.90 834.0 2.66	59	131.29 1179.4 2.66	60	131.29 1179.4 2.66	61	131.29 1179.4 2.66	62	131.29 1179.4 2.66	63	131.29 1179.4 2.66	64	131.29 1179.4 2.66	65	131.29 1179.4 2.66	66	131.29 1179.4 2.66	67	131.29 1179.4 2.66	68	131.29 1179.4 2.66	69	131.29 1179.4 2.66	70	131.29 1179.4 2.66	71	131.29 1179.4 2.66	72	131.29 1179.4 2.66	73	131.29 1179.4 2.66	74	131.29 1179.4 2.66	75	131.29 1179.4 2.66	76	131.29 1179.4 2.66	77	131.29 1179.4 2.66	78	131.29 1179.4 2.66	79	131.29 1179.4 2.66	80	131.29 1179.4 2.66	81	131.29 1179.4 2.66	82	131.29 1179.4 2.66	83	131.29 1179.4 2.66	84	131.29 1179.4 2.66	85	131.29 1179.4 2.66	86	131.29 1179.4 2.66	87	131.29 1179.4 2.66	88	131.29 1179.4 2.66	89	131.29 1179.4 2.66	90	131.29 1179.4 2.66	91	131.29 1179.4 2.66	92	131.29 1179.4 2.66	93	131.29 1179.4 2.66	94	131.29 1179.4 2.66	95	131.29 1179.4 2.66	96	131.29 1179.4 2.66	97	131.29 1179.4 2.66	98	131.29 1179.4 2.66	99	131.29 1179.4 2.66	100	131.29 1179.4 2.66	101	131.29 1179.4 2.66	102	131.29 1179.4 2.66	103	131.29 1179.4 2.66
5	Rb Rubidium [Kr] 5s ¹	85.468 403.0 0.82	37	87.62 403.0 0.95	38	88.906 548.5 0.95	39	89.81 589.0 1.22	40	90.900 640.1 1.33	41	91.924 652.1 1.60	42	92.900 683.1 2.12	43	93.95 683.4 2.16	44	94.00 692.8 1.90	45	94.06 702.0 2.20	46	94.11 713.7 2.28	47	94.16 723.0 1.92	48	94.21 734.0 2.20	49	94.26 745.0 1.90	50	94.31 756.0 1.85	51	94.36 767.0 1.91	52	94.41 778.0 1.89	53	94.46 789.0 1.87	54	94.51 799.0 1.85	55	94.56 810.0 1.83	56	94.61 821.0 1.81	57	94.66 832.0 1.80	58	94.71 843.0 1.80	59	94.76 854.0 1.80	60	94.81 865.0 1.80	61	94.86 876.0 1.80	62	94.91 887.0 1.80	63	94.96 898.0 1.80	64	95.01 909.0 1.80	65	95.06 920.0 1.80	66	95.11 931.0 1.80	67	95.16 942.0 1.80	68	95.21 953.0 1.80	69	95.26 964.0 1.80	70	95.31 975.0 1.80	71	95.36 986.0 1.80	72	95.41 997.0 1.80	73	95.46 1008.0 1.80	74	95.51 1019.0 1.80	75	95.56 1030.0 1.80	76	95.61 1041.0 1.80	77	95.66 1052.0 1.80	78	95.71 1063.0 1.80	79	95.76 1074.0 1.80	80	95.81 1085.0 1.80	81	95.86 1096.0 1.80	82	95.91 1107.0 1.80	83	95.96 1118.0 1.80	84	96.01 1129.0 1.80	85	96.06 1140.0 1.80	86	96.11 1151.0 1.80	87	96.16 1162.0 1.80	88	96.21 1173.0 1.80	89	96.26 1184.0 1.80	90	96.31 1195.0 1.80	91	96.36 1206.0 1.80	92	96.41 1217.0 1.80	93	96.46 1228.0 1.80	94	96.51 1239.0 1.80	95	96.56 1250.0 1.80	96	96.61 1261.0 1.80	97	96.66 1272.0 1.80	98	96.71 1283.0 1.80	99	96.76 1294.0 1.80	100	96.81 1305.0 1.80	101	96.86 1316.0 1.80	102	96.91 1327.0 1.80	103	96.96 1338.0 1.80																																				
6	Cs Cesium [Kr] 5s ¹	132.91 370.0 0.75	55	137.33 503.8 0.89	56	138.91 538.1 1.10	57	139.57 563.8 0.65	58	140.91 589.8 0.89	59	144.24 624.0 1.14	60	145.0 640.0	61	145.4 644.5 1.17	62	150.36 654.5 1.20	63	151.96 659.3 1.20	64	157.25 665.8 1.20	65	158.93 670.8 1.20	66	162.50 675.0 1.22	67	164.93 681.0 1.23	68	168.25 689.3 1.24	69	173.05 697.1 1.25	70	174.97 723.5 1.27	71	175.97 733.5 1.27	*	* Ce Cerium [Kr] 4f ¹ 5d ¹ 6s ²	*	* Pr Praseodymium [Kr] 4f ² 5d ¹ 6s ²	*	* Nd Neodymium [Kr] 4f ³ 5d ¹ 6s ²	*	* Pm Promethium [Kr] 4f ⁴ 5d ¹ 6s ²	*	* Sm Samarium [Kr] 4f ⁵ 5d ¹ 6s ²	*	* Eu Europium [Kr] 4f ⁶ 5d ¹ 6s ²	*	* Gd Gadolinium [Kr] 4f ⁷ 5d ¹ 6s ²	*	* Tb Terbium [Kr] 4f ⁸ 5d ¹ 6s ²	*	* Dy Dysprosium [Kr] 4f ⁹ 5d ¹ 6s ²	*	* Ho Holmium [Kr] 4f ¹⁰ 5d ¹ 6s ²	*	* Er Erbium [Kr] 4f ¹¹ 5d ¹ 6s ²	*	* Tm Thulium [Kr] 4f ¹² 5d ¹ 6s ²	*	* Yb Ytterbium [Kr] 4f ¹³ 5d ¹ 6s ²	*	* Lu Lucentium [Kr] 4f ¹⁴ 5d ¹ 6s ²	*	* Hf Hafnium [Kr] 4f ¹⁴ 5d ² 6s ²	*	* Ta Tantalum [Kr] 4f ¹⁴ 5d ³ 6s ²	*	* W Tungsten [Kr] 4f ¹⁴ 5d ⁴ 6s ²	*	* Re Rhenium [Kr] 4f ¹⁴ 5d ⁵ 6s ²	*	* Os Osmium [Kr] 4f ¹⁴ 5d ⁶ 6s ²	*	* Ir Iridium [Kr] 4f ¹⁴ 5d ⁷ 6s ²	*	* Pt Platinum [Kr] 4f ¹⁴ 5d ⁸ 6s ²	*	* Au Gold [Kr] 4f ¹⁴ 5d ⁹ 6s ²	*	* Hg Mercury [Kr] 4f ¹⁴ 5d ¹⁰ 6s ²	*	* Ti Thallium [Kr] 4f ¹⁴ 5d ¹ 6p ¹	*	* Pb Lead [Kr] 4f ¹⁴ 5d ² 6p ¹	*	* Bi Bismuth [Kr] 4f ¹⁴ 5d ³ 6p ¹	*	* Po Polonium [Kr] 4f ¹⁴ 5d ⁴ 6p ¹	*	* At Astatine [Kr] 4f ¹⁴ 5d ⁵ 6p ¹	*	* Rn Radon [Kr] 4f ¹⁴ 5d ⁶ 6p ¹	*	* Rf Rutherfordium [Kr] 5f ¹⁴ 6d ¹ 7s ²	*	* Db Dubnium [Kr] 5f ¹⁴ 6d ² 7s ²	*	* Sg Seaborgium [Kr] 5f ¹⁴ 6d ³ 7s ²	*	* Bh Bohrium [Kr] 5f ¹⁴ 6d ⁴ 7s ²	*	* Hs Hassium [Kr] 5f ¹⁴ 6d ⁵ 7s ²	*	* Mt Meitnerium [Kr] 5f ¹⁴ 6d ⁶ 7s ²	*	* Ds Darmstadtium [Kr] 5f ¹⁴ 6d ⁷ 7s ²	*	* Rg Roentgenium [Kr] 5f ¹⁴ 6d ⁸ 7s ²	*	* Cn Copernicium [Kr] 5f ¹⁴ 6d ⁹ 7s ²	*	* Nh Nihonium [Kr] 5f ¹⁴ 6d ¹⁰ 7s ²	*	* Fl Flerovium [Kr] 5f ¹⁴ 6d ¹¹ 7s ²	*	* Mc Moscovium [Kr] 5f ¹⁴ 6d ¹² 7s ²	*	* Lv Livermorium [Kr] 5f ¹⁴ 6d ¹³ 7s ²	*	* Ts Tennessine [Kr] 5f ¹⁴ 6d ¹⁴ 7s ²	*	* Og Oganesson [Kr] 5f ¹⁴ 6d ¹⁵ 7s ²																																																



Notes

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

by Helen Camper / updated 2018.2018

alkali metals

alkaline earth metals

lanthanides

transition metals

actinides

unknown properties

post-transition metals

metalloids

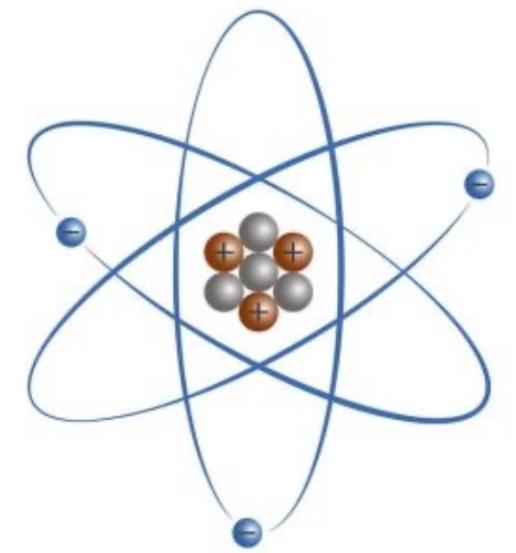
reactive nonmetals

noble gases

First: Science Review

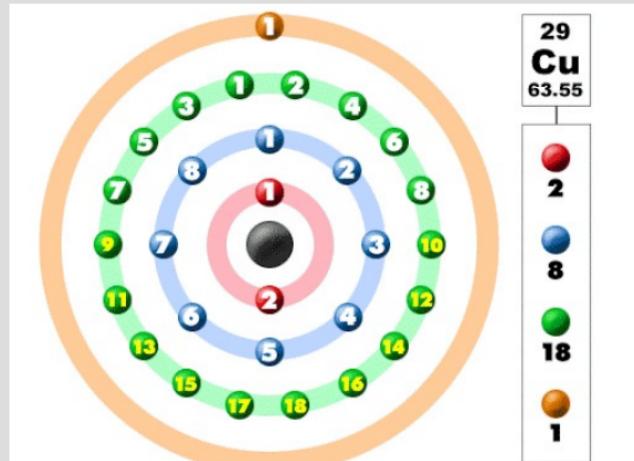
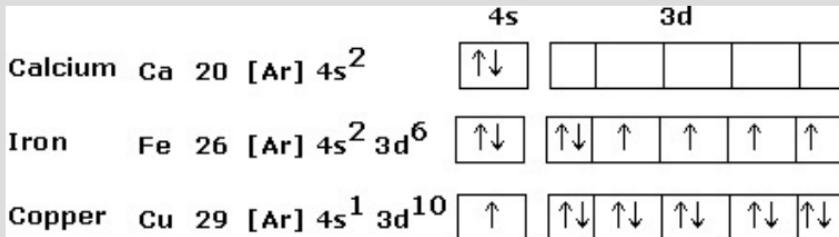


First: Science Review



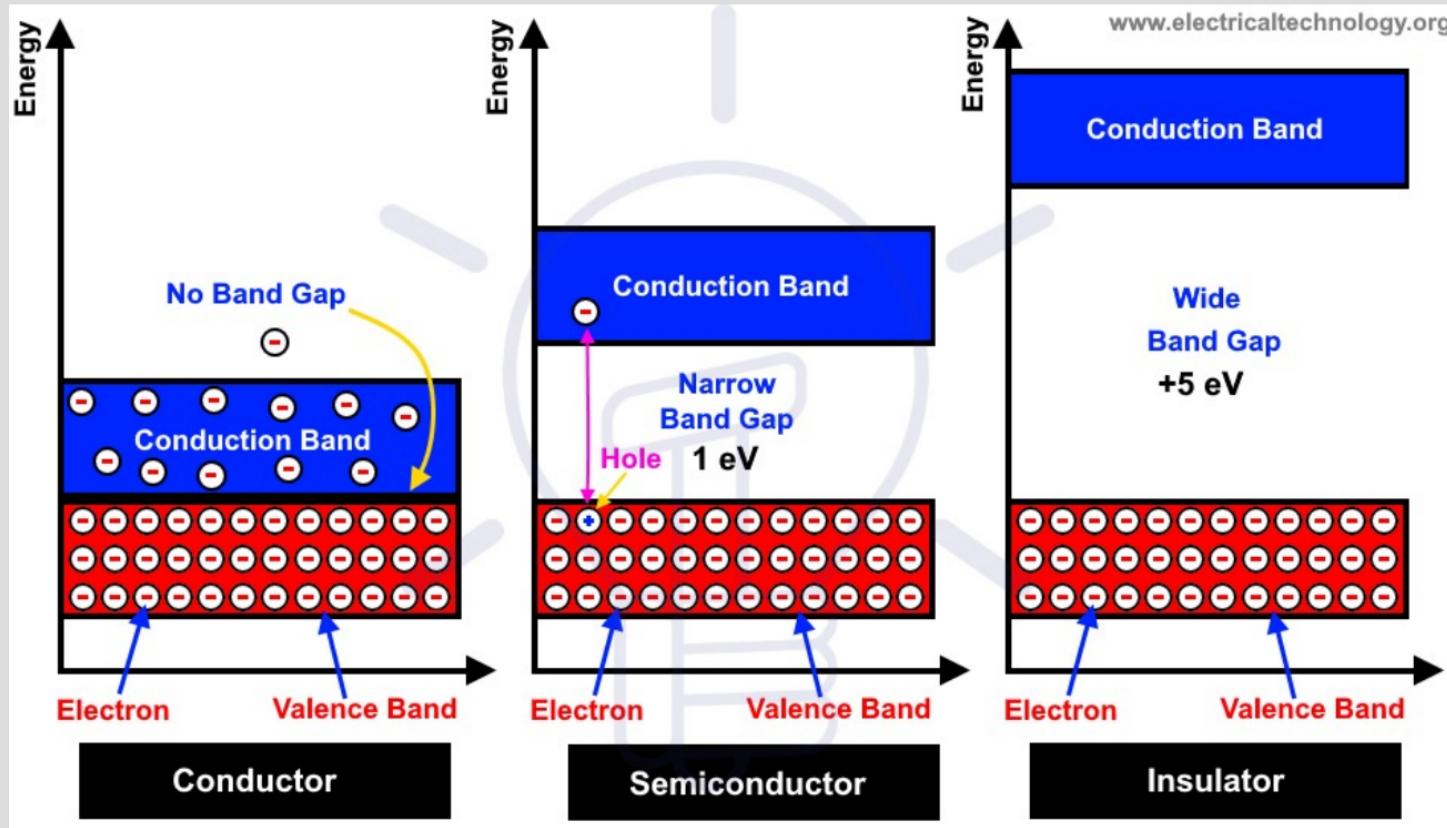
Atom structure

- ⊕ Proton
 - ⊗ Neutron
 - ⊖ Electron



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

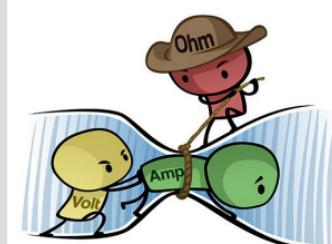
Electrical Quantities

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

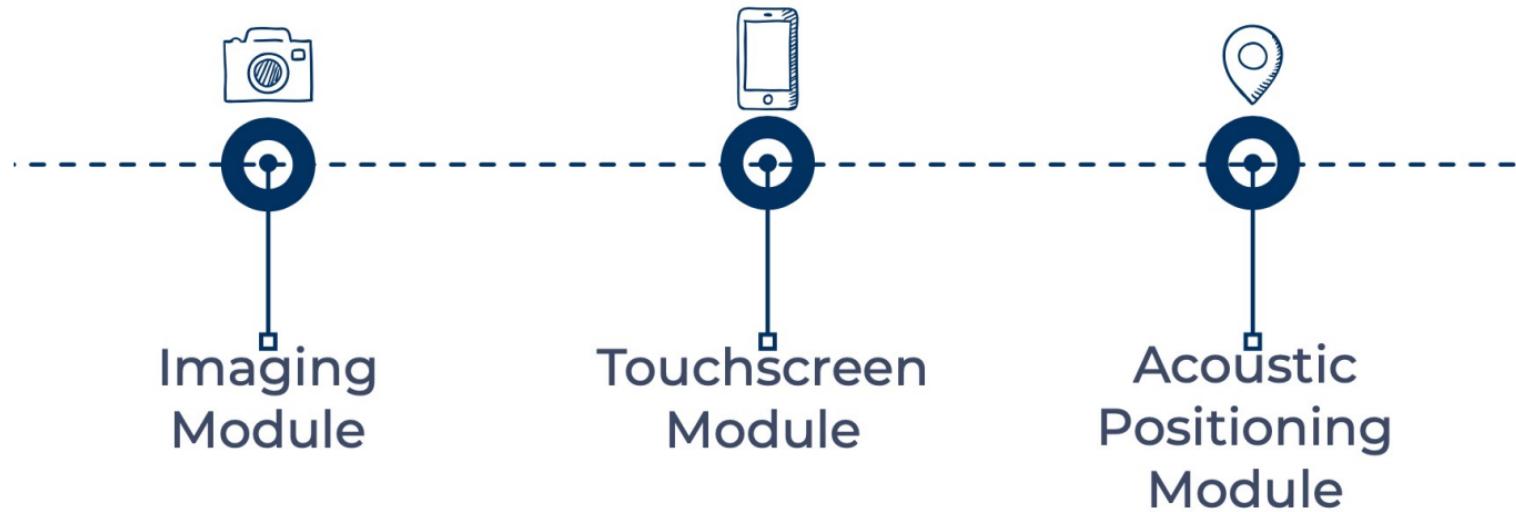
$I \Rightarrow$ flows through an element

$V \Rightarrow$ applied across an element

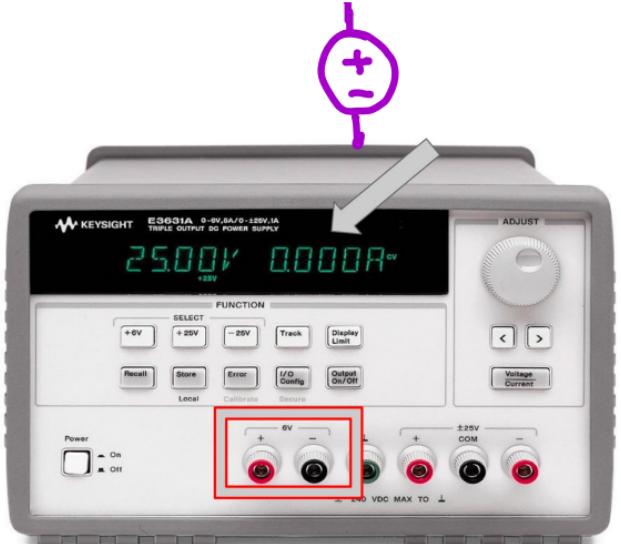
$R \Rightarrow$ opposition to current flow



In the lab

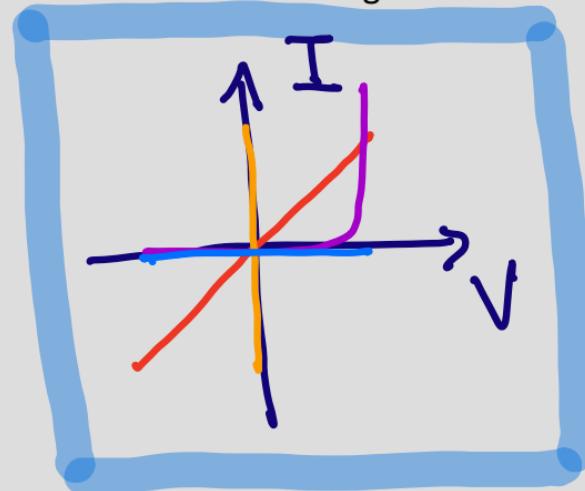
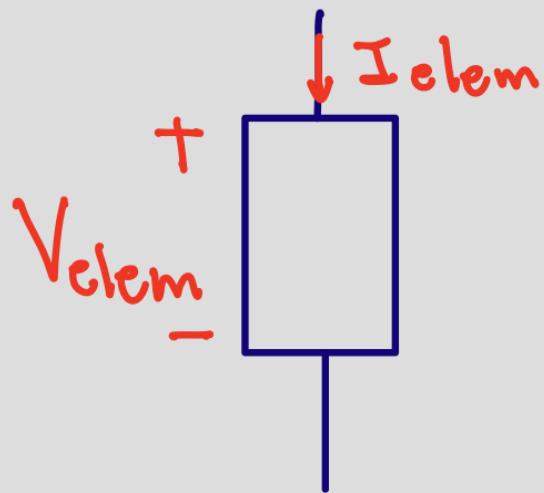


In the lab



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

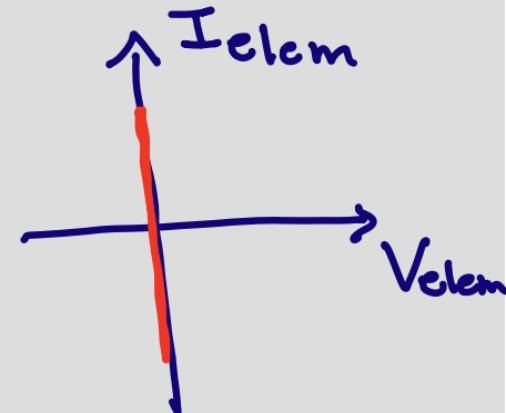
Key circuit elements: Wire



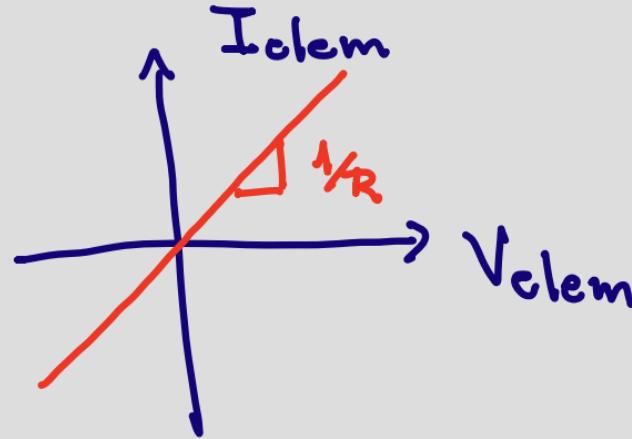
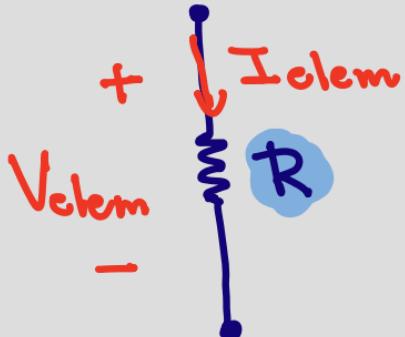
$$V_{\text{clem}} = 0$$

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

(set by the external circuit)



Key circuit elements: Resistor

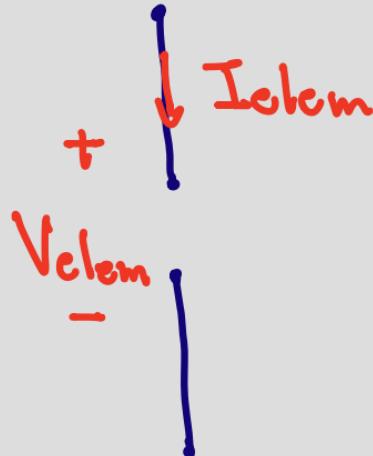


$$V_{clem} = R \cdot I_{clem}$$

Ohm's Law



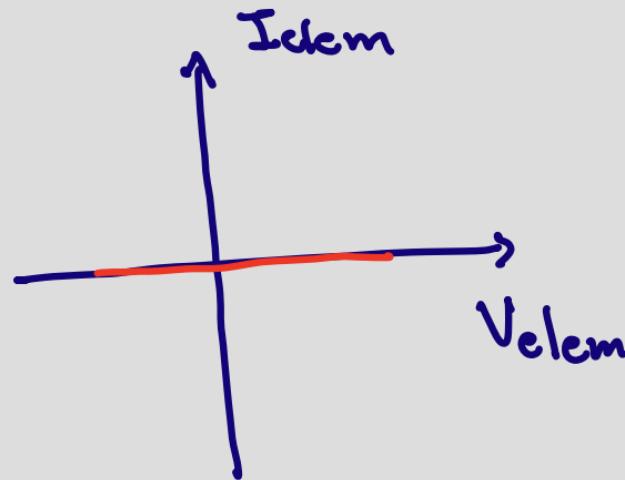
Key circuit elements: Open circuit



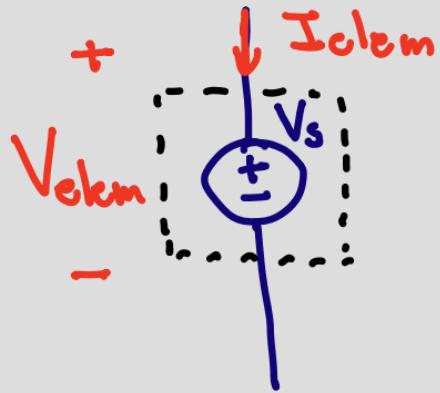
$$I_{elem} = 0$$

$$V_{elem} = ?$$

(V is set by
the external
circuit)



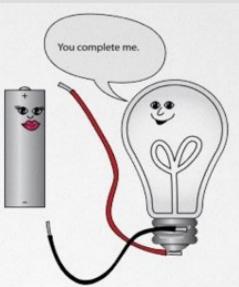
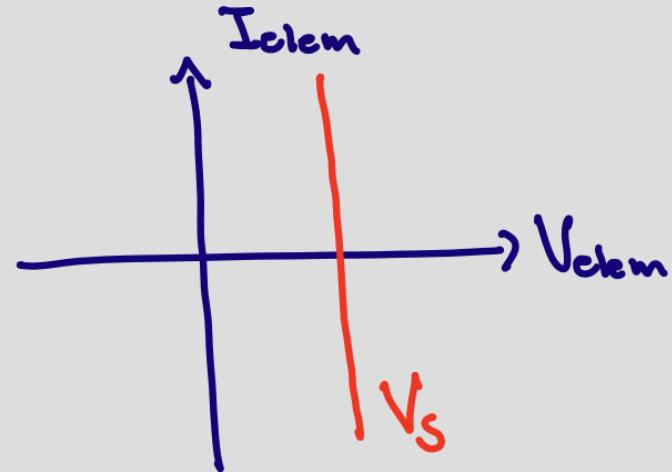
Key circuit elements: Voltage Source



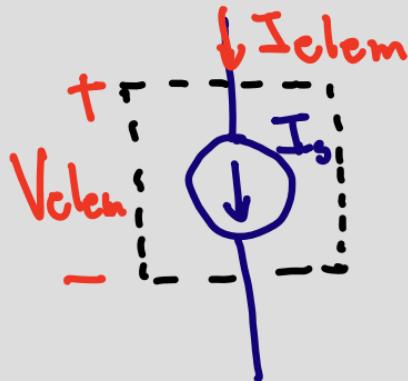
$$V_{clem} = V_s$$

$$I_{clem} = ?$$

(I set by
external
circuit)



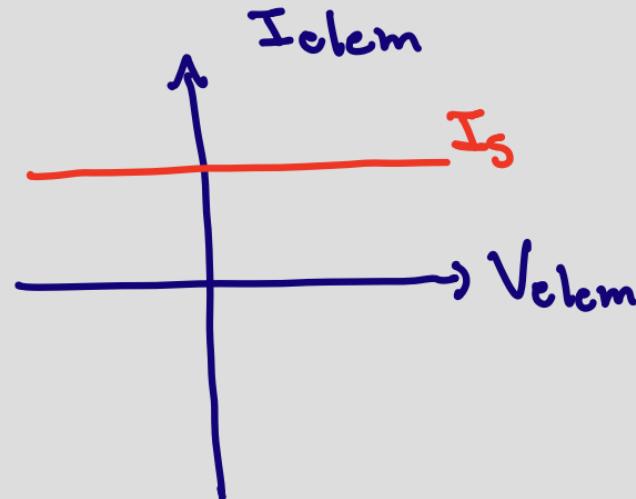
Key circuit elements: Current Source



$$I_{clm} = I_s$$

$$V_{clm} = ?$$

(V is set by
external
circuit)



V_{clm} and I_{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

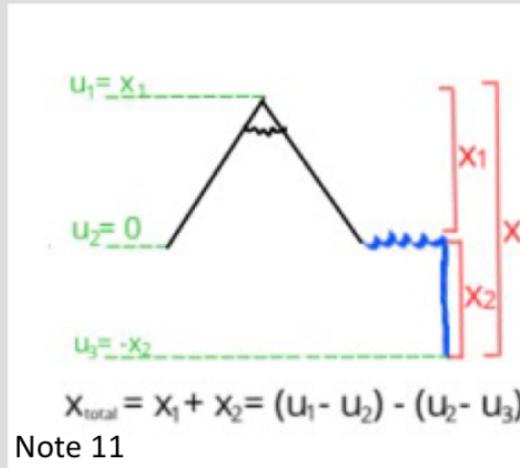
Nodes : point where
elements meet

Junction : point where
different materials
meet

Circuit Analysis Algorithm

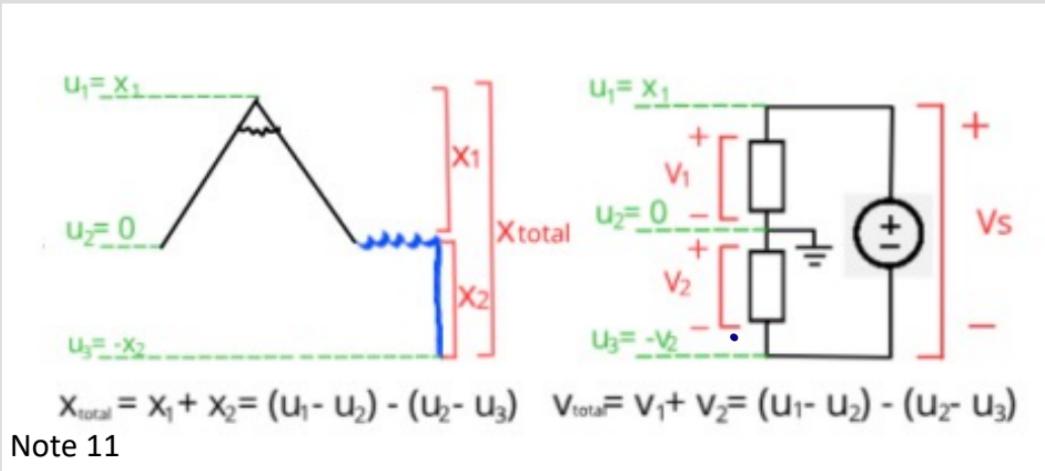
Voltage = difference of two potential

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

$$V_1 = U_1 - U_2$$

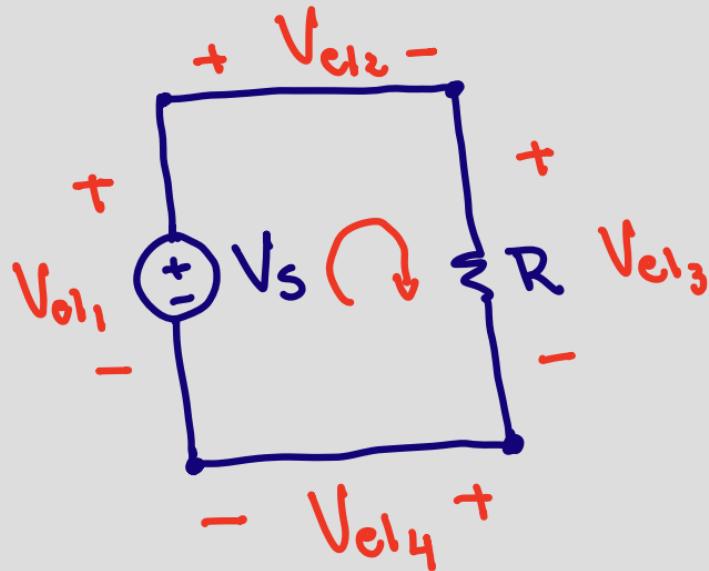
$$V_2 = U_2 - U_3$$

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

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

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

Sum of Voltages across the elements in a loop equal zero



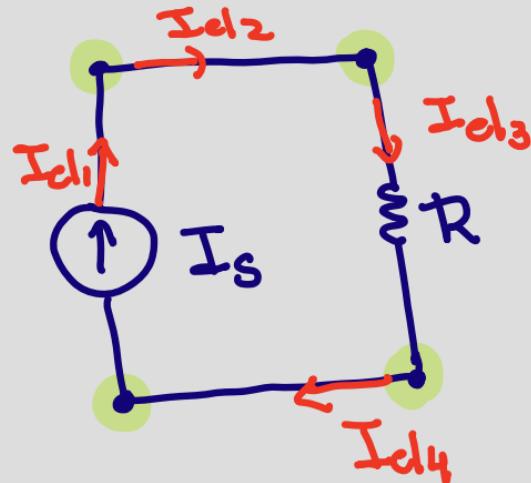
$$V_{el_1} - V_{el_2} - V_{el_3} - V_{el_4} = 0$$

$$\begin{array}{rcl} + & \stackrel{+}{\cancel{-}} V_{el_2} \\ V_{el_1} & \stackrel{+}{\cancel{-}} V_{el_3} \\ - & \stackrel{+}{\cancel{-}} V_{el_4} \end{array}$$

$$V_{el_1} = V_s$$

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

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



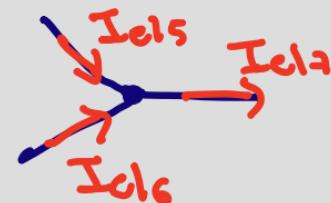
$$I_{cl1} = I_{cl2}$$

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

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

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

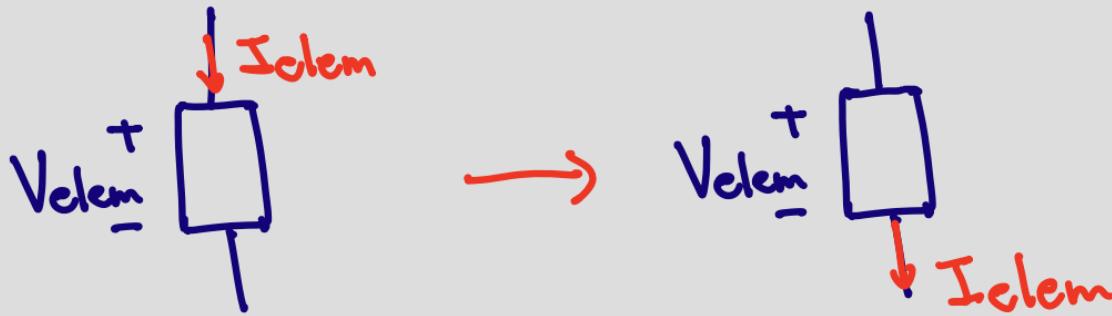
Example 2:



$$I_{cl5} + I_{cl6} = I_{cl7}$$

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