

# Welcome to EECS 16A!

## Designing Information Devices and Systems I

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Fall 2021

Module 2  
Lecture 6  
Capacitors  
(Note 16)

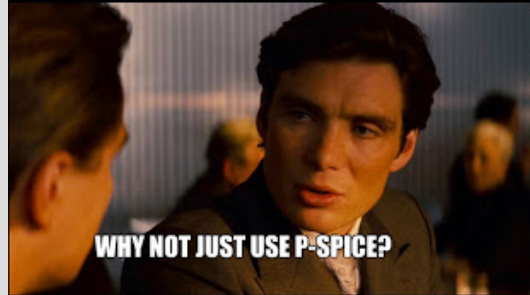
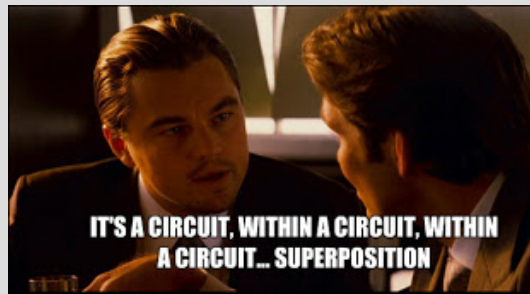


# Superposition

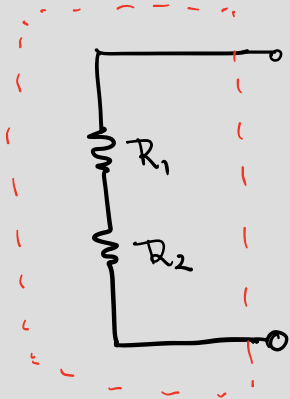
For each independent source  $k$  (either voltage source or current source)

- Set all other independent sources to 0
- Voltage source: replace with a wire
- Current source: replace with an open circuit
- Compute the circuit voltages and currents due to this source  $k$
- Compute  $V_{out}$  by summing the  $v_{outks}$  for all  $k$ .

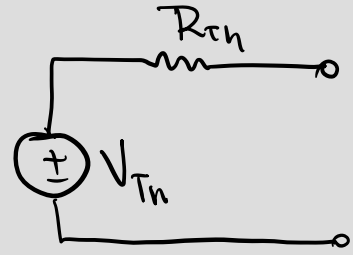
*New technique!*



# Practice – Example 1



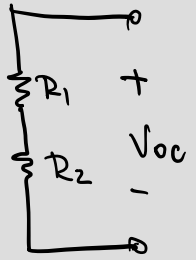
⇒



$$R_{Th} = \frac{V_{test}}{I_{test}} = (R_1 + R_2)$$

In series means that the same  $I$  flows through the elements.

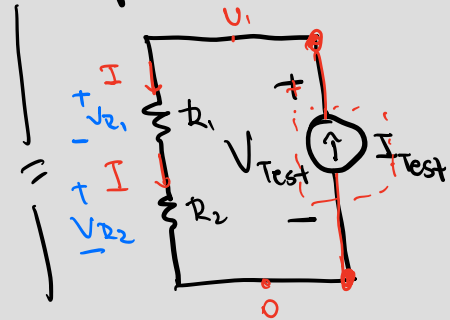
Step 1:



$$V_{oc} = 0$$

$$V_{Th} = 0$$

Step 2: No sources



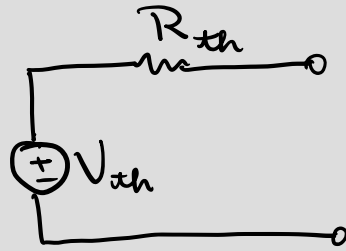
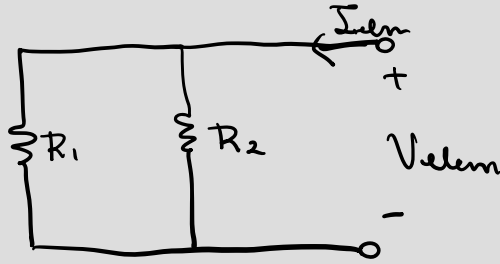
$$V_{Test} = V_{R1} + V_{R2}$$

$$V_{Test} = IR_1 + IR_2$$

$$= I_{test} R_1 + I_{Test} R_2$$

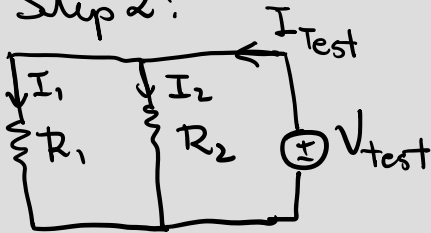
$$V_{Test} = (R_1 + R_2) \cdot I_{Test}$$

# Practice – Example 2



Step 1

Step 2:



$$I_1 = \frac{V_{test}}{R_1}$$

$$I_2 = \frac{V_{test}}{R_2}$$

$$V_{th} = 0$$



Parallel operator

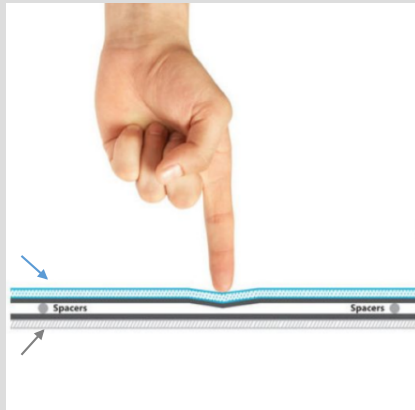
$$I_{test} = I_1 + I_2 = V_{test} \left( \frac{1}{R_1} + \frac{1}{R_2} \right)$$

$$R_{Th} = \frac{V_{test}}{I_{test}} = \frac{V_{test}}{V_{test} \left( \frac{1}{R_1} + \frac{1}{R_2} \right)} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{R_1 R_2}{R_1 + R_2} = R_1 || R_2$$

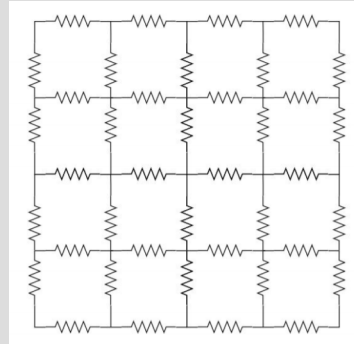


# Now that we understand 2D resistive touchscreen, let's change it!

resistive sheet



resistive sheet



Circuit model for each resistive sheet is a grid of resistors

**real-world touchscreens are usually capacitive, not resistive:**

- don't need to be flexible
- multi-touch is easier
- more sensitive
- increased contrast on screen

# First: Science Review

## Periodic Table of the Elements

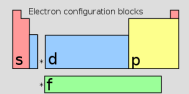
Group 1																		Group 18																														
Period 1	1																	2																														
1	H Hydrogen 1.008 1312.0 2.20																	He Helium 4.0026 2372.3																														
2	3		4														5		6		7		8		9		10																					
2	Li Lithium 6.94 3082.1 0.82		Be Beryllium 9.0122 989.5 1.57														B Boron 10.81 800.9 2.08		C Carbon 12.011 1201.2 2.55 6		N Nitrogen 14.007 1401.2 3.04		O Oxygen 15.999 1511.3 3.44		F Fluorine 18.998 1681.0 3.98		Ne Neon 20.180 1681.0 3.98																					
3	11		12														13		14		15		16		17		18																					
3	Na Sodium 22.990 485.8 0.93		Mg Magnesium 24.305 737.7 1.31														Al Aluminum 26.982 577.5 1.61		Si Silicon 28.085 786.5 1.90		P Phosphorus 30.974 1011.8		S Sulfur 32.06 999.8 2.58		Cl Chlorine 35.45 1201.2 3.16		Ar Argon 39.948 1520.6																					
4	19		20														21		22		23		24		25		26		27		28		29		30		31		32		33		34		35		36	
4	K Potassium 39.098 861.8 0.82		Ca Calcium 40.078 589.8 1.00														Sc Scandium 44.956 931.1 1.36		Ti Titanium 47.867 658.8 1.54		V Vanadium 50.942 650.9 1.63		Cr Chromium 51.996 685.9 1.66		Mn Manganese 54.938 717.3 1.55		Fe Iron 55.845 762.5 1.83		Co Cobalt 58.933 760.4 1.91		Ni Nickel 58.693 737.1 1.88		Cu Copper 63.546 745.5 1.90		Zn Zinc 65.38 900.4 1.65		Ga Gallium 69.723 578.9 1.81		Ge Germanium 72.630 762.0 2.01		As Arsenic 74.922 949.7 2.18		Se Selenium 78.971 941.7 2.55		Br Bromine 79.904 1139.0 2.96		Kr Krypton 83.798 1150.8 3.00	
5	37		38														39		40		41		42		43		44		45		46		47		48		49		50		51		52		53		54	
5	Rb Rubidium 85.468 802.0 0.82		Sr Strontium 87.62 843.8 0.95														Y Yttrium 88.906 806.0 1.22		Zr Zirconium 91.224 602.1 1.33		Nb Niobium 92.906 688.3 1.56		Mo Molybdenum 95.95 738.0 1.56		Tc Technetium 98.906 720.0 1.90		Ru Ruthenium 101.07 710.2 2.20		Rh Rhodium 102.91 719.7 2.28		Pd Palladium 106.42 884.4 2.20		Ag Silver 107.87 732.0 1.93		Cd Cadmium 112.41 800.8 1.62		In Indium 114.82 896.3 1.78		Sn Tin 118.71 708.4 1.56		Sb Antimony 121.76 834.0 2.05		Te Tellurium 127.60 891.8 2.10		I Iodine 126.90 1008.4 2.66		Xe Xenon 131.29 1170.4 2.50	
6	55		56														57		58		59		60		61		62		63		64		65		66		67		68		69		70		71			
6	Cs Cesium 132.91 737.7 0.79		Ba Barium 137.33 502.9 0.89														La Lanthanum 138.91 538.1 1.10		Hf Hafnium 178.49 761.0 1.50		Ta Tantalum 180.95 761.0 1.50		W Tungsten 183.84 770.0 2.36		Re Rhenium 186.21 776.0 1.90		Os Osmium 190.23 770.0 2.20		Ir Iridium 192.22 761.0 2.20		Pt Platinum 195.08 776.9 2.54		Au Gold 196.97 800.8 1.92		Hg Mercury 200.59 1007.1 2.00		Tl Thallium 204.38 589.4 1.62		Pb Lead 207.2 793.0 2.02		Bi Bismuth 208.98 762.0 2.02		Po Polonium (210) 883.0 2.00		At Astatine (210) 883.0 2.00		Rn Radon (222) 1037.0	
7	87		88														89		90		91		92		93		94		95		96		97		98		99		100		101		102		103			
7	Fr Francium (223) 880.0 0.70		Ra Radium (226) 501.0 1.10														Ac Actinium (227) 503.0 1.10		Rf Rutherfordium (261) 584.5 1.75		Db Dubnium (262) 584.5 1.75		Sg Seaborgium (266) 589.3 1.75		Bh Bohrium (264) 589.3 1.75		Hs Hassium (277) 589.3 1.75		Mt Meitnerium (268) 589.3 1.75		Ds Darmstadtium (271) 589.3 1.75		Rg Roentgenium (272) 589.3 1.75		Cn Copernicium (285) 589.3 1.75		Nh Nihonium (284) 589.3 1.75		Fl Flerovium (289) 589.3 1.75		Mc Moscovium (288) 589.3 1.75		Lv Livermorium (292) 589.3 1.75		Ts Tennessine (294) 589.3 1.75		Og Oganesson (294) 589.3 1.75	

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

55.845 26 atomic number  
762.5 1.83 electronegativity

chemical symbol  
Fe  
Iron  
name  
[Ar] 3d<sup>6</sup> 4s<sup>2</sup> 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 Conner / updated 2018, 2019

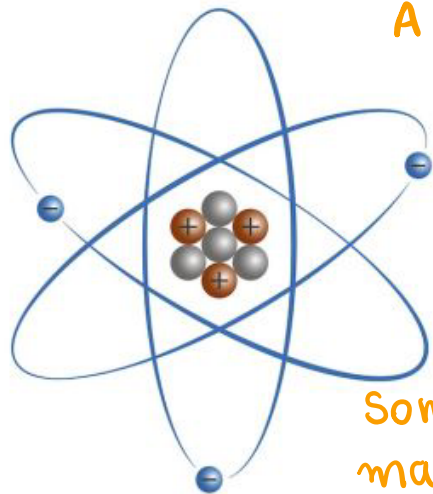
- alkali metals
- alkaline earth metals
- lanthanides
- transition metals
- unknown properties
- post-transition metals
- metalloids
- reactive nonmetals
- noble gases
- actinides

# First: Science Review



# First: Science Review

A solid contains many atoms!

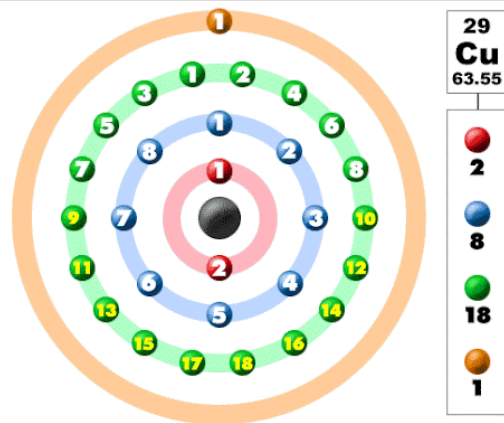


Atom structure

- Proton
- Neutron
- Electron

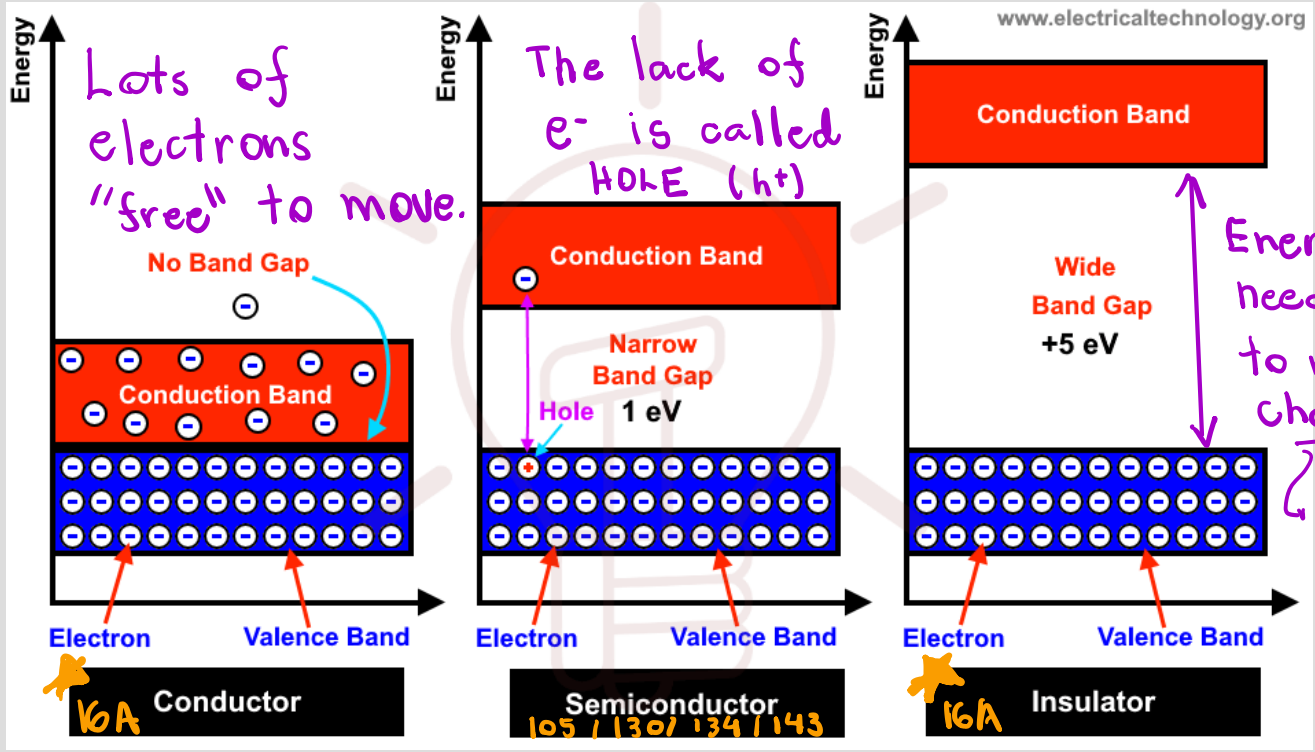
Some materials have many valence e<sup>-</sup>.

				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></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>	↑↓	↑↓	↑↓	↑↓	↑↓
↑											
↑↓	↑↓	↑↓	↑↓	↑↓							



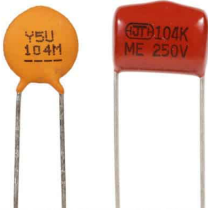
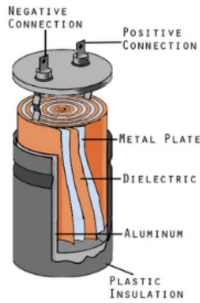
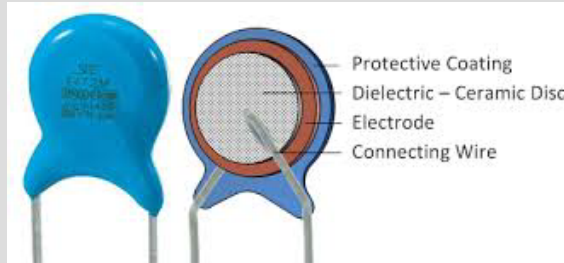
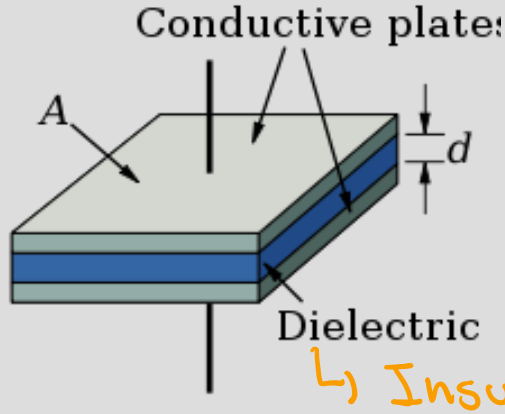
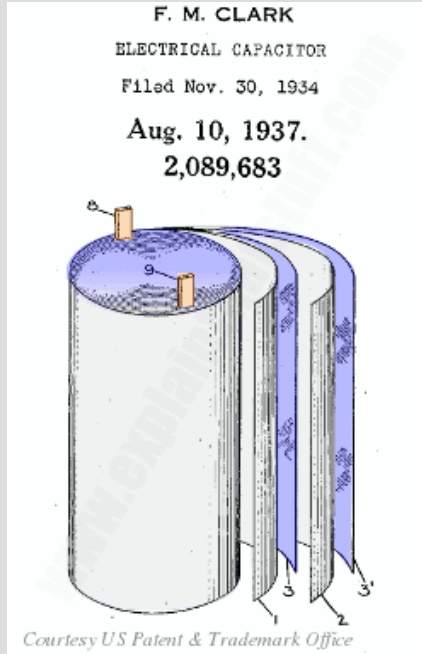
Element	Symbol	Electronic Configuration
Scandium	Sc	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup> 3d <sup>1</sup> 4s <sup>2</sup>
Titanium	Ti	1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup> 3d <sup>2</sup> 4s <sup>2</sup>
Vanadium	V	1s <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



# Now, Capacitors!

- Charge storage device (like a 'bucket' for charge)

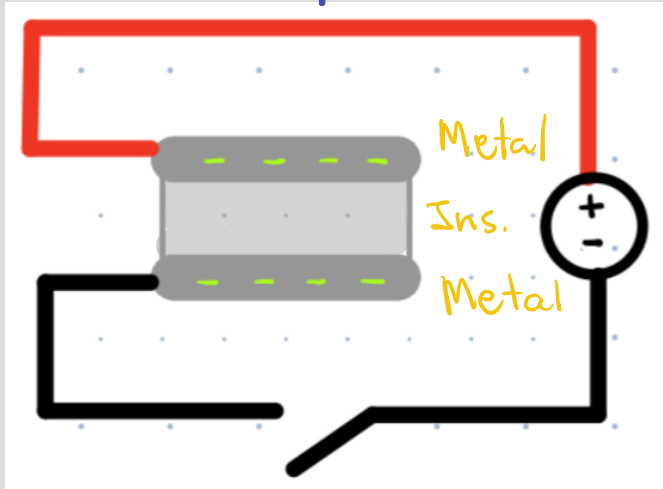


↳ Insulator

↳ Higher Energy is needed to move charge.

# The Physics of a Capacitor

\* Energy is needed to move charge.



$e^-$

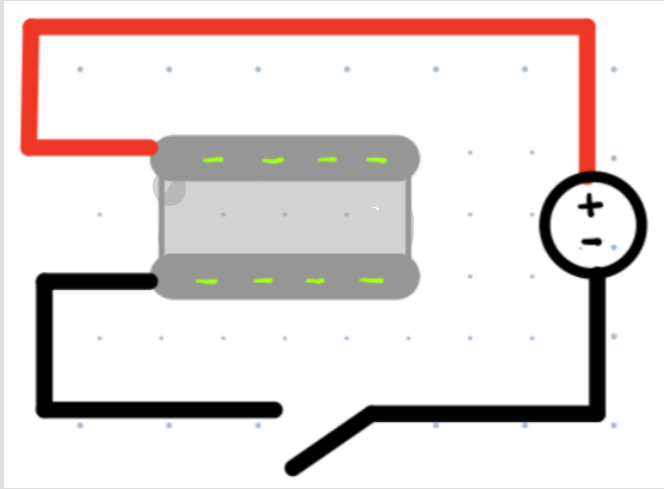
→ No current across the capacitor plates

→ Voltage Source provides Energy needed for flow of charges ( $e^-$ )

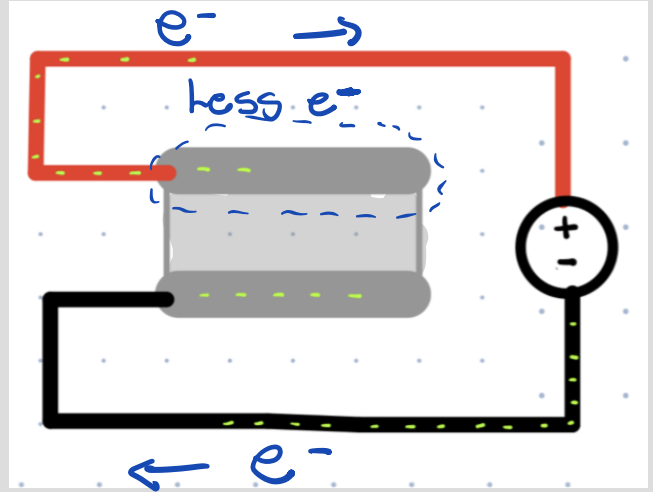
# The Physics of a Capacitor

→ Once the switch is ON  $e^-$  flow!

$t_0$



$t_1$

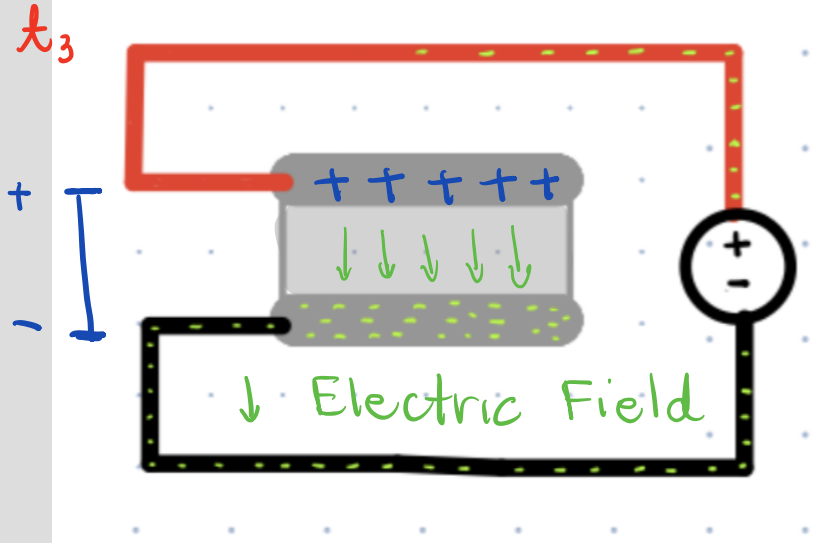
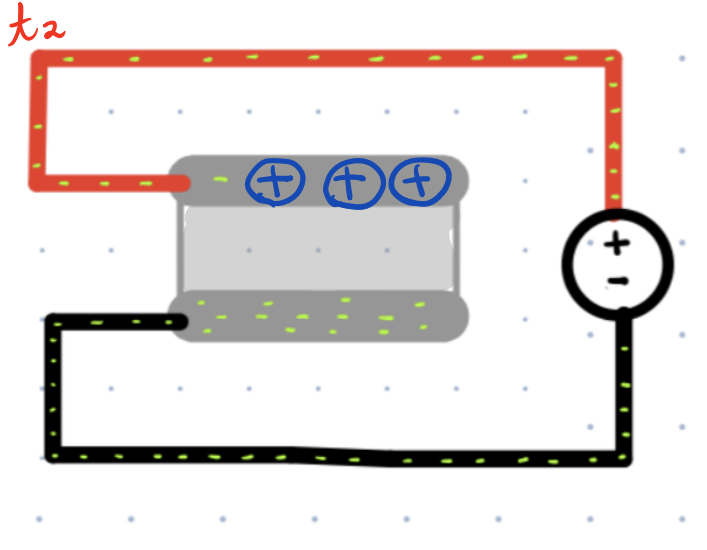




# The Physics of a Capacitor

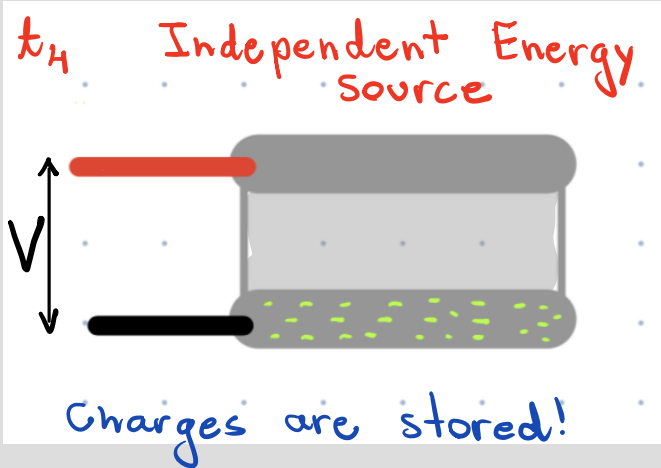
lack of electrons means holes!

$h^+$



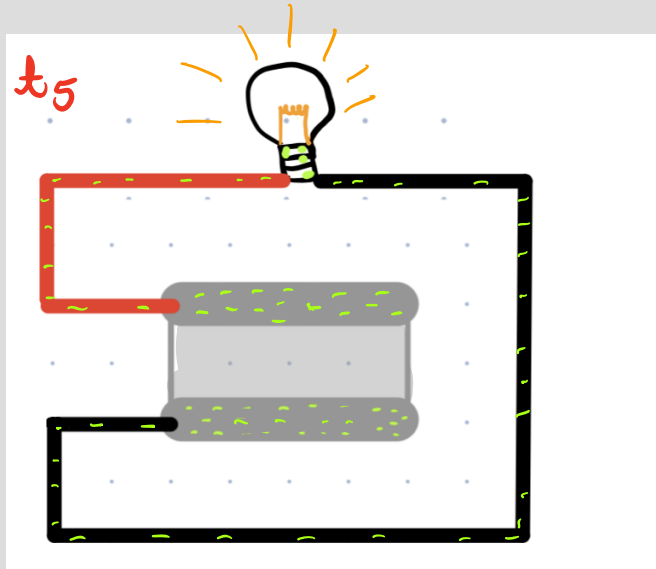
Potential difference  
between the two  
plates! }  $V$

# The Physics of a Capacitor



Every Capacitor can be charged up to a fixed Voltage.

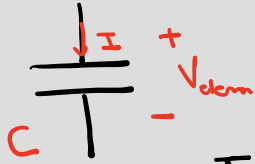
<https://www.youtube.com/watch?v=X4EUwTwZ110>



The capacitor will charge a "load" until the charges on the plate are equalized. (No change in  $V$ )

# Circuit Model: IV relationship

Capacitor Symbol



$$Q_{elem} = C \cdot V_{elem}$$

$[C]$        $[F]$        $[V]$   
(Farad)

We know:  $I_{elem} = \frac{dQ_{elem}}{dt}$

$$I_{elem} = \frac{d}{dt} C \cdot V_{elem}$$

$C = \text{constant over time}$

$$I_{elem} = C \cdot \frac{dV_{elem}}{dt}$$

→ Can use the same 7-step analysis.

