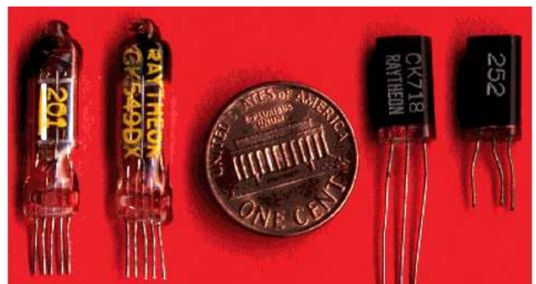
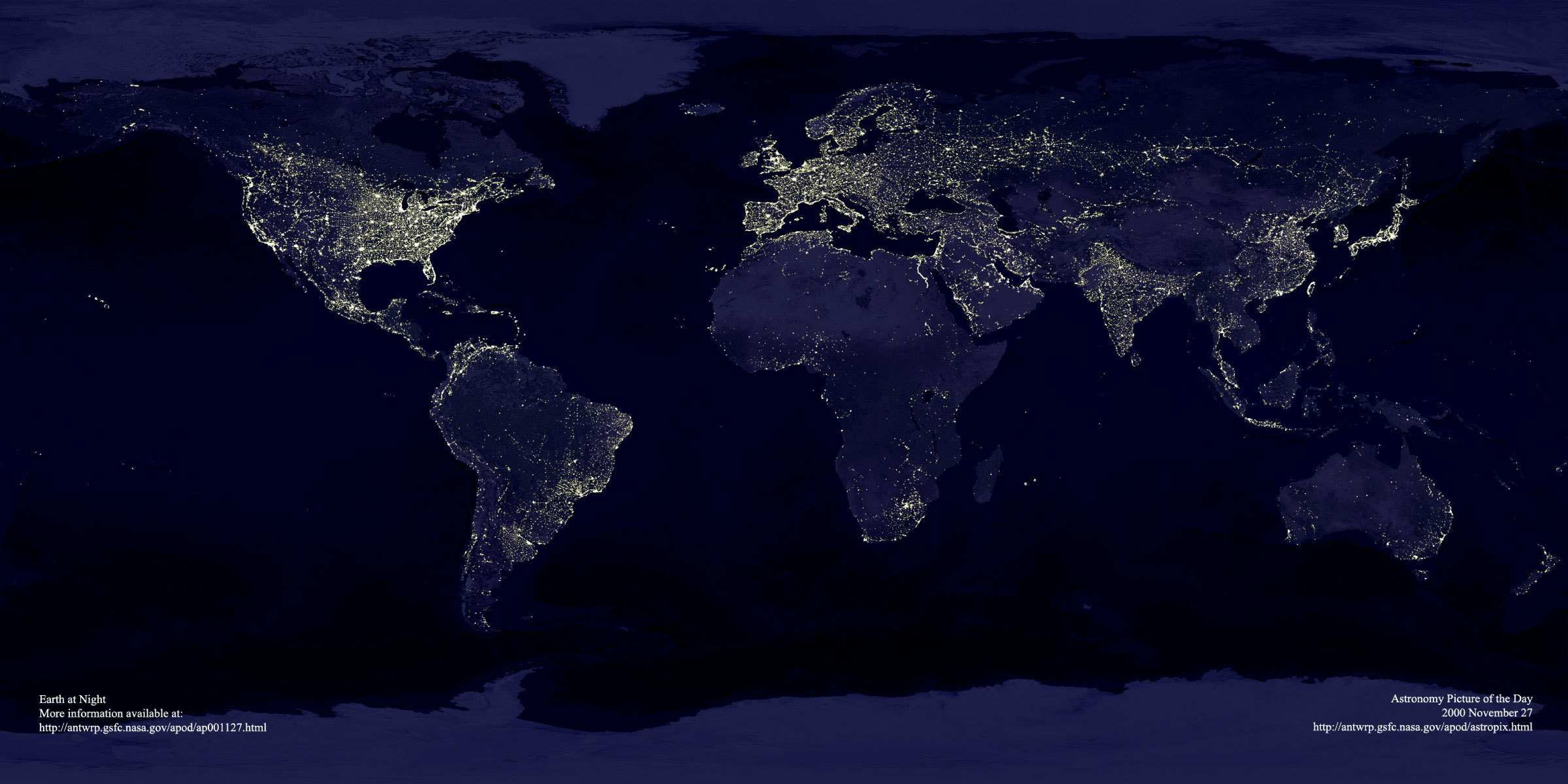
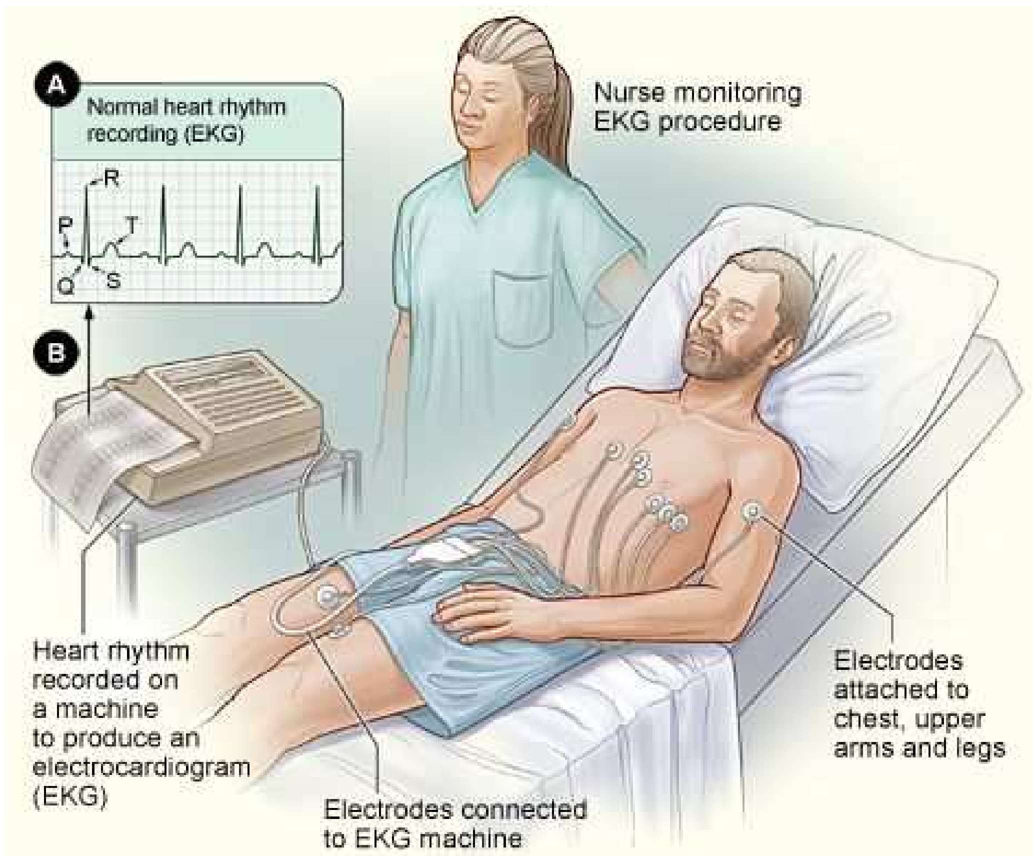
Real equipment glows in the dark!

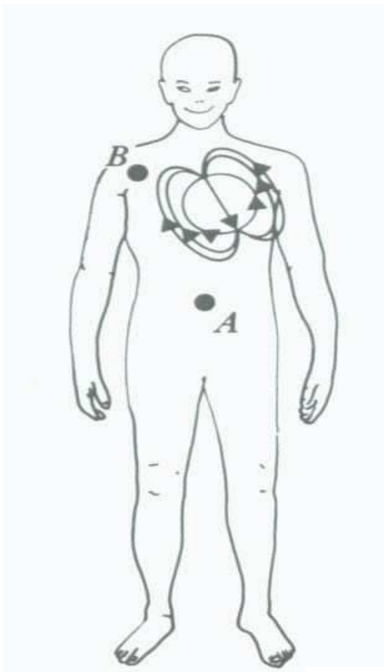


TRANSISTORS REPLACE TUBES
On the left are submini tubes used in a Zenith Royal hearing aid. The 201 date code represents week 1, 1952. On the right are examples of CK718 junction transistors used in a Zenith Royal "T" hearing aid, with 252 representing week 52, 1952. In less than one year transistors had replaced the dominant vacuum tube technology in hearing aids.


Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap001127.html
Astronomy Picture of the Day
2000 November 27
http://antwrp.gsfc.nasa.gov/apod/astropix.html

In this course, we are going to look at a “real world” problem, i.e. how do we measure a person’s electrocardiogram? (ECG)

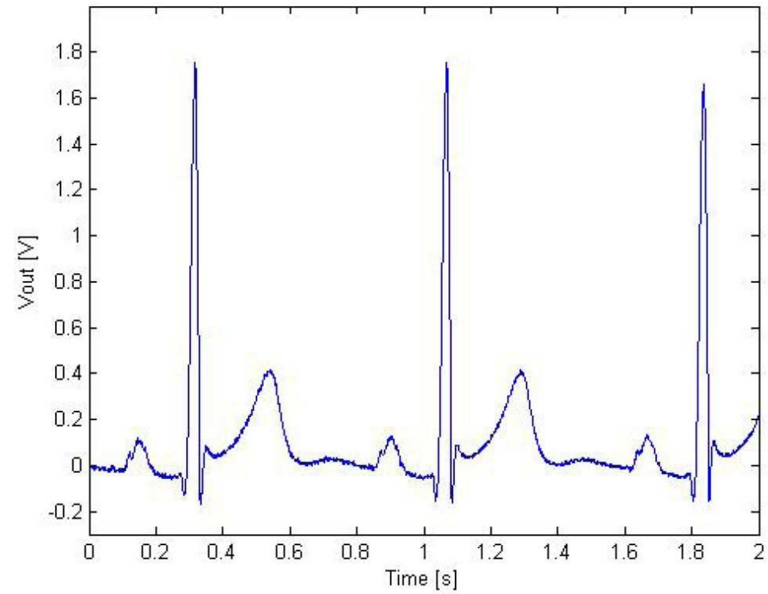


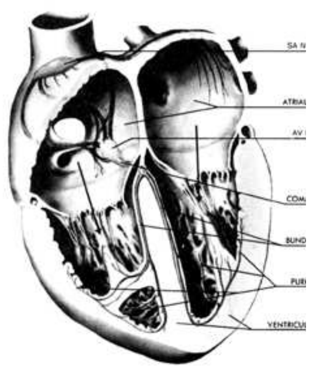


How do we get a heart signal ("bio-potential")

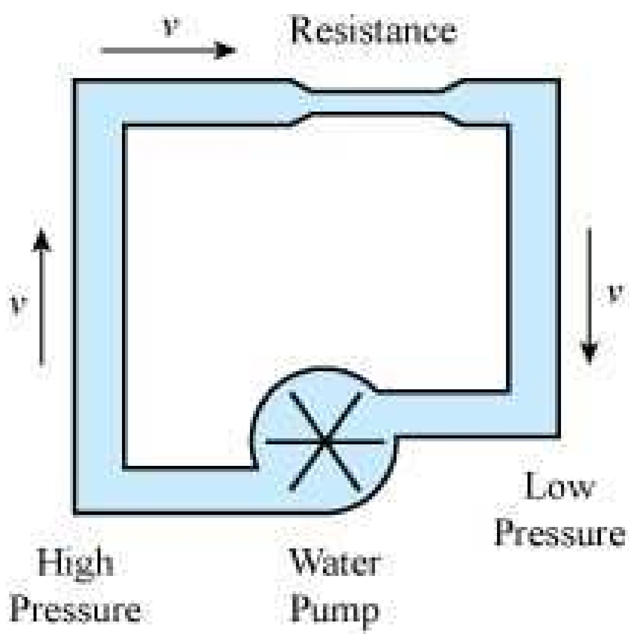
from the surface of our skin

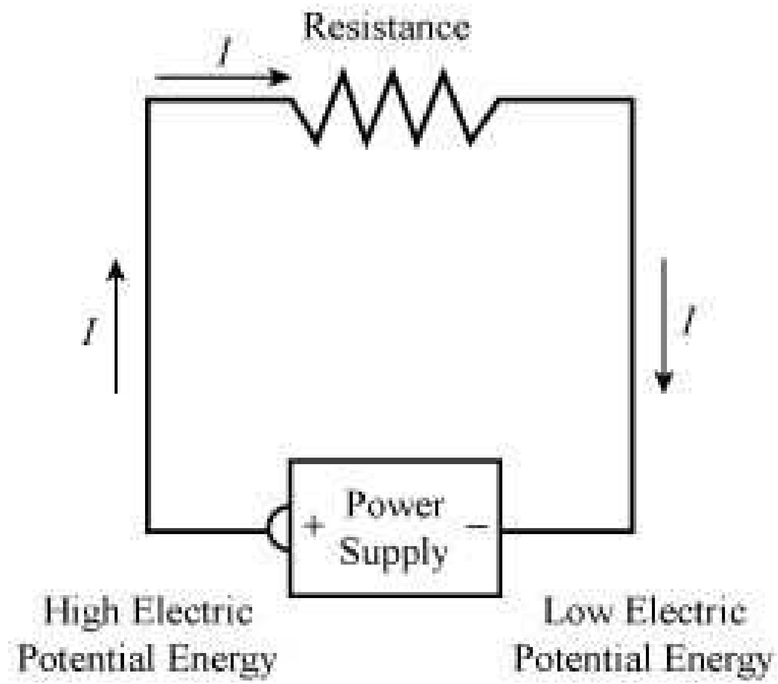
onto a computer screen?





Fluid Circuit / Electrical Circuit

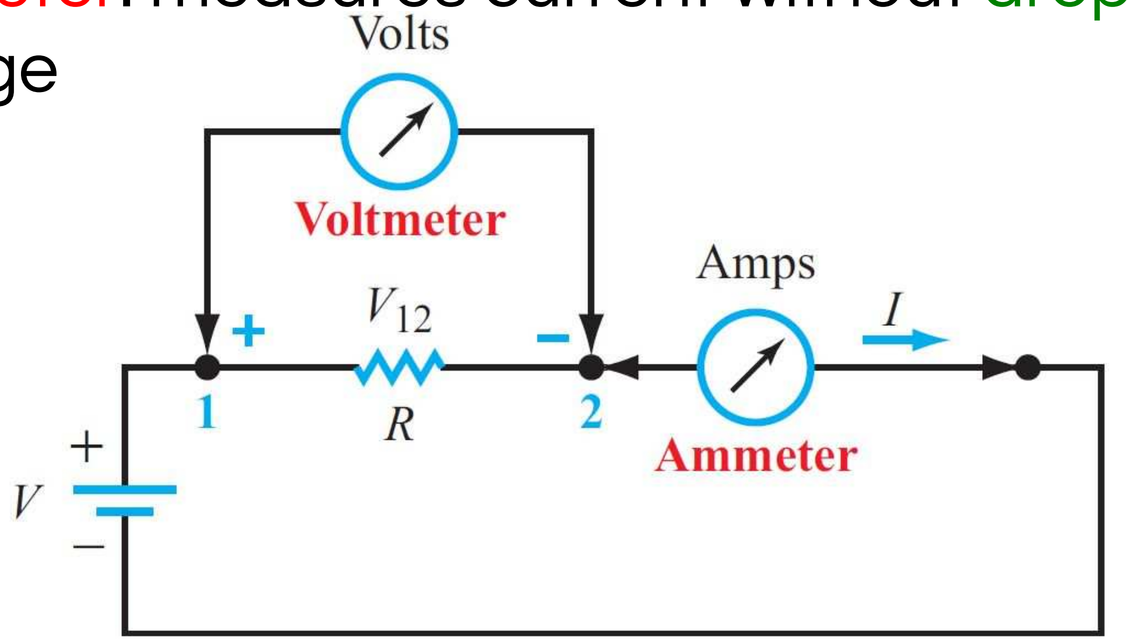




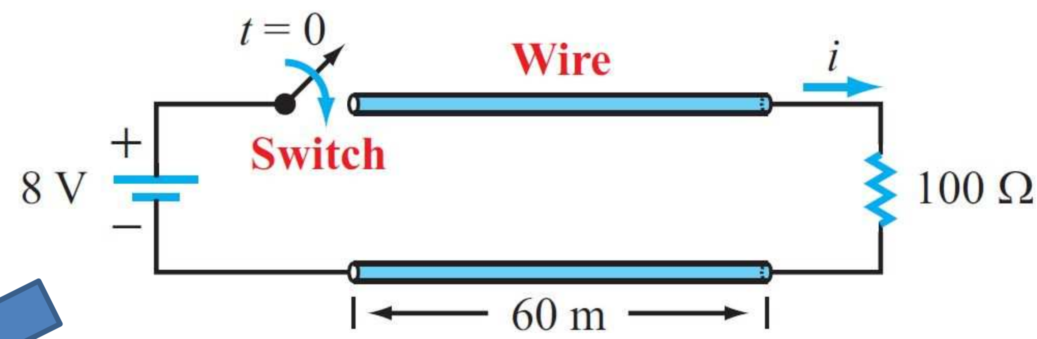
What flows?
How do we measure pressure?
How do we measure flow?

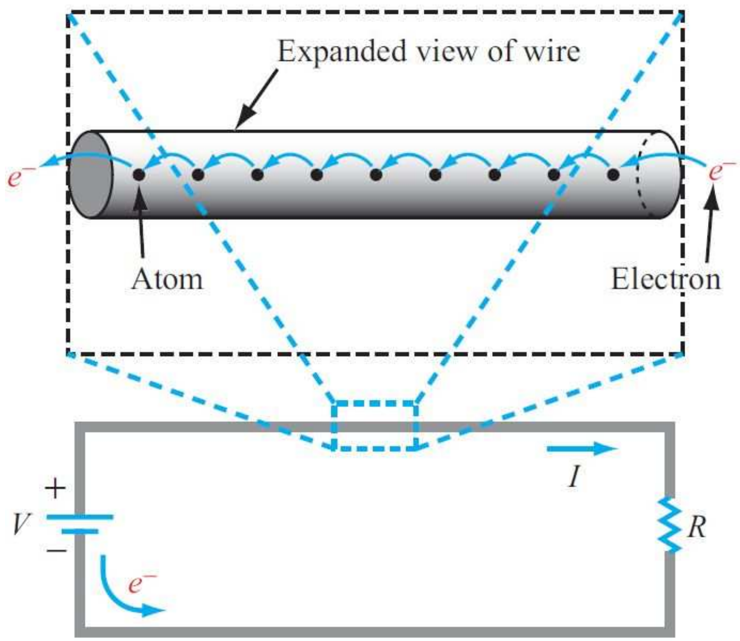
What flows?
How do we measure voltage?
How do we measure flow (current)?

- Voltmeter: measures voltage without drawing current
- Ammeter: measures current without dropping voltage



The Basics:



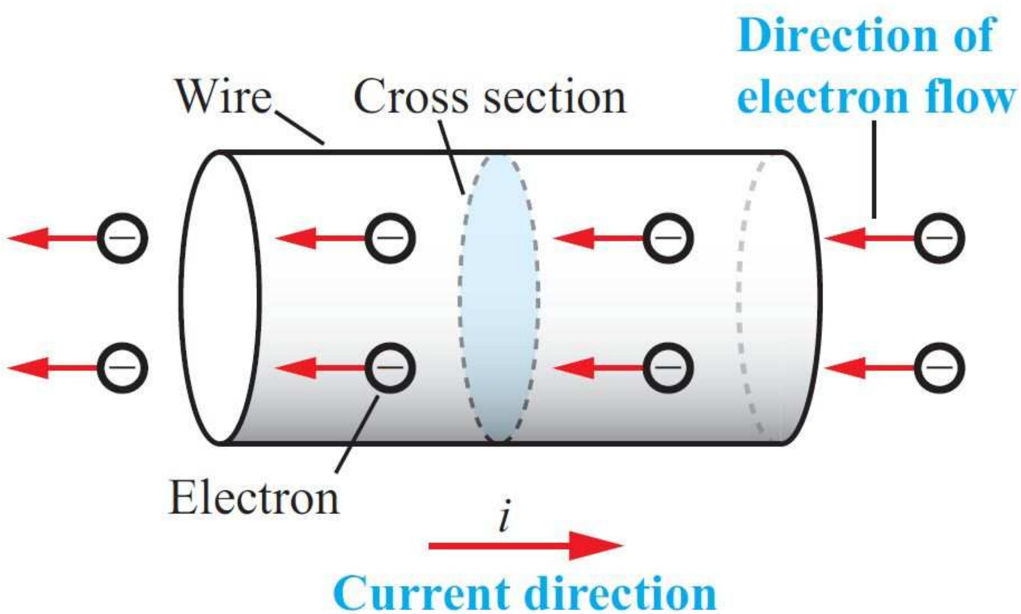


Unit of charge = coulomb

$$e = 1.6 \times 10^{-19} \quad \text{(C)}$$

1. Charge can be either positive or negative.
2. The fundamental (smallest) quantity of charge is that of a single electron or proton. Its magnitude usually is denoted by the letter *e*.
3. According to the law of conservation of charge, the (net) charge in a closed region can neither be created nor destroyed.
4. Two like charges repel one another, whereas two charges of opposite polarity attract.

Current Flow



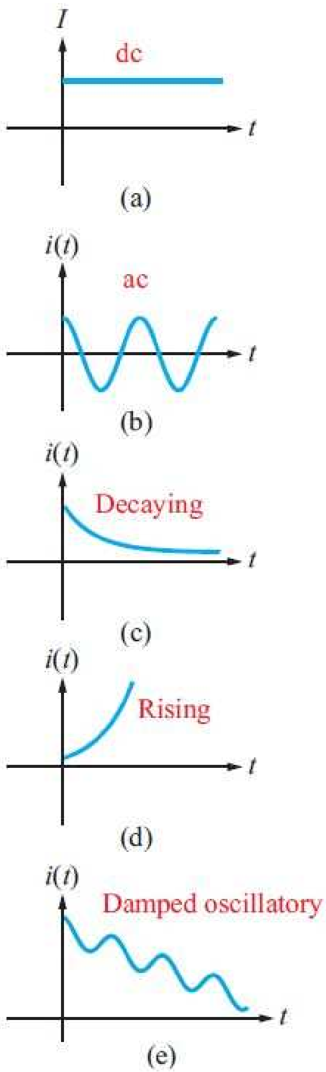
Current Flow

Can be:

- Constant with time, DC, Direct Current
    - a battery in your phone, flashlight etc.

- Oscillate sinusoidally with time, AC, Alternating current
    - what comes out of the wall, 60 cycles/s (Hz)

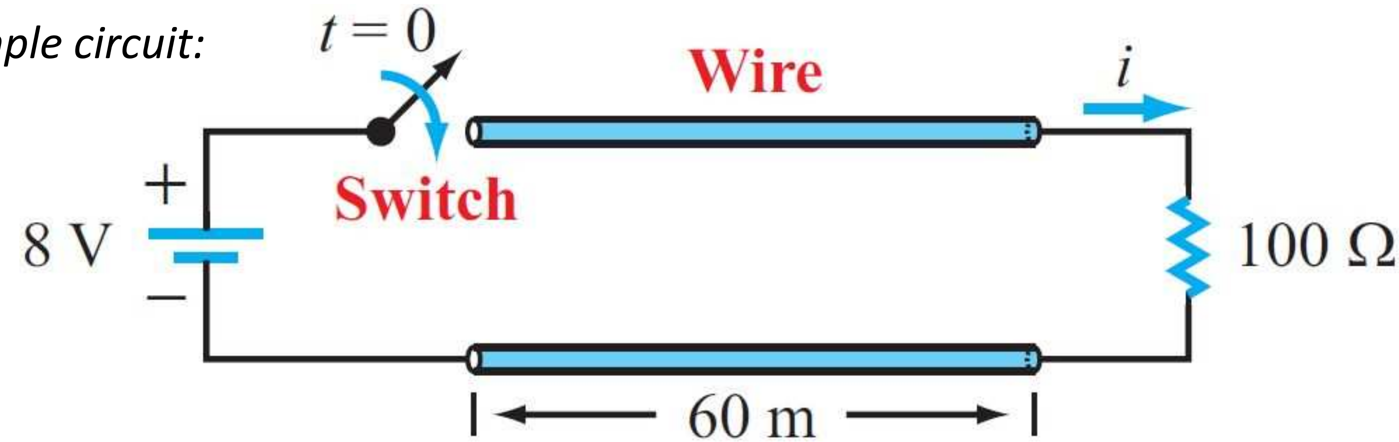
- Any arbitrary function, decaying, rising, etc.



The Basics: What is an electric circuit?

"a complete or partial path over which current may flow"

A very simple circuit:



Electric circuits consist of "elements" – voltage sources, current sources, resistors, capacitors, inductors, etc.

Electrons move in the conductors (wires, elements) in a circuit, giving current flow. (Also current flow could be other charges (such as???)).

Figure 1.5 An ideal basic circuit element.

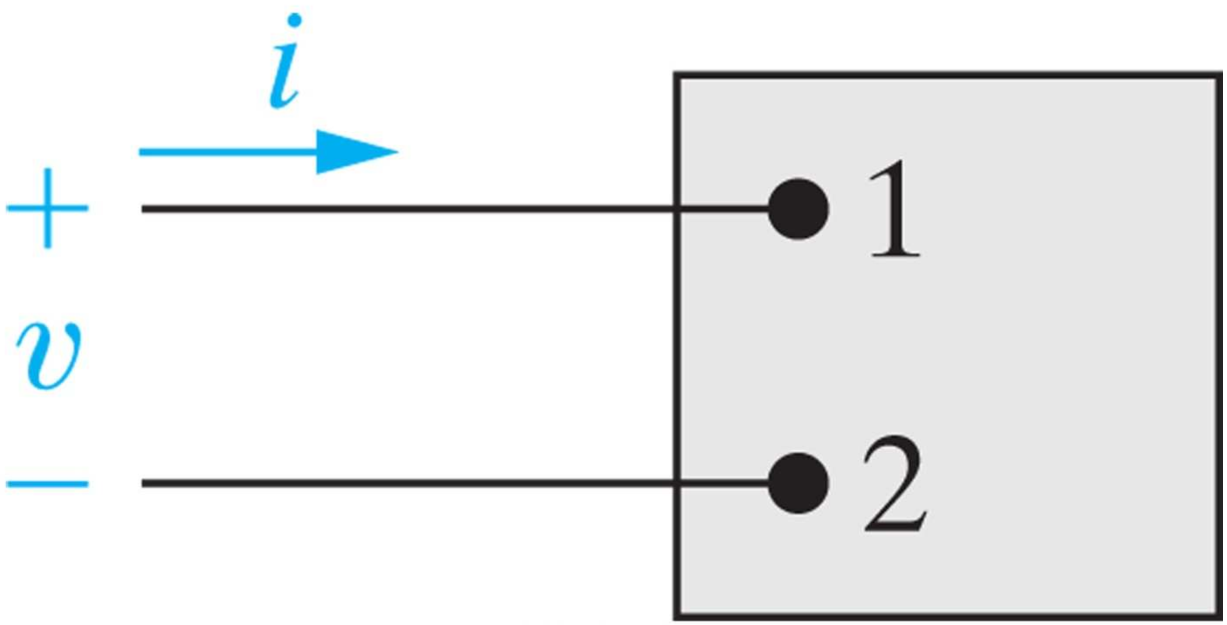
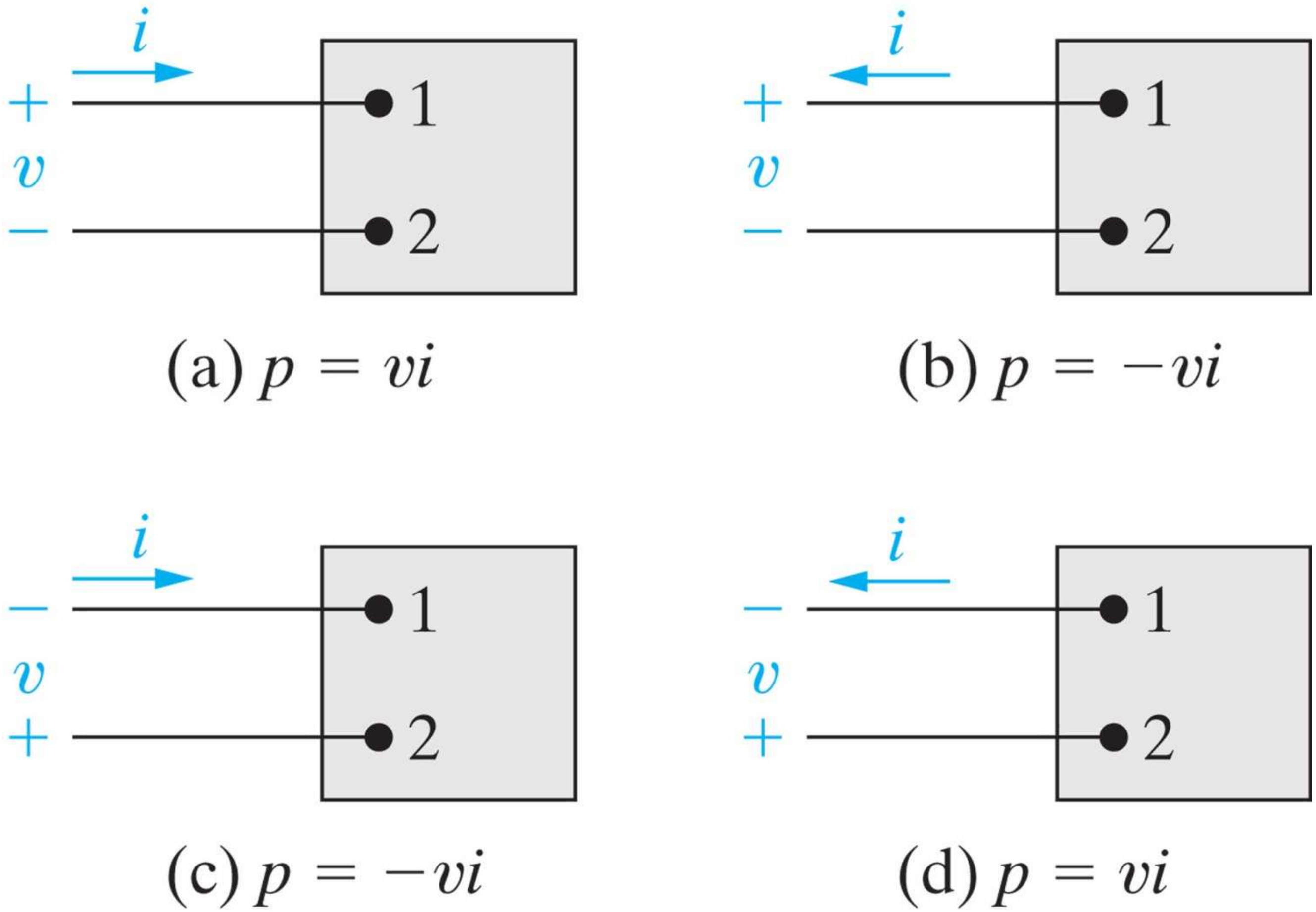


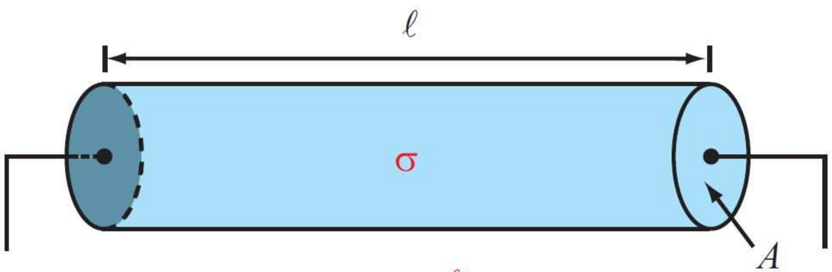
Figure 1.6 Polarity references and the expression for power.



Conductivity, Resistivity:

A resistor is a device (element) which resists charge (electric) flow.

Resistance is a function of <u>size</u>, <u>shape</u> and <u>media properties</u>:



$R = \frac{\ell}{\sigma A}$

$$R = \frac{\ell}{\sigma A} = \rho \frac{\ell}{A} \qquad (\Omega),$$

ρ= **resistivity**

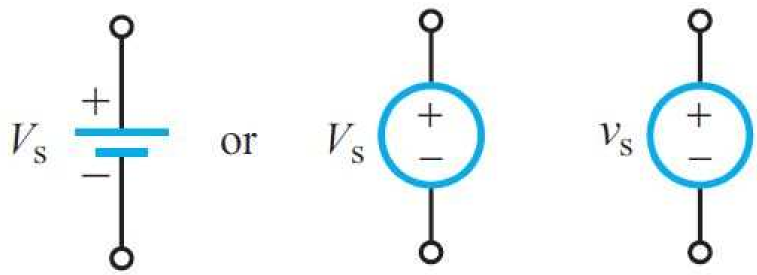
σ = **conductivity =** 1/ρ

Table 2-1: Conductivity and resistivity of some common materials at 20°C.

Material	Conductivity σ (S/m)	Resistivity ρ (Ω-m)
Conductors		
Silver	6.17×10^7	1.62×10^{-8}
Copper	5.81×10^7	1.72×10^{-8}
Gold	4.10×10^7	2.44×10^{-8}
Aluminum	3.82×10^7	2.62×10^{-8}
Iron	1.03×10^7	9.71×10^{-8}
Mercury (liquid)	1.04×10^6	9.58×10^{-8}
Semiconductors		
Carbon (graphite)	7.14×10^4	1.40×10^{-5}
Pure germanium	2.13	0.47
Pure silicon	4.35×10^{-4}	2.30×10^3
Insulators		
Paper	$\sim 10^{-10}$	$\sim 10^{10}$
Glass	$\sim 10^{-12}$	$\sim 10^{12}$
Teflon	$\sim 3.3 \times 10^{-13}$	$\sim 3 \times 10^{12}$
Porcelain	$\sim 10^{-14}$	$\sim 10^{14}$
Mica	$\sim 10^{-15}$	$\sim 10^{15}$
Polystyrene	$\sim 10^{-16}$	$\sim 10^{16}$
Fused quartz	$\sim 10^{-17}$	$\sim 10^{17}$

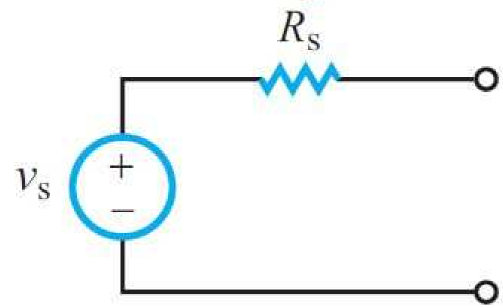
Independent Sources

Ideal Voltage Source



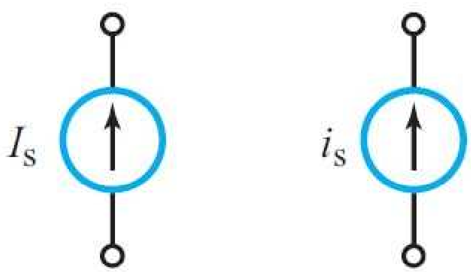
Battery — dc source — Any source*

Realistic Voltage Source



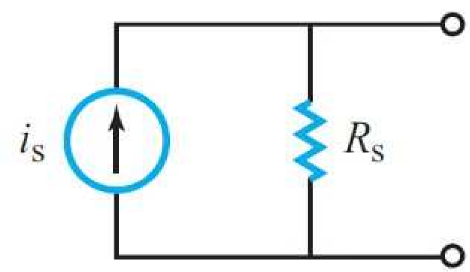
Any source

Ideal Current Source



dc source — Any source

Realistic Current Source

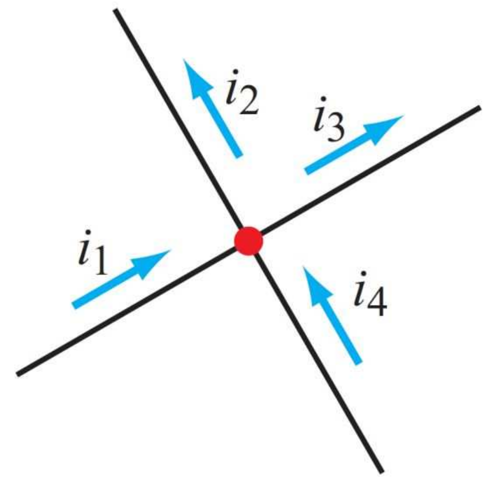


Any source

Kirchhoff's Current Law: (KCL):

Sum of currents entering a node is zero

Also holds for closed boundary



$$\sum_{n=1}^{N} i_n = 0 \qquad \text{(KCL)},$$

$$i_1 - i_2 - i_3 + i_4 = 0$$

$$i_1 + i_4 = i_2 + i_3$$

Kirchhoff's Voltage Law:

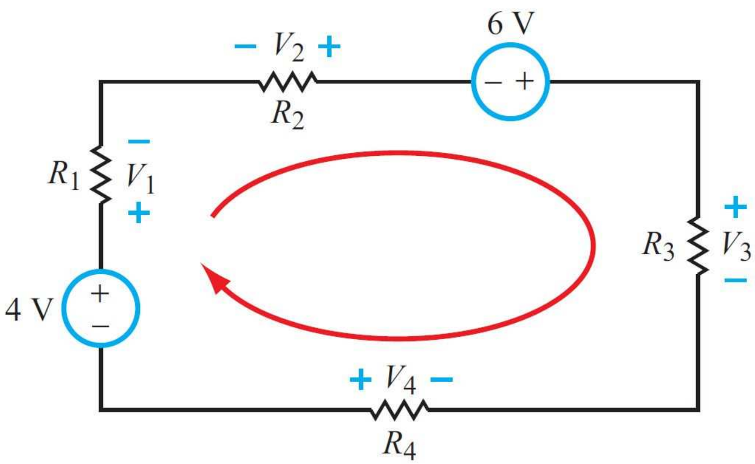
(KVL): **Sum of voltages around a closed path is zero**

Sum of voltage drops = sum of voltage rises

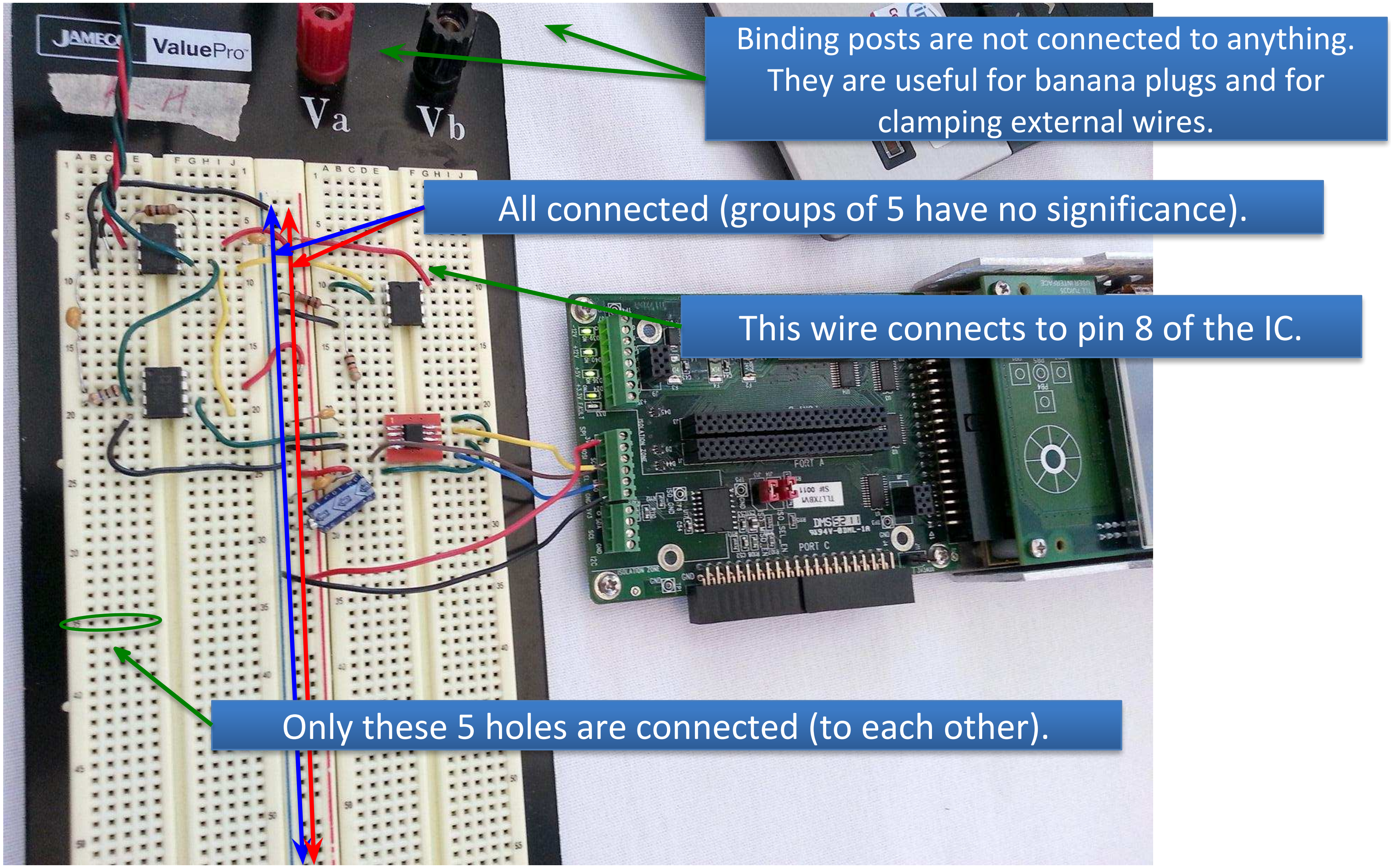
$$\sum_{n=1}^{N} v_n = 0 \qquad \text{(KVL)},$$

Sign Convention

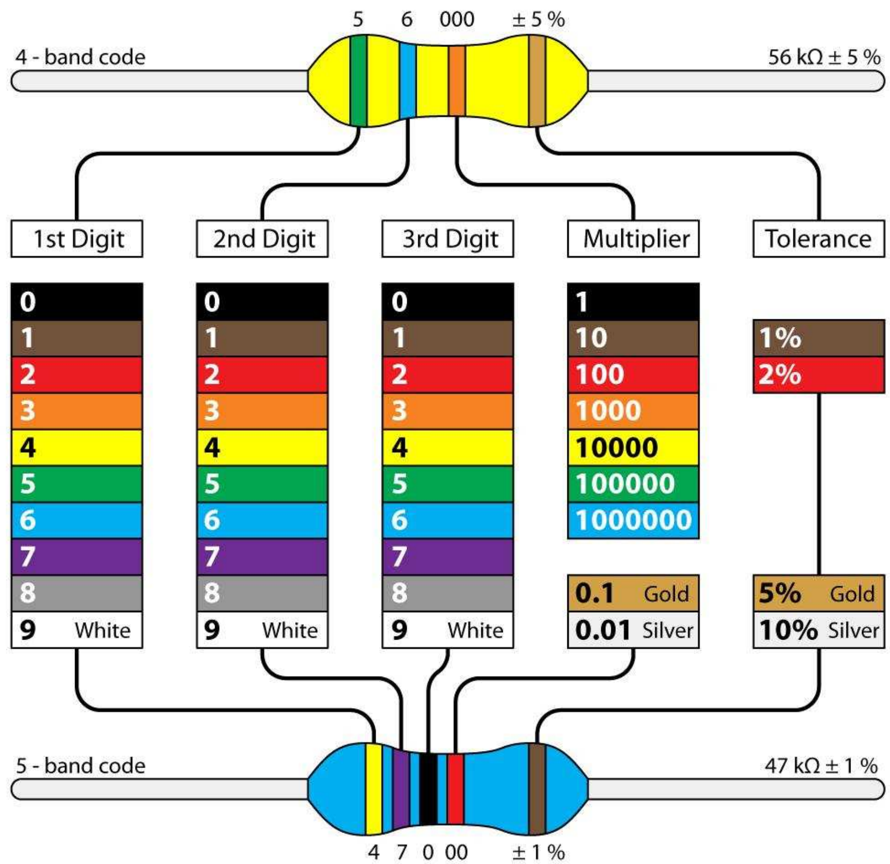
- Add up the voltages in a systematic clockwise movement around the loop.
- Assign a positive sign to the voltage across an element if the (+) side of that voltage is encountered first, and assign a negative sign if the (−) side is encountered first.



$$-4 + V_1 - V_2 - 6 + V_3 - V_4 = 0$$

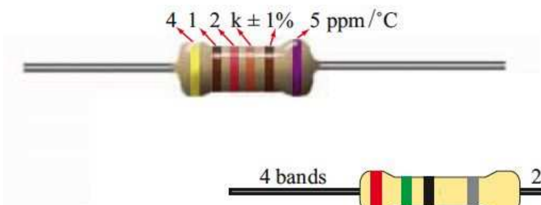

Binding posts are not connected to anything. They are useful for banana plugs and for clamping external wires.
All connected (groups of 5 have no significance).
This wire connects to pin 8 of the IC.
Only these 5 holes are connected (to each other).
ValuePro
Va
Vb

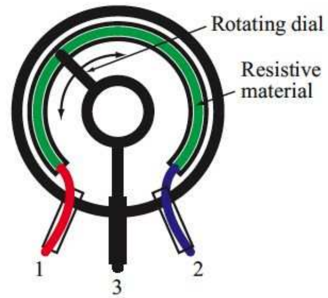
Resistor colour code



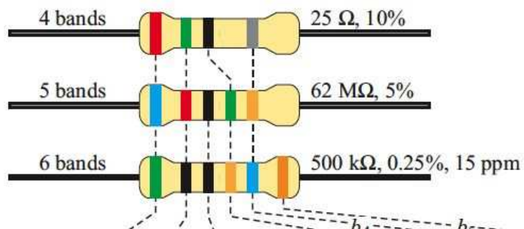
Resistors:

1-kΩ high-power resistor



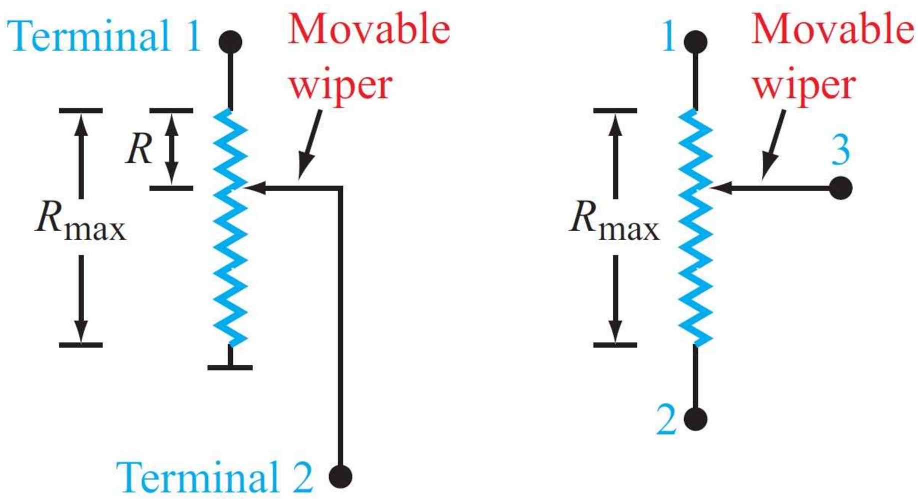


Potentiometer resistor



Color	1st digit (b_1)	2nd digit (b_2)	3rd digit (b_3)	Multiplier $\times 10^{b_4}$ # of zeros (b_4)	Tolerance (b_5)	Temperature coefficient ppm/°C (b_6)
Silver				0.01	10%	
Gold				0.1	5%	
Black	0	0	0	1		
Brown	1	1	1	10	1%	100 ppm
Red	2	2	2	100	2%	50 ppm
Orange	3	3	3	1K		15 ppm
Yellow	4	4	4	10K		25 ppm
Green	5	5	5	100K	0.5%	
Blue	6	6	6	1M	0.25%	10 ppm
Purple	7	7	7	10M	0.1%	5 ppm
Gray	8	8	8			
White	9	9	9			

4-, 5-, and 6-band color code system



(a) Rheostat (b) Potentiometer