Basic Fundamentals

- ***Charge*** (q):
  - Elementary charge particle: ***electron***
  - Has a negative charge of magnitude

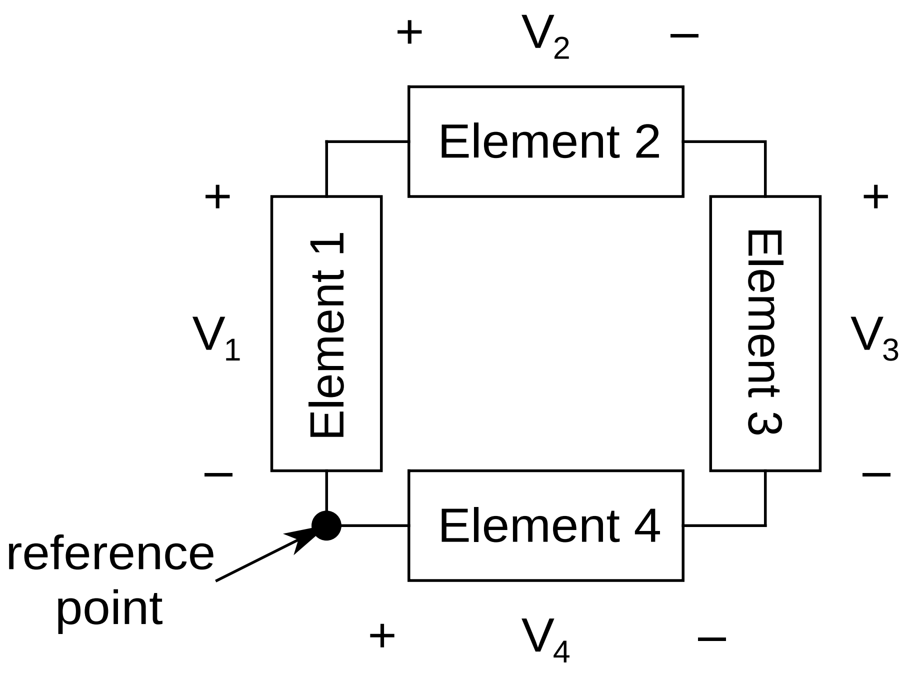
    $q = 1.6 \times 10^{-19}$ Coulomb (C)
- ***Voltage*** (V) (also referred to as ***potential***):
  - Work done (or energy spent) to move a unit charge between two points
  - (work done)/(unit charge) => 1 V = 1 J/1 C
  - Also, known as the ***potential difference*** (p.d.) between two points, expressed in Volt

- For charges to flow between two points in a closed circuit, a p.d. must exist between these two points
- ***Scalar*** quantity: always measured with respect to some reference
  - If the reference is not explicitly specified, then it is taken to be ***ground*** (zero volt)
  - Example:
    - V_A - potential of point A with respect to ground
    - V_{AB} - potential of point A with respect to potential of point B
- All circuits must have a ***reference*** point
  - If the reference point is not explicitly shown, then any node can be taken as a reference point

- ***Actual Ground*** and ***Reference Ground***:
  - Ground provides a return path for the current
  - Earth is considered to be an infinite source/sink of charge
    - ***Zero resistance*** => can absorb unlimited amount of current without changing its potential
  - Power supply in your homes have a ground connection, so does all big electrical and electronic appliances
    - 3-pin plugs: Live, Neutral, and Ground
    - 2-pin: Only Live and Neutral (floating ground)
  - Lightning arrester is a classic example of an actual ground

- Small and portable appliances (cell-phones, ipods, etc.) do not have actual ground
  - They have something known as ***floating ground*** (also referred to as ***chassis ground***)
    - Typically a metal plate running at the periphery of the PCB
- Floating ground apparatus are dangerous, since they may give electric shocks
- Another example is electrostatic discharge (lightning is also an electrostatic discharge)
  - On a dry day, we may get shock upon touching a metal object (like door-knob) => electrostatic discharge
- The equipments that you will be using in the lab will all have ***actual ground***

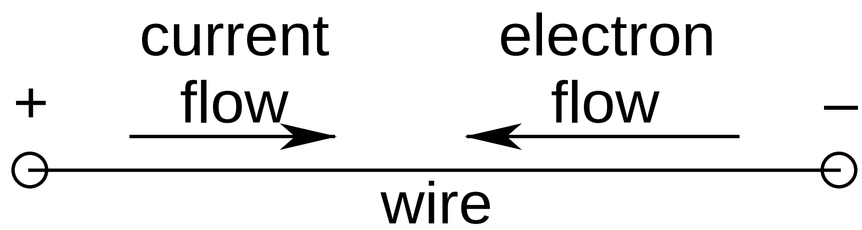
- ***Kirchhoff's Voltage Law***:
  - Net voltage around a closed circuit must be zero
  - Origin: ***Law of energy conservation***:
    - Total energy generated in a circuit must equal total energy dissipated in the circuit



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

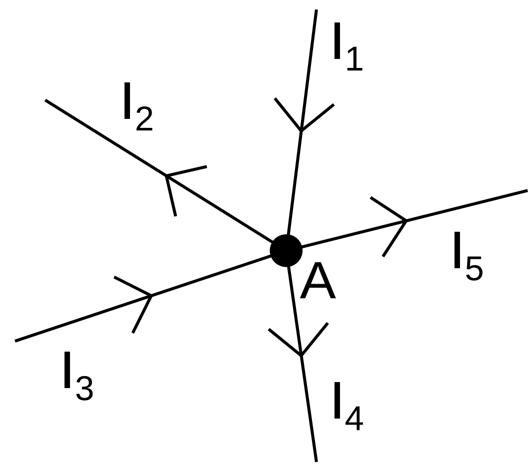
Take care of the polarities of the potentials while applying this law

- ***Current*** (I):
  - Measure of charge transport
  - Defined as incremental charge change with respect to incremental time change
  - Expressed as: $i = \Delta q/\Delta t$ (Coulomb/sec = Ampere)
  - In the limit, as $\Delta t \rightarrow 0$, $i = dq/dt$ (differential form)
  - If dq/dt is constant => ***direct current*** (dc)
  - If dq/dt exists => ***alternating current*** (ac)
  - Note: 1 A of current implies about 10^{19} electrons flowing per second through a cross-sectional area



- By convention, positive direction of current is defined as the direction of flow of positive charges
  - Electrons flow opposite to the direction of current flow
- Electrons always move from lower potential to higher potential (attractive for them)
  - Actual flow of current from higher potential to lower potential

- For current to flow, the circuit must be closed
- ***Kirchhoff's Current Law*** (KCL):
  - Sum of currents at a node must be zero
  - Origin: Law of charge conservation:
    - In a closed circuit, no charge is lost
- States that:
  - the sum of currents flowing into a node must equal the sum of currents flowing out of the node



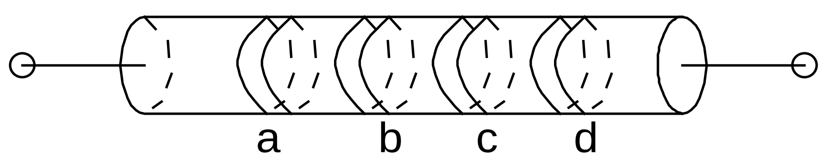
At node A:

$$I_1 + I_3 = I_2 + I_4 + I_5$$

- ***Power*** (P):
  - Defined as work done per unit time
  - Thus, P = (work done)/(unit charge) x (unit charge)/(unit time) = voltage × current = VI
  - Unit of P is Joules/sec or Watt (W)
  - In an element, if the current flows from:
    - lower to higher potential, then that element is ***generating power***
    - higher to lower potential, then that element is ***absorbing or dissipating power***
  - Within an electric circuit, the total power generated must equal the total power dissipated

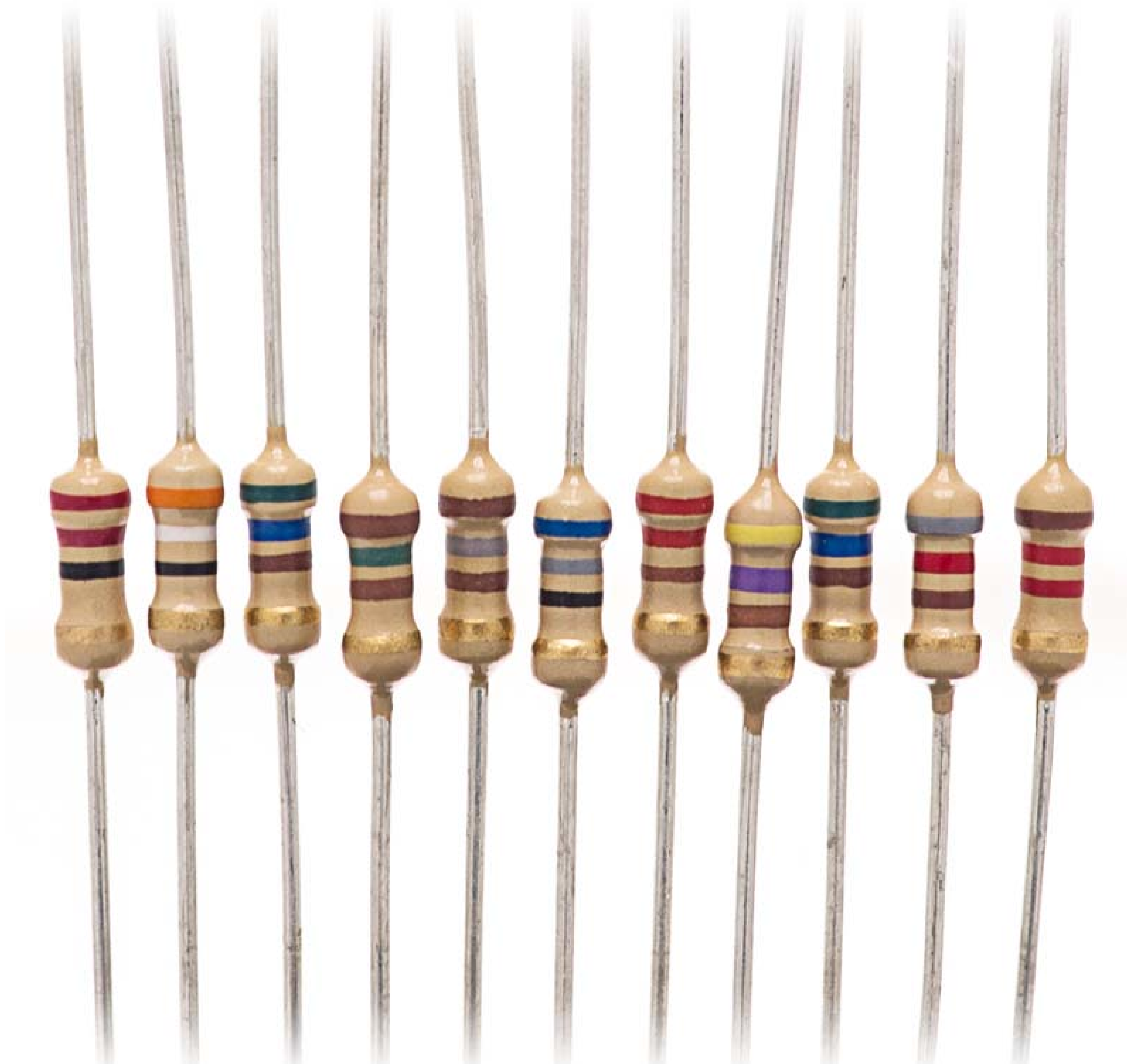
- ***Ohm's Law***, ***Resistance***, & ***Conductance***:
  - Fundamental principle of electric circuit
  - Relates the current (I) that flows through a resistor under an applied p.d. of V
  - V = IR, with R being the resistance of the resistor
  - Thus, resistors are ***linear*** elements
  - Alternate form: I = GV, with G being the ***conductance*** of the resistor
  - Note that G = 1/R
  - Current always flows from higher to lower potential
  - The unit of resistance is Ohm (Ω), while that of conductance is Mho (℧)

- ***Resistance*** (R):
  - Typically cylindrical, having length l and radius r, with cross-sectional area $A = \pi r^2$
  - Expressed as: $R = \rho l/A$, where ρ = ***resistivity*** (Ω-cm) = $1/\sigma$, with σ = ***conductivity*** $(\Omega\text{-cm})^{-1}$
  - Usually, nichrome wires wound around a base with an insulating material, bonded with resin



  - Resistor value: $R = ab \times 10^c \pm d\%$

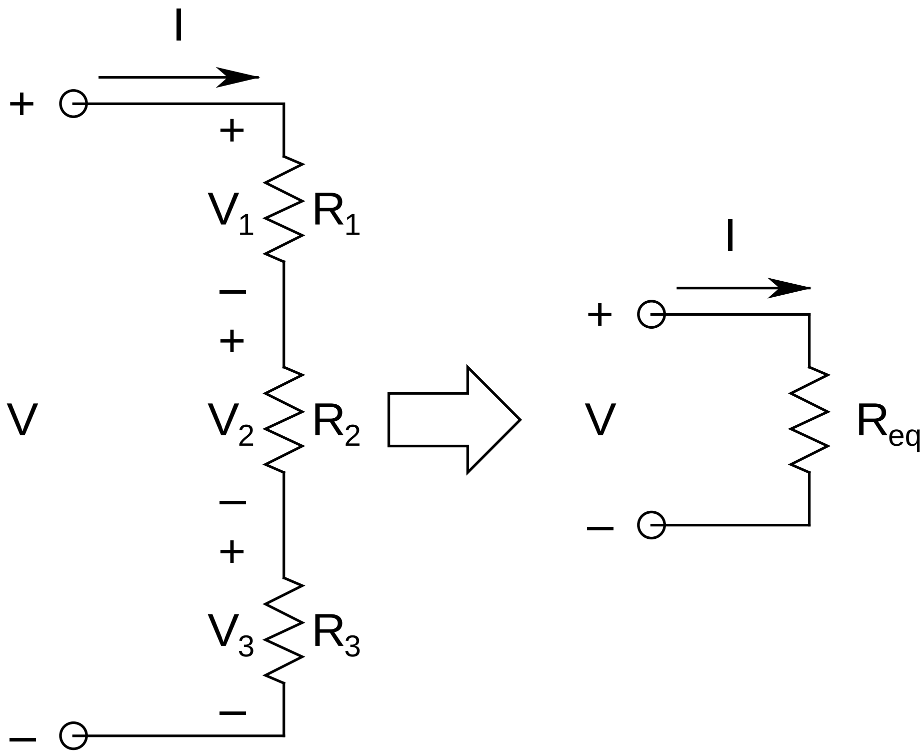
- ***Resistor Color Code***:
  - ***B B Roy of Great Britain has a Very Good Wife***
  - BBROYGBVGW: Black (0), Brown (1), Red (2), Orange (3), Yellow (4), Green (5), Blue (6), Violet (7), Gray (8), White (9)
  - Band d is tolerance band: Violet - 0.1%, Blue - 0.25%, Green - 0.5%, Brown - 1%, Red - 2%, Gold - 5%, Silver - 10%, None - 20%
  - Example: brown black brown gold - 100 Ω with $\pm$5% tolerance, blue gray yellow - 680 kΩ with $\pm$20% tolerance



- ***Resistor Temperature & Power Ratings***:
  - Power dissipated in a resistor = VI = $V^2/R = I^2R$
  - Causes a rise in temperature of the resistor due to ***Joule heating***
  - Causes a change in the resistor value, determined by its ***temperature coefficient*** (TCF)
  - TCF = $\alpha = (1/R)(dR/dT)$, expressed in /K or /°C
  - $R = R_{nom}[1 + \alpha(T - T_{nom})]$, where T_{nom} is the nominal temperature, and R_{nom} is the value of the resistance at T_{nom}

- Resistors should be able to effectively dissipate the generated heat, otherwise, they may burn out
- Resistors have ***safe power ratings***
- Common power ratings: 1/8 W, 1/4 W, 1/2 W, 1 W, and 2 W
- Resistors having power rating of more than 2 W are referred to as ***high-power resistors***
- In power electronics applications, the power rating of resistors may even be kW or more

- ***Series Combination of Resistors***:



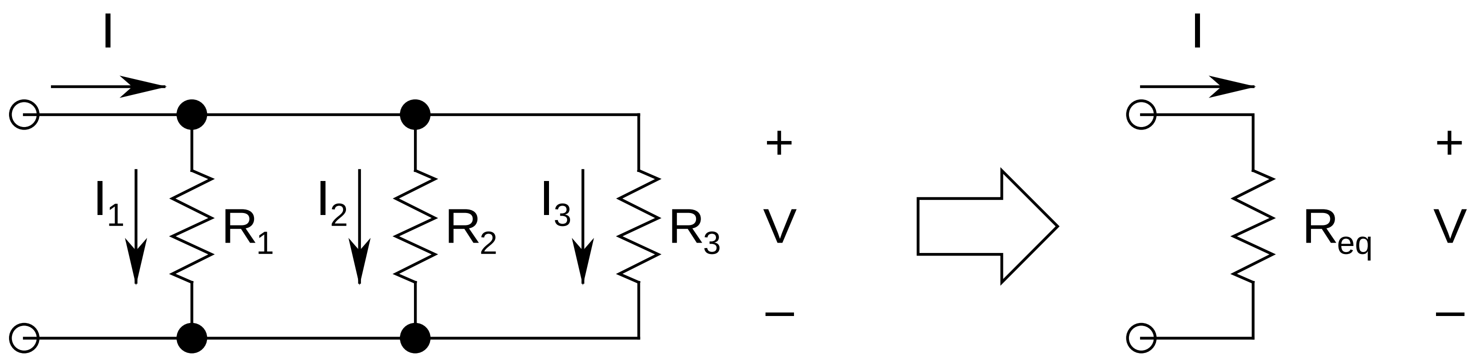
$$
\begin{aligned}
V &= V_1 + V_2 + V_3 \\
&= I\left(R_1 + R_2 + R_3\right) \\
&= IR_{eq} \\
\Rightarrow R_{eq} &= R_1 + R_2 + R_3
\end{aligned}
$$

Largest R

dominates

- Note that all resistors are dissipating power, supplied by the source => $VI = I^2R_{eq}$

- ***Parallel Combination of Resistors***:



$$I = I_1 + I_2 + I_3 = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)V = \frac{V}{R_{eq}}$$

$$\Rightarrow R_{eq} = R_1 \parallel R_2 \parallel R_3 = \left(R_1^{-1} + R_2^{-1} + R_3^{-1}\right)^{-1}$$

$$= \left(G_1 + G_2 + G_3\right)^{-1}$$

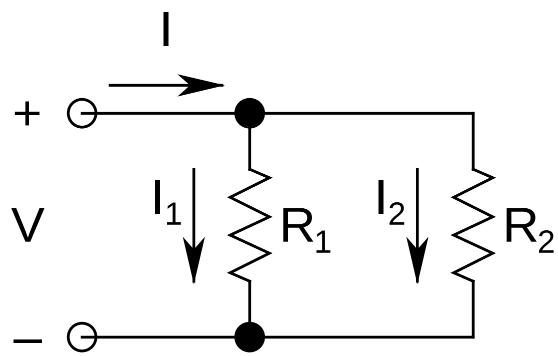
Smallest R

(highest G)

Dominates

- Note: Resistances in parallel is equivalent to conductances in series

- ***Current Branching between Two Parallel Resistors***:



$$V = IR_{eq}, \quad R_{eq} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

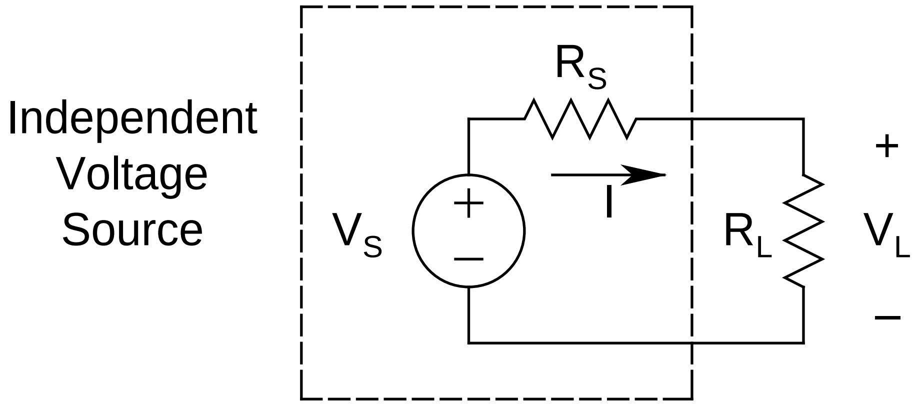
$$I_1 = \frac{V}{R_1} = \frac{R_2}{R_1 + R_2} I, \text{ and } I_2 = \frac{R_1}{R_1 + R_2} I$$

– Extremely important relation
  - If $R_2 >> R_1$, then $I_1 \approx I$, and $I_2 \approx 0$
  - If $R_1 >> R_2$, then $I_2 \approx I$, and $I_1 \approx 0$
  - If $R_1 = R_2$, then $I_1 = I_2 = I/2$ (equal split)

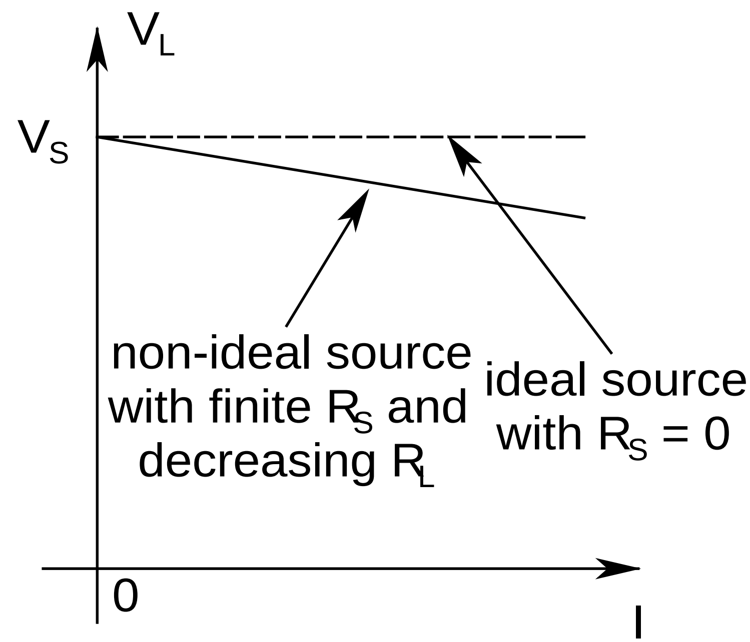
– The larger resistor carrier lesser current, since the voltage drop across both of them is same

- ***Sources***:
  - Elements that supply power (or energy)
  - Voltage and Current
  - Independent and Dependent
- ***Notational Convention*** (IEEE Standard):
  - Capital letter with capital suffix - pure DC
    - Example: V_S
  - Small-case letter with small-case suffix - pure ac
    - Example: i_a
  - Capital letter with small-case suffix, or small-case letter with capital suffix - instantaneous
    - Example: I_s or v_A

• ***Independent Voltage Source***:



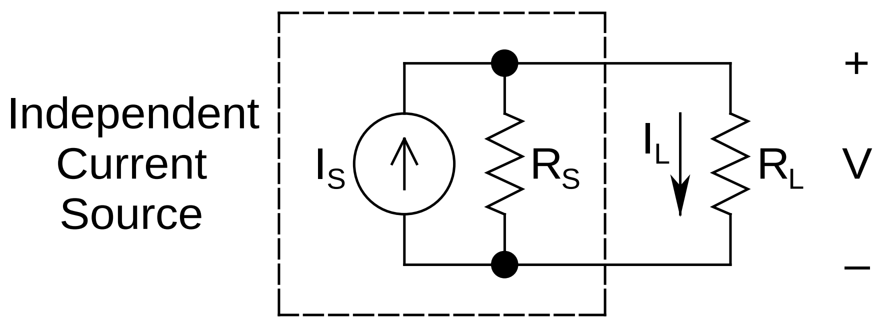
V_S: Rated Voltage
R_S: Series Resistance of Source
R_L: Load Resistance
V_L: Load Voltage



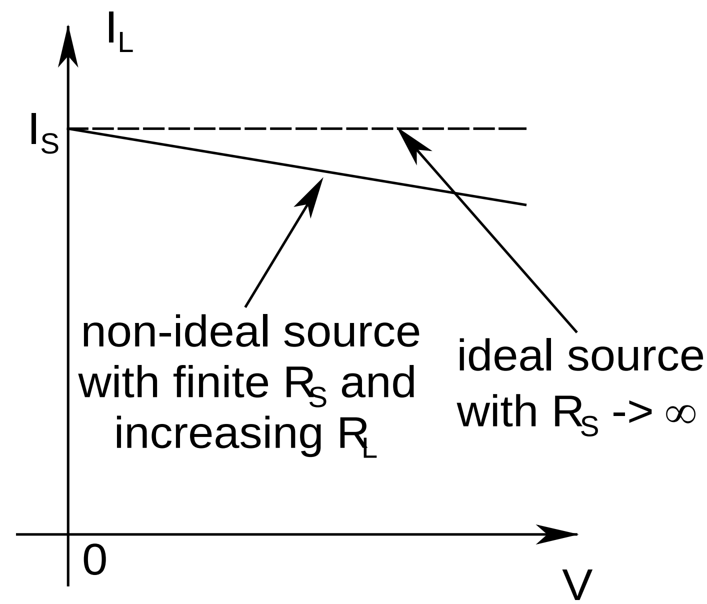
$$I = \frac{V_S}{R_S + R_L}, V_L = IR_L = \frac{R_L}{R_S + R_L} V_S$$

- For $V_L = V_S$, R_S must be zero - an important requirement for a good voltage source
  - Known as ***Ideal Voltage Source*** => ***lossless***
- For finite R_S, V_L will drop with decreasing R_L
  - Known as ***loading effect***
- Practical voltage sources have series resistance of the order of a few kΩ
- For well designed sources, it may be less than 100 Ω
- Effect of loading becomes more and more pronounced as R_L and R_S start to become comparable

- ***Independent Current Source***:



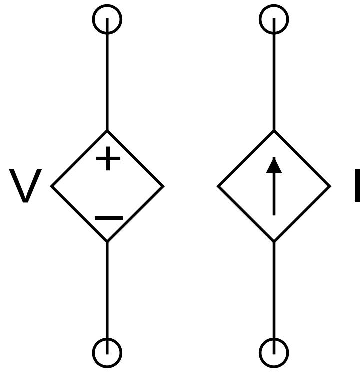
I_S: Rated Current
R_S: Shunt Resistance of Source
R_L: Load Resistance
I_L: Load Current



$$I_L = \frac{R_S}{R_S + R_L} I_S, \quad V = I_L R_L = \frac{R_S R_L}{R_S + R_L} I_S$$

– For $I_L = I_S$, R_S must be infinite - an important requirement for a good current source
  - Known as ***Ideal Current Source*** => ***lossless***
– For finite R_S, I_L will drop with increasing R_L
  - Known as ***loading effect***
– Practical current sources have shunt resistance of the order of a few hundreds of kΩ
– For well designed sources, it may be even greater than 1 MΩ
– Effect of loading becomes more and more pronounced as R_L and R_S start to become comparable

- ***Dependent (or Controlled) Sources***:

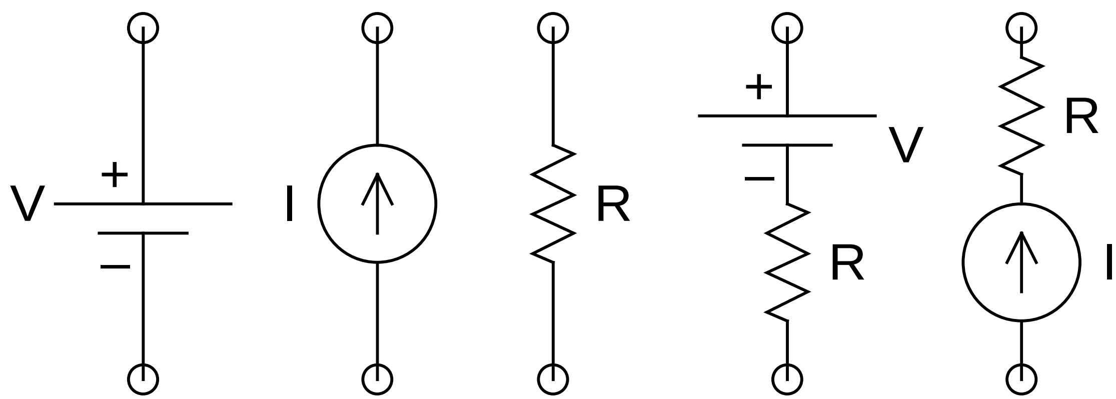


Source voltage (current) dependent on another voltage (current) somewhere else in the circuit

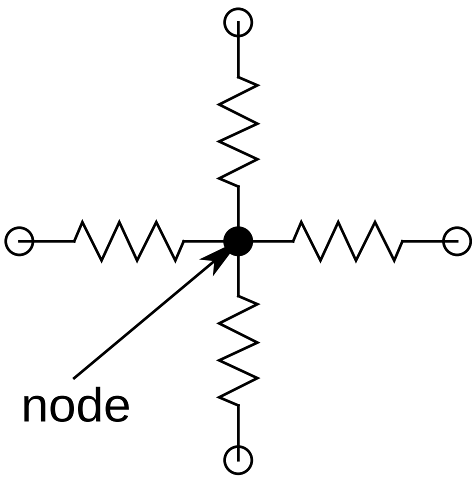
Note the diamond shape, which distinguishes these from independent sources (round)

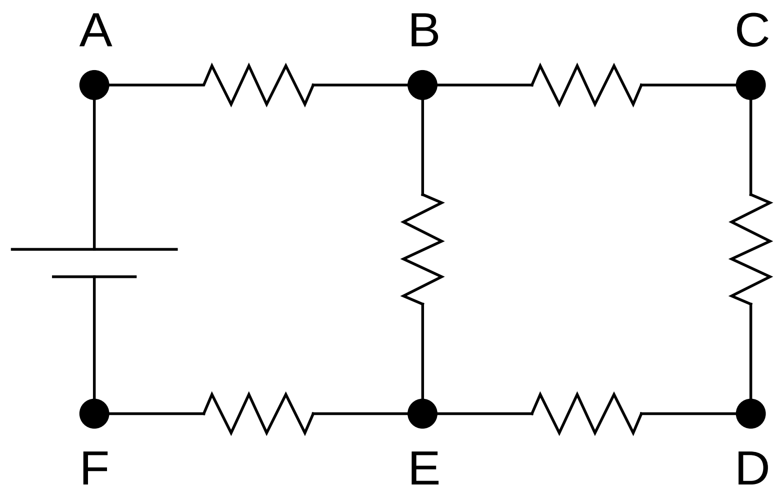
  – Four possibilites:
    - ***VCVS*** (Voltage-Controlled Voltage Source)
      – $V = A_v V_x$, A_v: ***voltage gain***, V_x: controlling voltage
    - ***VCCS*** (Voltage-Controlled Current Source)
      – $I = G_m V_x$, G_m: ***transconductance***
    - ***CCCS*** (Current-Controlled Current Source)
      – $I = A_i I_x$, A_i: ***current gain***, I_x: controlling current
    - ***CCVS*** (Current-Controlled Voltage Source)
      – $V = R_m I_x$, R_m: ***transresistance***

- ***Electrical Network***:
  - Connection of elements to form a closed path through which current flows
- ***Branch***:
  - Any portion of a circuit with two terminals connected to it
  - May contain one or more circuit elements



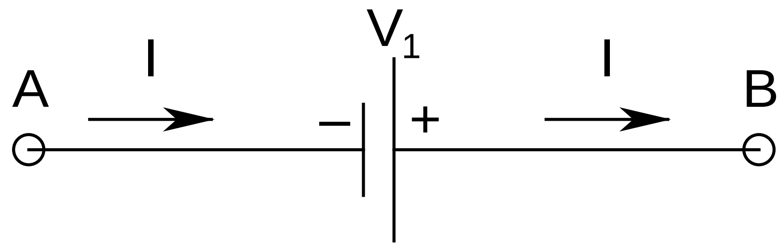
- ***Node***:
  - Junction point of two or more branches
  - Junction point of only two branches is also known as ***trivial node***





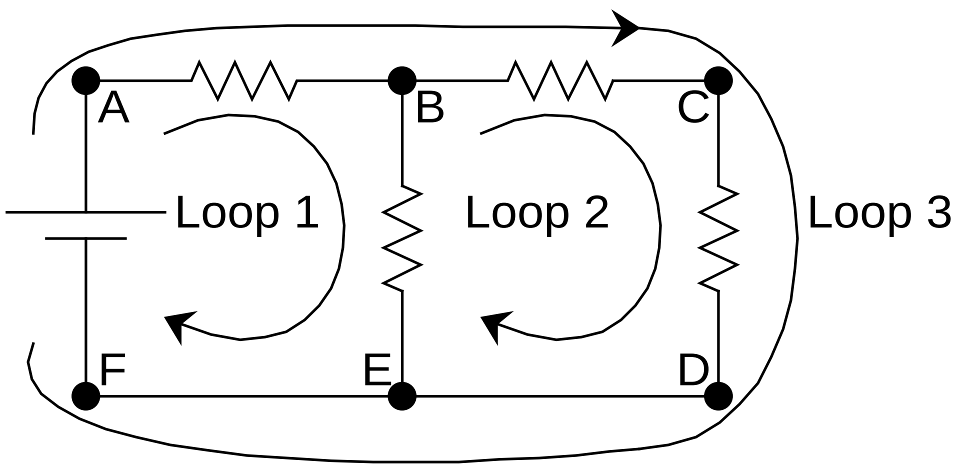
A, B, C, D, E, F: Nodes
A, C, D, F: Trivial Nodes

- ***Supernode***:
  - 2 nodes connected by a dc voltage source is denoted as a ***supernode***
  - Voltages at the two nodes of a supernode are not independent, e.g., $V_B = V_A + V_1$



  - Important condition for a supernode:
    - At any supernode, net current entering = net current leaving

- ***Loop***:
  - Closed connection of branches
  - Different loops in the same circuit may include some of the same elements or branches
- ***Mesh***:
  - A loop that does not contain other loops



Loops 1 and 2 are meshes, but Loop 3 is not a mesh, since it includes Loops 1 and 2

- ***Measuring Instruments***:
  - ***Ohmmeter***:
    - Measures the resistance of a resistor
    - The resistance is put across the two terminals of the instrument, which injects a small current (I) through the resistor, and measures the voltage (V) dropped across it => then $R = V/I$
    - The meter is calibrated to show the output in terms of the ohmic value of the resistor

– ***Voltmeter***:

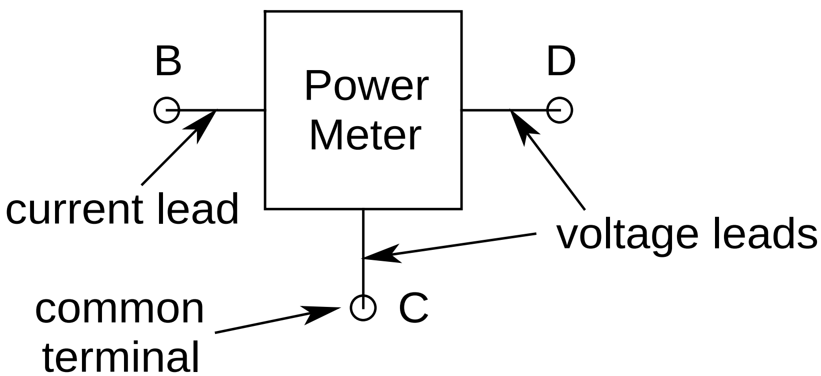
- Measures the voltage (or potential) dropped across any element in the circuit
- Always put in ***parallel*** to the two nodes across which the potential is to measured
- To prevent loading caused by this instrument, it has ***extremely high resistance***
- Never put a voltmeter in series with any element in a circuit, since due to the high resistance of this instrument, that branch will immediately become open-circuited

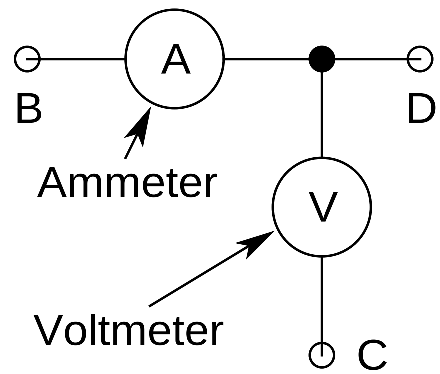
– ***Ammeter***:

- Measures the current flowing through any branch in a network
- Always put in ***series*** with the branch through which the current flow is to be measured
- To prevent loading caused by this instrument, it has ***negligible resistance***
- Never put an ammeter in parallel with any element in a circuit, since due to the extremely small resistance of this instrument, a huge amount of current will flow through this instrument and burn it

– ***Wattmeter***:

- Also known as ***Power Meter***
- Measures the power consumed by a branch





- Involves both current (I) and voltage (V) measurements, and then performs a multiplication of the two in order to get the power