# Introduction to Electricity

# Charge

- Symbol: (q)
- Unit: Coulomb (C)

–The fundamental electric quantity is charge.

–Atoms are composed of charge carrying particles: **electrons** and **protons**, and neutral particles, **neutrons**.

–The smallest amount of charge that exists is carried by an electron and a proton.

–Charge in an electron:

$$q_e = -1.602 \times 10^{-19}\ C$$

–Charge in a proton:

$$q_p = 1.602 \times 10^{-19}\ C$$

# Current

- Symbol: I
- Unit: Ampere

– Current moves through a circuit element "through variable."

– Current is rate of flow of negatively-charged particles, called electrons, through a predetermined cross-sectional area in a conductor.

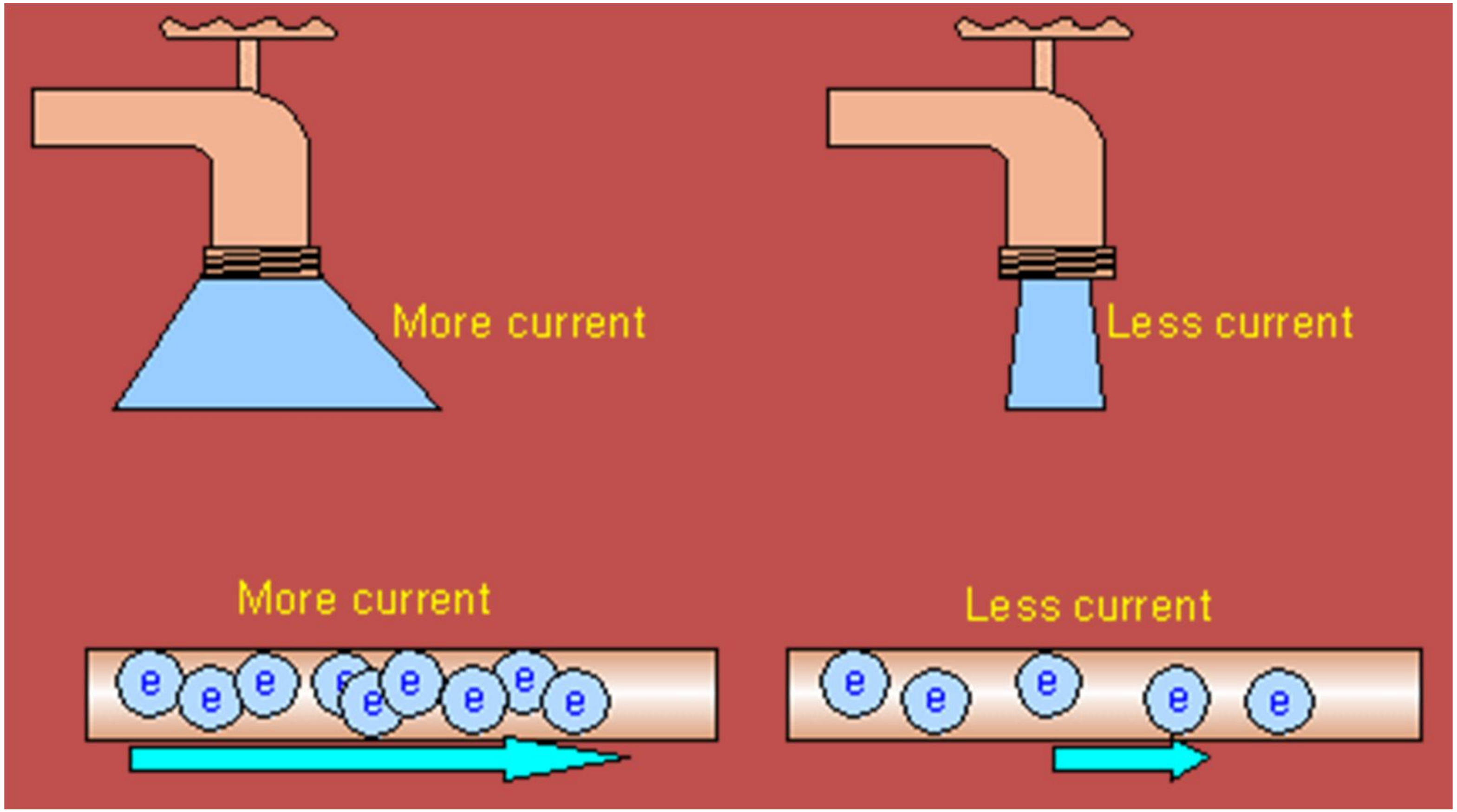
– Like water flow.

– Essentially, flow of electrons in an electric circuit leads to the establishment of current.

$$I(t) = \frac{dq}{dt}$$

- q : relatively charged electrons (C)
- Amp = C/sec
- Often measured in milliamps, mA

# Current-Water Analogy



# Voltage

- Symbol: V
- Unit: Volt

– Potential difference across two terminals in a circuit "across variable."

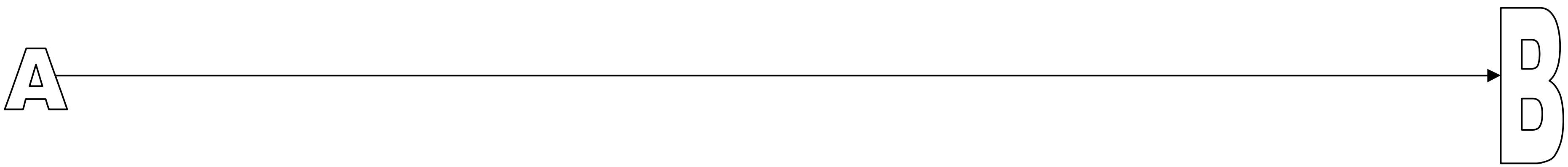
– In order to move charge from point A to point B, work needs to be done.

– Like potential energy at a water fall.

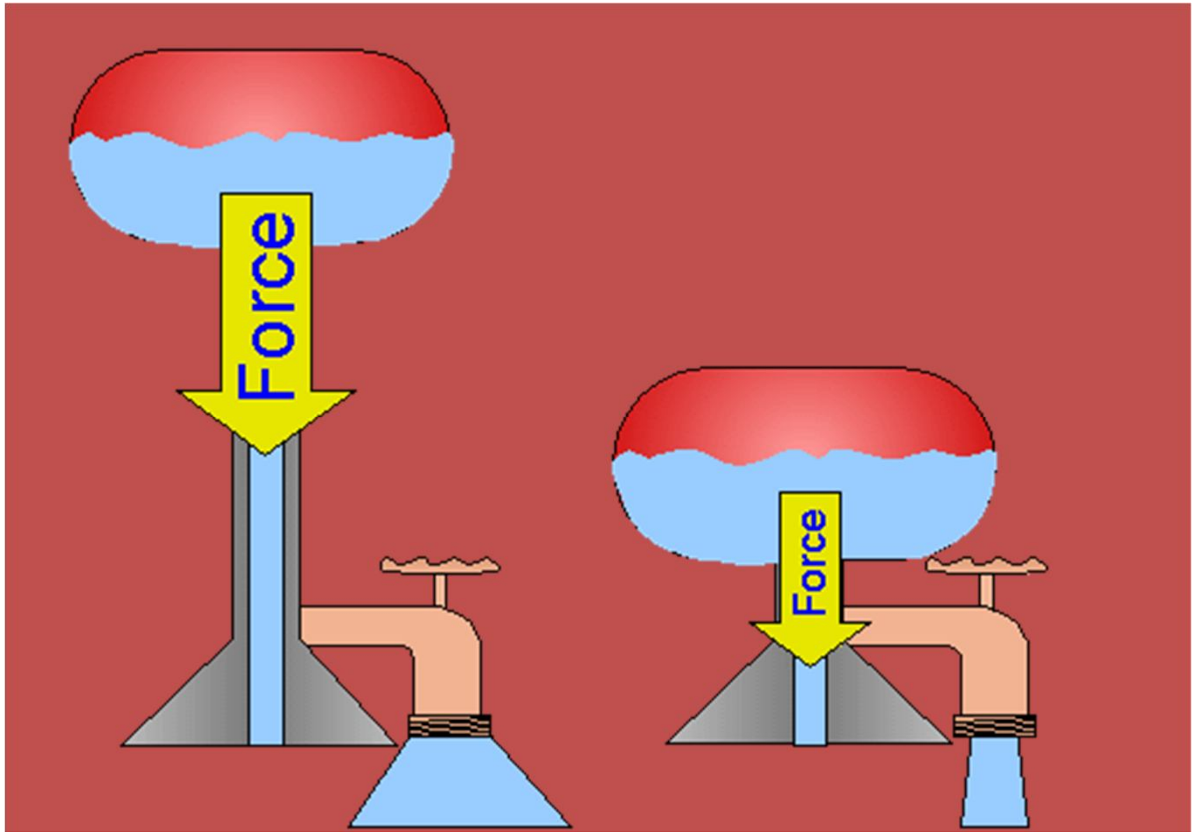
– Let A be the lower potential/voltage terminal

– Let B be the higher potential/voltage terminal

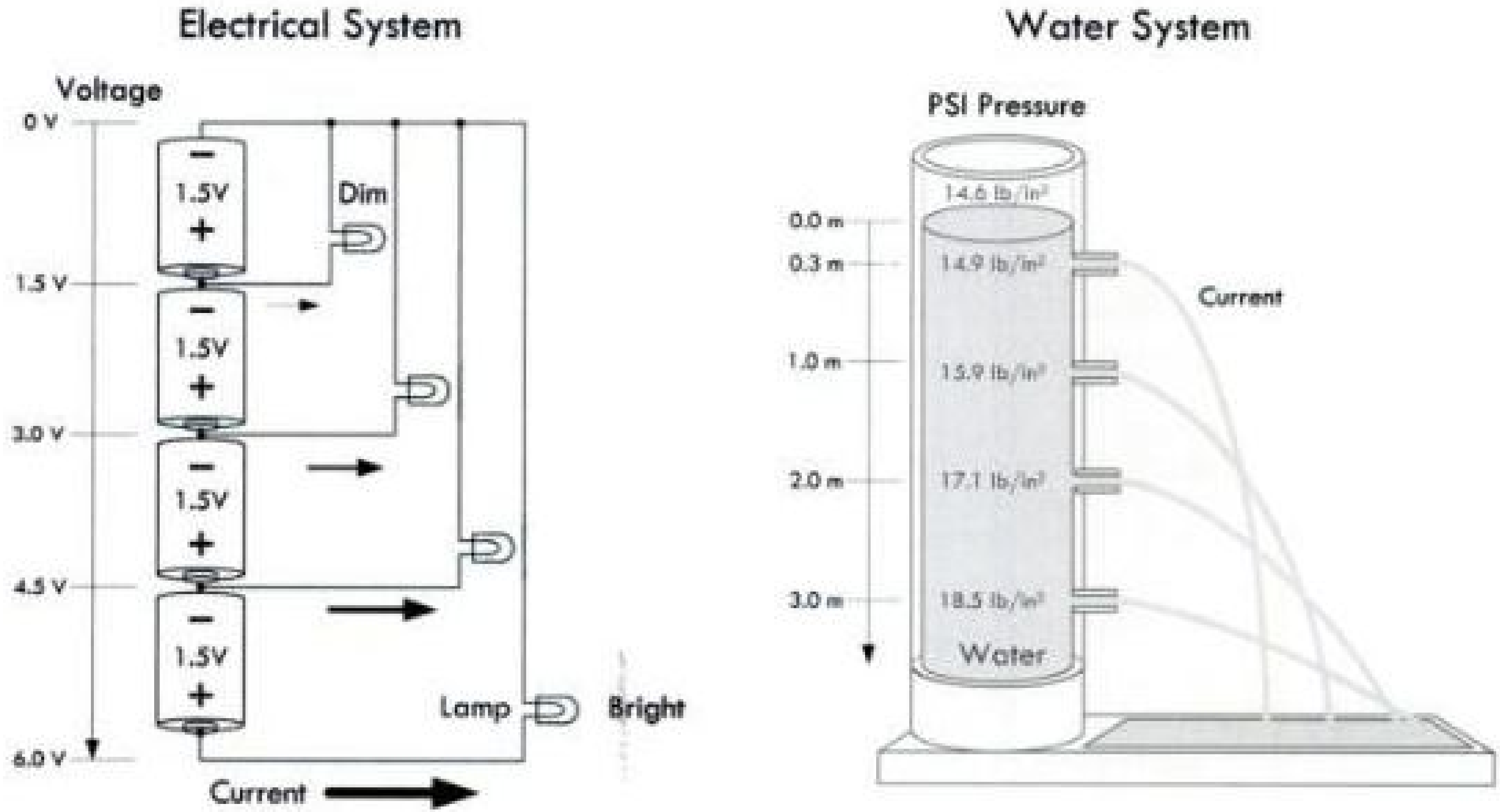
  - o Then, voltage across A and B is the cost in energy required to move a unit positive charge from A to B.



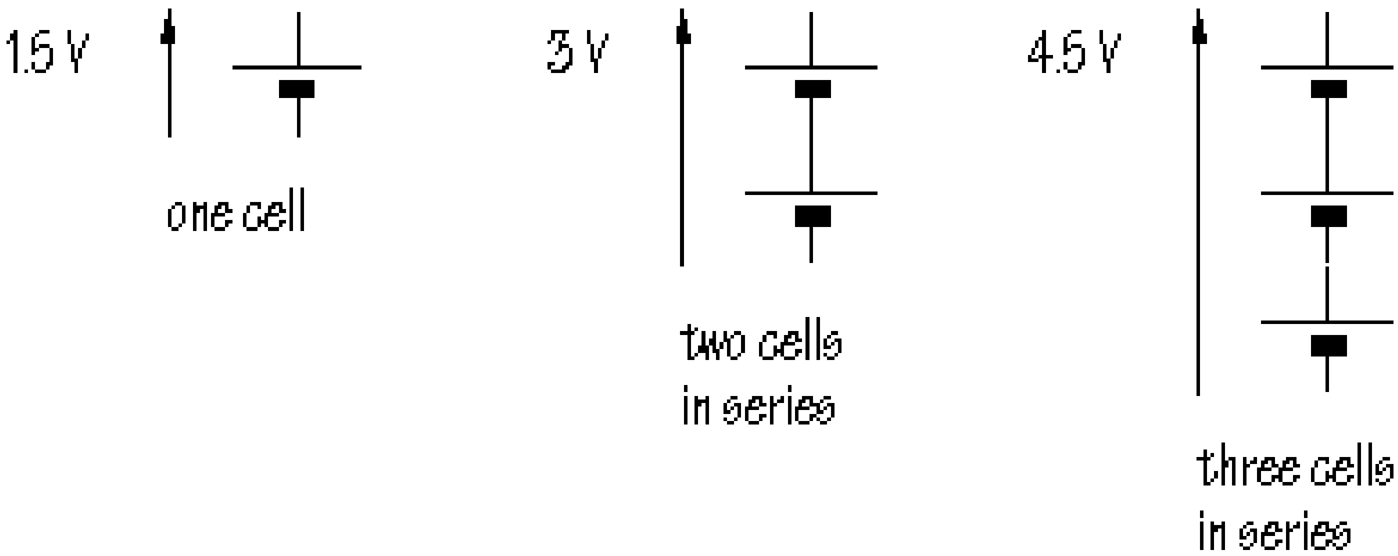
# Voltage-Water Analogy



# Voltage/Current-Water Analogy

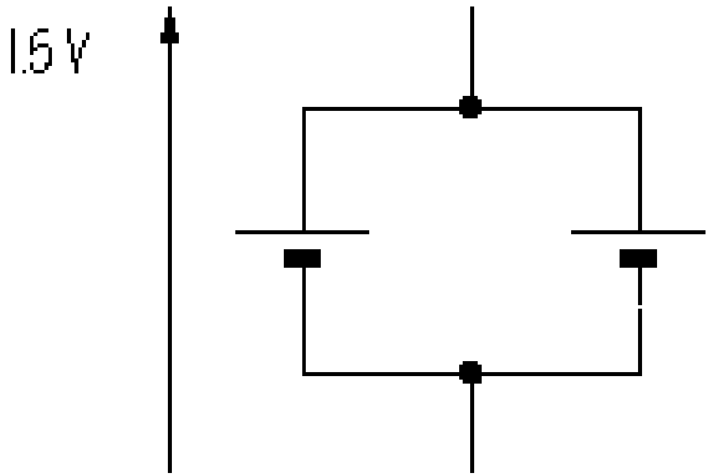


# Series Connection of Cells



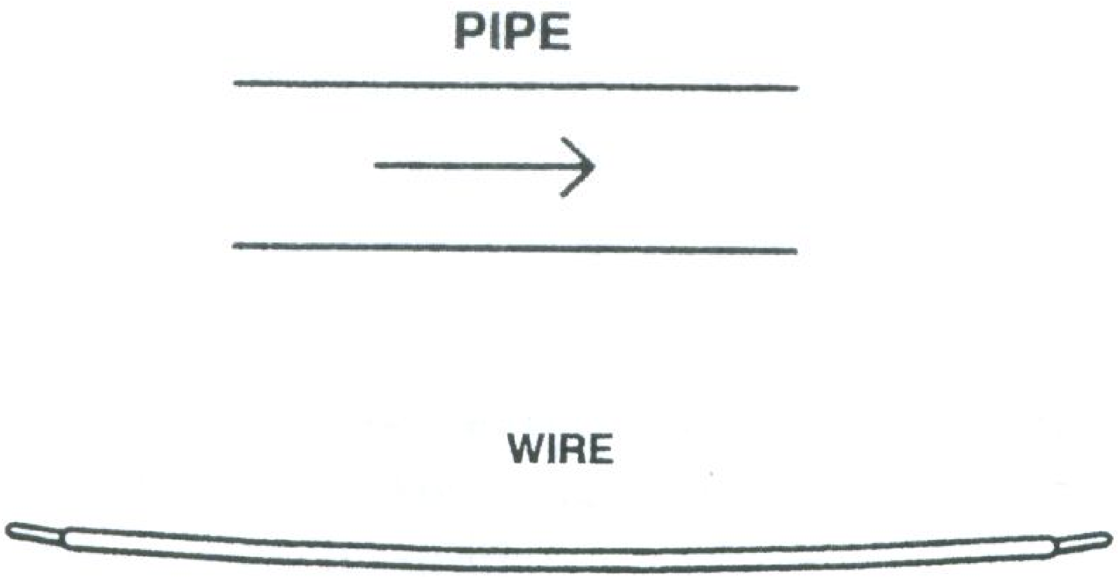

- Each cell provides 1.5 V
- Two cells connected one after another, **in series**, provide 3 V, while three cells would provide 4.5 V
- Polarities matter

# Parallel Connection of Cells



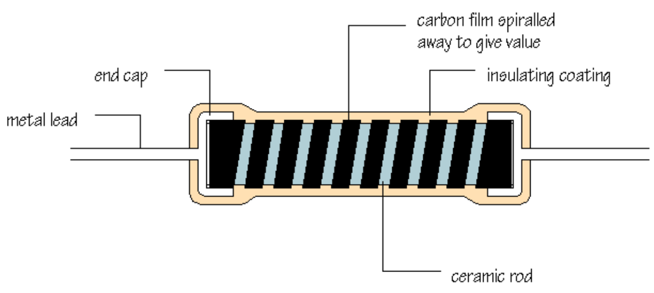

- If the cells are connected in parallel, the voltage stays at 1.5 V, but now a larger current can be drawn.

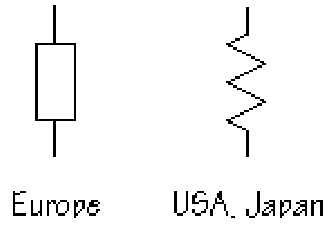
# Wire-Water Analogy



# Resistor Concept —I

- Flow of electric current through a conductor experiences a certain amount of resistance.
- The resistance, expressed in ohms ($\Omega$, named after George ohm), kilo-ohms ($k\Omega$, $1000\Omega$), or mega-ohms ($M\Omega$, $10^6\Omega$) is a measure of how much a resistor resists the flow of electricity.
- The magnitude of resistance is dictated by electric properties of the material and material geometry.
- This behavior of materials is often used to control/limit electric current flow in circuits.
- Henceforth, the conductors that exhibit the property of resisting current flow are called resistors.



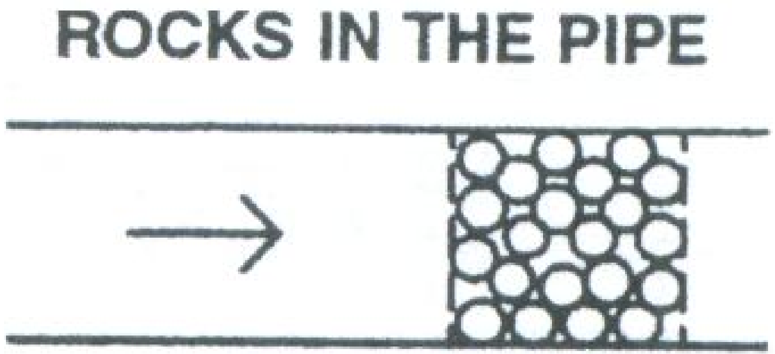



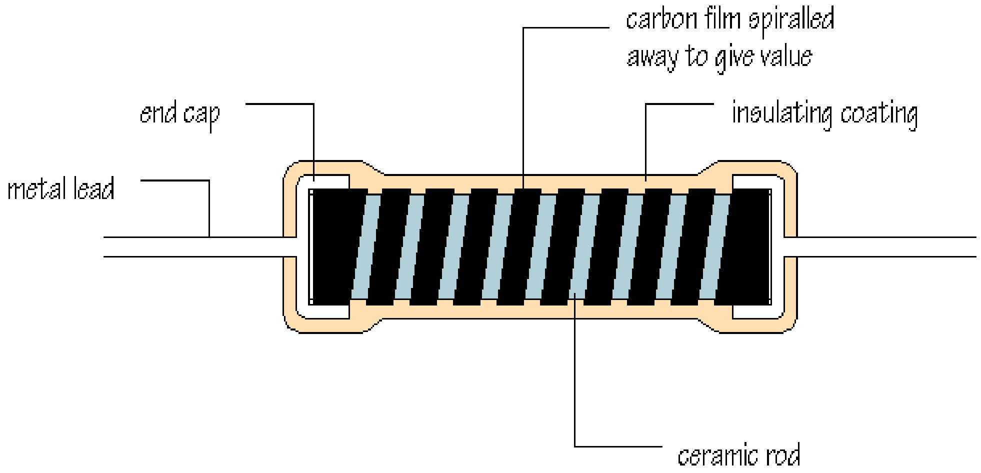

**Resistor Symbols**

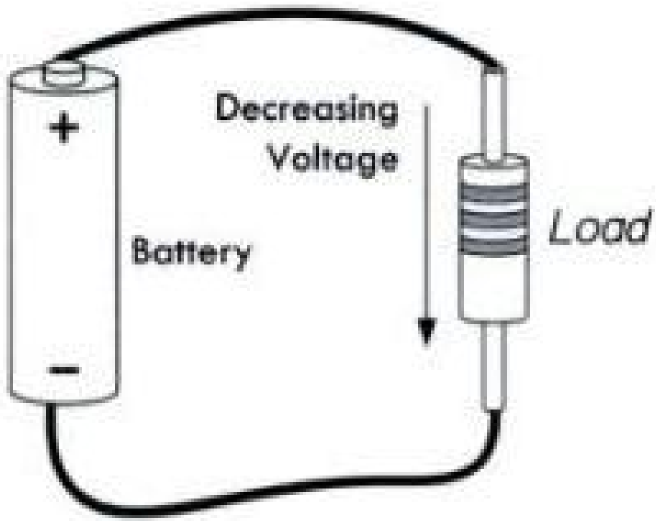
# Resistor Concept —II

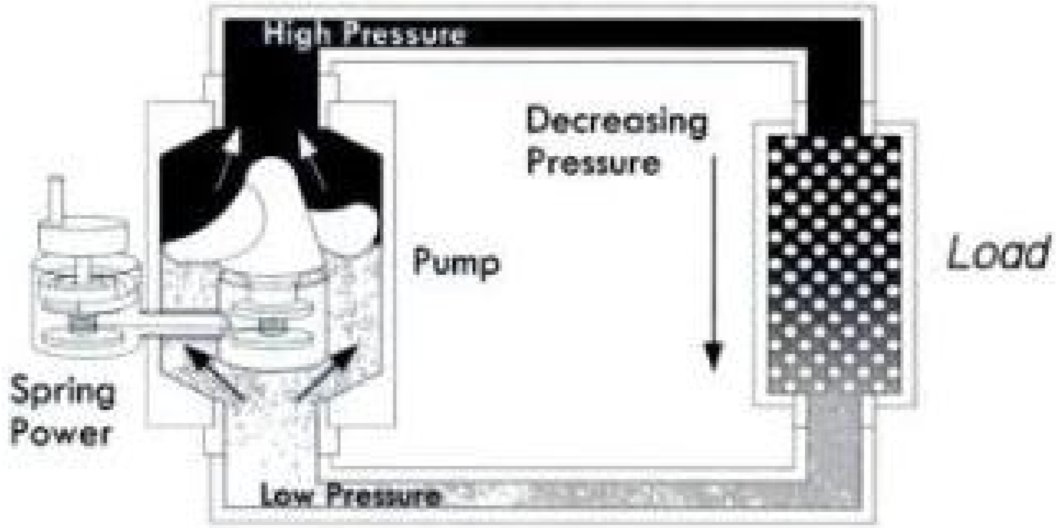
- A resistor is a dissipative element. It converts electrical energy into heat energy. It is analogous to the viscous friction element of mechanical system.
- When electrons enter at one end of a resistor, some of the electrons collide with atoms within the resistor. These atoms start vibrating and transfer their energy to neighboring air molecules. In this way, a resistor dissipates electrical energy into heat energy.
- Resistors can be thought of as analogous to water carrying pipes. Water is supplied to your home in large pipes, however, the pipes get smaller as the water reaches the final user. The pipe size limits the water flow to what you actually need.
- Electricity works in a similar manner, except that wires have so little resistance that they would have to be very very thin to limit the flow of electricity. Such thin wire would be hard to handle and break easily.

# Resistors-Water Analogy



# Resistor V-I Characteristic

- In a typical resistor, a conducting element displays linear voltage-current relationship. (i.e., current through a resistor is directly proportional to the voltage across it).

$\mathbf{I} \propto \mathbf{V}$

- Using G as a constant of proportionality, we obtain:

$$I = GV$$

- Equivalently,

$$V = RI \quad (\text{or } V = IR)$$

where R = 1/G.

  - R is termed as the resistance of conductor (ohm, $\Omega$)
  - G is termed as the conductance of conductor (mho ℧ )

# Resistor Applications

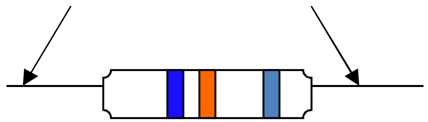
- Resistors are used for:
  - Limiting current in electric circuits.
  - Lowering voltage levels in electric circuits (using voltage divider).
  - As current provider.
  - As a sensor (e.g., photoresistor detects light condition, thermistor detects temperature condition, strain gauge detects load condition, etc.)
  - In electronic circuits, resistors are used as pull-up and pull-down elements to avoid floating signal levels.

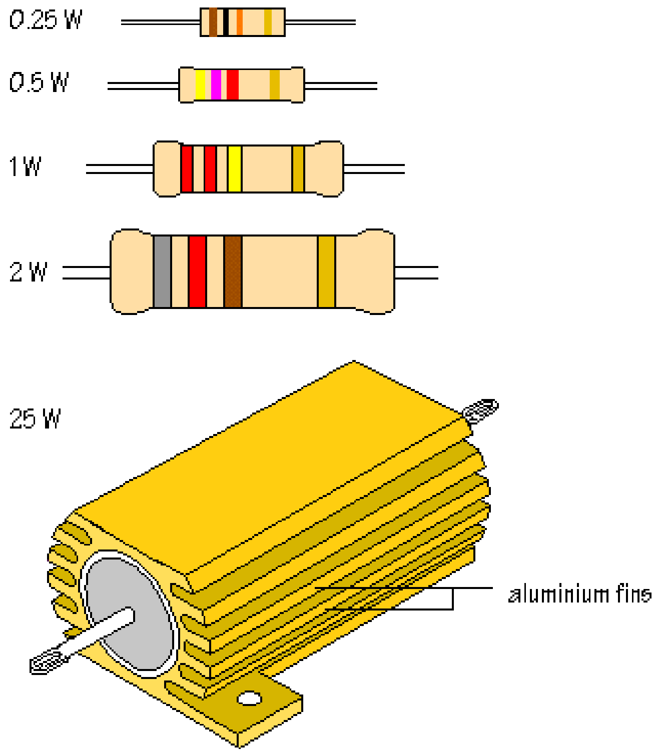
# Resistors: Power Rating and Composition

- It is very important to be aware of power rating of resistor used in circuits and to make sure that this limit is not violated. A higher power rating resistor can dissipate more energy that a lower power rating resistor.
- Resistors can be made of**:**
  - Carbon film (decomposition of carbon film on a ceramic core).
  - Carbon composition (carbon powder and glue-like binder).
  - Metal oxide (ceramic core coated with metal oxide).
  - Precision metal film.
  - High power wire wound.

# Resistor Examples

Symbol for resistor

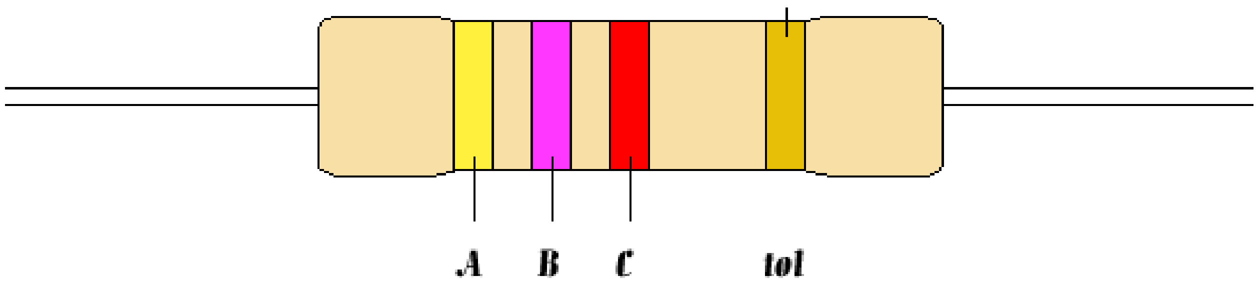



# Resistor Labels

- Wire-wound resistors have a label indicating resistance and power ratings.
- A majority of resistors have color bars to indicate their resistance magnitude.
- There are usually 4 to 6 bands of color on a resistor. As shown in the figure below, the right most color bar indicates the resistor reliability, however, some resistor use this bar to indicate the tolerance. The color bar immediately left to the tolerance bar (C), indicates the multipliers (in tens). To the left of the multiplier bar are the digits, starting from the last digit to the first digit.

$$\text{Resistor value} = AB \times 10^{C} \pm tol\%(\Omega)$$

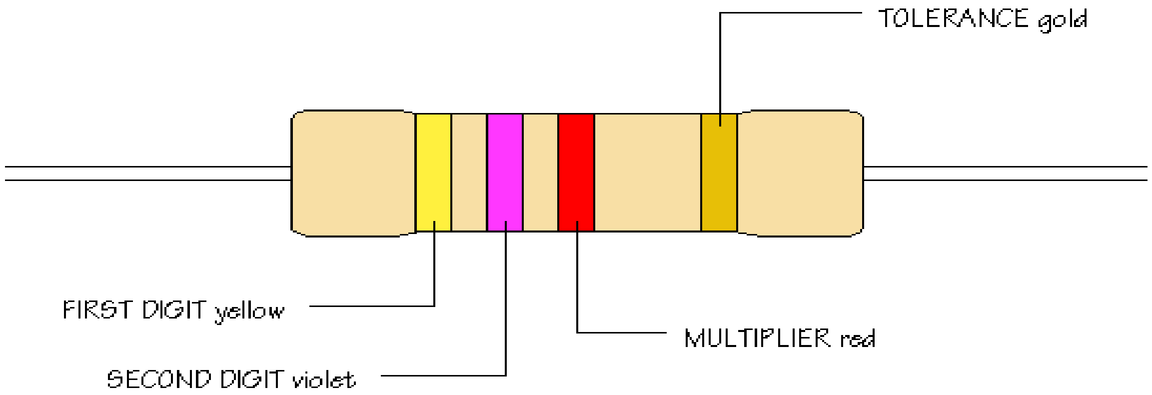


# Resistor Color Codes

| Color | Tolerance |
|---|---|
| Brown | ±1% |
| Red | ±2% |
| Gold | ±5% |
| Silver | ±10% |
| None | ±20% |

| Band color | Digit | Multiplier |
|---|---|---|
| Black | 0 | X1 |
| Brown | 1 | X10 |
| Red | 2 | X100 |
| Orange | 3 | X1000 |
| Yellow | 4 | X10000 |
| Green | 5 | X100000 |
| Blue | 6 | X1000000 |
| Purple | 7 | X10000000 |
| Grey | 8 | X100000000 |
| White | 9 | X1000000000 |
| Silver | - | x.01 |
| Gold | - | x.1 |

# Example

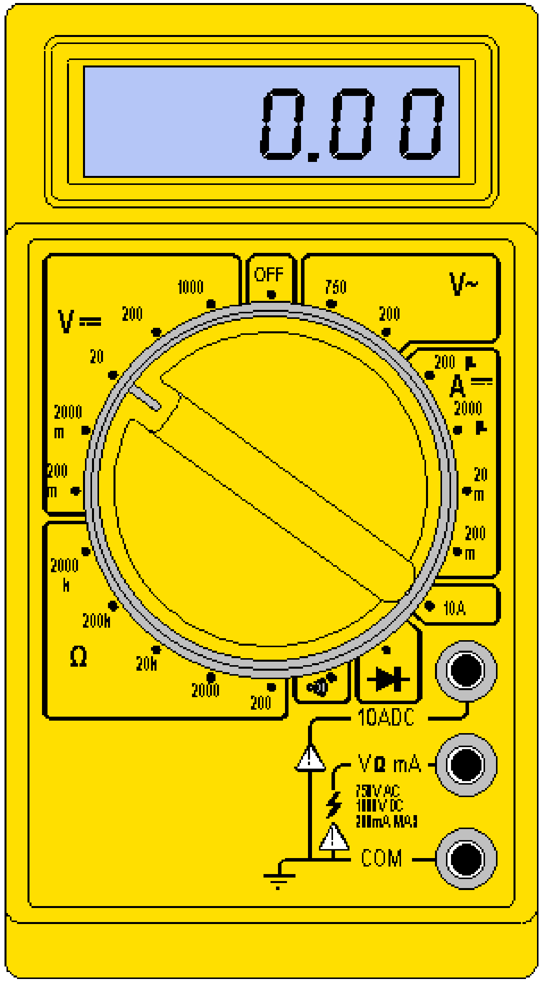



- The first band is yellow, so the first digit is 4
- The second band is violet, so the second digit is 7
- The third band is red, so the multiplier is $10^2$
- Resistor value is $47 \times 10^2 \pm 5\% (\Omega)$

# Metric Units and Conversions

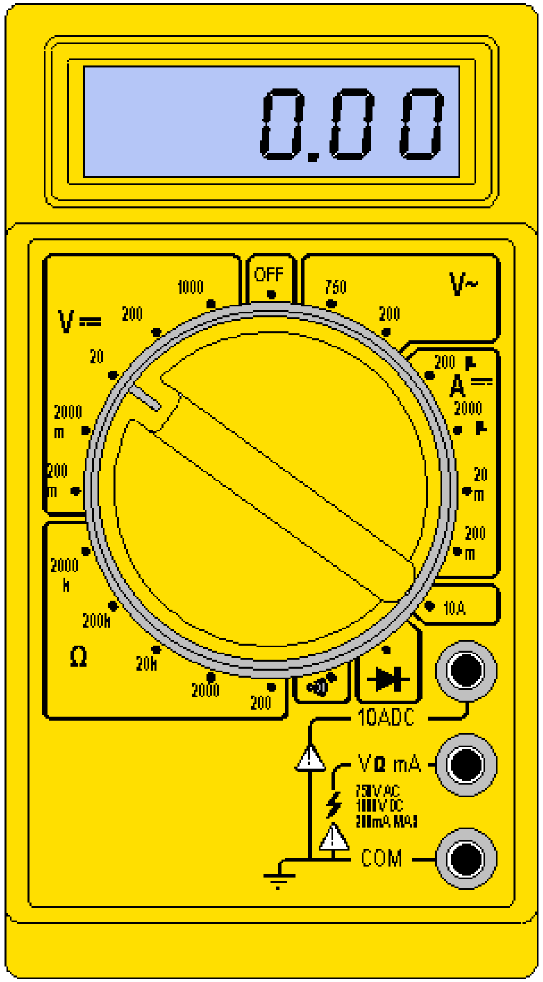
| Abbreviation | Means | Multiply unit by | Or |
|---|---|---|---|
| p | pico | .000000000001 | $10^{-12}$ |
| n | nano | .000000001 | $10^{-9}$ |
| µ | micro | .000001 | $10^{-6}$ |
| m | milli | .001 | $10^{-3}$ |
| . | Unit | 1 | $10^{0}$ |
| k | kilo | 1,000 | $10^{3}$ |
| M | mega | 1,000,000 | $10^{6}$ |
| G | giga | 1,000,000,000 | $10^{9}$ |

# Digital Multimeter 1



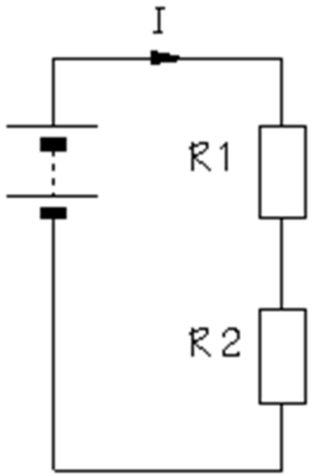

- DMM is a measuring instrument
- An **ammeter** measures current
- A **voltmeter** measures the potential difference (voltage) between two points
- An **ohmmeter** measures resistance
- A **multimeter** combines these functions, and possibly some additional ones as well, into a single instrument

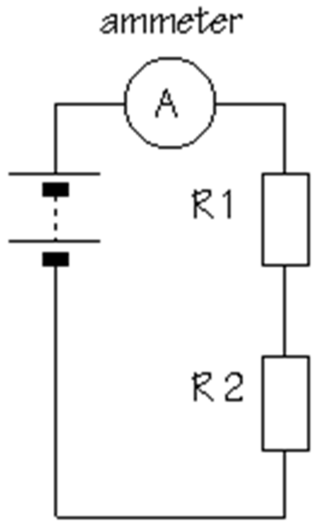
# Digital Multimeter 2




- Voltmeter
  - Parallel connection
- Ammeter
  - Series connection
- Ohmmeter
  - Without any power supplied
- Adjust range (start from highest limit if you don’t know)

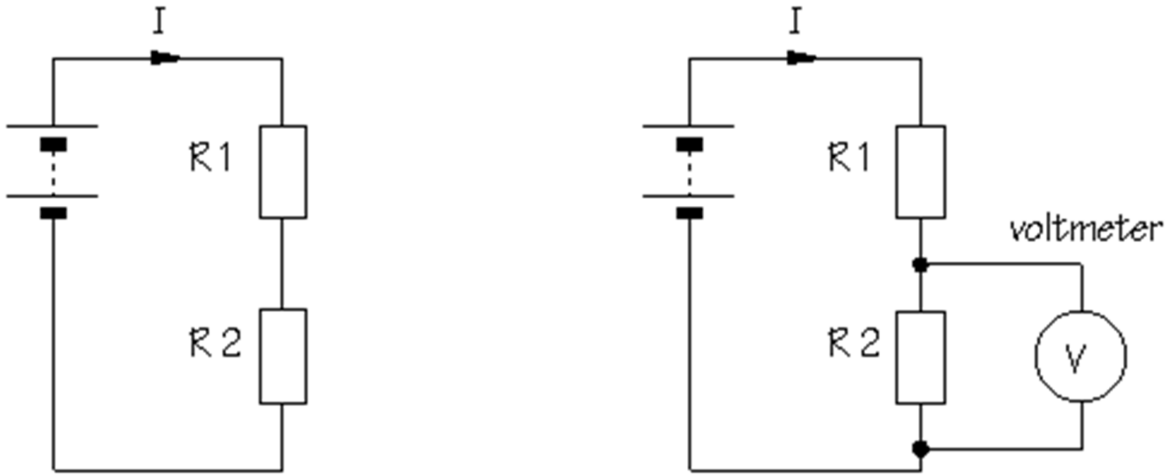
# Ammeter Connection



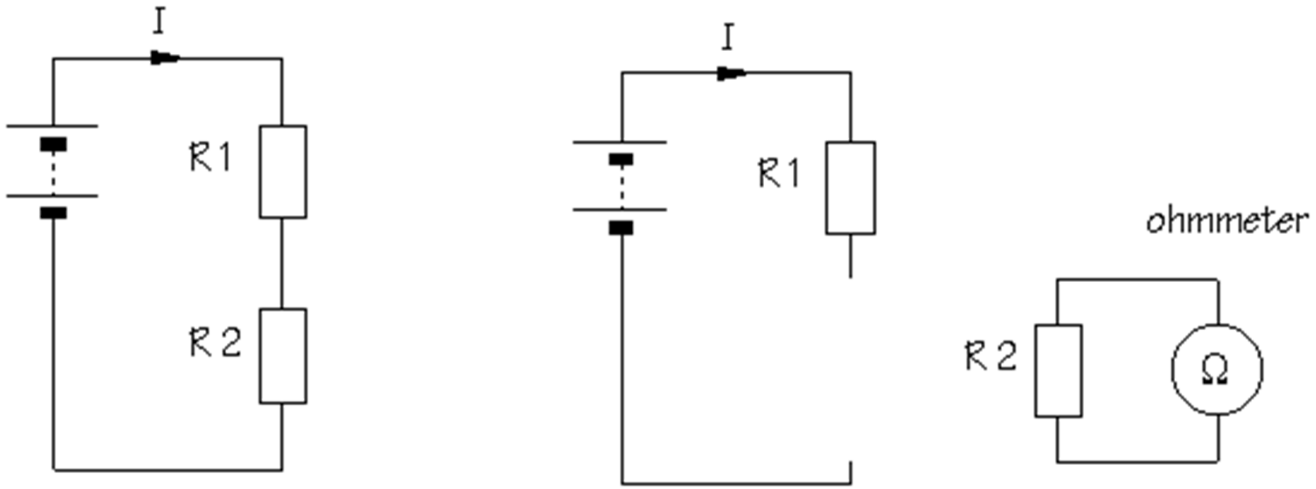

- Break the circuit so that the ammeter can be connected in series
- All the current flowing in the circuit must pass through the ammeter
- An ammeter must have a very LOW input impedance

# Voltmeter Connection



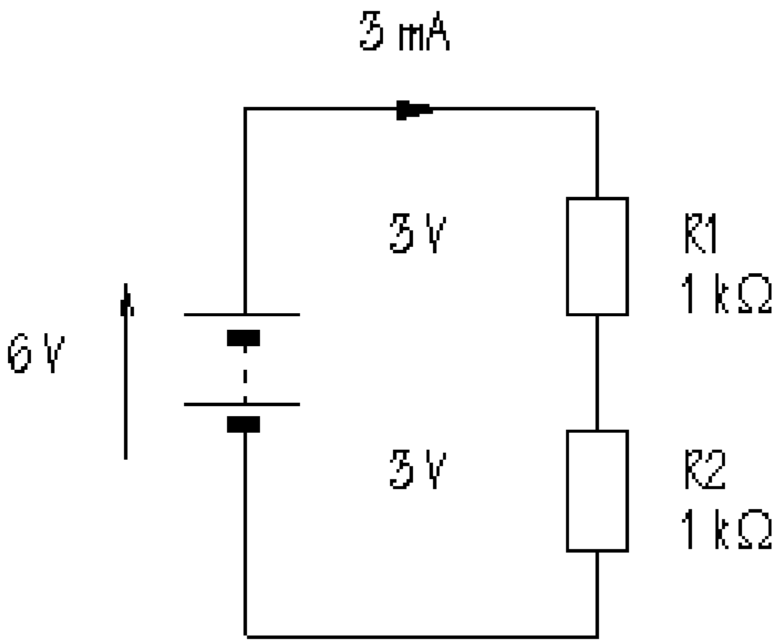

- The voltmeter is connected in parallel between two points of circuit
- A voltmeter should have a very HIGH input impedance

# Ohmmeter Connection




- An ohmmeter does not function with a circuit connected to a power supply
- Must take it out of the circuit altogether and test it separately

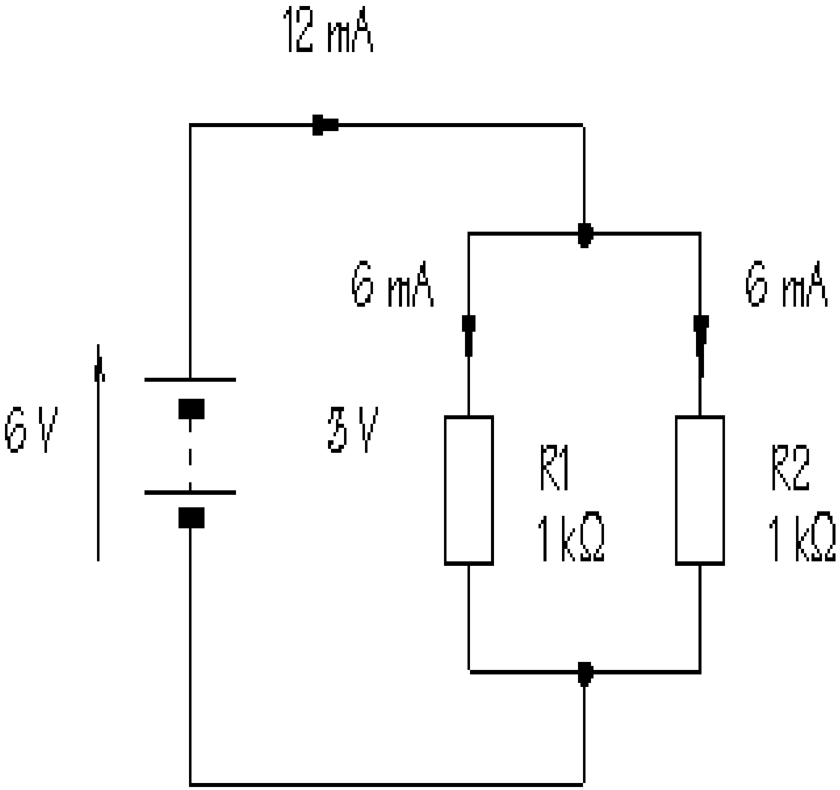
# Resistors in Series




$R_{total}=R_1+R_2$

$R_{total}=1+1=2k\Omega$

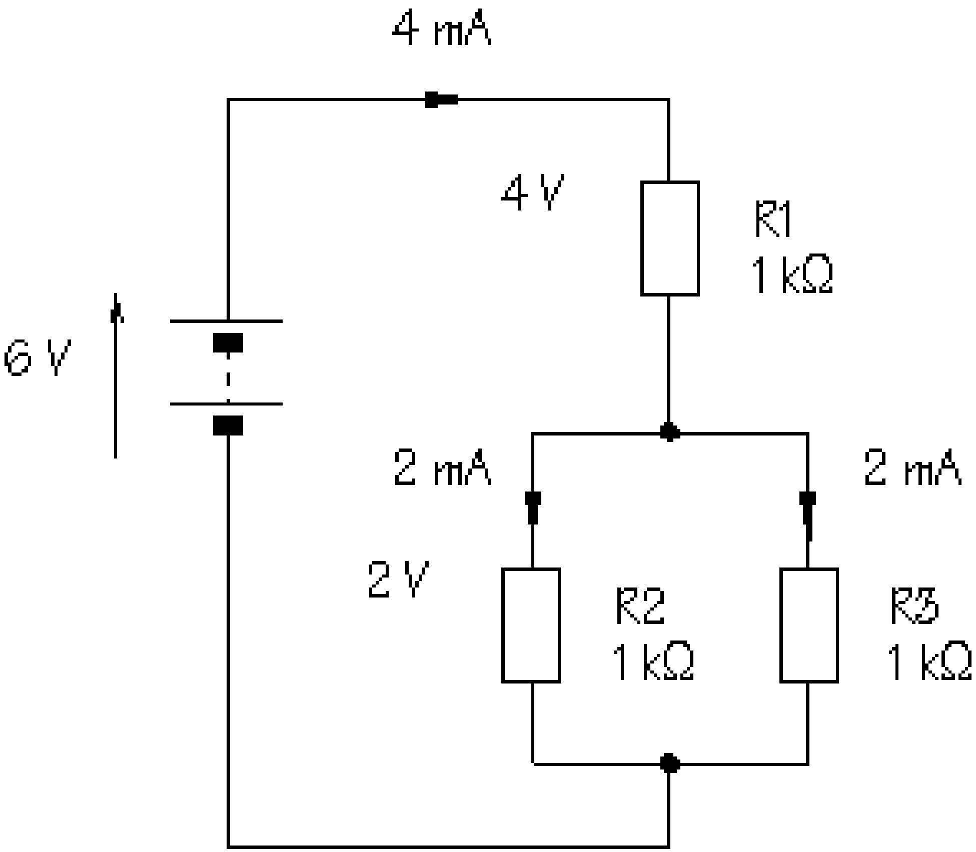
# Resistors in Parallel




$$R_{total} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_{total} = \frac{1 \times 1}{1 + 1} = \frac{1}{2} = 0.5 k\Omega$$

# Exercise 1

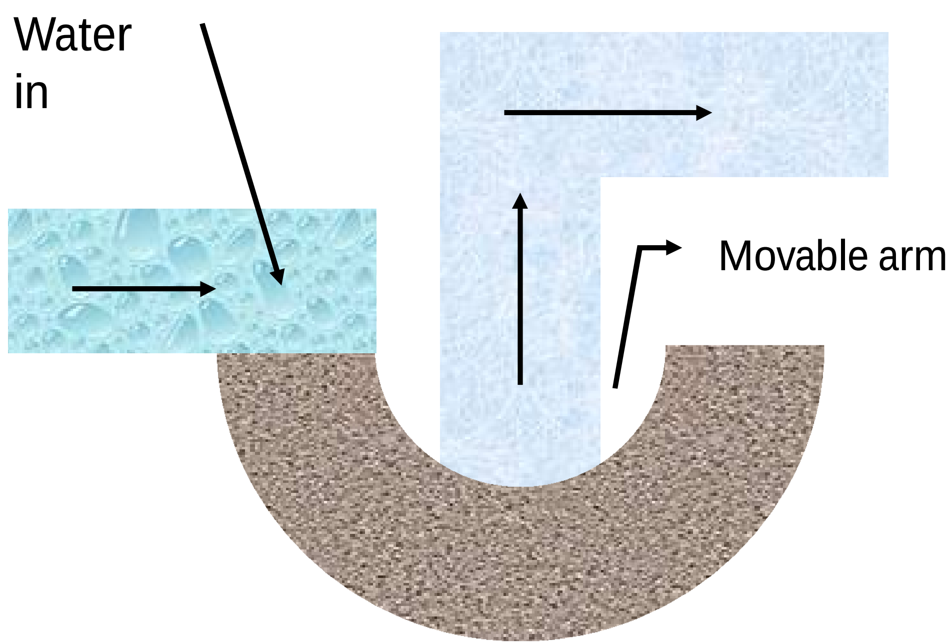



$$R_{total} = R_1 + \frac{R_2 \times R_3}{R_2 + R_3}$$

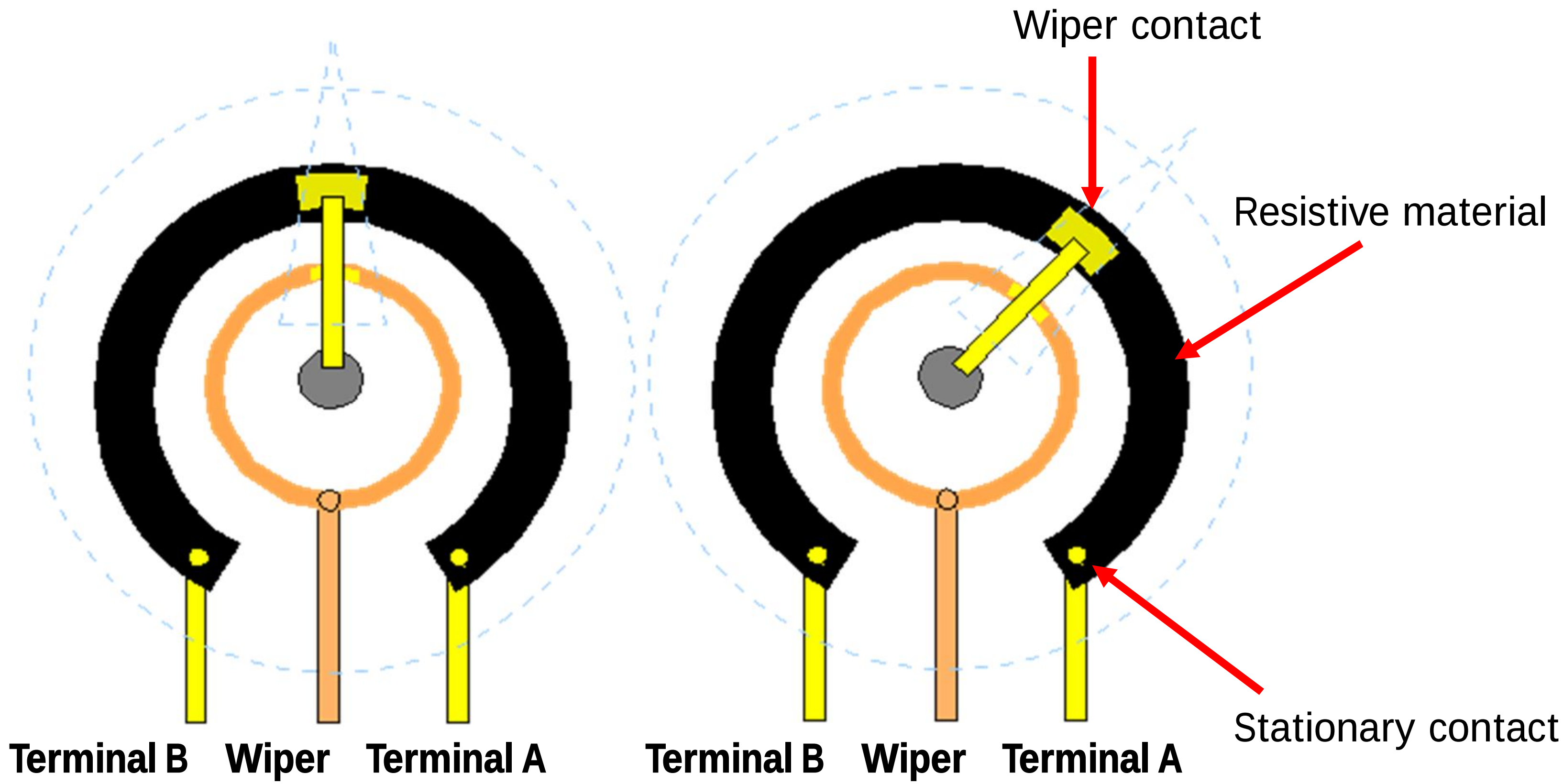
$$R_{total} = 1 + \frac{1 \times 1}{1+1} = \frac{3}{2} = 1.5k\Omega$$

# Variable Resistor Concept

- In electrical circuit, a switch is used to turn the electricity on and off just like a valve is used to turn the water on and off.
- There are times when you want some water but don't need all the water that the pipe can deliver, so you control water flow by adjusting the faucet.
- Unfortunately, you can't adjust the thickness of an already thin wire.
- Notice, however, that you can control the water flow by forcing the water through an adjustable length of rocks, as shown to the right.



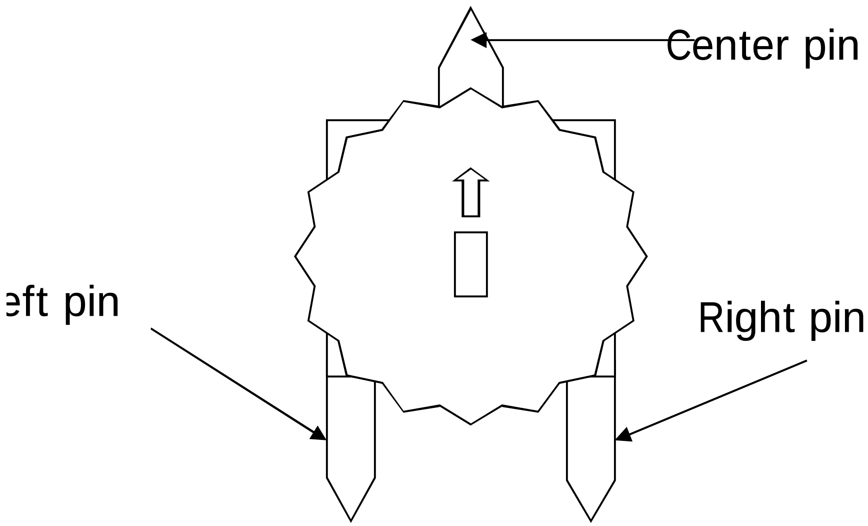
# Variable Resistor Construction



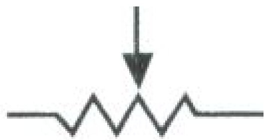

- To vary the resistance in an electrical circuit, we use a variable resistor.
- This is a normal resistor with an additional arm contact that can move along the resistive material and tap off the desired resistance.

# Variable Resistor Operation

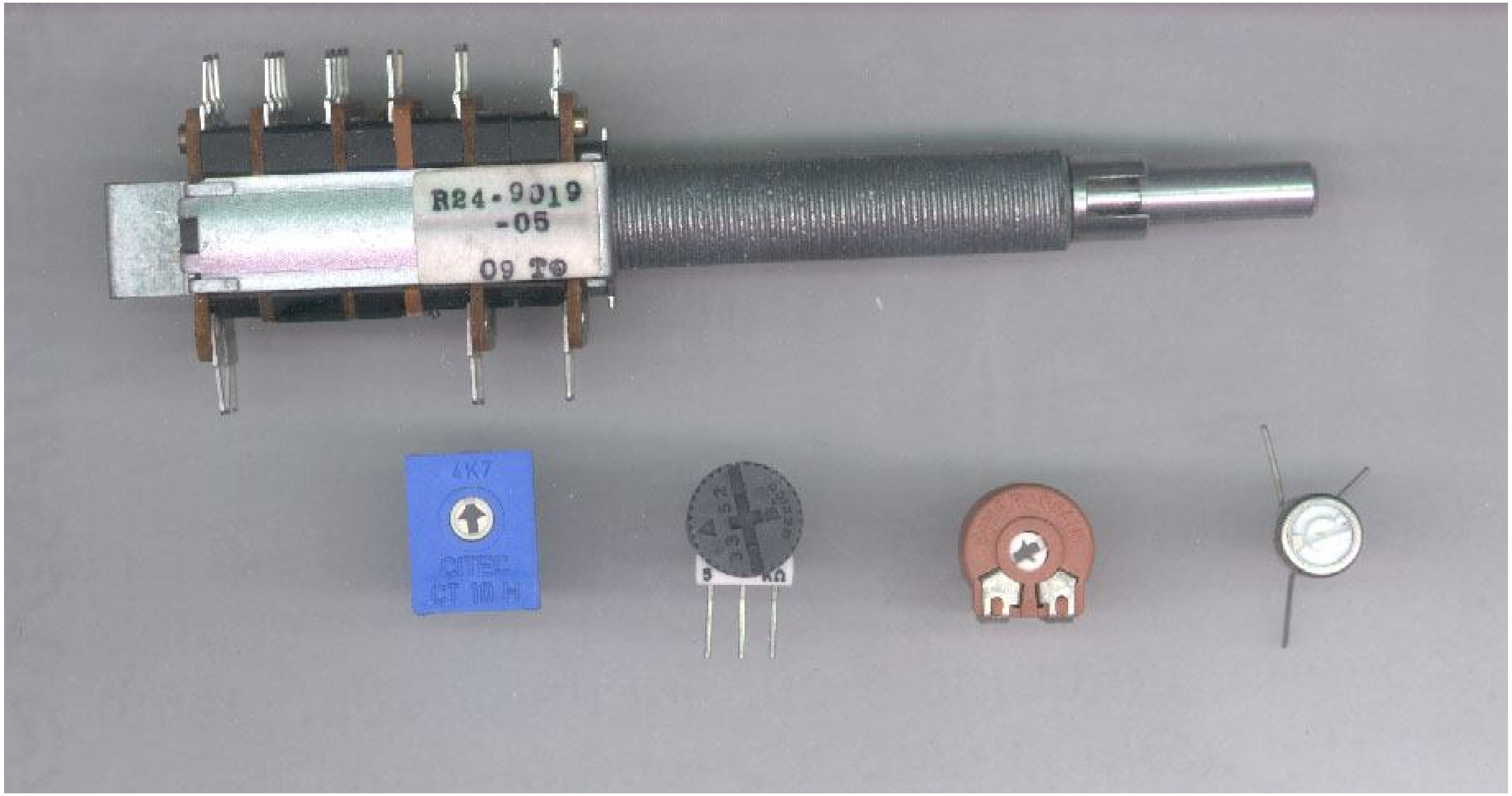
- The dial on the variable resistor moves the arm contact and sets the resistance between the left and center pins. The remaining resistance of the part is between the center and right pins.
- For example, when the dial is turned fully to the left, there is minimal resistance between the left and center pins (usually 0Ω) and maximum resistance between the center and right pins. The resistance between the left and right pins will always be the total resistance.




Symbol for variable resistor

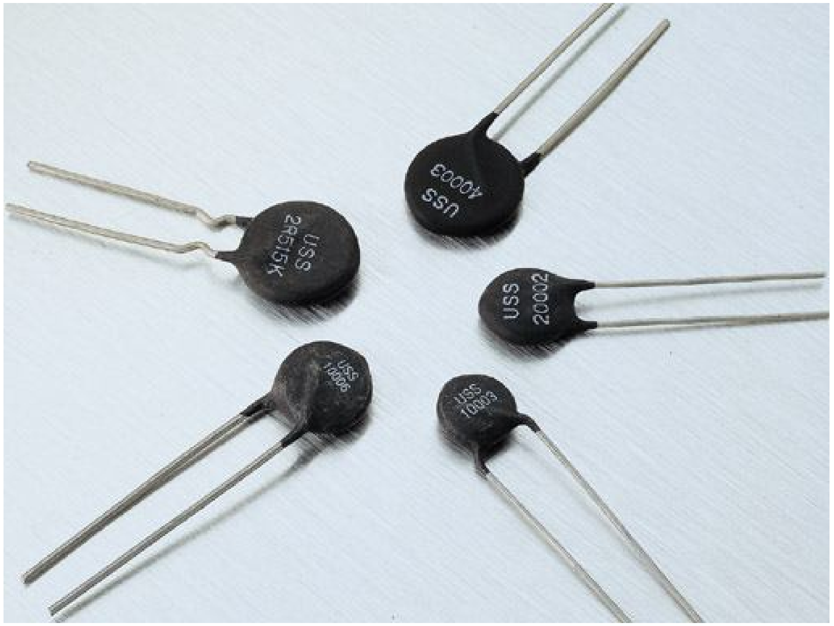


# Variable Resistor: Rotary Potentiometers



# Variable Resistor: Other Examples

Photoresistor




Thermistor

# Resistance Formula

- For a resistor made using a homogenous material

$$R = \frac{\rho L}{A}$$

where

$\rho$ = specific resistance of material (material property)

L = length of conductor used to make the resistor

A = cross-section area of conductor used to make the resistor