Chapter 3

Ohm's Law

Topics Covered in Chapter 3

3-1: The Current $I = V/R$

3-2: The Voltage $V = IR$

3-3: The Resistance $R = V/I$

3-4: Practical Units

3-5: Multiple and Submultiple Units

Topics Covered in Chapter 3

- 3-6: The Linear Proportion between *V* and *I*
- 3-7: Electric Power
- 3-8: Power Dissipation in Resistance
- 3-9: Power Formulas
- 3-10: Choosing a Resistor for a Circuit
- 3-11: Electric Shock
- 3-12: Open-Circuit and Short-Circuit Troubles

3-1—3-3: Ohm's Law Formulas

- There are three forms of Ohm's Law:
  - $I = V/R$
  - $V = IR$
  - $R = V/I$
- where:
  - I = Current
  - V = Voltage
  - R = Resistance

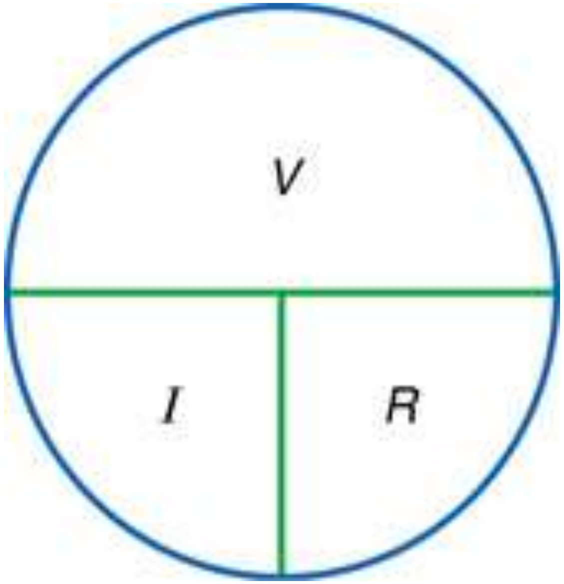


Fig. 3-4: A circle diagram to help in memorizing the Ohm's Law formulas V = IR, $I = V/R$, and $R = V/I$. The V is always at the top.

3-1: The Current *I* = *V*/*R*

- *I* = *V*/*R*
- In practical units, this law may be stated as:
  - amperes = volts / ohms

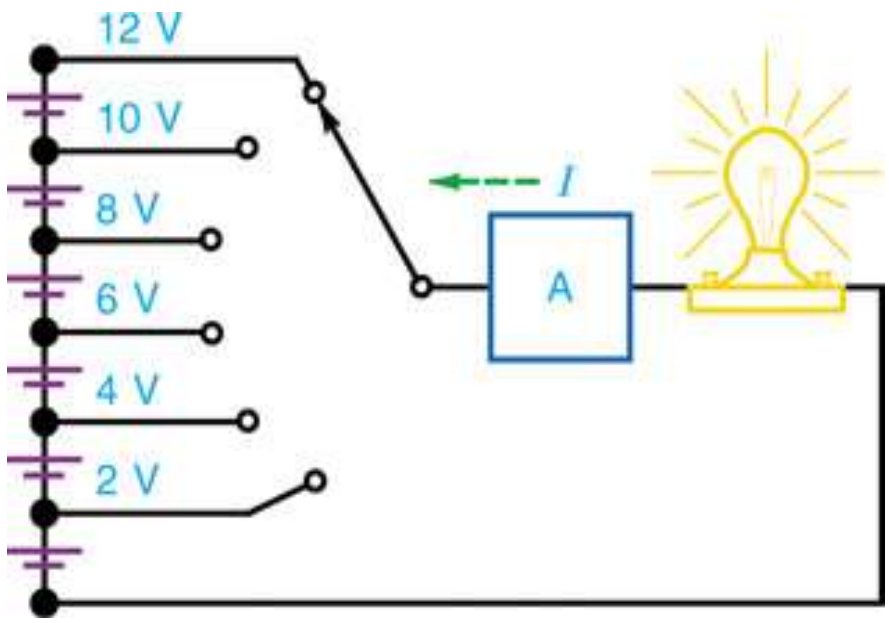


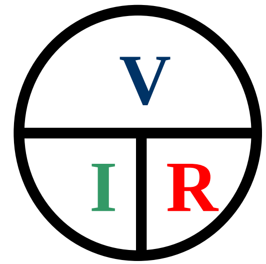
Fig. 3-1: Increasing the applied voltage *V* produces more current *I* to light the bulb with more intensity.

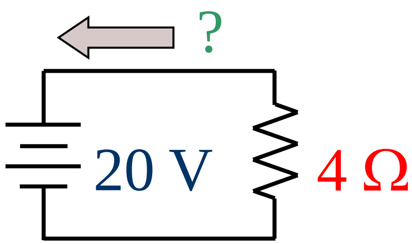
3-4: Practical Units

- The three forms of Ohm’s law can be used to define the practical units of current, voltage, and resistance:
  - 1 ampere = 1 volt / 1 ohm
  - 1 volt = 1 ampere × 1 ohm
  - 1 ohm = 1 volt / 1 ampere

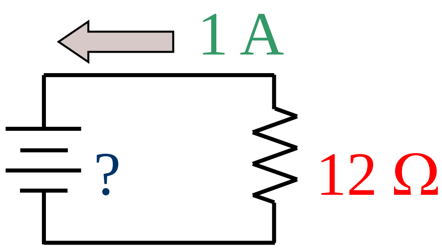
3-4: Practical Units

Applying Ohm's Law

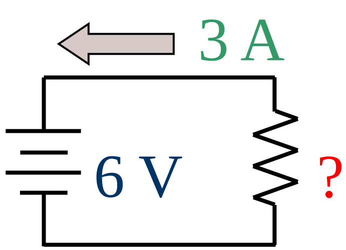




$$I = \frac{20\ \text{V}}{4\ \Omega} = 5\ \text{A}$$



$$V = 1\text{A} \times 12\ \Omega = 12\ \text{V}$$



$$R = \frac{6\ \text{V}}{3\ \text{A}} = 2\ \Omega$$

3-5: Multiple and Submultiple Units

- Units of Voltage
  - The basic unit of voltage is the **volt (V).**
    - Multiple units of voltage are:
      - **kilovolt (kV)**
        1 thousand volts or 10^3 V
      - **megavolt (MV)**
        1 million volts or 10^6 V
    - Submultiple units of voltage are:
      - **millivolt (mV)**
        1-thousandth of a volt or 10^{-3} V
      - **microvolt (μV)**
        1-millionth of a volt or 10^{-6} V

3-5: Multiple and Submultiple Units

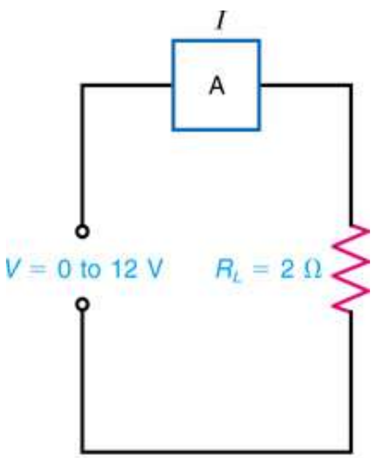
- **Units of Current**
  - The basic unit of current is the **ampere (A).**
  - Submultiple units of current are:
    - **milliampere (mA)**
      1-thousandth of an ampere or 10^{-3} A
    - **microampere (μA)**
      1-millionth of an ampere or 10^{-6} A

3-5: Multiple and Submultiple Units

- Units of Resistance
  - The basic unit of resistance is the **Ohm (Ω).**
  - Multiple units of resistance are:
    - **kilohm (kW)**
      1 thousand ohms or 10^3 Ω
    - **Megohm (MW)**
      1 million ohms or 10^6 Ω

3-6: The Linear Proportion between *V* and *I*

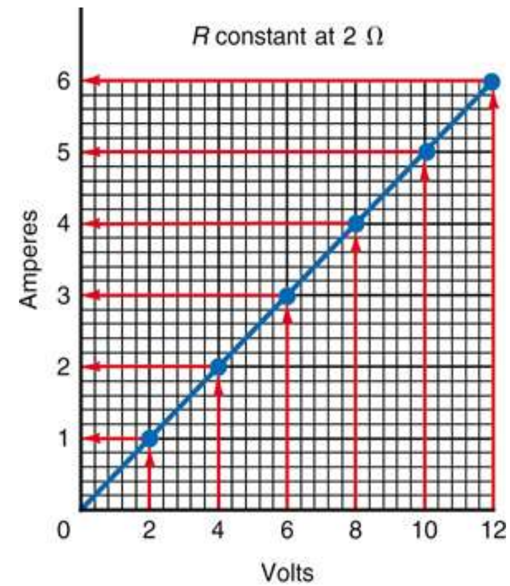
- The Ohm's Law formula $I = V/R$ states that *V* and *I* are directly proportional for any one value of *R.*



(*a*)

Volts V	Ohms Ω	Amperes A
0	2	0
2	2	1
4	2	2
6	2	3
8	2	4
10	2	5
12	2	6

(*b*)



(*c*)

Fig. 3.5: Experiment to show that *I* increases in direct proportion to *V* with the same *R*. (*a*) Circuit with variable *V* but constant *R*. (*b*) Table of increasing *I* for higher *V.* (*c*) Graph of *V* and *I* values. This is a linear volt-ampere characteristic. It shows a direct proportion between *V* and *I.*

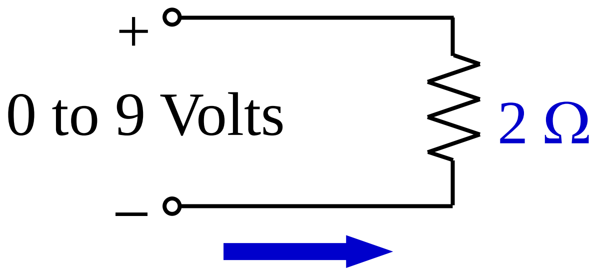
3-6: The Linear Proportion between *V* and *I*

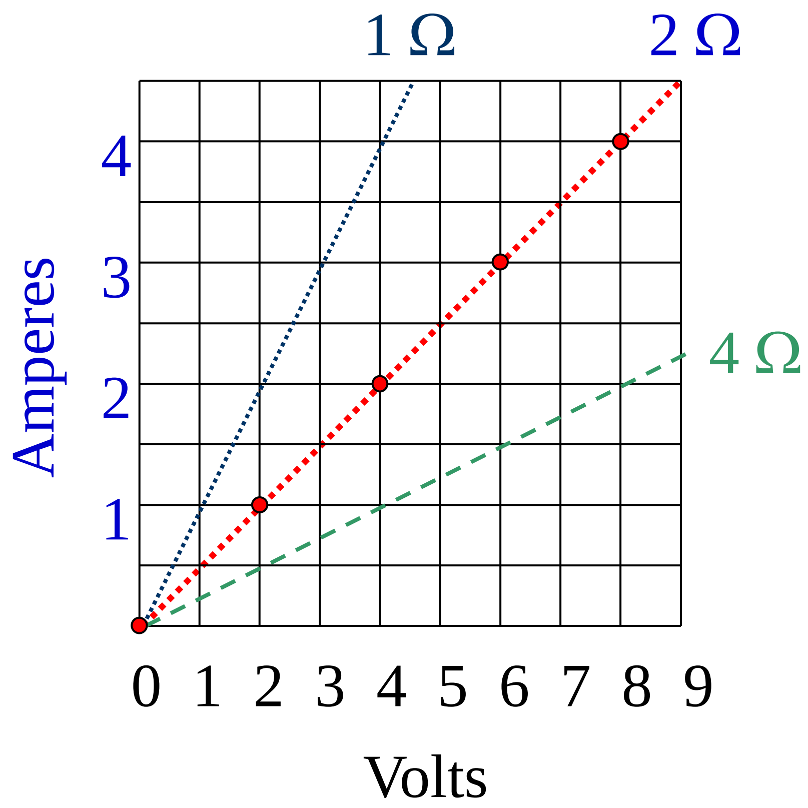
- When V is constant:
  - *I* decreases as *R* increases.
  - *I* increases as *R* decreases.
- Examples:
  - If *R* doubles, *I* is reduced by half.
  - If *R* is reduced to ¼, *I* increases by 4.
  - This is known as an *inverse relationship*.

3-6: The Linear Proportion between *V* and *I*

- Linear Resistance
  - A linear resistance has a constant value of ohms. Its *R* does not change with the applied voltage, so *V* and *I* are directly proportional.
  - Carbon-film and metal-film resistors are examples of linear resistors.

3-6: The Linear Proportion between *V* and *I*

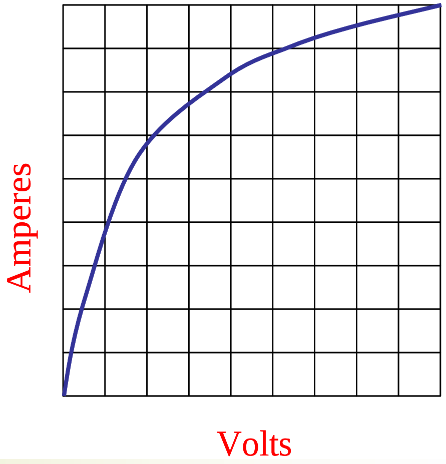




The smaller the resistor, the steeper the slope.

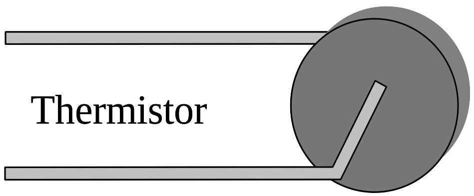
3-6: The Linear Proportion between *V* and *I*

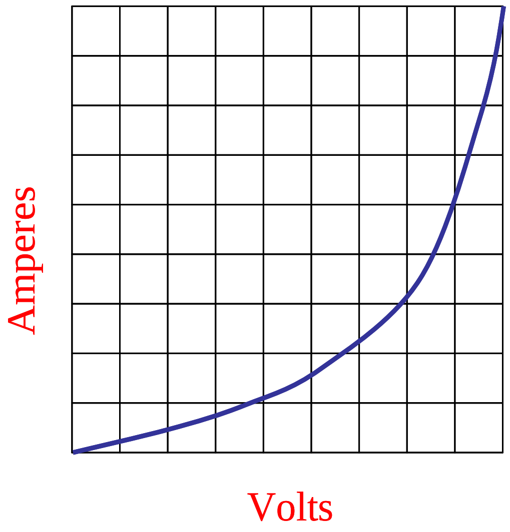
- Nonlinear Resistance
  - In a nonlinear resistance, increasing the applied *V* produces more current, but *I* does not increase in the same proportion as the increase in *V*.
  - Example of a Nonlinear Volt–Ampere Relationship:
    - As the tungsten filament in a light bulb gets hot, its resistance increases.



3-6: The Linear Proportion between *V* and *I*

- Another nonlinear resistance is a **thermistor.**
- A thermistor is a resistor whose resistance value changes with its operating temperature.
- As an **NTC (negative temperature coefficient)** thermistor gets hot, its resistance decreases.





3-7: Electric Power

- The basic unit of power is the watt (W).
  - Multiple units of power are:
    - **kilowatt (kW):**
      1000 watts or 10^3 W
    - **megawatt (MW):**
      1 million watts or 10^6 W
  - Submultiple units of power are:
    - **milliwatt (mW):**
      1-thousandth of a watt or 10^{-3} W
    - **microwatt (μW):**
      1-millionth of a watt or 10^{-6} W

3-7: Electric Power

- Work and energy are basically the same, with identical units.

- Power is different. It is the time rate of doing work.
  - Power = work / time.
  - Work = power × time.

3-7: Electric Power

- Practical Units of Power and Work:
  - The rate at which work is done (power) equals the product of voltage and current. This is derived as follows:
  - First, recall that:

$$1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}} \quad \text{and} \quad 1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

3-7: Electric Power

Power = Volts × Amps, or

$$P = V \times I$$

$$\text{Power (1 watt)} = \frac{1\text{ joule}}{1\text{ coulomb}} \times \frac{1\text{ coulomb}}{1\text{ second}} = \frac{1\text{ joule}}{1\text{ second}}$$

3-7: Electric Power

- Kilowatt Hours
  - The kilowatt hour (kWh) is a unit commonly used for large amounts of electrical work or energy.
  - For example, electric bills are calculated in kilowatt hours. The kilowatt hour is the billing unit.
  - The amount of work (energy) can be found by multiplying power (in kilowatts) × time in hours.

3-7: Electric Power

To calculate electric cost, start with the power:

- An air conditioner operates at 240 volts and 20 amperes.
- The power is $P = V \times I = 240 \times 20 = 4800$ watts.
  - Convert to kilowatts:

    4800 watts = 4.8 kilowatts
  - Multiply by hours: (Assume it runs half the day)

    energy = 4.8 kW × 12 hours = 57.6 kWh
  - Multiply by rate: (Assume a rate of $0.08/ kWh)

    cost = 57.6 × $0.08 = $4.61 per day

3-8: Power Dissipation in Resistance

- When current flows in a resistance, heat is produced from the friction between the moving free electrons and the atoms obstructing their path.

- Heat is evidence that power is used in producing current.

3-8: Power Dissipation in Resistance

- The amount of power dissipated in a resistance may be calculated using any one of three formulas, depending on which factors are known:
  - $P = I^2 \times R$
  - $P = V^2 / R$
  - $P = V \times I$

3-9: Power Formulas

There are three basic power formulas, but each can be in three forms for nine combinations.

$$P = VI$$

$$I = \frac{P}{V}$$

$$V = \frac{P}{I}$$

$$P = I^2R$$

$$R = \frac{P}{I^2}$$

$$I = \sqrt{\frac{P}{R}}$$

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P}$$

$$V = \sqrt{PR}$$

Where:

P = Power V = Voltage I = Current R=Resistance

3-9: Power Formulas

- Combining Ohm's Law and the Power Formula
  - All nine power formulas are based on Ohm's Law.

$$V = IR$$

$$I = \frac{V}{R}$$

$$P = VI$$

  - Substitute *IR* for *V* to obtain:
    - $P = VI$
    - $= (IR)I$
    - $= I^2R$

3-9: Power Formulas

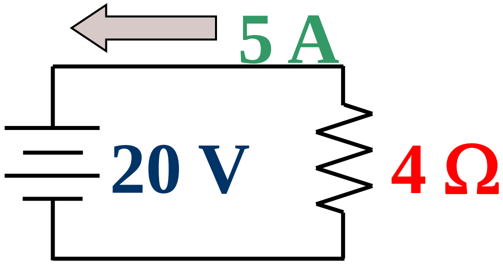
- Combining Ohm's Law and the Power Formula
  - Substitute *V/R* for *I* to obtain:
    - $P = VI$

      $= V \times V / R$

      $= V^2 / R$

3-9: Power Formulas

- Applying Power Formulas:



$$P = VI = 20 \times 5 = 100 \text{ W}$$

$$P = I^2R = 25 \times 4 = 100 \text{ W}$$

$$P = \frac{V^2}{R} = \frac{400}{4} = 100 \text{ W}$$

3-10: Choosing a Resistor for a Circuit

- Follow these steps when choosing a resistor for a circuit:
  - Determine the required resistance value as $R = V / I$.
  - Calculate the power dissipated by the resistor using any of the power formulas.
  - Select a wattage rating for the resistor that will provide an adequate cushion between the actual power dissipation and the resistor's power rating.

3-10: Choosing a Resistor for a Circuit

- Maximum Working Voltage Rating
  - A resistor's maximum working voltage rating is the maximum voltage a resistor can withstand without internal arcing.
  - The higher the wattage rating of the resistor, the higher the maximum working voltage rating.

3-10: Choosing a Resistor for a Circuit

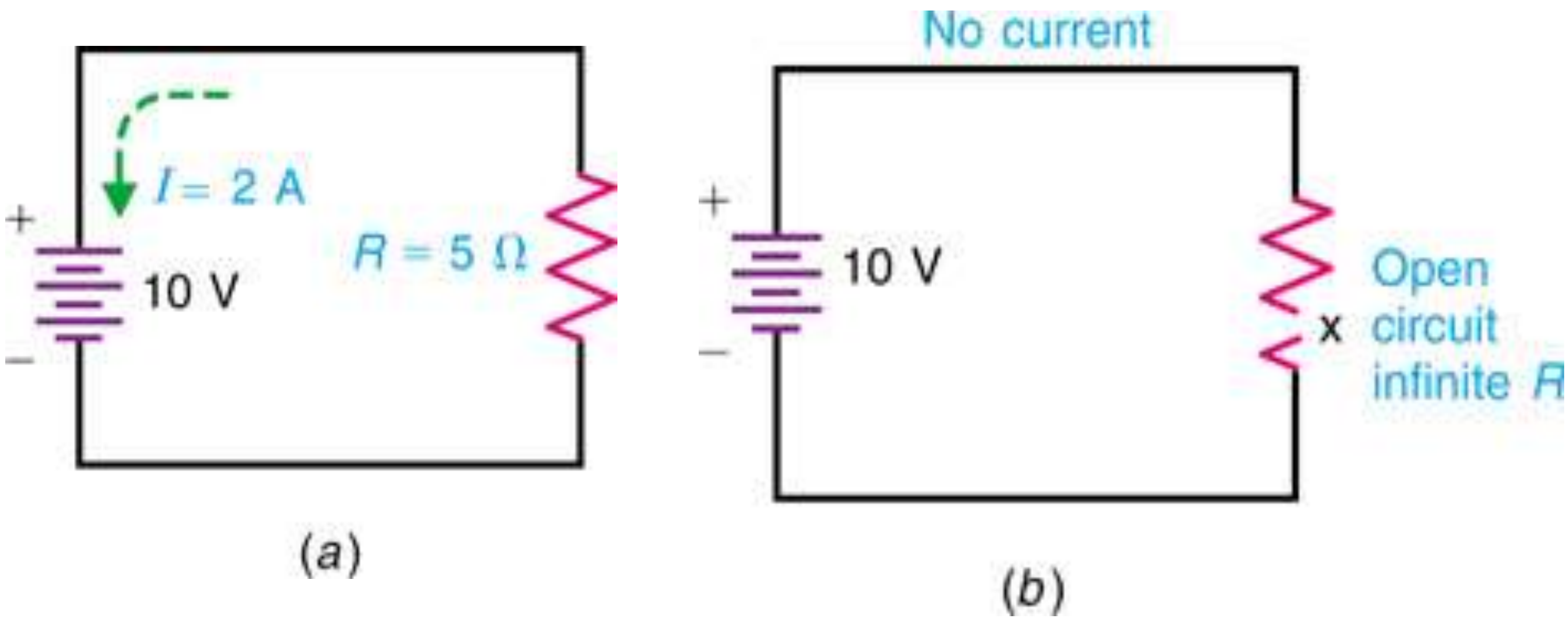
- Maximum Working Voltage Rating
  - With very large resistance values, the maximum working voltage rating may be exceeded before the power rating is exceeded.
  - For any resistor, the maximum voltage which produces the rated power dissipation is:
    - $V_{max} = \sqrt{P_{rating} \times R}$

3-11: Electric Shock

- When possible, work only on circuits that have the power shut off.
- If the power must be on, use only one hand when making voltage measurements.
- Keep yourself insulated from earth ground.
- Hand-to-hand shocks can be very dangerous because current is likely to flow through the heart!

3-12: Open-Circuit and Short-Circuit Troubles

An open circuit has zero current flow.



3-12: Open-Circuit and Short-Circuit Troubles

A short circuit has excessive current flow.

As *R* approaches 0, *I* approaches ∞.