**Elements in Series (1/2)**

- Series-connected circuit elements:
  - When only two elements connect at a single node, they are said to be **in series**
  - Elements in series carry the same current
  - E.g., resistors connected in series (Fig. 3.1)

**Elements in Series (2/2)**

- Series resistors with a single unknown current
  - Equivalent resistance:
    \[
    R_{eq} = \sum_{i=1}^{n} R_i
    \]

**Resistors in Parallel (1/3)**

- Parallel-connected circuit elements
  - When two elements connect at a single node pair, they are said to be **in parallel**
  - Parallel elements have the same voltage across their terminals
  - E.g., resistors in parallel (Fig. 3.5):

**Resistors in Parallel (2/3)**

- By KCL, \( i_i = i_1 + i_2 + i_3 + i_4 \)
- From Ohm’s Law: \( v_i = i_1 R_1 + i_2 R_2 + i_3 R_3 + i_4 R_4 \)
- Combining KCL and Ohm’s Law:
  \[
  i_i = \frac{v_i}{R_1} - \frac{i_1}{R_1} \frac{v_i}{R_2} - \frac{i_2}{R_2} \frac{v_i}{R_3} - \frac{i_3}{R_3} \frac{v_i}{R_4} - \frac{i_4}{R_4}
  \]

\[
\Rightarrow i_i = v_i \left( \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \right)
\]

**Resistors in Parallel (3/3)**

- \[
  \frac{1}{R_{eq}} = \sum_{i=1}^{n} \frac{1}{R_i} \Rightarrow R_{eq} = \frac{1}{\left( \sum_{i=1}^{n} \frac{1}{R_i} \right)}
  \]
- Also, \( G_{eq} = \sum_{i=1}^{n} G_i \)

- E.g., \( k = 2 \): \[
  \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1 R_2} \Rightarrow R_{eq} = \frac{R_1 R_2}{R_1 + R_2}
  \]
Voltage Divider Circuit (1/3)

• It may be necessary to develop more than one voltage from a single voltage supply

\[ i = v_i \frac{R_1}{R_1 + R_2} \]

\[ v_1 = iR_1 \]

\[ v_2 = iR_2 = v_i \frac{R_2}{R_1 + R_2} \]

Voltage Divider Circuit (2/3)

• A load consists of one or more circuit elements that draw power from the circuit

\[ v_s = \frac{R_m}{R_1 + R_m} v_i \]

\[ v_o = \frac{R_2}{R_1 + R_2} v_i \]

\[ R_m = \frac{R_1 R_2}{R_1 + R_2} \]

Voltage Divider Circuit (3/3)

• As long as \( R_1 \gg R_2 \), the voltage ratio \( v_o/v_s \) is essentially undisturbed by the load

• Effectiveness of the voltage divider circuit is sensitive to the tolerance of the resistor circuit values

Current Divider Circuit

\[ v = i R_1 = i_2 R_2 \]

\[ i_1 = \frac{R_1}{R_1 + R_2} i_2 \]

\[ i_2 = \frac{R_2}{R_1 + R_2} i_1 \]

Measure Voltage and Current (1/3)

• An **ammeter** is an instrument designed to measure current

  – Placed in series with the circuit element whose current is being measured

  – Ideal ammeter has equivalent resistance of 0 Ω and functions as a short circuit

Measure Voltage and Current (2/3)

• An **voltmeter** is an instrument designed to measure voltage

  – Placed in parallel with the circuit element whose voltage is being measured

  – Ideal voltmeter has infinite equivalent resistance and functions as an open circuit
Measure Voltage and Current (3/3)

- D’Arsonval meter (Fig. 3.20)
  - Movable electrical coil suspended between the poles of magnet (e.g., Fig. 3.20)
  - A DC (direct current) flowing the coil creates a torque and coil rotates
  - Characterized by full-scale deflection current ($I_m$)
  - Coil modeled with internal resistance ($R_m$)
  - Shunt resistance ($R_s$) in parallel

Wheatstone Bridge (1/2)

- A circuit to measure resistance

Wheatstone Bridge (2/2)

- When $i_g = 0$, $v_{ab} = 0$ and $R_x$ may be derived:

$$i_1 = i_s$$
$$i_1 R_3 = i_s R_x \quad \text{and} \quad i_1 R_1 = i_2 R_2$$

$$\Rightarrow i_s R_3 = i_s R_x \quad (3.34)$$
$$\Rightarrow R_x = \frac{R_3}{R_2} \quad (3.35)$$
$$\Rightarrow R_x = \frac{R_3 R_1}{R_1}$$

Delta-to-Wye Transform (1/2)

$$R_a = \frac{R_3 R_1}{R_x + R_3 + R_1}$$
$$R_b = \frac{R_3 R_2}{R_x + R_3 + R_2}$$
$$R_c = R_x + R_3 + R_1$$

Delta-to-Wye Transform (2/2)

$$R_a = \frac{R_3 R_1}{R_x + R_3 + R_1}$$
$$R_b = \frac{R_3 R_2}{R_x + R_3 + R_2}$$
$$R_c = R_x + R_3 + R_1$$