(a) An **ideal voltage source** is a circuit element that maintains a prescribed voltage across its terminals regardless of the current flowing in those terminals.

(b) An **ideal current source** is a circuit element that maintains a prescribed current through its terminals regardless of the voltage across those terminals.
Batteries – Alkaline, Silver-oxide, Lead-acid etc.

In any battery, an **electrochemical reaction** moves ions from one pole to the other. The actual metals and electrolytes used control the voltage of the battery -- each different reaction has a characteristic voltage.

In an alkaline battery, the **anode** (negative terminal) is made of **zinc powder** (which allows more surface area for increased rate of reaction therefore increased electron flow) and the **cathode** (positive terminal) is composed of **manganese dioxide**.
Solar Cells

“Solar revolution" is the idea that one day we will all use free electricity from the sun.

On a bright, sunny day, the sun shines approximately 1,000 watts of energy per square meter of the planet's surface.
1967 - **Soyuz 1** was the first manned spacecraft to be powered by solar cells.

The spacecraft crashed during its return to Earth. One of the reasons: the left solar panel deployment failure.
Hydroelectricity is electricity generated by hydropower, i.e., the production of power through use of the gravitational force of falling or flowing water. It is the most widely used form of renewable energy. Once a hydroelectric complex is constructed, the project produces no direct waste.
Wind is a renewable energy because it uses the wind's energy. It is also a non-polluting energy because it does not produce any greenhouse effect gases.
Internal resistance of a battery (of a voltage supply)

Battery is typically considered as an example of ideal voltage source.

Simple circuit representing the actual battery. According to this circuit, the voltage across ANY resistor connected to it, $V_L = 9V$. This is NOT TRUE.

The current flowing in any circuit connected to the battery also flows THROUGH the battery (through the electrolyte and the electrodes forming the battery). Both electrolyte and electrodes have resistance. This is called “internal” resistance.
Internal resistance of a battery (of a voltage supply)

More accurate equivalent circuit of the battery (and many other voltage sources). \( R_i \) is the internal resistance of the battery. Gray rectangle represents the battery. \( V_B = 9 \text{ V} \) is the “open-circuit” voltage of the battery.

The voltage across the load resistance, \( V_L = I \times R_L \);
The current in this circuit, \( I = V_B/(R_i + R_L) \);
The voltage across the load:

\[
V_L = V_B \frac{R_L}{R_i + R_L} < V_B
\]

Example: \( R_L = 100 \ \Omega; R_i = 20 \ \Omega; \)

The voltage across the load: \( V_L = 9\text{ V} \times \frac{100}{120} = 7.5 \text{ V} \)
Internal resistance of a battery (of a voltage supply)

\[ V_L = V_B \frac{R_L}{R_i + R_L} \]

- 9V battery
- \( V_L = 0.9V_B \)
- \( V_L = V_B/2 \)
- \( R_L = R_i \)
- \( R_L = 10*R_i \)
Problem 1

A 9V battery has an internal resistance $R_i = 10$ Ohm. The battery is supplying the power to the fire alarm sensor that has an equivalent resistance of 50 Ohm.

What is the voltage across the sensor (in Volts)?
A 9V battery has an internal resistance $R_i = 10$ Ohm. The battery is supplying the power to the fire alarm sensor that has an equivalent resistance of 50 Ohm.

**What is the voltage across the sensor?**

**Solution**

$V_B = 9V$

$R_{EQ} = R_i + R_L = 10$ Ohm + 50 Ohm = 60 Ohm

$I = \frac{V_B}{R_{EQ}} = \frac{9 V}{60$ Ohm} = 0.15$ A

$V_L = I \times R_L = 0.15$ A $\times 50$ Ohm = 7.5 V
Problem 2

A 9V battery has an internal resistance $R_i = 10$ Ohm. The battery is supplying the power to the fire alarm sensor that has an equivalent resistance of 50 Ohm.

What is the current flowing through the sensor (in Amperes)?
Problem 3

A 1.5V battery has an internal resistance $R_i = 20$ Ohm. Two batteries are connected in series to power up the MP3 player with the equivalent resistance of 410 Ohm.

What is the voltage across the MP3 player (in Volts)?
A 1.5V battery has an internal resistance $R_i = 20$ Ohm.

Two batteries are connected in series to power up the MP3 player with the equivalent resistance of 410 Ohm.

**What is the voltage across the MP3 player?**

**Solution**

$V_B = 2 \times 1.5 \text{ V} = 3 \text{ V}$

$R_{EQ} = 2*R_i + R_L = 2\times20 \text{ Ohm} + 410 \text{ Ohm} = 450 \text{ Ohm}$

$V_L = \frac{V_B \times R_L}{R_{EQ}} = 3 \text{ V} \times 410 \text{ Ohm} / 450 \text{ Ohm} = 2.73 \text{ V}$
Problem 4

To determine the internal resistance of a battery the test is set up as follows.
1. The open circuit voltage has been measured and found to be 12.4 V.
2. The voltage at the battery terminals was measured with the 20-Ohm load connected and found to be 11.9 V.

What is the internal resistance of the battery (in Ohms)?
1. The open circuit voltage has been measured and found to be 12.4 V.
2. The voltage at the battery terminals was measured with the 20-Ohm load connected and found to be 11.9 V.

**What is the internal resistance of the battery?**

**Solution**

\[ V_B = 12.4 \text{ V} \]
\[ R_L = 20 \text{ Ohm} \]
\[ R_{EQ} = R_i + R_L - \text{unknown variable.} \]
\[ V_L = \frac{V_B \times R_L}{R_{EQ}} \]

\[ R_{EQ} = \frac{V_B \times R_L}{V_L} = \frac{12.4 \text{ V} \times 20 \text{ Ohm}}{11.9 \text{ V}} = 20.84 \text{ Ohm}; \]

\[ R_i = R_{EQ} - R_L = 20.84 \text{ Ohm} - 20 \text{ Ohm} = 0.84 \text{ Ohm} \]
Assuming an **ideal** battery, the power delivered to the load resistor $R_L$, $P_L = I \times V_L = \left(\frac{V_B}{R_L}\right) \times V_B = \frac{V_B^2}{R_L}$.

According to this, reducing the load resistance one can obtain infinitely high power from the battery.

Using more **realistic** equivalent circuit of the battery, the power in the load, $P_L = I \times V_L$, where

$$V_L = V_B \frac{R_L}{R_i + R_L} \quad \text{and} \quad I = \frac{V_B}{R_i + R_L}$$

Hence, the power

$$P_L = V_B^2 \frac{R_L}{\left(R_i + R_L\right)^2}$$
Power delivered to the load

\[ P_L = \frac{V_B^2}{R_L} \left( \frac{R_L}{R_i + R_L} \right)^2 \]

Example: \( R_L = 100 \ \Omega; \)

For ideal battery, the power in the load would be:

\[ P_L = \frac{9^2 V^2}{100 \ \Omega} = 0.81 \ \text{W} \]

For real battery with the internal resistance \( R_i = 20 \ \Omega, \)

\[ P_L = 9^2 V^2 \left[ \frac{100}{(100+20)^2} \right] = 81 \times \frac{100}{14400} = 0.56 \ \text{W} \]
Problem 5

The vacuum cleaner rated power is 1500 W with the nominal voltage $V=120$ V. When the vacuum is plugged into the outlet, the actual voltage across the cleaner was 112 V. What was the actual power consumed by the vacuum (in Watts)?
The vacuum cleaner rated power is 1500 W with the nominal voltage \( V = 120 \text{ V} \).

When the vacuum is plugged into the outlet, the actual voltage across the cleaner was 112 V.

**What was the actual power consumed by the vacuum?**

**Solution**

The nominal current of the vacuum cleaner

\[
I_N = \frac{P_N}{V_N} = \frac{1500 \text{ W}}{120 \text{ V}} = 12.5 \text{ A}
\]

The resistance of the unit

\[
R_U = \frac{V_N}{I_N} = 9.6 \text{ Ohm}
\]

The actual current through the unit:

\[
I = \frac{V}{R_U} = \frac{112 \text{ V}}{9.6 \text{ Ohm}} = 11.6 \text{ A}
\]

The actual power:

\[
P = V * I = 112 \text{ V} * 11.6 \text{ A} = 1306 \text{ W}
\]