1. Impedance and loading effects.

Input impedance: \( \frac{V}{i} \)

Output impedance: \( R_{th} \)

- Power sources and sensors should have a small output impedance (\( V_0 \approx V_{th} \) when \( i \) is flowing to the load or measurement instrument).

- Readout instruments and amplifiers should have a large input impedance to minimize loading of the sensor/source connected to it.
**Example:** The voltage divider.

**Unloaded voltage divider:**

\[
\begin{align*}
\text{Vin} & \quad \text{R} \quad \text{Vout} \\
\text{i} & \quad \text{Rout} & \text{Vout} \\
\text{Vin} & \quad \text{R} \\
\text{Rout} & \quad \text{Vin}
\end{align*}
\]

The purpose of this circuit is to reduce the input voltage (from a sensor, for example) by a known factor.

Here, \( i = \frac{\text{Vin}}{\text{R} + \text{Rout}} \), so \( \text{Vout} = \left( \frac{\text{Rout}}{\text{R} + \text{Rout}} \right) \text{Vin} \) known

In open-circuit conditions, the divider has an ideal relationship.

**Loaded divider:**

\[
\begin{align*}
\text{Vin} & \quad \text{R} \\
\text{i} & \quad \text{Rat} \quad \text{Vout} \\
\text{i_0} & \quad \text{Rat} \quad \text{Vout} \\
\text{i_L} & \quad \text{RL}
\end{align*}
\]

Now: \( i = i_0 + i_L \)

\[
\begin{align*}
\text{Vout} &= \text{Vin} - i \text{R} \\
i_0 &= \frac{\text{Vout}}{\text{Rat}} \quad i_L = \frac{\text{Vout}}{\text{RL}}
\end{align*}
\]

So we obtain \( \text{Vout} = \frac{\text{Vin}}{1 + \frac{\text{R}}{\text{Rat}} + \frac{\text{R}}{\text{RL}}} \)
Observations:

1. If \( R_L \to \infty \) (open circuit), we obtain the ideal \( V_{out} \).

2. If \( R_L < \infty \), \( V_{out} < V_{out \text{ ideal}} \) (loading effect).

If \( R_L \) is unknown (what is the \( R_L \) of a volt meter?), we can't predict the relationship between \( V_{out} \) and \( Vin \).

3. If \( R_L \) is small, \( \frac{R}{R_L} \gg \frac{R}{R_{out}} \) (in comparison to \( R_{out} \)).

so \( 1 + \frac{R}{R_L} + \frac{R}{R_{out}} \approx 1 + \frac{R}{R_L} \)

\[ V_{out} = \frac{Vin}{1 + \frac{R}{R_L}} = \left( \frac{RL}{R + RL} \right) Vin \]

( the connected load (readout instrument) drives the measurement! )

\[ \Rightarrow \text{Highly undesirable} \]

4. When the measured device has a high \( R_{th} \) (output impedance), a very high instrument \( R_L \) (input impedance) is necessary.