Topic 2

Current, Voltage and Power

Prof Peter Cheung
Dyson School of Design Engineering
Imperial College London

URL: www.ee.ic.ac.uk/pcheung/teaching/DE1_EE/
E-mail: p.cheung@imperial.ac.uk
What will you learn on this module?
What will you learn on this module?
What are electrical circuits?

- A **circuit** consists of electrical or electronic components interconnected with metal wires.
- Every electrical or electronic device is a circuit.

- The function of the circuit is determined by which components are used and how they are interconnected: the physical positioning of the components usually has hardly any effect.

Breadboard  |  Printed  |  Integrated
A **circuit diagram** shows the way in which the components are connected.

- Each component has a special symbol
- The interconnecting wires are shown as lines

A **node** in a circuit is all the points that are connected together via the interconnecting wires. One of the four nodes in the diagram is coloured red. **Assumption**: Interconnecting wires have zero resistance so everywhere along a node has the same voltage.

![Diagram of circuit components]

Indicate three meeting wires with a • and crossovers without one.

Avoid having four meeting wires in case the • disappears; stagger the wires instead.
Electrical charge

◆ **Charge** is an electrical property possessed by some atomic particles.
◆ Charge is measured in Coulombs (abbreviated C).
◆ An electron has a charge $-1.6 \times 10^{-19}$C, a proton $+1.6 \times 10^{-19}$C.
◆ Unlike charges attract; like charges repel.
◆ The force is **fantastically** huge:

Two people 384,000 km apart
Each with 1% extra electrons
Force = $2 \times 10^{-8}$ N
= $360,000 \times$ their weight

◆ **Consequence**: Charge never accumulates in a conductor: everywhere in a conducting path stays electrically neutral at all times.
**Electrical Current**

- **Current** is the flow of charged particles past a measurement boundary.
- Using an ammeter, we measure current in Ampères (usually abbreviated to Amps or A): 1 A = 1 C/s.
- **Analogy**: the flow of water in a pipe or river is measured in litres per second.
- The arrow in a circuit diagram indicates the direction we choose to measure the current:

\[ I = +1 \, \text{A} \Rightarrow 1 \, \text{C} \text{ of } +\text{ve} \text{ charge passes each point every second in the direction of the arrow (or else } 1 \, \text{C} \text{ of } -\text{ve} \text{ charge in the opposite direction)} \]

\[ I = -1 \, \text{A} \Rightarrow 1 \, \text{C} \text{ of } +\text{ve} \text{ charge in the direction opposite to the arrow.} \]

- Average electron velocity is surprisingly slow (e.g. 1 mm/s) but (like a water pipe) the signal travels much faster.
- In metals the charge carriers (electrons) are actually –ve: in this course you should ignore this always.
Potential Energy

- When a ball falls from a shelf, it loses potential energy of $mg$, or, equivalently, $gh$ per kg.

- The potential energy per kg of any point on a mountain range is equal to $gh$ where $h$ is measured relative to an equipotential reference surface (e.g. the surface of a lake).

The potential energy difference between any two points is the energy needed to move 1 kg from one point to the other.

The potential energy difference does not depend on the route taken between the points.

The potential energy difference does not depend on your choice of reference surface (e.g. lake surface or sea level).
The **electrical potential difference** (or **voltage difference**) between any two nodes in a circuit is the energy per coulomb needed to move a small +ve charge from one node to the other.

- We usually pick one of the nodes as a reference and define the voltage at a node to be the voltage difference between that node and the reference.

The four nodes are labelled: $A, B, C, G$. We have chosen $G$ as the reference node; indicated by the "ground" symbol.

- The potential difference between $A$ and the ground reference, $G$, is written $V_A$ and is also called “the voltage at $A$”.
- The potential difference between $A$ and $B$ is written as $V_{AB}$ and shown as an arrow pointing towards $A$. This is the energy per coulomb in going from $B$ to $A$ and satisfies $V_{AB} = V_A - V_B$. (**Different from vectors**)
- Easy algebra shows that $V_{AB} = -V_{BA}$ and that $V_{AC} = V_{AB} + V_{BC}$. 

**Voltage**
Resistors – the link between current and voltage

- A **resistor** is made from a thin strip of metal film deposited onto an insulating ceramic base.

- The **characteristic** of a component is a graph showing how the voltage and current are related. We always choose the current and voltage arrows in opposite directions.

- For a resistor, \( I \propto V \) and \( \frac{V}{I} = R \) its **resistance** which is measured in Ohms (\( \Omega \)). **This is Ohm’s Law.** Sometimes it is more convenient to work in terms of the **conductance**, \( G = \frac{1}{R} = \frac{I}{V} \) measured in Siemens (S).

- The graph shows the characteristic of a 12.5 \( \Omega \) resistor. The gradient of the graph equals the conductance \( G = 80 \text{ mS} \). **Alternative zigzag symbol.**
Ohm’s law relates the voltage drop across a resistor to the current flowing in it.

- If the voltage, \( V \), is fixed elsewhere in the circuit, it is convenient to think that \( V \) causes the current \( I \) to flow.
- If the current, \( I \), is fixed elsewhere in the circuit, it is more convenient to think that \( V \) is caused by the current \( I \) flowing through the resistor.
- Neither statement is “more true” than the other. It is perhaps truer to say that \( I \) and \( V \) are constrained to satisfy \( V = I \times R \).
Resistor Power Dissipation

◆ Gravitational potential energy, \( mgh \), lost by a falling object is transformed into kinetic energy or heat.

Current in a resistor always flows from a high voltage (more positive) to a low voltage (more negative).

◆ When current flows through a resistor, the electrical potential energy that is lost is transformed into heat.

◆ The power dissipated as heat in a resistor is equal to \( V \times I \) Watts (W). 1 Watt equals one Joule of energy per second. Since \( V \) and \( I \) always have the same sign (see graph) the power dissipation is always positive.

◆ Any component: \( P = V I \) gives the power absorbed by any component.

◆ For a resistor only

\[
\frac{V}{I} = R \quad \Rightarrow \quad P = VI = \frac{V^2}{R} = I^2R.
\]

P31-33
Voltage and Current Sources

- Energy in an electrical circuit is supplied by voltage and current sources.

  An **ideal voltage source** maintains the same value of $V$ for all currents. Its characteristic is a vertical line with infinite gradient. There are two common symbols:

  ![Voltage Source Symbol]

  An **ideal current source** maintains the same value of $I$ for all voltages. Its characteristic is a horizontal line with zero gradient. Notice that $I$ is negative.

  ![Current Source Symbol]

- If the source is **supplying** electrical energy to a circuit, then $VI < 0$.
- However, when a rechargeable battery is charging, $VI > 0$.

P31-33
In any circuit some circuit elements will be supplying energy and others absorbing it. At all times, the power absorbed by all the elements will sum to zero.

The circuit has two nodes whose potential difference is 10 V.

Ohm’s Law: \( I = \frac{V}{R} = 0.01 \, \text{A} \)

Power absorbed by resistor:

\[
P_R = V_1 \times I_1 = (+10) \times (+0.01) = +0.1 \, \text{W}
\]

- For Ohm’s law or power dissipation, \( V \) and \( I \) can be measured either way round but **must** be in opposite directions.

\[
P_R = V_2 \times I_2 = (-10) \times (-0.01) = +0.1 \, \text{W}
\]

Power absorbed by voltage source:

\[
P_S = V_S \times I_S = (+10) \times (-0.01) = -0.1 \, \text{W}
\]

Total power absorbed by circuit elements:

\[
P_S + P_R = 0
\]
Summary

- Circuits and Nodes
- Charge, Current and Voltage
- Resistors, Voltage Source and Current Sources
- Power Dissipation and Power Conservation