Topic 2

Current, Voltage and Power

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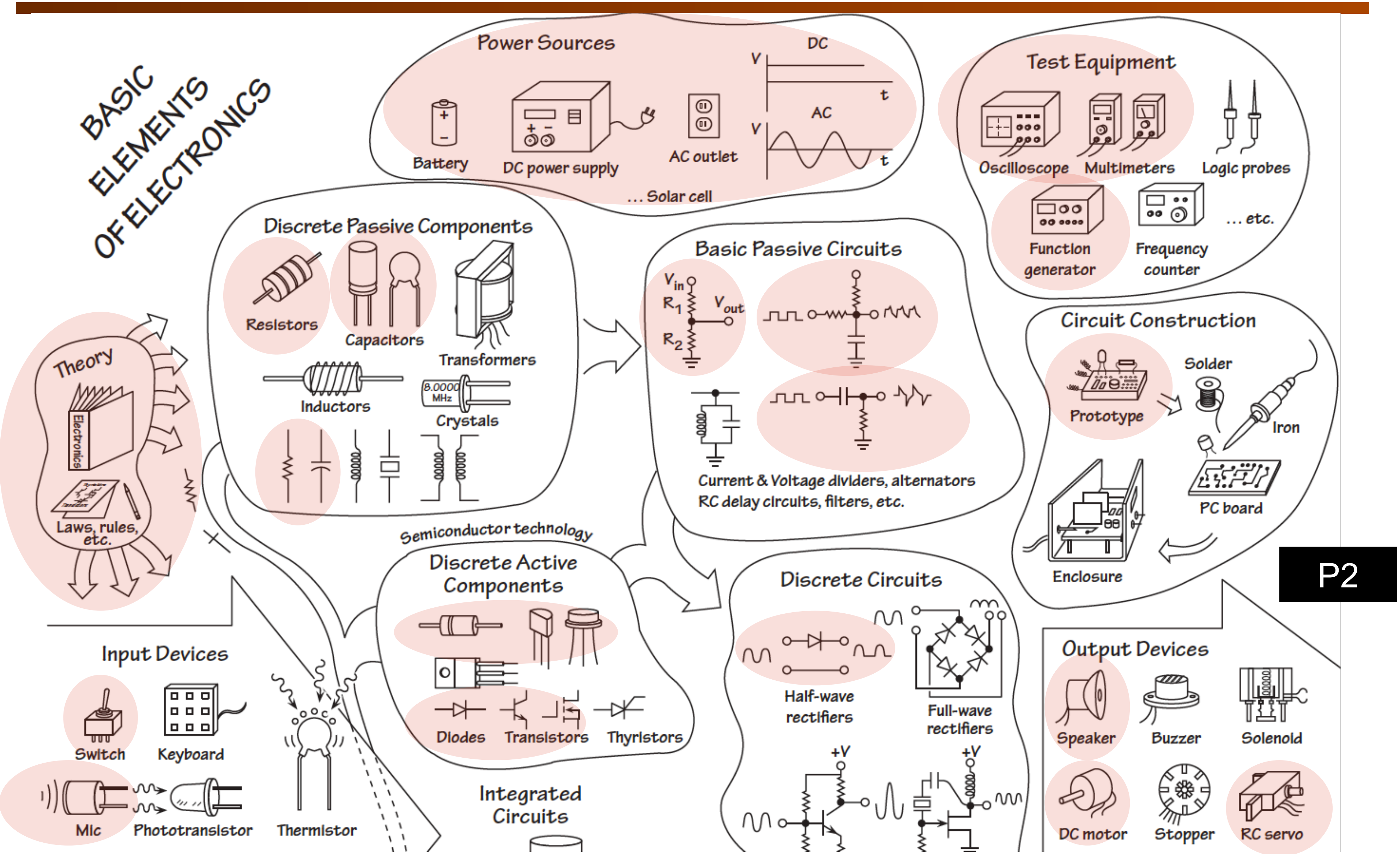
What will you learn on this module?



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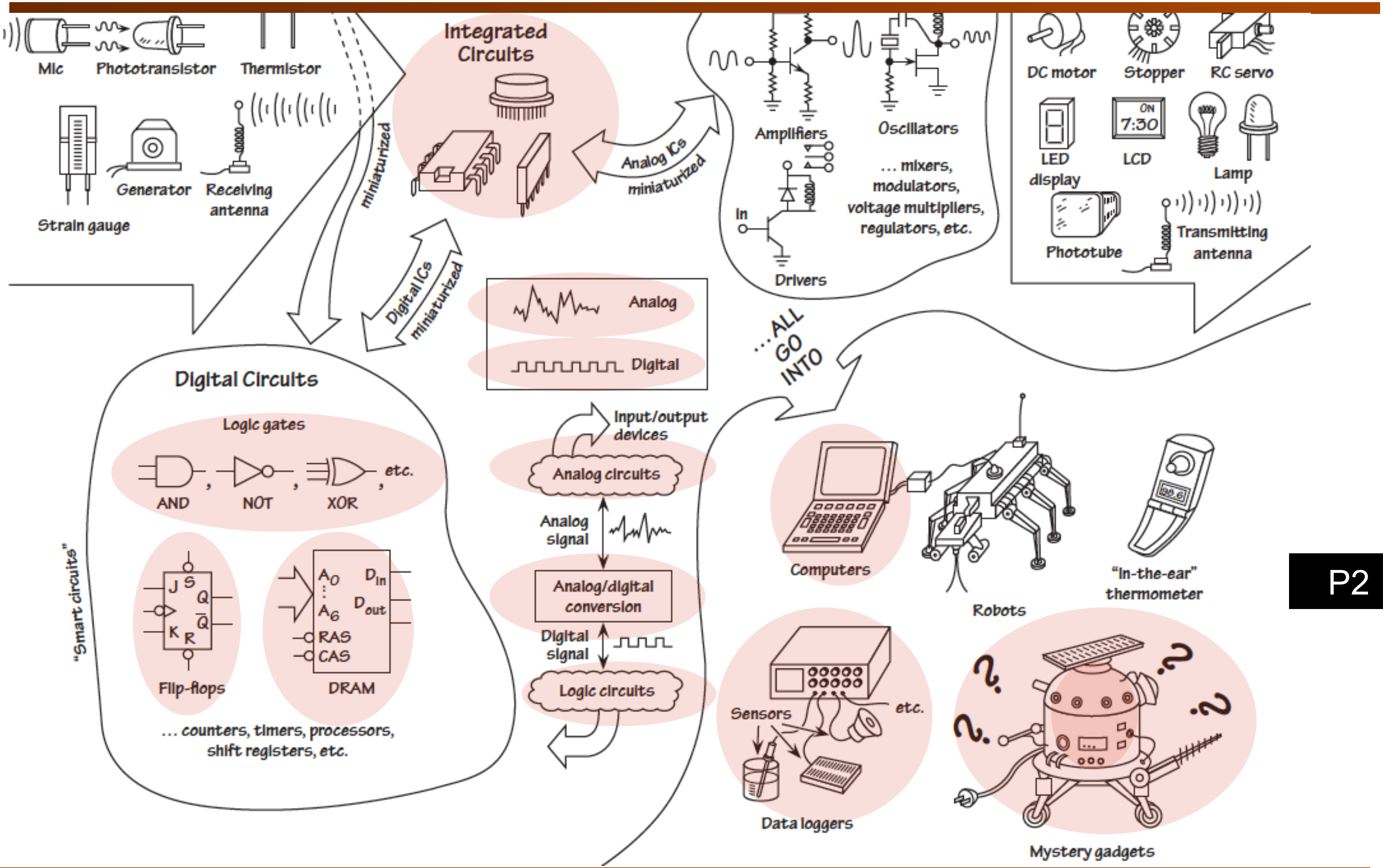
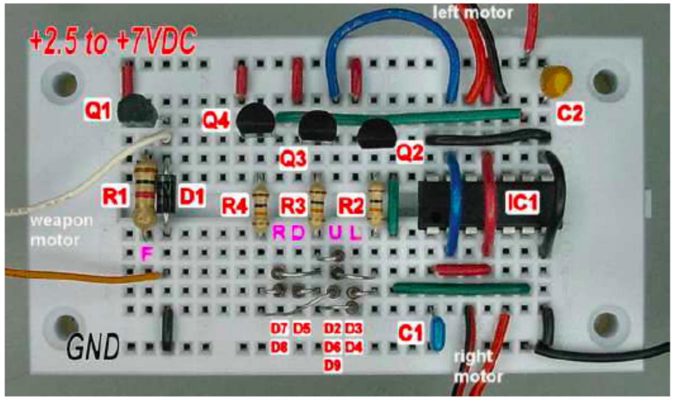


P2

What are electrical circuits?

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



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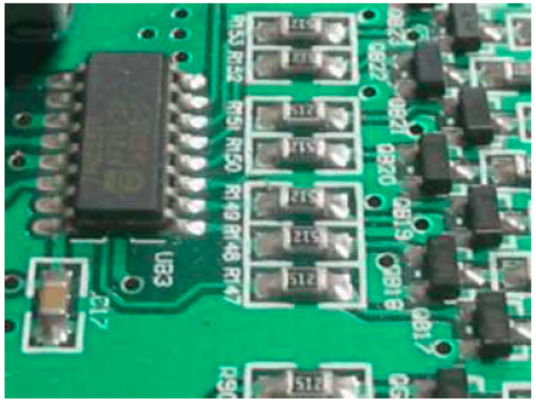

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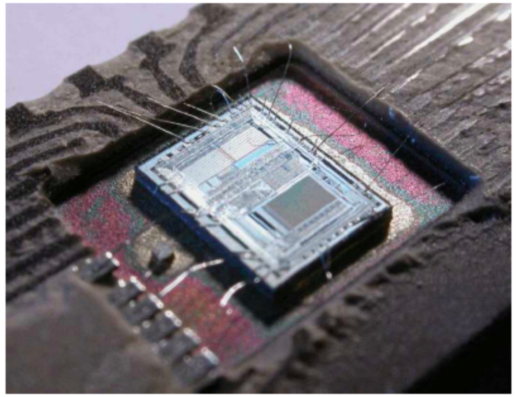


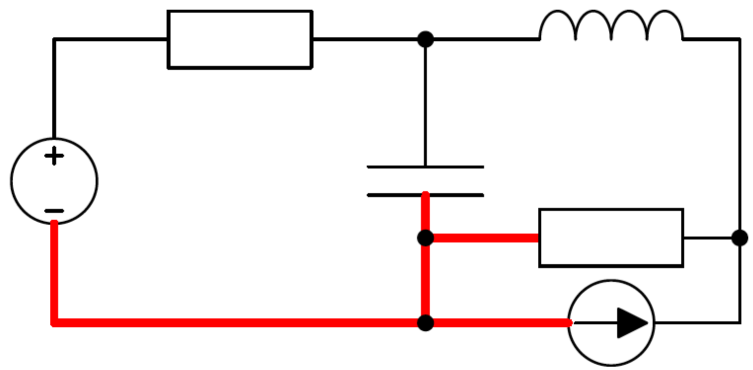
Integrated

- 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.

P1-3

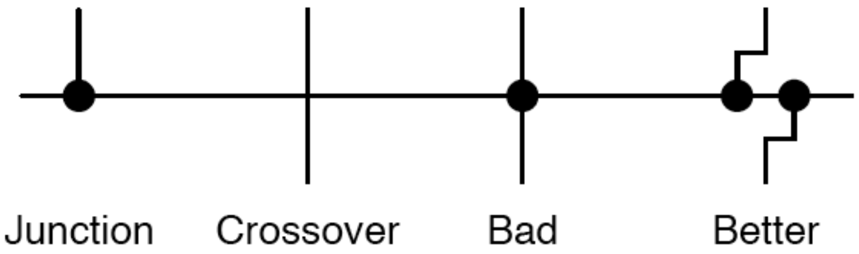
Circuit Diagrams

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.



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 -1.6×10^{-19}C, a proton $+1.6 \times 10^{-19}$C.
- Unlike charges attract; like charges repel.
- The force is fantastically huge:

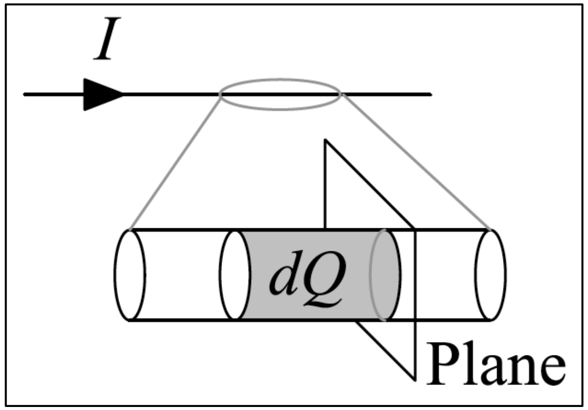
Two people 384,000 km apart
Each with 1% extra electrons
Force = 2×10^{-8} N
= $360,000 \times$ their weight

- Consequence: Charge never accumulates in a conductor: everywhere in a conducting path stays electrically neutral at all times.

P5-6

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 A $\Rightarrow$ 1 C of +ve charge passes each point every second in the direction of the arrow (or else 1 C of –ve charge in the opposite direction)

$I = -1$ A $\Rightarrow$ 1 C of +ve charge in the direction opposite to the arrow.

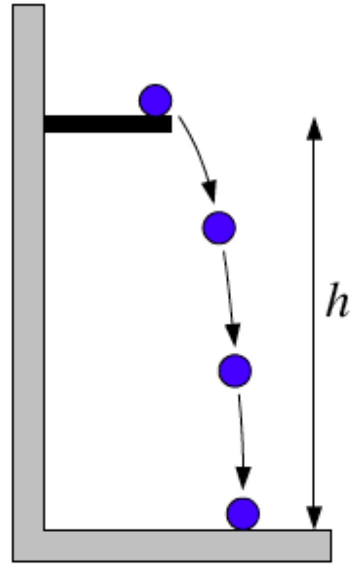
- Average electron velocity is surprisingly slow (e.g. 1 mm/s) but (like a water pipe) the signal travels much faster.
- In metals the charge carriers (electrons) are actually –ve: in this course you should ignore this always.

P7-9

Potential Energy

- When a ball falls from a shelf, it loses ***potential energy*** of mgh 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.

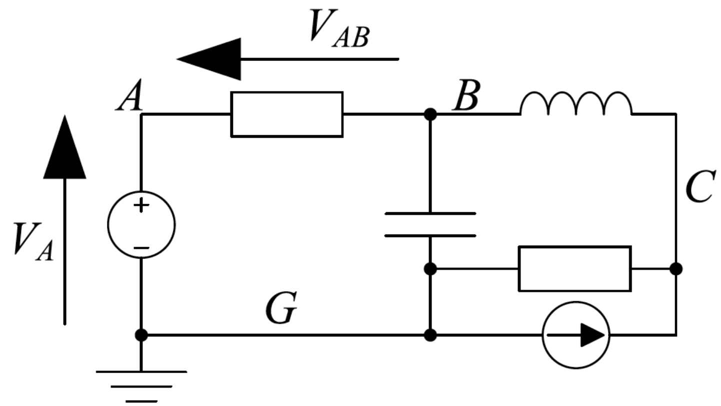
The potential energy difference **does not depend on the route** taken between the points.

The potential energy difference **does not depend on your choice of reference** surface (e.g. lake surface or sea level).

Voltage

- 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 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.

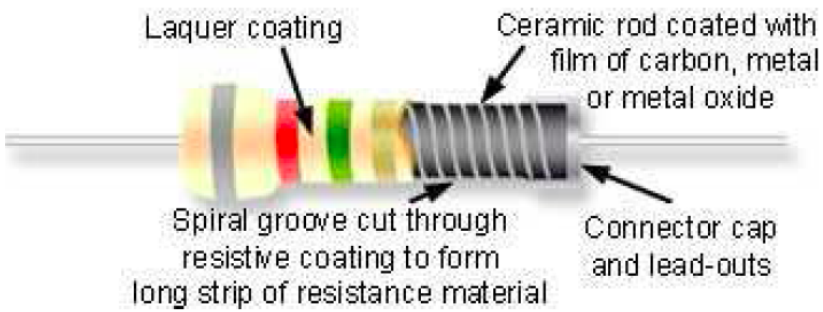


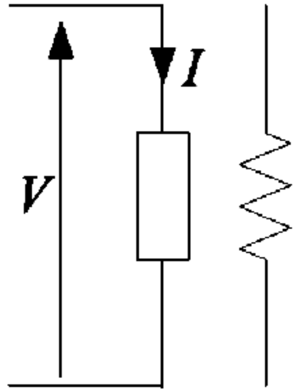
- The potential difference between A and the ground reference, G, is written V_A and is also called "the voltage at A".
- The potential difference between A and B is written as V_{AB} and shown as an arrow pointing towards A. This is the energy per coulomb in going from B to A and satisfies $V_{AB} =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

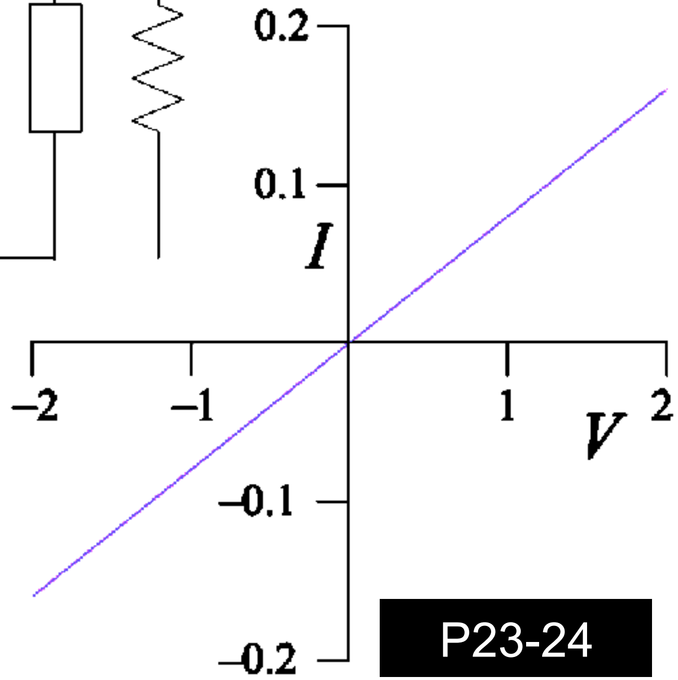
P9-12

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 (Ω). **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 Ω resistor. The gradient of the graph equals the conductance $\mathrm{G} = 80\ \mathrm{mS}$. Alternative zigzag symbol.



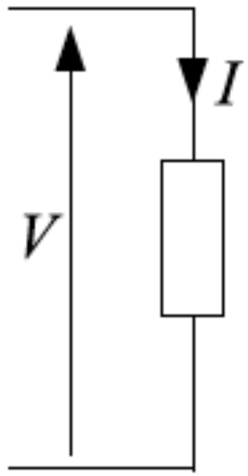


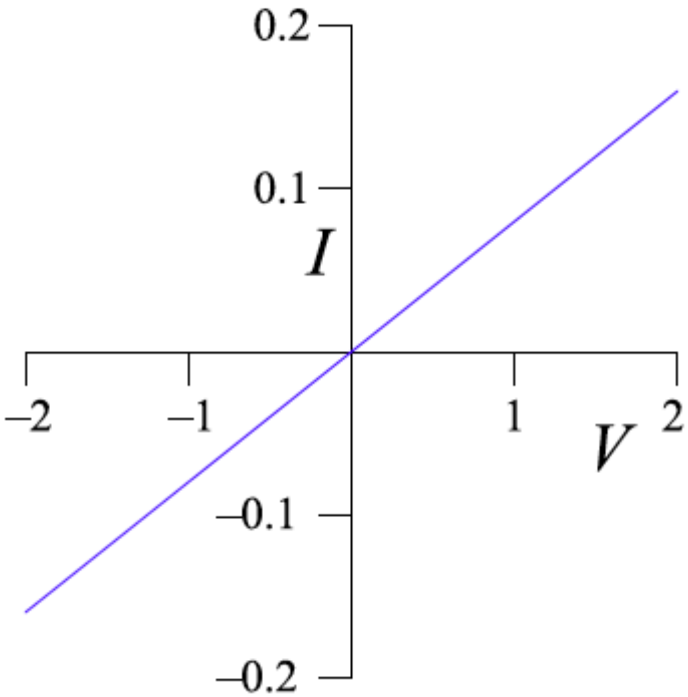


P23-24

Cause and Effect

Ohm's law relates the voltage drop across a resistor to the current flowing in it.



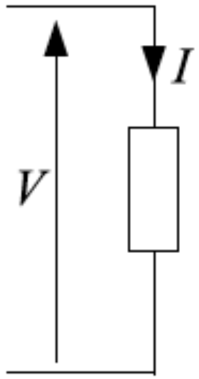


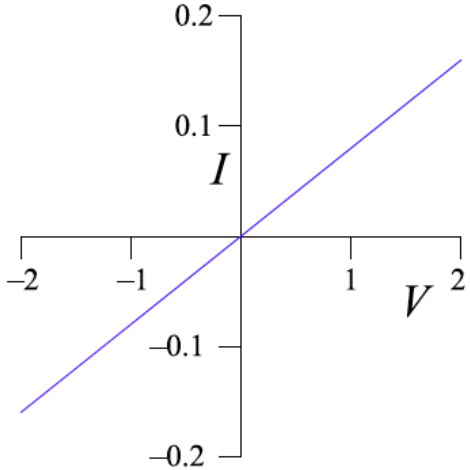
- If the voltage, V , is fixed elsewhere in the circuit, it is convenient to think that V ***causes*** the current I to flow.
- If the current, I, is fixed elsewhere in the circuit, it is more convenient to think that V is ***caused by*** the current I flowing through the resistor.
- Neither statement 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).





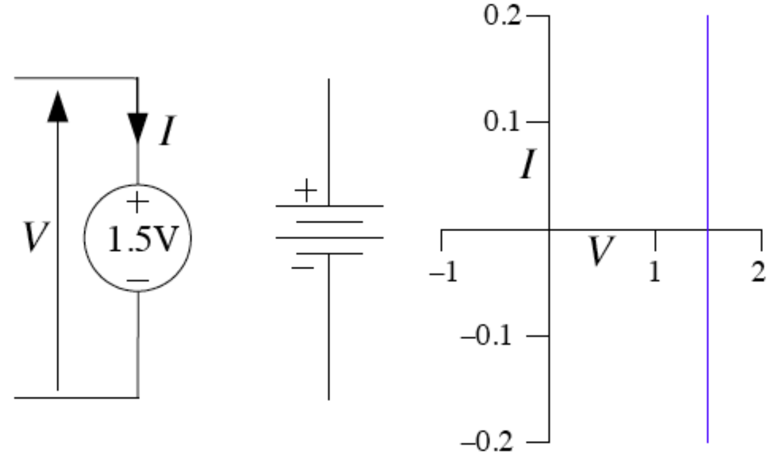
- When current flows through a resistor, the electrical potential energy that is lost is transformed into heat.
- The power dissipated as heat in a resistor is equal to $V \times I$ Watts (W). 1 Watt equals one Joule of energy per second. Since V and I always have the same sign (see graph) the **power dissipation is always positive**.
- **Any component**: P = V I gives the power absorbed by any component.
- **For a resistor only** $\frac{V}{I} = R \quad \Rightarrow \quad P = VI = \frac{V^2}{R} = I^2 R.$

P31-33

Voltage and Current Sources

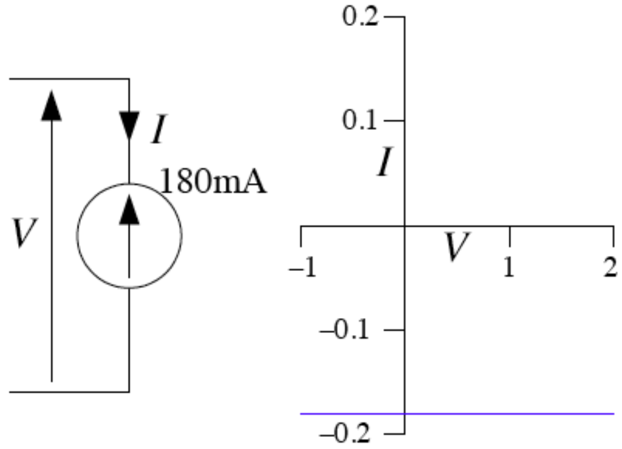
- Energy in an electrical circuit is supplied by voltage and current sources

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:



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.

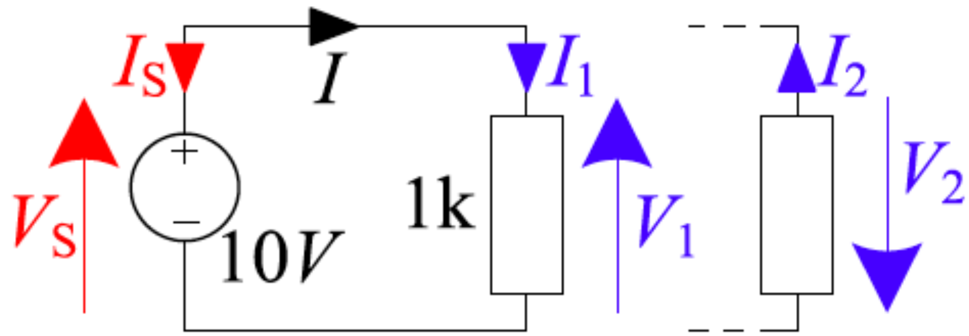


- If the source is ***supplying*** electrical energy to a circuit, then $VI < 0$.
- However, when a rechargeable battery is charging, $VI > 0$.

P31-33

Power Conservation

- 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