Year 11 Physics Electricity and Magnetism

Lesson 4 Ohm’s Law Sample resources

MATRIX EDUCATION

1. Electric current (I) [A]

☐ What is electric current?

- **Electric current,** I, is defined as the **rate at which charge flows** past a given point in a conductor.

- This can be expressed mathematically as

$$I = \frac{q}{t}$$

where:

I = electric current (A)

q = net charge (C)

t = time elapsed (s)

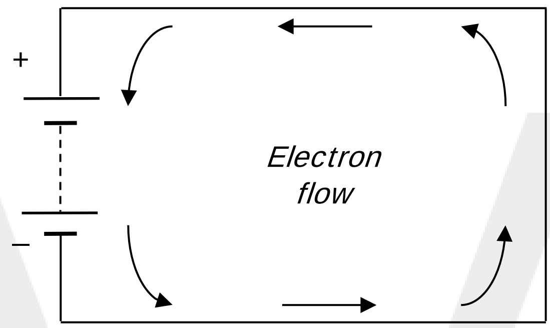
  - The SI unit of current is the **Ampere** (A) (equal to coulombs/second).
  - If thirty electrons pass a particular point in a conductor in 2 seconds, what is the magnitude of electric current?[1]

- One ampere is defined as the flow of one coulomb of charge past a fixed point in a conductor in one second.
  - 1 A = 1 C/s.
  - If a current of 1 A flows through a conductor, how many electrons are passing a point per second?[2]

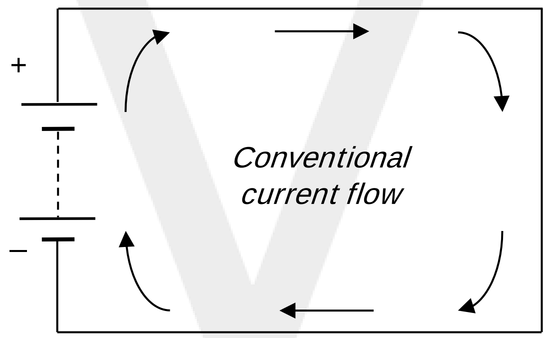
- Watch video (Length 5:19): The fundamentals of current and voltage explained.

☐ Conventional current

- Both positive and negative charges may flow to create current. However, in Lesson 1 we learned that the electrical behaviour of solids is actually a result of the movement of **negative charges** (electrons) only.
  - Electrons move from the negative terminal to the positive terminal. This **flow of negative charge** is called **electron flow.**



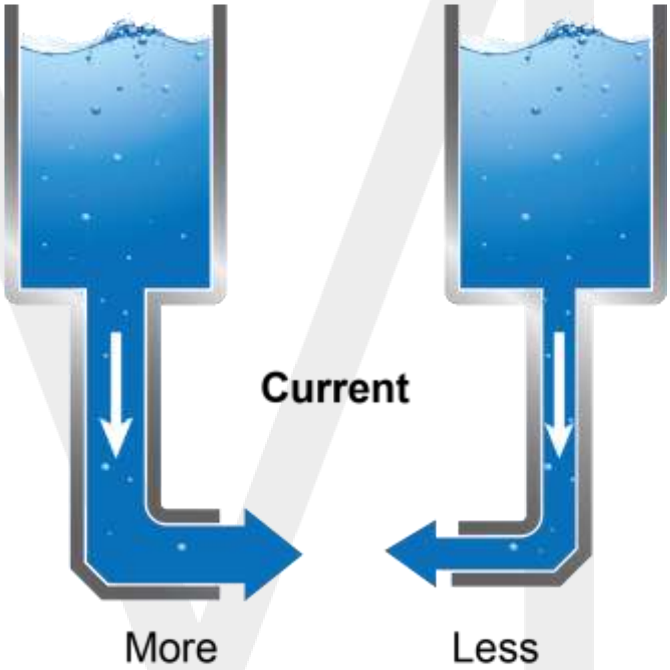
  - However, current I is defined as a flow of positive charge.
  - This flow of positive charge is from the positive to the negative terminals. This flow is called conventional current.



- When we talk about current, we will always mean the flow of positive charges, conventional current.
  - **Conventional current** then describes the **imaginary flow of positive charges** in the opposite direction to the actual electron flow.
  - However, **conventional current is electrically the same as electron flow in the opposite direction,** so it doesn't matter that we use conventional current to solve problems in circuits.

☐ Water analogy for current

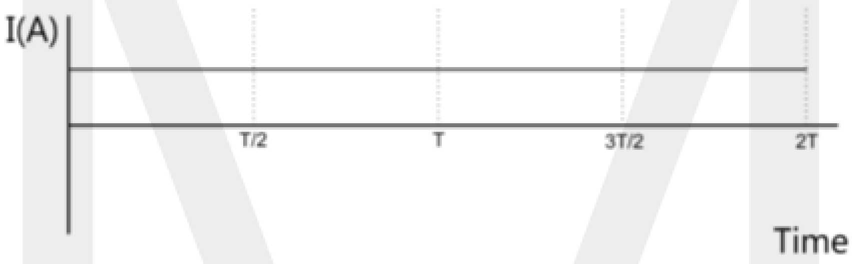
- A common analogy that is made when discussing the behaviour of electric currents is water through a pipe.
  - You can think of the **amount of current** as analogous to the **amount of water flowing** through the pipe.
  - The pipe on the left is larger and has more water flowing through it. That represents more current.
  - The pipe on the right has less water flowing through it. That represents less current.



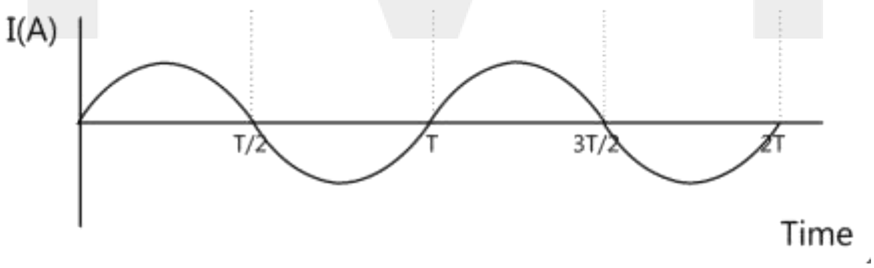
☐ Types of electric current

- There are two types of electric current:
  - Direct Current (DC)
  - Alternating Current (AC)

- **In DC**, the net flow of charge carriers is **moving in one direction**.
  - Many everyday gadgets containing batteries such as calculators and phones run on DC.
  - A graph of current versus time for **Direct Current** (**DC**) is shown below:



- **In AC**, the charge carriers are flowing **backwards and forwards** periodically.
  - AC is obtained from the mains supply and is mainly used for operating motors and for power transmission because it is easily transformed.
  - AC is converted into DC to power electronic devices such as phones, tablets and computers.
  - A graph of current versus time for **Alternating Current** (**AC**) is shown below:



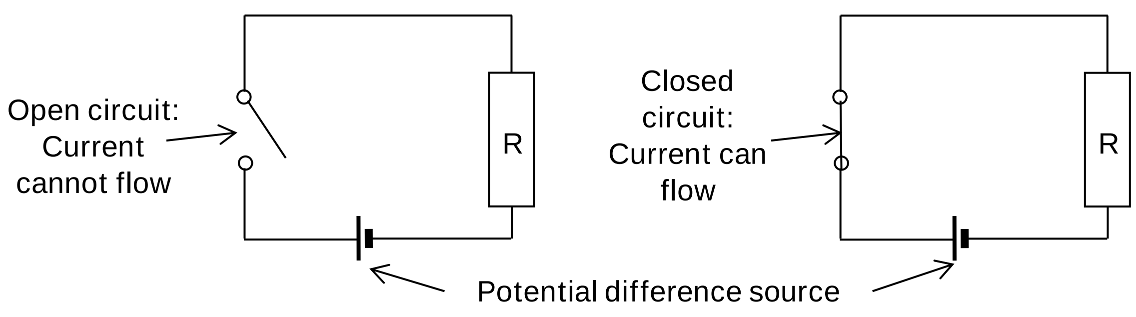
- <u>Watch video (Length: 0:42):</u> Electricity can be measured and displayed using a device called an oscilloscope.

☐ Conditions for current flow

- In order for an electric current to exist between two points, there must be:
  - A **closed conducting path** between the two points for charges to flow.
  - A **potential difference** across the two ends of the conducting path.
- Let's use the water analogy again to explain the conditions for current flow.

Condition	Water pipes	Electric circuit
Closed conducting path	There must be an **unbroken** and unblocked tube for water to flow through. If there is a blockage in the pipe, the water flow will stop.	The circuit must be complete. If there is a **break** in the circuit, the flow of charge will stop. This is referred to as an **open** circuit.
Potential difference across the conducting path	There must be a height difference between the two ends of the pipe to cause the water to flow (downhill). When there is a greater height difference between the two ends of the pipe, the flow of water is increased. The height difference allows gravitational potential energy to be converted into kinetic energy, causing the water to flow.	There must be a potential difference across the circuit to cause current to flow. When there is a greater potential difference across the two ends of the circuit, the flow of current is increased. The **potential difference** between the start and end of the circuit **provides the energy to do work** on the charge and "pump" it through the circuit.

- The conditions are illustrated below:



☐ Current and electric potential difference

- Recall that **electric potential difference** or **voltage** V is defined as the **change in electric potential energy per unit charge** when moving a charge between two points in a conductor. Mathematically,

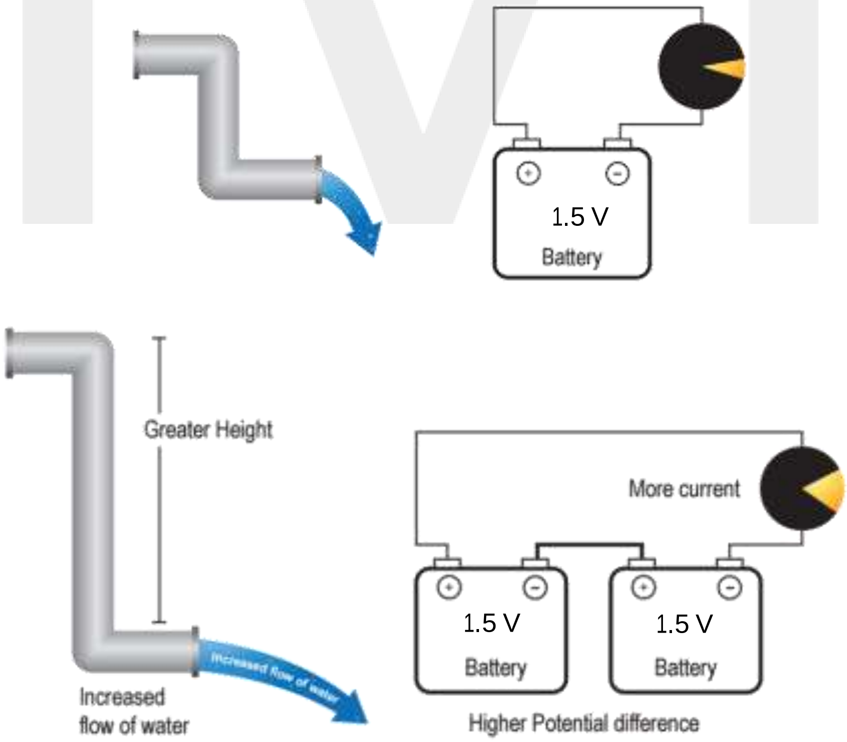
$$V = \frac{\Delta U}{q}$$

  – One volt means one joule of energy per coulomb of charge, 1 V = 1 J/C.

- This allowed us to determine the work done on a charge by an electric field as

$$W = qV$$

- Let's use the water analogy to explain why a greater current flows as a result of a greater difference in potential between two points in a circuit.
  – A greater difference in potential energy for water in a pipe is achieved by raising one end of the pipe to a greater height.
  – The rate of flow of water in a pipe will increase by having the water fall through a greater height, which increases the pressure in the pipe and thus applies more force on each parcel of water.



- Similarly the current in a wire may be increased by increasing the potential difference across it.
  - **Increasing the potential difference** across the terminals of the circuit leads to a **stronger electric field** being established. This in turn means the charges flowing across the terminals are given **a greater "push"** ($F = qE$) and are able to flow through the circuit at a **faster rate**.
  - As a result, current (the rate of flow of charge) through the wire increases.

- The natural direction for particles to move is from a region of **higher to lower potential energy** (think of things falling downhill).
  - A large difference in potential means a large "push" is given to each particle and hence there is a **greater rate of current flow.**
  - In the water pipe analogy, gravitational potential energy is converted into kinetic energy as the water flows through the pipe.
  - What energy transformations occur in the electrical circuit?[3]

- Electrochemical cells such as batteries are often used to produce this potential difference.
  - An AA battery produces a potential difference of 1.5 V between its terminals.
  - Calculate the amount of energy used per coulomb of charge in moving it between the terminals.[4]

☐ Current flow in DC circuits

- **Direct current** (DC) is the one-directional flow of charge. DC is produced by sources such as batteries (**electrochemical cell**) and solar cells.
  - **Figure (a)** represents a DC circuit in which conventional current flows through the wire from the positive terminal to the negative terminal of the electrochemical cell in an external circuit.
  - **Figure (b)** represents the circuit diagram of the DC circuit.

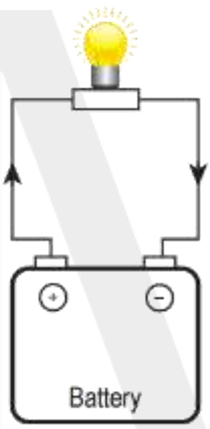


Figure (a)

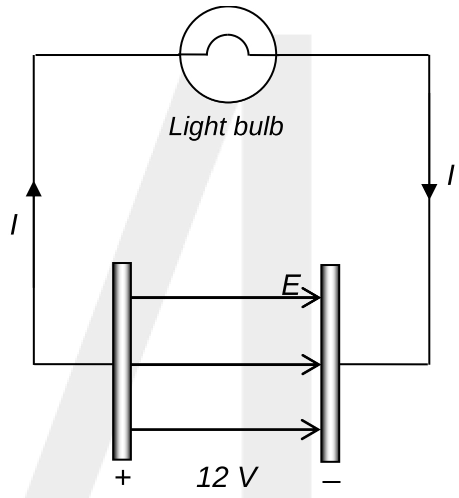


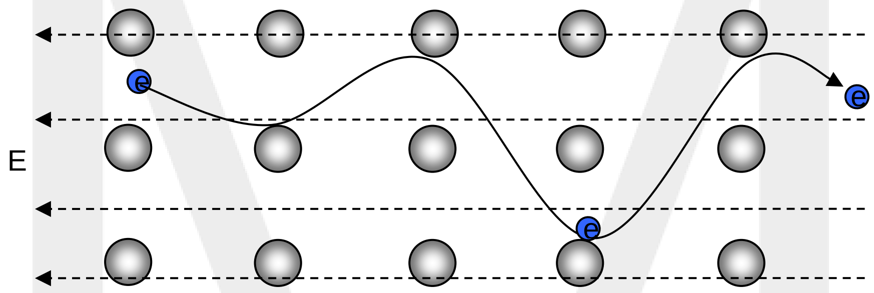
Figure (b)

- How do the positive charges move against the electric field produced by the positive and negative terminals?
  - The positive terminal of the cell is at a higher electric potential than the negative terminal of the cell.
  - Charges will flow from a point of higher potential energy to a point of lower potential energy. Therefore, positive charges will flow through the circuit and to the negative terminal.
  - When the positive charges reach the negative terminal, work must be done against the field to move the charge against the electric field.
  - The electrochemical cell provides this energy in the form of **chemical potential energy**.

2. Resistance (R) [Ω]

☐ What is resistance?

- Resistance is defined as a material's **tendency to resist the flow of charge**.
  - Conductors are materials through which electric charges move quite freely. These have low resistance.
  - The diagram below shows the structure of a metal. Electrons move through the metal colliding with the metal atoms, losing speed, generating heat and reducing the current.



  - **Insulators** are materials through which **charge cannot move freely**. The electrons are fixed to the individual atoms so charge cannot flow. These have **very high resistance**.

- Following the water analogy, you can think of resistance like friction through a pipe or a constriction in the pipe.
  - The water is set moving by potential energy. A narrower or longer pipe will cause more friction (more resistance) and will result in a smaller volume of water flowing (less current).

More Flow Less Flow

Definition of resistance

- Applying a voltage on a circuit will result in the flow of current. How much current flows depends on the resistance.
  - Larger resistance results in a smaller current.
  - Smaller resistance results in larger current.

- The definition of resistance is the ratio of the voltage to the current:

$$R = \frac{V}{I}$$

Where: R is the resistance. The SI unit for resistance is the **ohm** (Ω)
V is the voltage measured in volts (V)
I is the current measured in amps (A)

  - What does it mean for a circuit to have a resistance of $1\ \Omega$? [5]

- Simulation: (PhET HTML5) Circuit construction kit.

3. Ohm's Law

☐ Definition of Ohm's Law

- **Ohm's Law** states that the **voltage** across an object and the **current** flowing through it are **proportional**: $V \propto I$.
  - This requires the resistance to be constant.
  - Mathematically, Ohm's Law is written as:

$$V = IR$$

Where: V = potential difference across the conductor (V)
I = current through the conductor (A)
R = electrical resistance (Ω), assumed to be **constant**.

  - A 20.0 Ω resistor has a current of 5.0 A flowing through it. What is the potential difference across the resistor?[6]

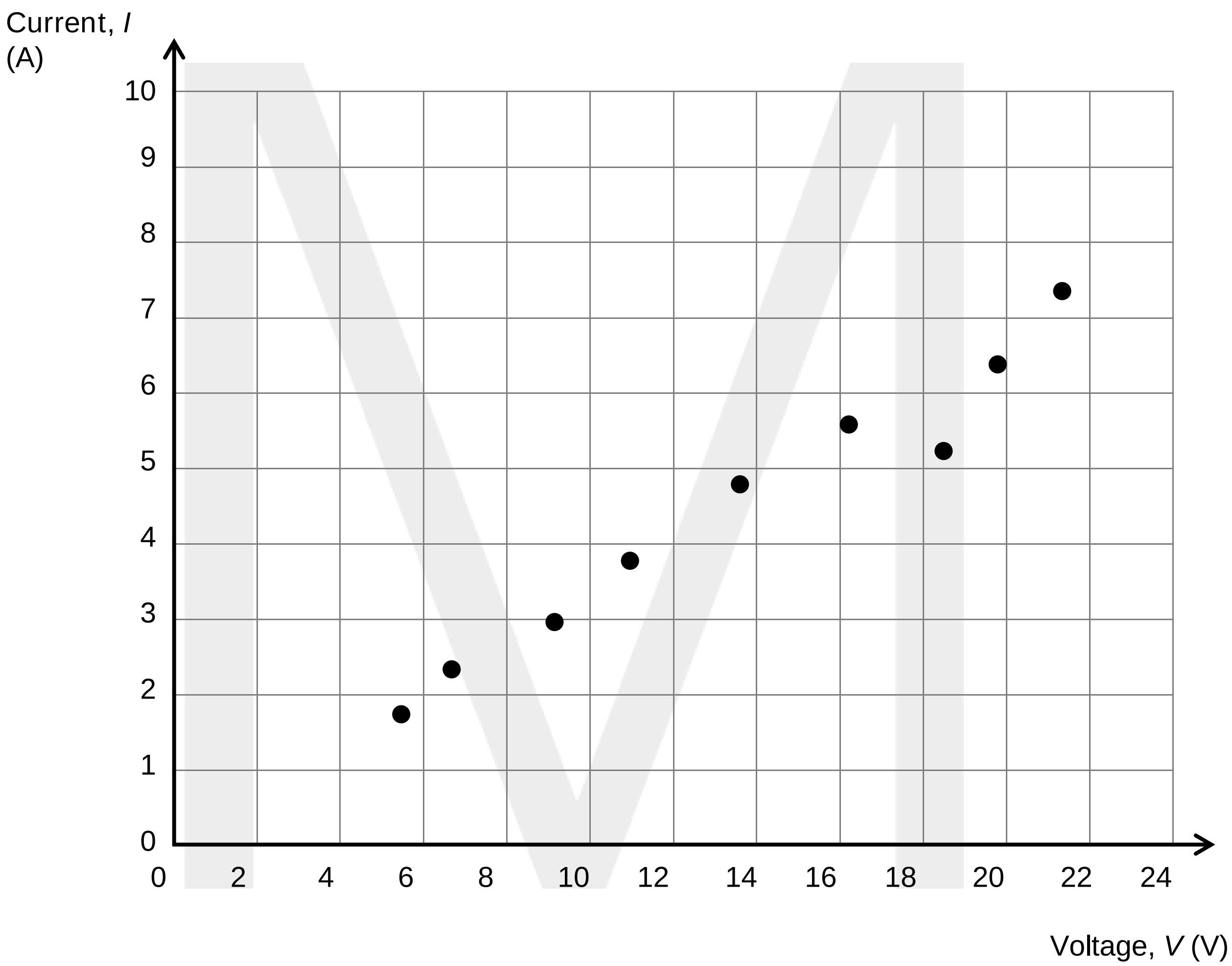
- Ohm's Law is not a fundamental physical principle, but rather an empirical relationship obeyed by most metals under a range of circumstances. It was first observed by German physicist Georg Simon Ohm.
  - Materials that **obey Ohm's Law** (have a constant resistance) are called **ohmic conductors** or ohmic resistors.
  - **Non-ohmic conductors do not obey Ohm's Law**. In these materials the resistance depends on other variables like voltage or current, and so the voltage and current are not proportional.

- Note that although the two equations are the same:
  - $R = \frac{V}{I}$ is the definition of resistance and applies to all situations.
  - Ohm's Law $V = IR$ assumes resistance is constant and applies to ohmic conductors only.

- <u>Demonstration:</u> (PhET HTML5) Ohm's Law relationship.

☐ Ohmic conductors

- For an ohmic conductor, the resistance is constant and does not depend on the voltage or current.
- Ohm's Law states that voltage and current are proportional. A graph of **current vs. voltage** for an ohmic conductor is shown below.
  - Draw the line of best fit on the graph below and **identify any outliers**.



  - Is this resistor ohmic? Justify your answer.[7]

– The graph shows that I is proportional to V. Ohm's Law tells us that $I = \frac{1}{R}V$. What does the slope of the graph represent? [8]

Note to students

Remember that the equation of a straight line is $y = mx + b$.

Graphs are drawn with the independent variable on the x axis and the dependent variable on the y axis.

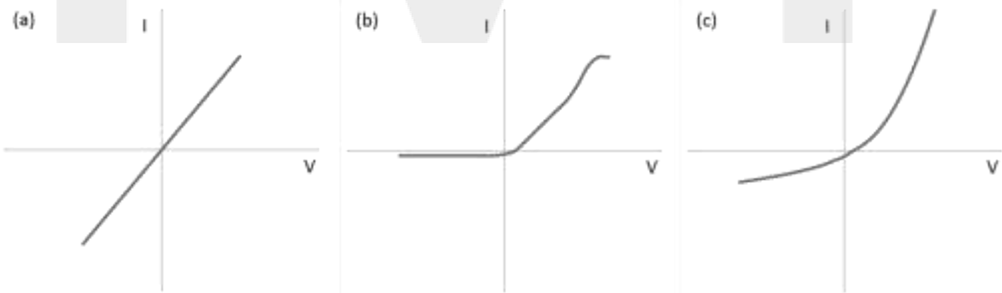
In experiments, it is most common to set the voltage (independent variable) and measure the current (dependent). The equation of the line will be $I = \frac{1}{R}V$ and the gradient will be $\frac{1}{R}$.

In exams you may be provided with a voltage vs current graph for convenience. The equation will be $V = IR$ and the gradient will be R.

– Use your graph to calculate the resistance of the resistor. [9]

■ The figure below shows the relationship between current and voltage for:

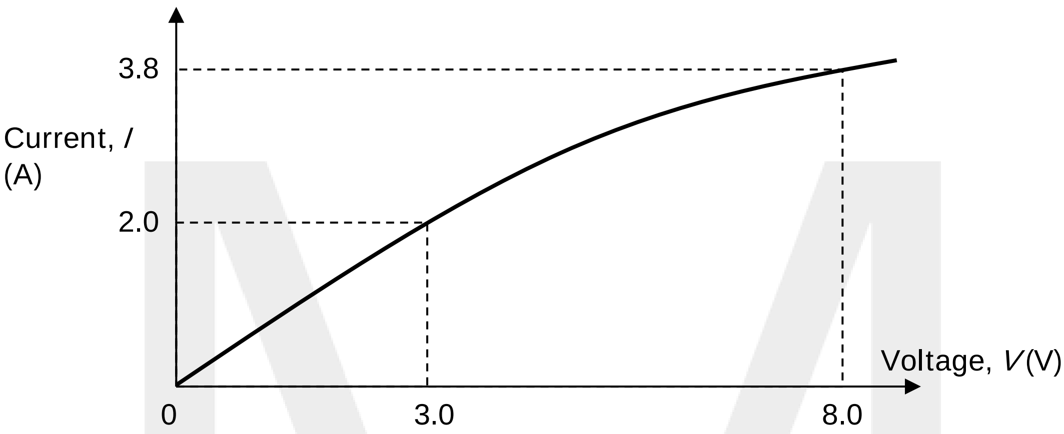
a metal a vacuum tube diode a semiconductor diode



– Which graph represents a material that obeys Ohm's Law? Explain your choice.[10]

☐ Non-ohmic conductors

- For a non-ohmic conductor, the resistance is not constant, and depends on other variables like the voltage or current.
- An example of a current vs voltage graph for a non-ohmic conductor is shown below.



– How does the graph show that this is a non-ohmic conductor?[11]

– What is the resistance when the voltage is 3.0 V?[12]

– What is the resistance when the voltage is 8.0 V?[13]

– Is the resistance constant?[14]

– What does the slope of the graph represent?[15]

4. Lesson review questions

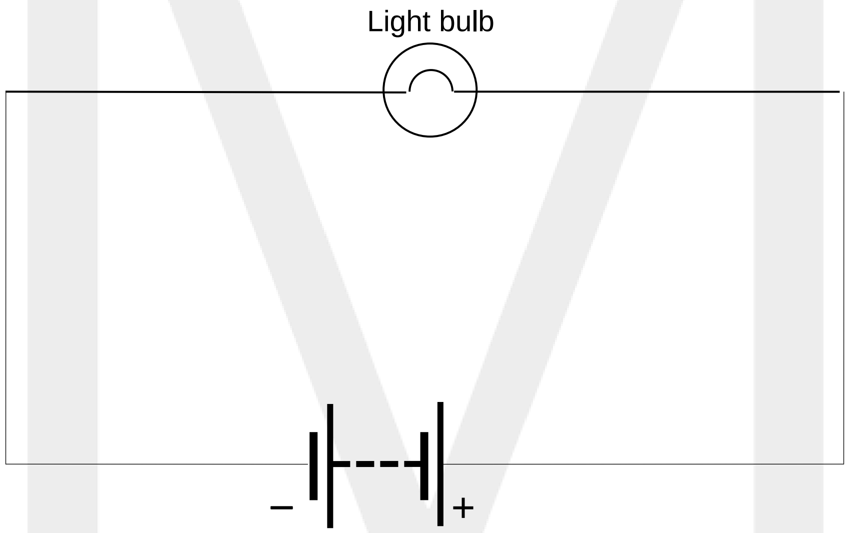
Concept Check 4.1

Complete the following statements. **2**

The conventional electric current from a battery flows from the ____________________[16] terminal to ____________________[17] terminal of the battery.
Electron flow therefore is from the ____________________[18] terminal to the ____________________[19] terminal of the battery.

Concept Check 4.2

(a) On the circuit diagram below, indicate the direction of electric current and the direction of electron flow.[20] **2**



(b) A current of 0.10 A flows through the light bulb for 30 s. How much charge passed through the conductor?[21] **1**

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(c) How many electrons flow past a point in a circuit in one second if the current through the circuit is 0.10 A?[22] **1**

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