Simple Circuit Calculations

Introduction

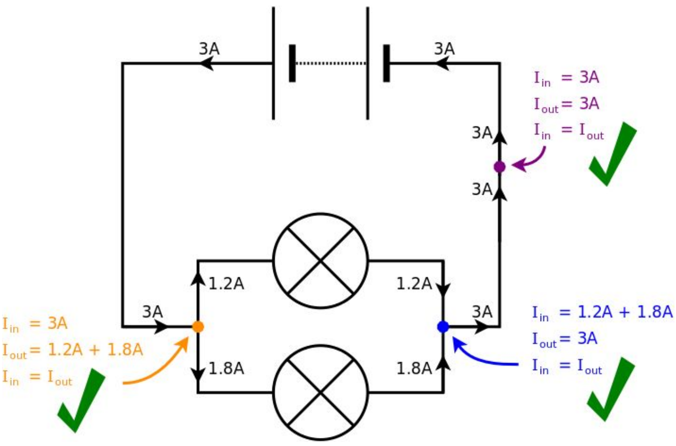
This section could easily be titled "Kirchhoff's Laws" but that is not a very descriptive title. These notes are about calculating voltage and current in series and parallel circuits using the aforementioned Kirchhoff's laws.

For the purposes of this section, simple circuits are circuits that contain basic components such as bulbs and resistors, batteries and switches - the connections may look complex but the circuits themselves are simple and we are interested in how they obey Kirchhoff's basic circuit rules.

The basic two circuits are **series circuits** and **parallel circuits.** All other circuits can be reduced to a combination of series and parallel connections.

Current Law

In a series circuit, current is the same at each point. In a parallel circuit current splits (not necessarily equally) at a junction.



This is Kirchhoff's current law:

"The sum of the currents flowing into a junction is zero"

… and means that for any point in the circuit the current flowing in (taken to be positive) is equal to the current flowing out (taken to be negative).

This is a consequence of the principle of conservation of charge.

Voltage Law

In a strictly series circuit the potential differences all add up to the total of the EMF's and in a purely parallel circuit the potential difference across each component has to be the same.

The voltage rules often cause some confusion and need to be carefully considered. Unless the circuit is just simply a series circuit, the voltages across all the components don't all just add up to the supply voltage. Voltages across two components in parallel - whether these be potential differences or EMF's - must be the same.

Kirchhoff's voltage law states "the sum of the EMF's is equal to the sum of the potential differences around any complete circuit loop". This means that if you start at some point in the circuit, trace a route around the circuit somehow and arrive back at the starting point, then all the EMF's add up to the same as all the potential differences. This is true for any closed loop around any circuit and is a consequence of the conservation of energy.

Voltage, EMF and Potential Difference

There is always some confusion about the terms 'Voltage', 'Potential Difference' and 'EMF' so we can think of them as follows:

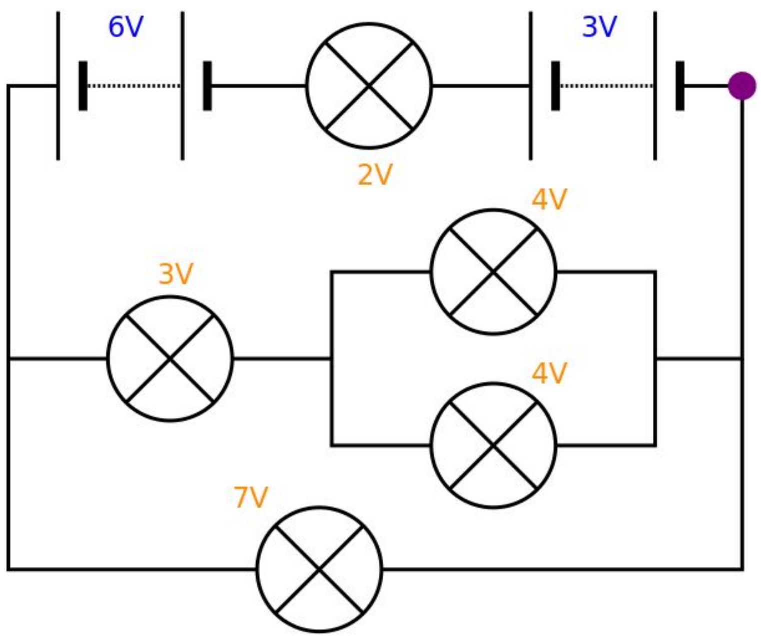
Voltage: A general term for the transfer of electrical energy. Voltage can be used casually to describe the 'voltage of a battery' or the 'voltage at this point in the circuit (relative to ground)' or the 'voltage across a resistor' but in all cases this is not strictly correct. Strictly voltage is a description of the unit - the volt. However, it is perfectly acceptable to just talk about voltage when discussing circuits, circuit building, circuit testing, component specifications etc.

EMF: This stands for Electromotive Force and is used to describe the energy transferred to electrical energy in energy sources in electrical circuits. A chemical cell (chemical to electrical), thermocouple (thermal to electrical), generator (kinetic to electrical) and photovoltaic (solar) cell (radiant to electrical) are all sources of electrical energy and, as such, they have an EMF measured in volts. Therefore, we should state that a double A (AA) cell has an EMF of 1.5 volts rather than saying it has a voltage of 1.5 volts.

Potential Difference (Pd): This is the electrical energy transferred in output transducers such as bulbs. A bulb (electrical to thermal & radiant), heater (electrical to thermal), speaker (electrical to sound), motor (electrical to kinetic) and solenoid (electrical to potential) all have an associated potential difference. We should say the potential difference across the bulb is 1.2 volts but it is more common to say the voltage across the bulb is 1.2 volts.

Demonstrating the Voltage Law

In this simple (containing only batteries and bulbs) but complex (having many parallel branches) circuit. The EMF of each battery is shown in BLUE and the potential difference across each bulb is shown in ORANGE (the bulbs are all different).

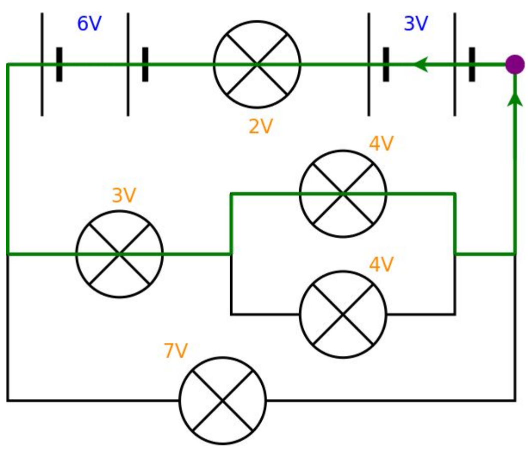


We will look at all the possible routes around the circuit adding up the EMF's and the potential differences as we go.

In each of the first few cases we will start at the purple dot at the top right hand corner of the circuit and travel in the direction of the current flow.

In actual fact you can start at any point in the circuit as will be seen in later examples.

Route 1

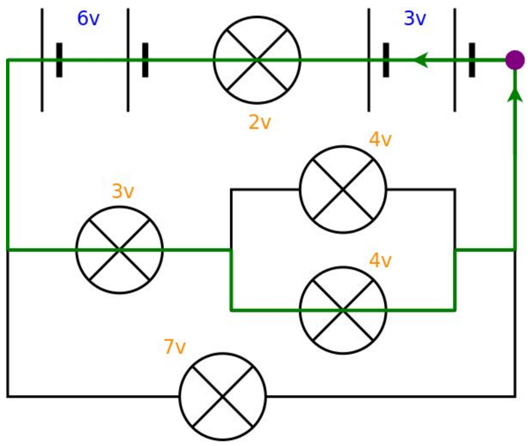


Sum EMF = 3 + 6 = 9 volts

Sum Pd = 2 + 3 + 4 = 9 volts

Sum EMF = Sum Pd

Route 2

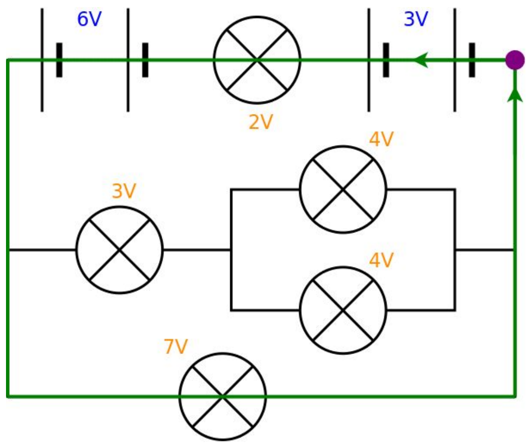


Sum EMF = 3 + 6 = 9 volts

Sum Pd = 2 + 3 + 4 = 9 volts

Sum EMF = Sum Pd

Route 3

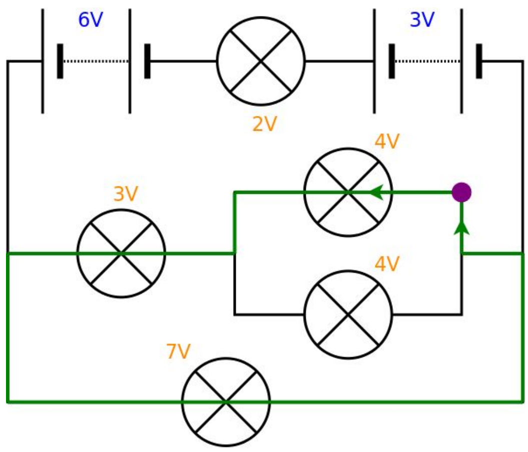


Sum EMF = 3 + 6 = 9 volts

Sum Pd = 2 + 7 = 9 volts

Sum EMF = Sum Pd

Route 4



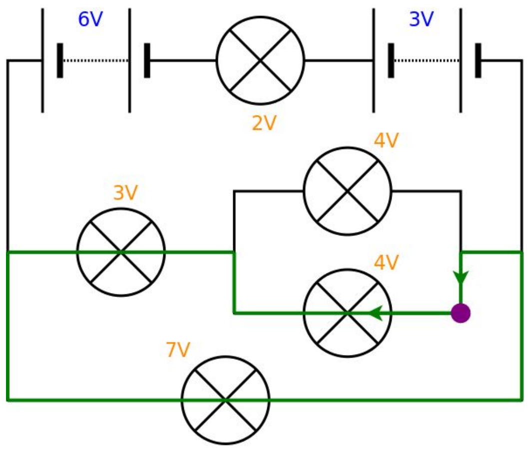
The green arrow represents the direction we travel round the route, NOT the direction of the current in the branch of the circuit. As we are travelling around the loop 'against' the current, the potential difference is negative for the first and second bulbs. As we travel with the current through the third bulb the potential difference is still positive

Sum EMF = 0 volts

Sum Pd = - 4 - 3 + 7 = 0 volts

Sum EMF = Sum Pd

Route 5

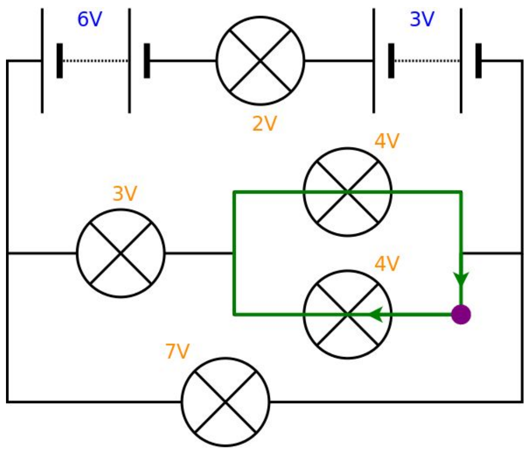


Sum EMF = 0 volts

Sum Pd = - 4 - 3 + 7 = 0 volts

Sum EMF = Sum Pd

Route 6



Sum EMF = 0 volts

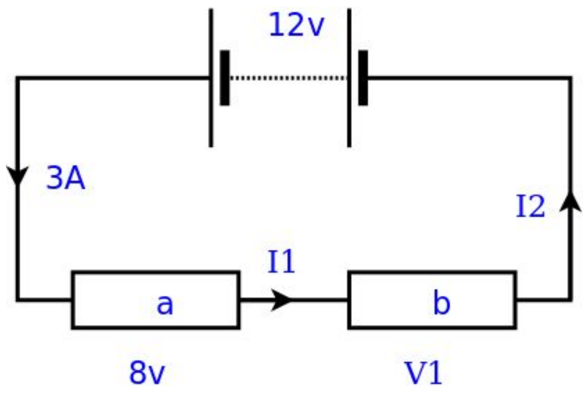
Sum Pd = - 4 + 4 = 0 volts

Sum EMF = Sum Pd

Examples

For each example, calculate the missing values of voltage and current in each case and then check the solutions.

Example 1

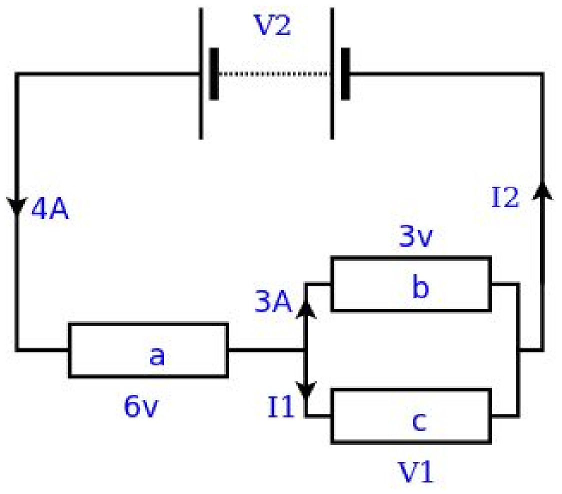


I1 = ?

I2 = ?

V1 = ?

Example 2



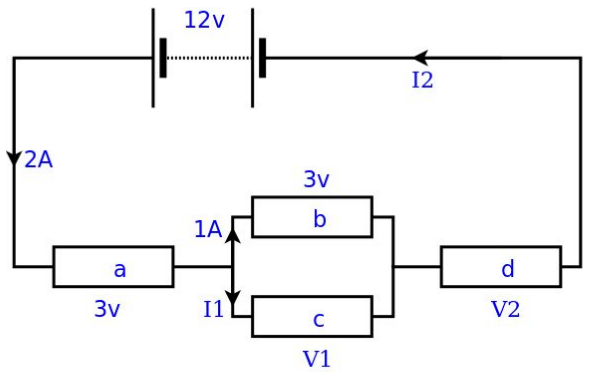
I1 = ?

I2 = ?

V1 = ?

V2 = ?

Example 3



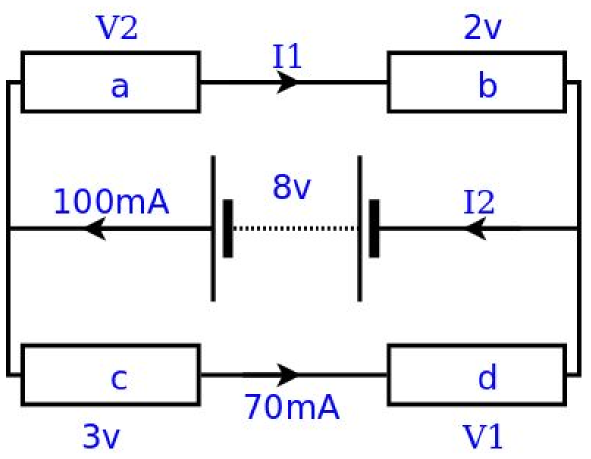
I1 = ?

I2 = ?

V1 = ?

V2 = ?

Example 4



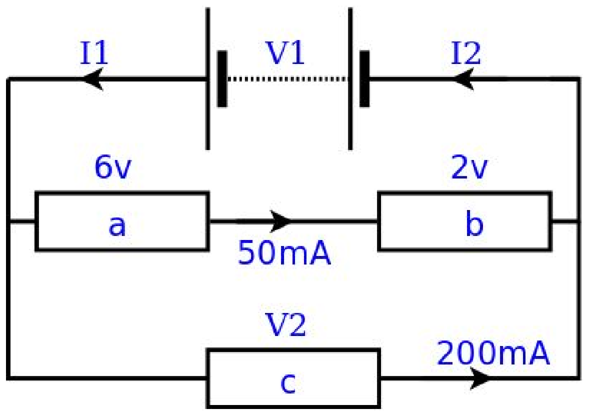
I1 = ?

I2 = ?

V1 = ?

V2 = ?

Example 5



I1 = ?

I2 = ?

V1 = ?

V2 = ?

Solutions

Example 1: The circuit is a simple series circuit and so the current is the same at all points. I1 = I2 = 3 A.

The potential differences across the two resistors must add up to the total EMF so V1 = 4 V.

Example 2: 4 A flows through **a** and into the junction, 3 A flows out through **b** so I1 = 1 A. The same current must return to the battery as left and so I2 = 4 A.

b and **c** are in parallel and so V1 = 3 V. Taking a route through **a** and **b**, V2 = 6 + 3 = 9 V.

Example 3: 2 A flows through **a** and into the junction, 1 A flows out through **b** so I1 = 1 A. The same current must return to the battery as left and so I2 = 2 A.

b and **c** are in parallel and so V1 = 3 V. Taking a route through **a**, **b** and **d**, 3 + 3 + V2 = 12 and so V2 = 6 V.

Example 4: 100 mA flows in to the left hand junction and 70 mA flows through **c** therefore 30 mA flows through **a**, I1 = 30 mA. The same current must return to the battery as left and therefore I2 = 100 mA.

Taking a route through **a** and **b**, V2 + 2 = 8 meaning V2 = 6 V. Similarly a route through **c** and **d** gives 3 + V1 = 8 and so V1 = 5 V.

Example 5: From the left hand junction, 50 mA flows through **a** and 200 mA flows through **c** therefore 250 mA must flow into the junction. I1 = 250 mA. The current returning to the battery must be the same as the current leaving the battery and so I2 = 250 mA.

Taking a route from the battery through **a** and **b** gives V1 = 6 + 2 = 8 V. As V2 is in parallel with V1, V2 = 8 V.

Website

http://www.pfnicholls.com/Electronics/simplecircuits.html

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