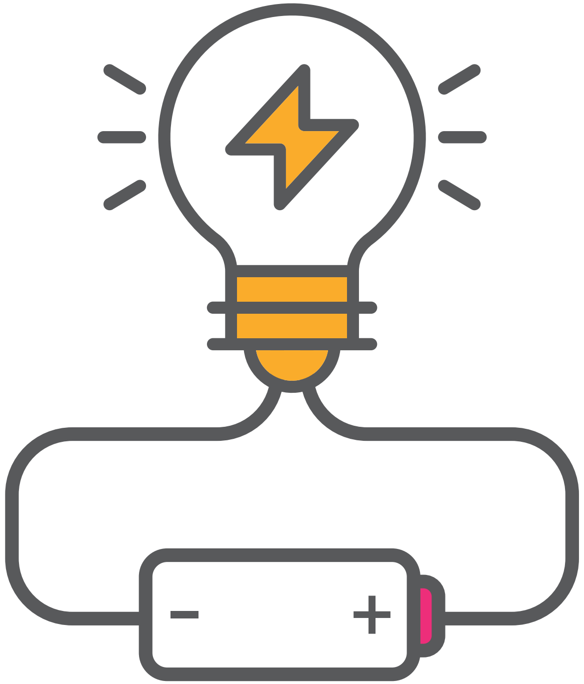
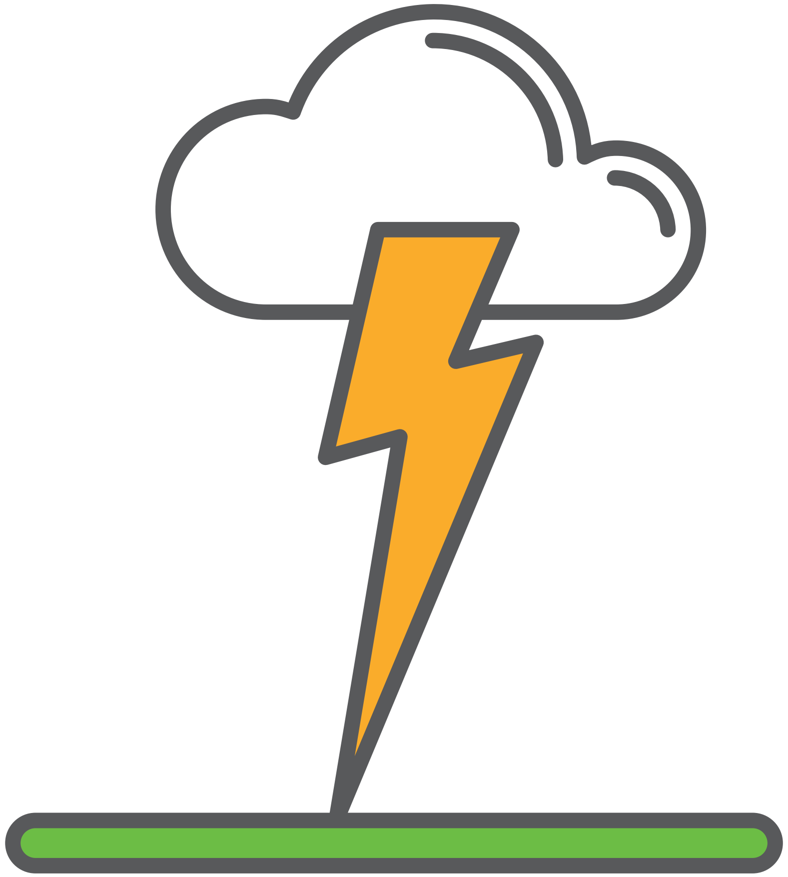
Electric Current





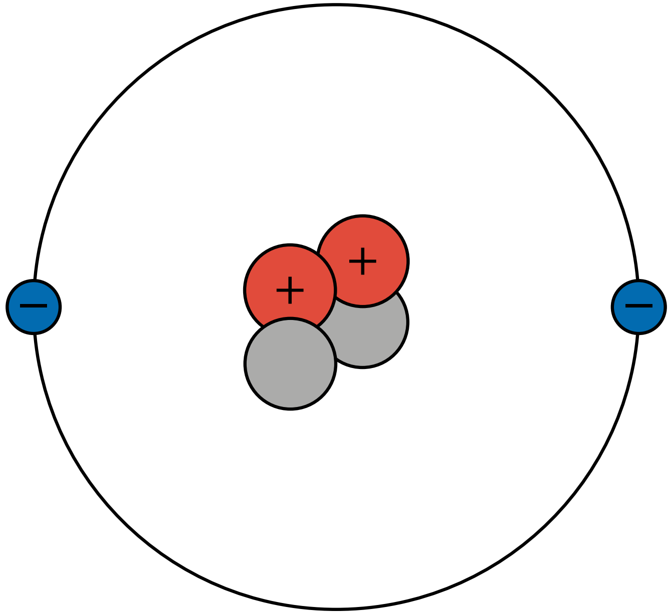
Lesson Objectives

You will be able to

- recall that electric charge is measured in coulombs,
- recall that electric current is measured in amperes (A),
- understand that electric current is the flow of electric charge,
- understand that in a typical electric circuit, current is the flow of negatively charged electrons along the wires,
- understand that the negatively charged electrons do move, but the positively charged nuclei do not,
- understand that conventional current is in the opposite direction to the movement of electrons and that this is because historically it was thought that the positive charges were moving, but this was later proven to be incorrect,
- use $I = \dfrac{Q}{t}$ in all permutations.

Charges in an Atom

Electric current is the flow of electric charge. Recall that different parts of the atom have different values of electric charge, as seen below.



Together, the positively charged protons, shown in red, and neutral neutrons, shown in gray, make up the nucleus. The negatively charged electrons, shown in blue, are outside the nucleus.

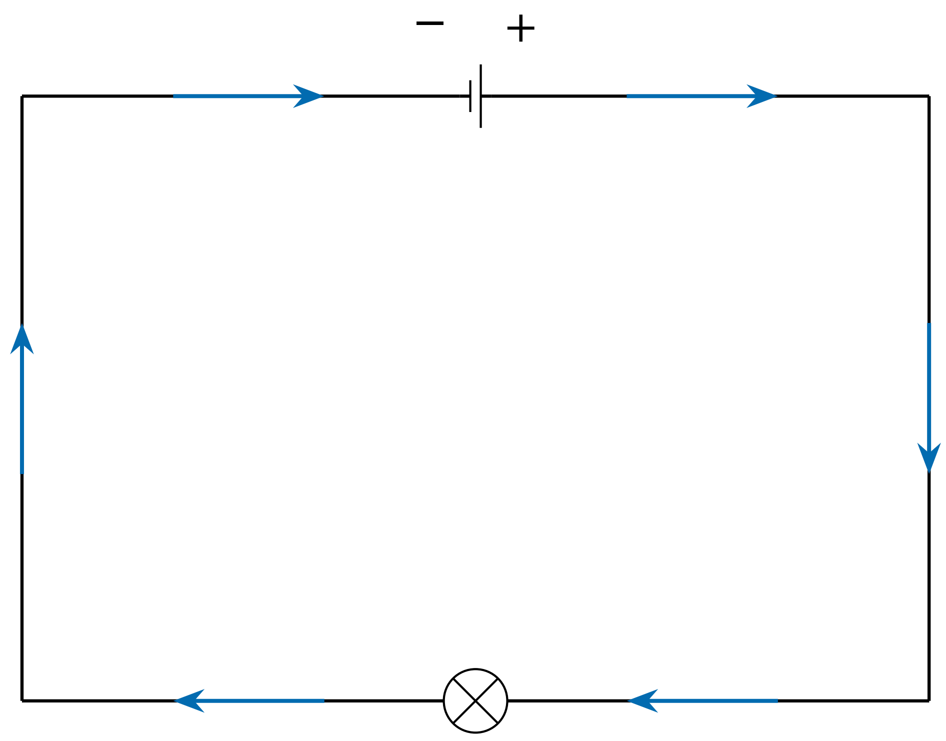
Conventional Current

In a wire, electrons can flow, but protons and neutrons cannot.

Early scientists did not know this. They assumed that only positive charges could flow. This convention is still used today.

Conventional current is the flow of charge, assuming that the electric charge carriers are positive. This means they move away from the positive terminal of a cell and toward the negative terminal.

When a current is indicated on a circuit diagram, we assume that it is showing the direction of the conventional current, not the flow of electrons. This is shown in the diagram to the right.



Definition: Electric Current

When measuring the amount of charge passing through a point, the current through that point can be expressed as

$$I = \frac{Q}{t},$$

where I is the current, Q is the total charge moving past a point, and t is the time taken.

Calculating Electric Current

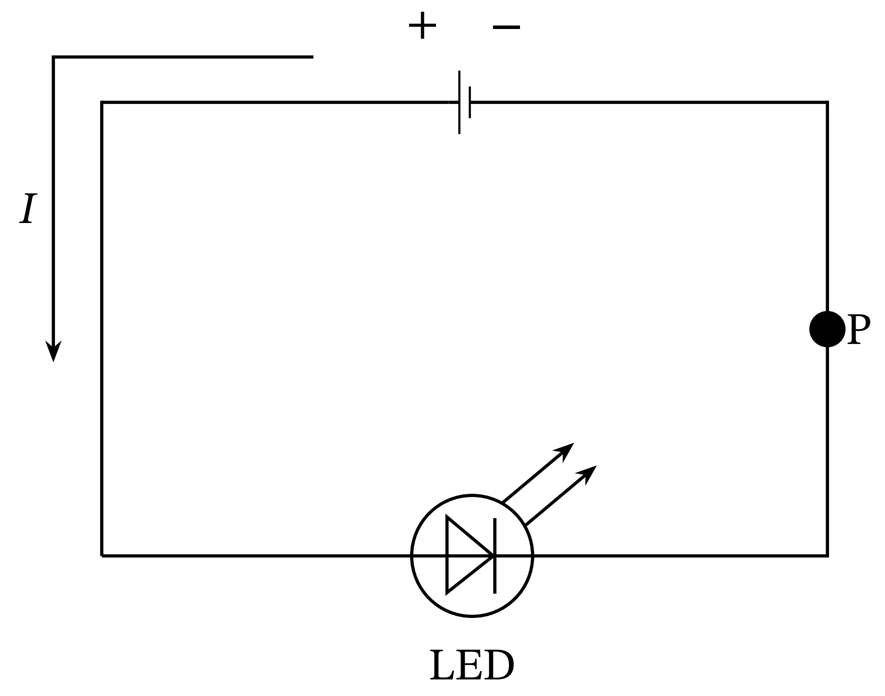
The SI unit for current is the ampere. One ampere is equal to one coulomb per second, $1\ \text{A} = 1\ \text{C/s}$.

Current is positive when its direction is the same as that of conventional current, the direction in which positive charges would flow.

Current is negative when its direction is opposite to that of conventional current, the direction in which the electrons are flowing.

Example 1: Finding the Current through a Point in a Circuit

The diagram shows a circuit consisting of a battery and a light-emitting diode (LED). Over a period of 25 seconds, a charge of 50 coulombs passes through point P in the circuit. What is the current in the circuit during this period?



Example 1 (Continued)

Answer

In this circuit, conventional current has a counterclockwise direction and passes through the LED on its way to point P. The electrons flowing through it are not used up; they just move.

Measuring the current just before the LED would give the same value as at point P and, indeed, at any point in the circuit. To find the current in the circuit during this period then, we can measure the current at point P.

Since we are given the time taken to pass point P, $t = 25$ seconds, and the total charge of the electrons, $Q = 50$ coulombs, we can solve for the current.

Example 1 (Continued)

Looking at the definition of electric current,

$$I = \frac{Q}{t},$$

we just need to put the values for Q and t in, 50 C and 25 s, respectively, as follows:

$$I = \frac{(50\,\mathrm{C})}{(25\,\mathrm{s})}.$$

The units of coulombs divided by seconds (C/s) are equal to the SI units of current, amperes, with the symbol A, so

$$\frac{(50\,\mathrm{C})}{(25\,\mathrm{s})} = 2\,\mathrm{A}.$$

Therefore, the current in the circuit during this period is 2 amperes.

Calculating Charge

Sometimes the current is known in a circuit but the electric charge flowing past a specific point is not. We can isolate this charge past a point, Q, in the equation in order to find it by itself.

Let's start with the defining equation for current:

$$I = \frac{Q}{t}.$$

We want just the electric charge, Q. To isolate this variable, we can multiply both sides by t:

$$I \times t = \frac{Q}{t} \times t.$$

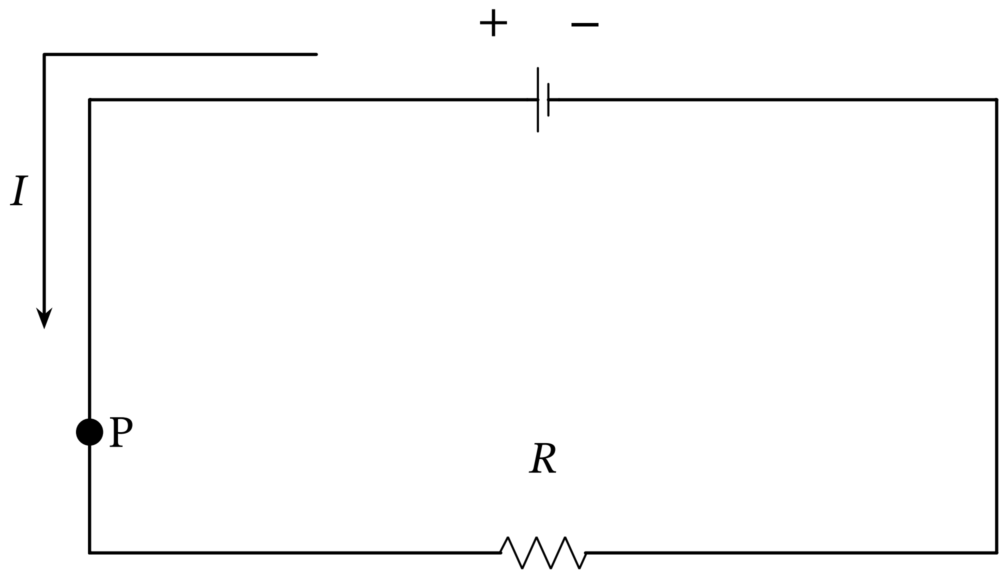
Multiplying through cancels t on the right-hand side, leaving behind

$$It = Q.$$

Therefore, the total charge, Q, passing a point is equal to the product of the current through that point, I, and the time taken to pass, t.

Example 2: Finding the Charge Flowing through a Point in a Circuit

The diagram shows a circuit consisting of a battery and a resistor. The current through the circuit is 2.0 A. Over a period of 45 seconds, how much charge flows past point P in the circuit?



Example 2 (Continued)

Answer

The current at point P is the same as the current at any point right before the negative terminal of the battery.

We are given current and a period of time. The amount of charge that flows past point P can be found by using the equation

$$It = Q.$$

The value of the current is $2\,\mathrm{A}$, and the value of the time is $45\,\mathrm{s}$. Hence,

$$(2\,\mathrm{A})\,(45\,\mathrm{s}) = Q.$$

Example 2 (Continued)

The units of amperes, A, are equivalent to coulombs per second, C/s. From this, we see that multiplying the terms I and t cancels the units of time:

$$\begin{aligned} \text{A} \times \text{s} &= (\text{C}/\text{s}) \times \text{s} \\ &= \text{C}. \end{aligned}$$

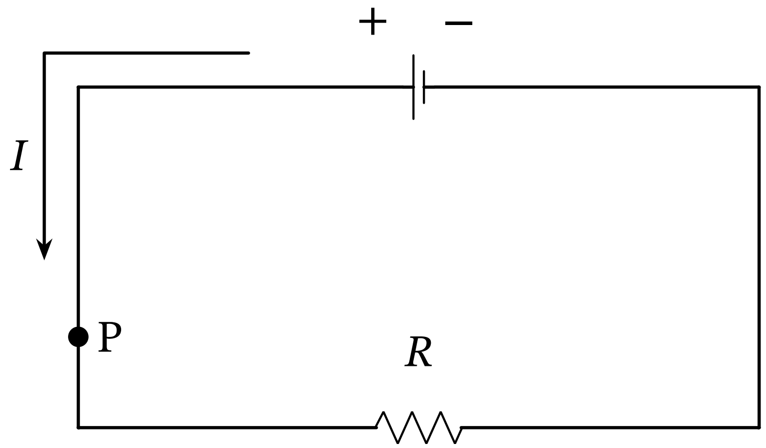
Multiplying through, thus, gives an answer in coulombs:

$$(2\,\text{C}/\text{s})\,(45\,\text{s}) = 90\,\text{C}.$$

Therefore, over a period of 45 seconds, there are 90 coulombs of charge that move past point P in this circuit.

Example 3: Finding the Charge Flowing through a Point in a Circuit

The diagram shows a circuit consisting of a battery and a resistor. The current through the circuit is 50 mA. Over a period of 1.5 hours, how much charge flows past point P in the circuit?



Example 3 (Continued)

Answer

We can use the equation

$$It = Q$$

to find the charge. However, current has a unit prefix, and the time period is given in hours. Let's try to get the answer in terms of coulombs.

For every 1 ampere, there are 1 000 milliamperes:

$$\frac{1\ \text{A}}{1\,000\ \text{mA}}.$$

This means that 50 mA is

$$\frac{1\ \text{A}}{1\,000\ \text{mA}} \times 50\ \text{mA} = 0.05\ \text{A}.$$

Example 3 (Continued)

For the value of time that we have been given, we will need to convert it from hours to seconds. There are 60 minutes in 1 hour:

$$\frac{60\,\text{min}}{1\,\text{h}}.$$

So, 1.5 hours gives us

$$\frac{60\,\text{min}}{1\,\text{h}} \times 1.5\,\text{h} = 90\,\text{min}.$$

Similarly, there are 60 seconds in 1 minute. So, 90 minutes gives us

$$\frac{60\,\text{s}}{1\,\text{min}} \times 90\,\text{min} = 5\,400\,\text{s}.$$

Example 3 (Continued)

Now that we have the values for I and t, 0.05 amperes and 5 400 seconds, we can put them into the equation to obtain the total charge flowing past point P:

$$(0.05\,\mathrm{A})\,(5\,400\,\mathrm{s}) = Q.$$

The units of amperes, A, are equivalent to coulombs per second, C/s. From this, we see that multiplying the terms I and t cancels the units of time:

$$\begin{aligned} \mathrm{A} \times \mathrm{s} &= (\mathrm{C/s}) \times \mathrm{s} \\ &= \mathrm{C}. \end{aligned}$$

The units left behind after multiplication are coulombs. The answer is thus

$$(0.05\,\mathrm{C/s})\,(5\,400\,\mathrm{s}) = 270\,\mathrm{C}.$$

So, over that period of time, 270 coulombs of charge have passed by point P.

Calculating Time

We can also rearrange the equation for electric current to make time the subject. This will allow us to discern the amount of time it takes for a certain amount of charge to pass by a point. Using the previously modified equation, we have

$$It = Q.$$

We can then divide both sides by I to isolate t:

$$\frac{It}{I} = \frac{Q}{I}.$$

The Is on the left-hand side cancel, giving us

$$t = \frac{Q}{I}.$$

The time taken for charge passing a certain point t can be found by dividing the total charge, Q, by the current, I.

Example 4: Finding the Time in Which a Charge Passes through a Point in a Circuit

A laptop charger passes a current of 5.0 A through a laptop battery. Over a period of time, 45 000 C of charge is transferred to the battery. For how many hours was the laptop left to charge?

Answer

The amount of time it takes for this laptop to charge can be found by using the equation

$$t = \frac{Q}{I}.$$

The charge, Q, is 45 000 C and the current, I, is 5 A. Putting these values into the equation gives us

$$t = \frac{(45\,000\text{ C})}{(5\text{ A})}.$$

The units of amperes, A, are equivalent to coulombs per second, C/s:

$$\text{A} = \text{C/s}.$$

Example 4 (Continued)

This means that the terms in the equation can be written as

$$\frac{(45\,000\text{ C})}{(5\text{ C/s})}.$$

Dividing a number by a fraction is the same as multiplying this number by the reciprocal of that fraction. We can use this relation to see how the units in the fraction cancel:

$$\begin{aligned}\frac{\text{C}}{(\text{C/s})} &= \text{C} \times (\text{s/C})\\ &= \text{s}.\end{aligned}$$

The units left behind are just seconds, so the answer will be in seconds:

$$\frac{(45\,000\text{ C})}{(5\text{ C/s})} = 9\,000\text{ s}.$$

Example 4 (Continued)

We still have to convert these seconds into hours. There are 60 seconds in 1 minute, so

$$\frac{1\,\text{min}}{60\,\text{s}} \times 9\,000\,\text{s} = 150\,\text{min}.$$

60 minutes in 1 hour means that 150 minutes is

$$\frac{1\,\text{h}}{60\,\text{min}} \times 150\,\text{min} = 2.5\,\text{h}.$$

So, it takes this battery 2.5 hours to gain 45 000 C of charge.

Example 5: Finding the Time in Which a Charge Passes through a Point in a Circuit

A rechargeable battery is left to charge for a period of time. It is charged with a current of 10 mA. After it has finished, the battery has gained 180 C of charge. For how many hours was the battery left to charge?

Answer

To find the amount of time needed to charge the battery, we just need to divide the total charge gained by this battery by the charging current:

$$t = \frac{Q}{I}.$$

For every 1 ampere, there are 1 000 milliamperes:

$$\frac{1\ \text{A}}{1\,000\ \text{mA}},$$

$$\frac{1\ \text{A}}{1\,000\ \text{mA}} \times 10\ \text{mA} = 0.01\ \text{A}.$$

Example 5 (Continued)

Now, we can use the equation by putting in the charge of 180 C and current of 0.01 A:

$$t = \frac{(180\,\mathrm{C})}{(0.01\,\mathrm{A})}.$$

The units of amperes are equivalent to coulombs per second, C/s:

$$\mathrm{A} = \mathrm{C/s}.$$

This makes the terms look like

$$t = \frac{(180\,\mathrm{C})}{(0.01\,\mathrm{C/s})}.$$

Dividing a number by a fraction is the same as multiplying this number by the reciprocal of that fraction. We can use this relation to see how the units in the fraction cancel:

$$\begin{aligned}\frac{\mathrm{C}}{(\mathrm{C/s})} &= \mathrm{C} \times (\mathrm{s/C}) \\ &= \mathrm{s}.\end{aligned}$$

Example 5 (Continued)

The units of coulombs cancel, leaving behind units of seconds:

$$\frac{(180)}{(0.01)}\,\mathrm{s} = 18\,000\,\mathrm{s}.$$

Now, we convert the seconds to hours, starting with converting to minutes first. There are 60 seconds in 1 minute, so

$$\frac{1\,\mathrm{min}}{60\,\mathrm{s}} \times 18\,000\,\mathrm{s} = 300\,\mathrm{min}.$$

There are 60 minutes in 1 hour, meaning that 300 minutes is thus

$$\frac{1\,\mathrm{h}}{60\,\mathrm{min}} \times 300\,\mathrm{min} = 5\,\mathrm{h}.$$

So, it takes this battery 5 hours to gain 180 C of charge.

Key Points

- Electric current is the flow of electric charge and is measured in amperes:

$$I = \frac{Q}{t},$$

  where I is the current, Q is the total electric charge past a point, and t is the time.
- Conventional current assumes that the charge carriers are positive, and it flows away from positive terminals and toward negative terminals.
- Electrons move along the wire of a circuit, but the nuclei of the atoms in the wire do not.
- To find the total charge past a point, the electric current equation can be rearranged to be

$$Q = It.$$

- To find the time it takes for some amount of charge to move past a point, the electric current equation can be rearranged to

$$t = \frac{Q}{I}.$$