Currents

Sanjin Zhao

1st Oct, 2022

Learning Outcome

I highly recommend you to finish this checklist to determine whether you've achieved the learning objectives.

- ☐ understand of the nature of electric current
- ☐ solve problems using the equation $Q = It$ or $I = {}^{\Delta Q}/_{\Delta t}$
- ☐ solve problems using the formula $I = nqvA$ or $I = nAve$
- ☐ solve problems involving the mean drift velocity of charge carriers

Leadin

The word currents means something that can flow, for example, water in a river or stream, seawater, and as of today's topic - the electric currents.

Electric Current

In last topic, we've discussed the *electrostatics*[1]. But when talking about the electric currents, the charges are moving.

[1] def:

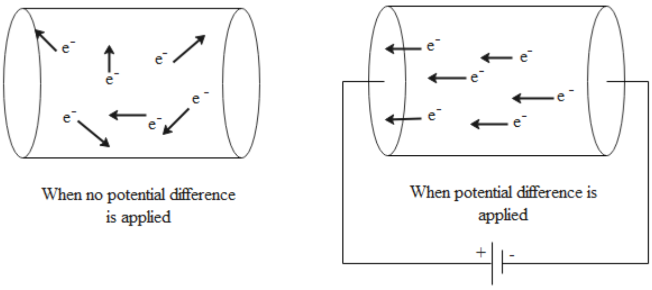


Figure 1: A current forms when the direction of electron are regular

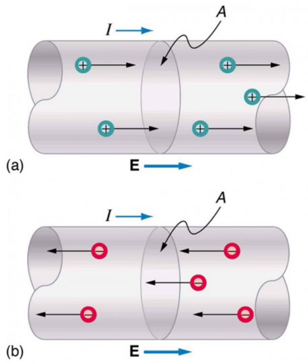


Figure 2: the direction of current may or may not be consistent with the direction of charge carriers

Essence of Currents

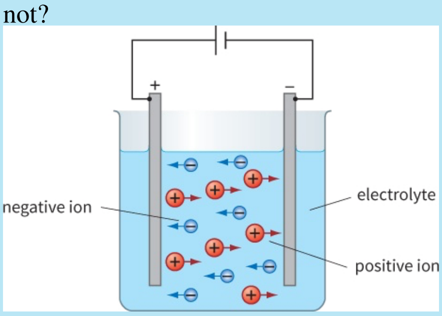
So electric current are in essence the *directed, regular flow of charge*. Which means any **charge carriers** has a regular moving will form a current in the interior of the material itself.

Thus, the direction of currents are defined as following:

- if the charge carriers are positive, the direction of current is ______________ with the direction of the carriers
- if the charge carriers are ______________, the direction of current is opposite as the direction of the carriers

Task

Specify the direction of cations and anions in the galvanic cells. Specify the direction of the electrons in the circuits Specify the direction of currents, and determine whether the circuit is closed or not?



The unit of coulomb and ampere

How to qualitatively describe the currents, it will naturally come to your mind that if more charges flows through a surface, the currents will be larger. Thus, the definition of current is stated below:

Summary

Current, I, is the rate of flow of electric _______________ past a point

$$I = \underline{\hspace{4cm}}$$

Rewrite the expression, we will achieve the equivalent expression $\Delta Q = I \cdot \Delta t$, because the ampere,A, is the SI base unit, thus 1 C = 1
.

So 1 C is defined as the charge that flows past a point in a circuit in a time of 1 s when the current is 1 A.

Task

How many electrons flow past a point when the current is 1 A.

A power bank is labelled '10 000 mA h' which means that it can supply a current of 1000 mA for 10 hours. For how long could the power bank supply a continous current of 2 A?

Microscopic Perspective

Since electron is the most frequent case when talking about the currents.

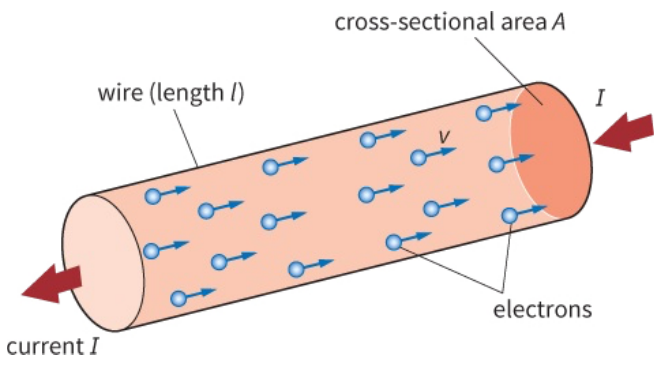


Figure 3: A microscopic view of currents

Before eliciting the formula for current, several concept shall be introduced.

Number Density,n

Silver, Copper, and nearly almost metal are good conductors because of the "sea of electron" exist in the metal, which has provided enough free electron to move, to form current in the metal wire. And

Summary

the *number density* is the number of conduction electrons(charge carriers) per unit volume.

Metals have a high electron number density–typically of the order of 10^{28} or 10^{29} m^{-3} . Semiconductors, such as silicon and germanium, have much lower values of n–perhaps 10^{23} m^{-3}. while electrical insulators, such as rubber and plastic, have very few conduction electrons per unit volume to act as charge carriers.

Drift Velocity

It will be apparent that if electron flows faster, the current it forms would be larger, but the problem is that not all electrons' velocities are exactly the same. Scientists has perfectly solved that problem by introducing the statistical method- average value. And specifically, such velocity is called mean drift velocity, which defined as:

Summary

mean drift velocity, v_d, is the average speed of a collection of charged particles when there is current in a conductor.

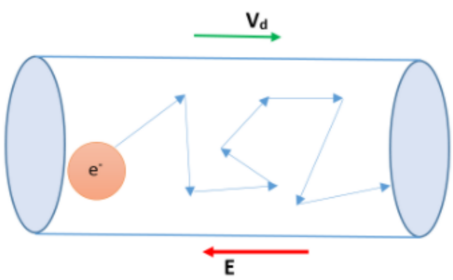


Figure 4: drift velocity is not the real speed of single electrons, but the average speed of a collection of electrons

Equation for Currents

In the Fig.3, several factors seem to be the deciding factors of currents- the number density, the drift velocity. Starting from the definiton $I = {}^{\Delta Q}/_{\Delta t}$.

- the amount of eletron passing a cross section of the conductor can be denoted as N
- due to the number density of electrons, $N = n \cdot V$
- in the time period of Δt, with the drift velocity being v, the cross sectional area being A. Thus the volume is $V =$ _______________

- thus, the total charge passing through the cross section is $\Delta Q = N \cdot e =$ ________________________

With the whole process, the currents can be expressed by

Summary

$$I = nevA$$

Sometimes, the charge carrier may not be the electrons, so the equation can be rewritten as $I = nqvA$, in which q is the charge for single carrier. it is usually a multiple of e.

Task

Check the homogeneity of the equation $I = nevA$

Calculate the mean drift velocity of electrons in a copper wire of diameter 1.0 mm with a current of 5.0 A. The electron number density for copper is $8.5 \times 10^{28}\,\mathrm{m}^3$.