Velocity of an Electric Current

Sjaak Uitterdijk
sjaakenlutske@hetnet.nl

Abstract-This article argues that the velocity of an electric current in a solid conductive wire most likely equals the orbital velocity of the valence electron(s) in the atom of the matter of the wire.

1. Introduction

The article considers two approaches to calculate the velocity of an electric current: one based on the current itself as starting point, the other one based on the source of the current as starting point. Only currents in a solid conductive (copper) wire are considered, so excluding the propagation velocity of EM-waves, of which their velocity in a medium, not moving relative to the source of the EM-wave, can simply be expressed by the equation: $v_p = 1/\sqrt{\varepsilon\mu}$, with ε the dielectric permittivity and μ the magnetic permeability of the medium under consideration.
In vacuum leading to: $\boldsymbol{c} = 1/\sqrt{\varepsilon_0\mu_0}$, relative to its source in the absence of another possible relevant reference.

2. The current as starting point

From the point of view of the phenomenon "electrical charge" Q, an electric current I is represented as Q/t, with t the time during which a charge Q passes a certain area where the current flows.
This principle has been applied developing a model of the generation of a photon [2].
Copied from this article:

> *"The fundamental part of the investigated model is the assumption that the orbit of an electron around the nucleus of an atom is equivalent to a circular shaped electric current, creating a magnetic field.*
>
> Suppose the "round trip" of an electron is t seconds and its electric charge is represented by the symbol q. Then the first approximation of the meant electric current is q/t = i . "

At the end of the day it turned out that the words "the first approximation of" are superfluous.

However, in the situation under consideration (an electric current through a solid wire) the starting point is the current instead of a (moving) charge. From this point of view Q will be calculated as $Q = n_eqS$, with:

Q	the electric charge per meter wire	[C/m]
n_e	the density of the valence electrons of copper	[m^{-3}]
q	the electric charge of an electron	[C]
S	the surface of the cross section of the wire	[m^2]

The purpose of the addition "per meter wire" in the definition of Q is to be able to introduce a velocity of the current in terms of [m/s].
Taking v_I as symbol for this velocity we can now write: $I = Q*v_I = n_eqS * v_I$.

> Of course, the question: why would an arbitrary length and arbitrary cross section of a wire be representative for the velocity of the electric current in that wire, arises. Anyway, the calculation process will be continued.

So: $v_I = I_d/n_eq$ [m/s],   with $I_d = I/S$, being the surface density [A/m^2] of the current in the wire.

The calculation below shows that $n_e = 8.5*10^{28}$ [m^{-3}] (a copper atom has 1 valence electron)
N.B. The accuracy of the values doesn't play any role in this consideration.

Specific weight of copper:	$9*10^3$ kg/m^3
Atomic weight of copper:	$1*10^{-25}$ kg
Number of copper atoms	$9*10^{28}$ m^{-3}

The charge of an electron equals $1.6*10^{-19}$ [C], so $v_I = I_d/n_eq = I_d * 7 * 10^{-11}$ [m/s]

A normal current density is between 1 and 10 A/mm^2, with the highest one representing the so-called "house-hold-configuration". This value (10^7 A/m^2) leads to $v_I = 7*10^{-4}$ [m/s].
The consequence of this number is that if we switch on a light in a normal room it would take 7 meter / $7*10^{-4}$ [m/s] = 10^4 s ≈ 2.5 hours before we would see the light!

We clearly have to look for a completely other approach, also looking back to the question asked above: why would an arbitrary length and arbitrary cross section of a wire be representative for the velocity of the electric current in that wire?

3. The source as starting point

It is generally accepted that the source of an electric current can be a generator or a battery.
Copied from: https://en.wikipedia.org/wiki/Electromotive_force

> "Electromotive force, abbreviated emf .... is the electrical intensity or "pressure" developed by a source of electrical energy such as a battery or generator. A device that converts other forms of energy into electrical energy (a "transducer") provides an emf at its output. "
>
> "In the case of a two-terminal device (such as an electrochemical cell) which is modeled as a Thévenin's equivalent circuit, the equivalent emf can be measured as the open-circuit potential difference or "voltage" between the two terminals. This potential difference can drive an electric current, if an external circuit is attached to the terminals."

But it can be, for example, also a charged capacitor.
Such an example shows that the source of an electric current in principle is an amount of electrical charge (on an object with respect to another object).
Such a charge will, getting the opportunity, flow from the one to the other object in order to create a balance between the charges on both. A wire, for example, can create such an opportunity.

It is generally accepted (there will always be exceptions) that electrons build up an amount of electric charge and that an electric field exists between opposite electric charged objects.

At the moment a wire is connected between such a pair of electric opposite charged objects, the mentioned electric field causes electrons at the one charged object to move to the other object through the wire in one way or another. The wire consists of so called valence electrons. The very first electron that leaves the wire to move to the positive charged object is replaced by a valence electron form an atom more close to the negative charged object. Both electrons can have only a velocity equal to their orbital velocity, because they just jump out of their orbit. This happens through the whole wire successively until an electron from the negative charged object replaces a valence electron most close to this object.

As a result the velocity of an electric current equals roughly the mentioned orbital velocity. The calculation of this velocity is as follows.
Based on Bohr's atomic model the radii of the discrete orbits of the electrons are mathematically represented by $r_n = n^2 a_0/Z$, with n is an integer, representing the n^{th} orbit.
The radius a_0 is the so-called Bohr's radius, the smallest (n=1) in the atom under consideration. The atom is characterized by its atomic number Z. Z=29 for copper.
a_0 is a constant, independent of whatever atom, expressed by: $h^2/(4\pi^2 k_e q^2 m)$, with:

h	Planck's constant	$6.6*10^{-34}$	kgm^2s^{-1}
k_e	Coulomb's constant (1/4πε$_0$)	$9*10^9$	Nm^2C^{-2}
q	electric charge of the electron	$1.6*10^{-19}$	C
m	mass of the electron	$9*10^{-31}$	kg

Given these values $a_0 = 5*10^{-11}$ m.
The 4^{th} orbit of the copper atom is the orbit of its valence electron, so its radius is:
$r_4 = 4^2 *5*10^{-11}/29 = 3*10^{-11}$ m. This result is necessary to calculate the orbital velocity.

The electron is held in its orbit by the centripetal and centrifugal forces applied to it. The centripetal one is the Coulomb force between nucleus and electron. The gravitational force between electron and nucleus is incomparably small compared to the Coulomb force.
The centrifugal force equals mv^2/r, with v the orbital velocity of the electron.
So $mv^2/r = k_eZq^2/r^2$, resulting in $v = (k_eZq^2/mr)^{½}$. More background can be found in [1].
Applying $r=r_4$ results in $v= 2*10^7$ m/s.

4. Heating of the wire explained at atomic level

An electric current through a wire generates heat in that wire. The generally accepted conception of heat is that the warmer the matter is, the more the atoms of the matter move/vibrate. In case of a gas and liquid the word 'move' is more applicable, while 'vibration' is used in case of solid matter.
The experience is that the higher the current the warmer the wire becomes. A high current means a lot of (valence) electrons per unit of time moving from one pole to the other. So the question is: what causes the atoms to vibrate more if its valence electrons move from the one to the other atom? Or the question is: is the more heat generation only a result of the fact that more atoms are going to vibrate? Based on the result obtained above, it has to be concluded that the velocity of the current, so of the valence electrons, is independent of the strength of the current. As a result the most direct and simple answer is that each collision of a valence electron with another valence electron, not only does jump that other valence electron out of its orbit, but also causes the atom to vibrate more than it did already, causing the extra heat. The second part of the answer is that the higher the current the more atoms contribute to this heat generation.
In a light bulb not only the heat generation is high, but also the light emission.
Reference [1] shows why this supports the correctness of the statement: the higher the current the more atoms contribute to this heat generation.

Conclusion

The velocity of an electric current is more or less equal to the orbital velocity of the valence electrons in the applied material, resulting in velocities of the order of 0.1 á 0.01 times the propagation velocity of light.

Reference

[1] Why a Photon is not a Particle: http://vixra.org/abs/1505.0225