A New Definition of an Electronvolt

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A typical definition of an electronvolt is expressed by professor Serway in his physics textbook: "A unit of energy commonly used in atomic and nuclear physics is the electron volt, which is defined as *the energy that an electron (or proton) gains when passing through a potential difference of magnitude of 1 V.*" [1] The value of this unit was determined experimentally to be 1.602 176 634x10^{-19} Joules.

All definitions of the electronvolt, including the one above, give the impression that an electronvolt represent all the energy an electron acquires when accelerated by passing through an electric field. This paper will show that the energy gained by an accelerated electron is greater than the value of an electronvolt. Thus, a new and a more precise definition of the electronvolt is needed.

This paper will introduce a new, more accurate and a more intuitive definition, where *"An electronvolt represents* internal energy *of the mass that an electron acquires as it travels through an electric field generated by the potential difference of 1 volt."*

When subtracting one internal energy from another, the difference must also be internal energy

According to physics textbooks, the kinetic energy of a slow moving electron is found from equation

$$m_0v^2/2 = mc^2 - m_0c^2 \tag{1}$$

or

$$KE = mc^2 - m_0c^2 \tag{2}$$

where mc^2 is the internal energy of the *accelerated electron* and m_0c^2 is the internal energy of the same *electron at rest*. [2]

What is on the right-hand side of the equation must also be on the left-hand side. On the right-hand side of the last equation, there are two internal energies. When we subtract one internal energy from the other, the difference must also be internal energy. However, in the above equation, the subtraction of two internal energies yields kinetic energy. It is like subtracting an orange from two oranges, where the result of subtraction is an apple instead of an orange.

Subtracting the internal rest energy of an electron before acceleration takes place from the internal energy of an electron after it passes through an electric field must yield the *internal energy* of the stuff the electron collects while passing through an electric field.

Because the kinetic energy of an electron (with the rest mass m_0) accelerated by 1 volt potential difference is equal to the energy value of an electronvolt, the above equation yields:

$$eV = mc^2 - m_0c^2 \tag{3}$$

The mass m in the term mc^2 indicates the mass of an accelerated electron, which is composed of the original mass of the electron m_0 plus the newly acquired mass m_a. An electronvolt is then

$$eV = (m_0+m_a)c^2 - m_0c^2 \tag{4}$$

or

$$eV = m_ac^2 \tag{5}$$

An electronvolt is equal to the internal energy of the mass difference of the total mass of an accelerated electron and its rest mass. This leads to a new and more intuitive understanding of the nature of an electronvolt.

New definition of an electronvolt

The term mc^2 (mass times the speed of light squared) represents the internal (or stored) energy of an object or a particle of mass m. This must be the case with the equation $eV=m_ac^2$. Hence:

An electronvolt represents internal energy of the mass that an electron acquires as it travels through an electric field generated by the potential difference of 1 volt.

More specifically, *an electronvolt represents* 1.602 176 634x10^{-19} *J of work the extra acquired mass of an electron can perform after the electron passes through the potential difference of 1 volt.*

Mass associated with an electronvolt

Equation $eV=m_ac^2$ states that an electronvolt is related to a certain mass m_a acquired by an accelerated electron. Because an eV is a known value, 1.602 176 634x10^{-19} J, the mass that is responsible for the amount of work an electronvolt can perform is:

$$m_a = m_{eV} = eV/c^2 \tag{6}$$

which yields

$$m_{eV} = 1.782\ 638\ 137\text{x}10^{-36}\ \text{kg}$$

By gaining extra mass m_{eV} and internal energy $m_{eV}c^2$, along with kinetic energy, an accelerated electron with the rest mass m_0 also gains the speed v and the kinetic energy $m_0v^2/2$ (where v is a slow non-relativistic speed). Because the newly gained mass m_{eV} and the rest mass of the electron m_0 are part of one particle, *both traveling at the same speed*, the internal energy of the mass m_{eV} equals the kinetic energy of the electron with the rest mass m_0. In other words,

$$eV = m_{eV}c^2 = m_0v^2/2 \tag{7}$$

Because an electron gains an equal amount of energy for every applied volt, and because this energy represents the internal energy of the collected mass, *an electron passing through an electric field generated by potential difference of 1 V must gain, at non-relativistic speeds, the same amount of mass for every volt of applied potential difference.*

Energy, internal or kinetic, is the function of mass and speed. Mass m is the constituent of every energy equation. Thus, energy cannot exist without mass. So it must be with the energy of an accelerated electron.

Because an electron gains an equal amount of energy for every applied volt, it must also gain an equal amount of mass.

While this comes directly from established theories and the way the mass of an accelerated particle is calculated in contemporary physics, no textbook ever states this in these terms. Yet the acquired *mass and speed* are the hallmarks of all particle accelerations and the source of energy of all accelerated particles.

Where does the proportionality between applied voltage and acquired electronvolts come from?

Physics textbooks tell us that for every applied volt, an electron gains a fixed amount of energy, 1.602 176 634x10^{-19} joules.

The electron gains the same number of electronvolts whether it passes through an electric field generated by 5V, or if it passes through five successive fields of 1V each (like in a linac), or in a combination of fields of 1V and 4V, or 2V and 3V. What makes this remarkable proportionality possible?

In order for this proportionality to exist, the above-mentioned proportionality must be related to or caused by another more fundamental proportionality.

There is only one: The strength of an electric field depends on the number of electrons on the negative plate. Electric charges only come in whole units of *e*, which is the charge of an electron. In other words, it cannot be half of an *e*, or any part of it. Therefore, the strength of an electric field can increase or decrease by a fixed value associated with the electric charges, or the number of electrons on the negative plate. One whole electron is either present on the plate or not present, and so is the case with an electric charge.

Because the strength of the electric field is related to these whole units of charge, an electric field is a *quantum field*. As an accelerated particle passes through this *quantum field, it* gains extra mass and speed, that is, gains energy. Hence, there must be a relationship between the quantum nature of an electric field and the energy of an accelerated particle, as electronvolts also come only in whole units.

The quantum nature of the energy of an accelerated particle, and the proportionality between this energy and the applied voltage, must come from the quantum nature of the electric field. Therefore, every extra volt of applied voltage means a proportional extra number of electrons on the negative plate. This means that an accelerated electron "communicates" in an equal manner with every electric charge on the plate.

The term *"communicates"* refers to the exchange of virtual photons between the accelerated electron and the electric charges. An accelerated electron must be exchanging and absorbing virtual photons in an *equal* manner with every electric charge that generates the electric field.

If this is the case, then the energy acquired by an accelerated electron will be proportional to applied voltage, and applied voltage will be proportional to the number of electrons on the negative plate, or the potential difference between the two plates.

Hence, an accelerated electron will gain the same amount of mass and energy for every applied volt.

An eV does not represent total energy acquired by an electron accelerated by 1 V

Let us find the speed of an electron accelerated by a potential difference of 1 volt. According to NIST-CODATA 2018 [3], the values of the following three constants are:

Speed of light	c = 299,792,458 m/s
Electronsvolt	eV= 1.602 176 634 x 10^{-19} J
Electron mass at rest	m_O = 9.109 383 701x10^{-31} kg

The speed v of an electron accelerated by 1 volt can be found from the energy equation of the moving electron [2]:

$$mc^2=m_0c^2+m_0v^2/2 \tag{8}$$

which yields

$$m_0v^2/2 = mc^2-m_0c2 \tag{9}$$

Since

$$mc^2-m_0c^2 = eV, \tag{10}$$

then

$$eV= m_0v^2/2. \tag{11}$$

or

$$v = \sqrt{2eV/m_0} \tag{12}$$

The speed v is then: v = 593,096.958 m/s

Because the electron starts from zero speed, the total kinetic energy that an electron gains during its passage through an electric field, KE_G, must equal to the sum of the kinetic energy of the electron with its original rest mass m_0 plus the kinetic energy of the newly acquired mass m_a, both moving at the newly acquired speed v. Or,

$$KE_G = KE_0 + KE_{m_a} \tag{13}$$

which yields

$$KE_G = m_0v^2/2 + m_av^2/2 \tag{14}$$

or

$$KE_G = (m_0 + m_a)v^2/2 \tag{15}$$

Hence,

$$KE_G = 1.602\ \underline{179}\ 837\text{x}10^{-19}\ \text{J}$$

The gained kinetic energy is greater than the value of an *eV*. The difference is equal to 0.000 $\underline{003}$x10^{-19} J, which is the kinetic energy of the mass acquired KE_a by the accelerated electron.

The energy gained, E_G, by an electron accelerated by 1 V potential difference is equal to the sum of the internal energy of the newly acquired mass m_ac^2 plus the gained kinetic energy KE_G. That is,

$$E_G= eV+ KE_G \tag{16}$$

or

which yields

$$E_G= m_ac^2+(m_0+ m_a)v^2/2 \tag{17}$$

$$E_G= 3.204\ 377\ 918\text{x}10^{-19}$$

Both the gained kinetic energy, KE_G, and the gained energy, E_G,of an electron after passing through the potential difference of 1 V are greater than the value of an electronvolt, eV=1.602 $\underline{176}$ 634x10^{-19} J, confirming the conclusion that an *eV does not represent all of the energy gained by an accelerated electron* and invalidates its current definitions.

The two equations for the electronvolt give the same numerical value, that is,

$$eV = m_ac^2 = m_0v^2/2 = 1.602\ 176\ 634\text{x}10^{-19}\ \text{J} \tag{18}$$

Equation $eV=m_0v^2/2$ tells us that the gained energy acquired by an electron comes from the newly gained speed v, and is a *part* of the total kinetic energy the electron gains during acceleration.

Equation $eV=m_ac^2$ tells us that the gained energy comes from the newly acquired mass, m_a.

Indeed, the gained energy, *eV*, is the result of the gained mass or gained speed as the electron passes through the electric field generated by the potential difference of 1 V.

References

[1] Raymond A. Serway, Physics for Scientists & Engineers, 3rd Edition, Saunders College Publishers, Chicago, 1990, p. 681

[2] Peter J. Nolan, *Fundamentals of College Physics*, Wm. C. Brown Publishers, Dubuque, IA, 2nd Edition, p. 879, 1995.

[3] http://physics.nist.gov/cgi-bin/cuu/Value?me|search _for=electron volt