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Calculation of Electron Stopping Power in Some Material Targets Using New Mass-Energy Concept

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Abstract

In this study, the new mass- energy concept theory, mbc, has been employed in the Beth-Bloch stopping power formula to calculate the total stopping power of electron in some materials, namely, air, tissue, water, skeletal muscle, plastic, copper and lead within the energy range of 0.01MeV to 1000MeV.The mass-energy formula mc^2 *has been over estimated since the speed of electron is below* $3x10^8$*. Therefore, the electron stopping power for low mass density materials: air, tissue, water, skeletal muscle and plastic and such others are lower for the mbc mass-energy formula; while for high mass density materials like copper and lead, the Einstein's mass-energy formula underestimates the electron stopping power because of their high excitation energies. We hereby recommend this non-relativistic mass-energy equivalence in the measurement of masses of various particles in low and high energy states to replace the relativistic mass-energy* mc^2*which results in various applications in nuclear physics and chemistry. The new mass – energy concept mbc can be employed in nuclear binding energy calculations for the investigation and interpretation of nuclear structure and nuclear reactions. The universal particle speed constant, b, can be applied in relating the frequencies and wavelengths of nuclear and elementary particles*

1.0. Introduction

The energy loss and the stopping power of charged particles through matter has been a great concern over the years due to its wide range of applications in nuclear physics[1]. Recently, the experimental and theoretical studies of the Stopping Power and range of charged particles have been increasing. Many theoretical, as well as experimental studies, have been conducted [2] as a result of continuous collision, the charged particles lose energy [3] .

The rate of energy loss per unit length is the stopping power. It is determined by the velocity and charge of the falling particles as well as the target material. Furthermore, understanding and predicting the energy loss of rapid ions in metals is critical for a variety of charged particle beam applications, including material characterization and modification. In more recent, modeling metal nanoparticle radio sensitization in ion beam is applicable in cancer therapy[13, 9] .The sum of the collision and the radiative stopping powers, was defined as total stopping power. For two reasons, separating the electron stopping power into two components was beneficial. First, the methods employed for evaluating the two components are vastly different. Second, the *energy* used to ionize

and excite atoms is absorbed in the medium relatively close to the electron track, whereas the majority of the energy lost as bremsstrahlung travels far away from the track before being absorbed [6].The Calculations of stopping power are mostly based on the ions' effective charge and velocity [7]
The average energy lose per unit path length by a charge particles in the medium, is known as the stopping power. The Collision and radiative stopping powers are the two halves of electron stopping power. The first is the most essential, and it occurs when incident particles collide with atomic electrons. To lessen the reliance on the medium density (**ρ**), mass collision stopping power is often utilized [8] .

1.1. Bethe-Bloch formula for the Electron Stopping Power

The Bethe-Bloch formula has the following full expression:

$$-\frac{dE}{dx}=\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\frac{4\pi Z^2 N_A Z\rho}{mc^2\beta^2 A}\left[ln\left(\frac{2mc^2\beta^2}{I}\right)-ln(1-\beta^2)-\beta^2\right] \quad (1)$$

The parameter -dE/dx is referred to as the stopping power, the negative sign indicate loss of energy, e is the electron charge, mass of electron, c is the speed of light, N_A is the Avogadro's constant, (Z/A) is the ratio of atomic number to the atomic mass, **ρ** is the density, β is the velocity of the particle relative to the speed of light and I is the excitation energy. The beth- bloch equation given in equation (1) is resolved into equation (2) and (2) for electron[8].

Collisonal and Radiative Stopping Powers

Collisonal Stopping power is the average energy loss per unit path length due to inelastic Coulomb collisions with bound atomic electrons in the medium which was expressed as follow

$$\left(\frac{dE}{dx}\right)_c=\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\frac{2\pi N_0 Z\rho}{mc^2\beta^2 A}\right]\left[\frac{T(T+mc^2)\beta^2}{2I^2mc^2}+(1-\beta^2)-\left(2\sqrt{1-\beta^2}-1+\beta^2\right)ln2-\frac{1}{2}\left(1-\sqrt{1-\beta^2}\right)^2\right] \quad (2)$$

T is the electron's kinetic energy, I is the excitation energy, **ρ** is the density.

Radiative Stopping Power is the average energy loss per unit path length due to bremsstrahlung emission in the electric field of the atomic nucleus and of the atomic electron and expressed by Beth as follows:

$$\left(\frac{dE}{dx}\right)_r=\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\frac{N_0 Z^2\rho(T+mc^2)}{137m^2c^4A}\right]\left[4ln\frac{2(T+mc^2)}{mc^2}-\frac{4}{3}\right] \quad (3)$$

The total electron stopping power: is the sum of the collisional and radiative stopping powers

$$\left(\frac{dE}{dx}\right)_T=\left(\frac{dE}{dx}\right)_C+\left(\frac{dE}{dx}\right)_r \quad (4)$$

1.2.The New Mass-Energy Concept:

It was reported that mass–energy relation $E=mc^2$ overestimates the nuclear energy. Therefore, the relativistic formula was suggested with a new conversion factor, other than $c^2$to help in the calculation of nuclear energy [5]
The energy of the thermal radiation was calculated using the two universal constants (**h_{plank}** =6.62606957x10^{-34} J.sec**)**, (**$K_{Boltzmann}$** $=1.3806488\text{x}10^{-23}$ J/K) which is given by; $E=h\nu$ and $E=KT$ [12] .
From the black body radiation and Boltzmann Constant K,

$$E=K_{\text{Boltzmann}}T_{blackbody} \quad (5)$$

The temperature of the thermal spectral of black body is related with the wavelength of the emitted radiation. The relation between T and λ_{max} (at high frequencies) was well described by Wien's displacement law [11] given by:

$$\lambda_{max} = \frac{b_{black}}{T_{blackbody}} \quad (6)$$

Where λ_{max} is the peak wavelength of the emission spectra at equilibrium; $T_{blackbody}$ is the temperature of the blackbody in Kelvin's (K), and b_{black}= 2.897768551x10^{-3}mK.

Hence,

$$T\ (K) = \frac{2.8977685\ \text{x}10^{-3}\ \text{m .K}}{\lambda_{max}}$$

From Debroglie theory

$$\lambda_{max} = \frac{h_{max}}{mc} \quad (7)$$

Hence $(J) = k_{Plank}\, x\, \frac{2.8977685\ \text{x}10^{-3}\ \text{m .K}}{\lambda_{max}}$

$$(J) = 1.3806488x\ 10^{-23}\ x\ \frac{2.8977685\ \text{x}10^{-3}\ \text{m .K}}{6.62606957\ \text{x}\ 10^{-34}}\ \text{x mc(J)} \quad (8)$$

Or $(J) = 0.6037970064\ x\ 10^{8} x\ mc$ (kg. meter^2/sec^2).

The derived equation was expressed as $E = (mb)c$where $(mb)$is the momentum of the particle and **c** is a conversion factor from momentum unit to energy unit or:

$$E = mbc \quad (9)$$

where$b$ =$0.6037970064\ x\ 10^{8}$

2.0. Methodology

By substituting the expression mbc in equation (9) for mc^2 in equations (2) and (3), we obtain our expression for the collisional stopping power and radiative stopping power as equations (10) and (11) respectively, hence the total stopping power, equation (4).

$$\left(\frac{dE}{dx}\right)_C = \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \left[\frac{2\pi N_0 Z\rho}{mbc\beta^2 A}\right]\left[\frac{T(T+mbc)\beta^2}{2I^2 mbc} + (1-\beta^2) - \left(2\sqrt{1-\beta^2} - 1 + \beta^2\right)ln2 - \frac{1}{2}\left(1-\sqrt{1-\beta^2}\right)^2\right] \quad (10)$$

$$\left(\frac{dE}{dx}\right)_r = \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \left[\frac{N_0 Z^2 \rho(T+mbc)}{137 m^2 b^2 c^2 A}\right]\left[4ln\frac{2(T+mbc)}{mbc} - \frac{4}{3}\right] \quad (11)$$

Where $\beta = \frac{2E}{mbc} = \frac{V^2}{bc}$

To obtain the energy loss by electron, we first calculate the relativistic mass of electron (mc^2), velocity of electron relative to speed of light (v^2/c^2 = 2E/mc^2= β^2) and electron density (n =$N_0\rho\frac{Z}{A}$) which employ collision and radiative stopping power formula as given in equation (2) and (3) by the use of computer excel program within the energy range 0.01MeV to 1000MeV. Secondly, we compute the new relativistic mass energy (mbc), electron velocity relative to the product of mass energy converting factor and speed of light (v^2/bc = 2E/mbc = β^2) and electron density. The electron stopping power fitting data of Table 1 is used.

Table 1: Computation of electron density n in air, tissue,water,skeletal muscle, plastic, copper and lead

Material	Density ρ (g/m^3)	Z/A	n =Nρ Z/A (electron/m^3)	I (eV)
Air	0.00129	0.499	3.63×10^{20}	85.7
Tissue	0.92	0.558	3.09×10^{29}	63.2
Water	1.00	0.555	3.34×10^{29}	75
Skeleton	1.04	0.549	3.44×10^{29}	75.3
Plastic	1.127	0.549	3.73×10^{23}	65.1
Copper	8.960	0.456	2.46×10^{24}	322
Lead	11.35	0.396	2.70×10^{24}	823

3.0. Results and Discussion

Table 1 shows the computation of electron density (n) of water, tissue, skeletal muscle, air, plastic, copper and lead. Observation shows that the materials are listed in order of increasing densities: air, tissue, water, skeletal muscle, plastic, copper and lead. However, in terms of electron density per unit volume the order is almost reversed: air, plastic, copper, lead, tissue, water, skeletal muscle, in increasing order. The atomic number per unit mass decreases from tissue down to lead, while the excitation energies are exceptionally high for metallic copper and lead.
The graphical presentations of the results shown in Figs. 1 to 7 are plots of total stopping power versus energy of electron. Correlations between the calculated electron stopping power in black using mc^2 and the blue is the calculated electron stopping power using the mass-energy concept, mbc. These have been represented by (a) and (b) respectively.

3.1. Observation

The electron stopping power (b) using mbc (blue), rides below that of (a) mc^2 for :air; tissue; water - but above at higher energy values; skeletal muscle; plastic –but at higher energy values become equal; and the curves ride above for copper - with uniform difference; and lead - but merges at higher energy values. The curves are hyperbolic at lower electron energies and at higher energy values approximate to straight lines.

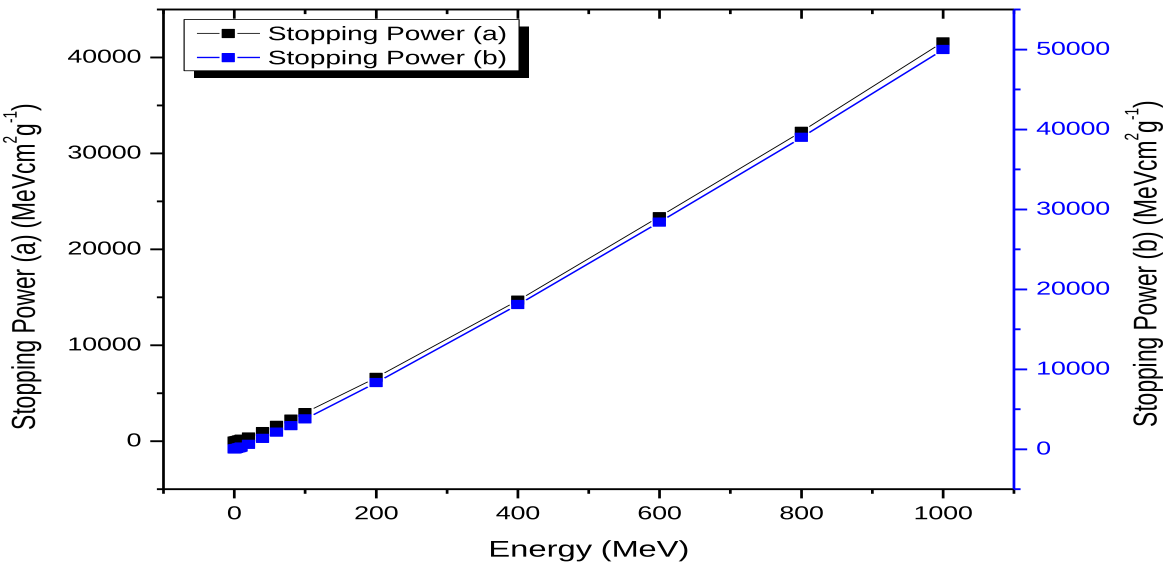

Fig 1: Correlation between electron Total stopping powers in Air

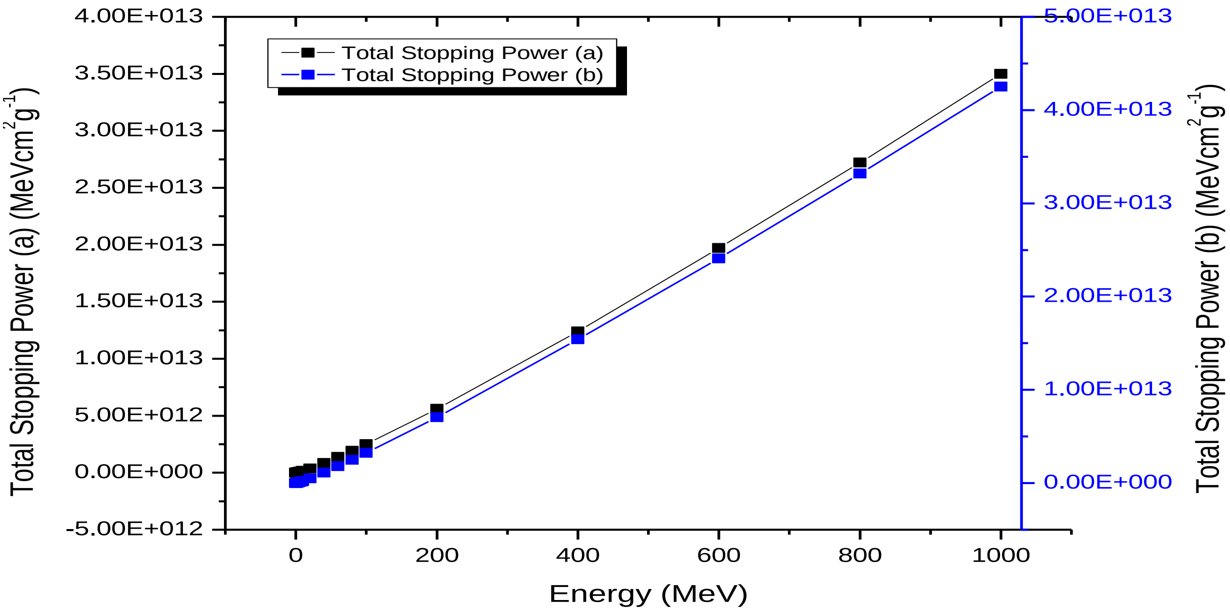

Fig 2: Correlation between electron Total stopping powers in tissue

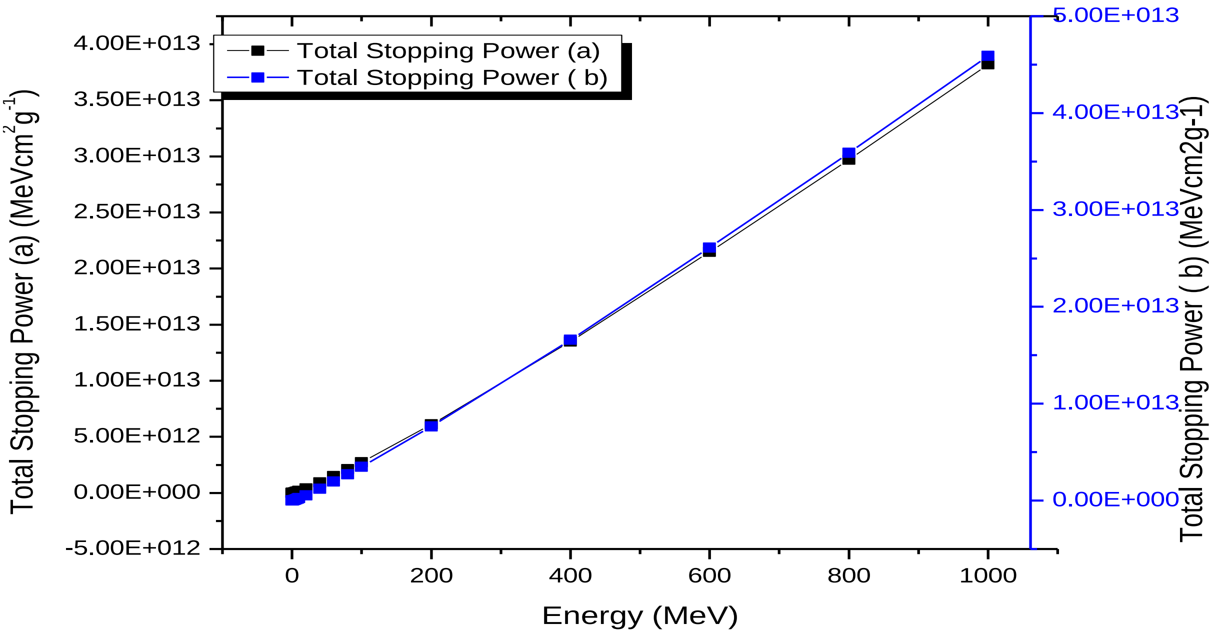

Fig 3: Correlation between the Calculated Total stopping Powers of electron in Water

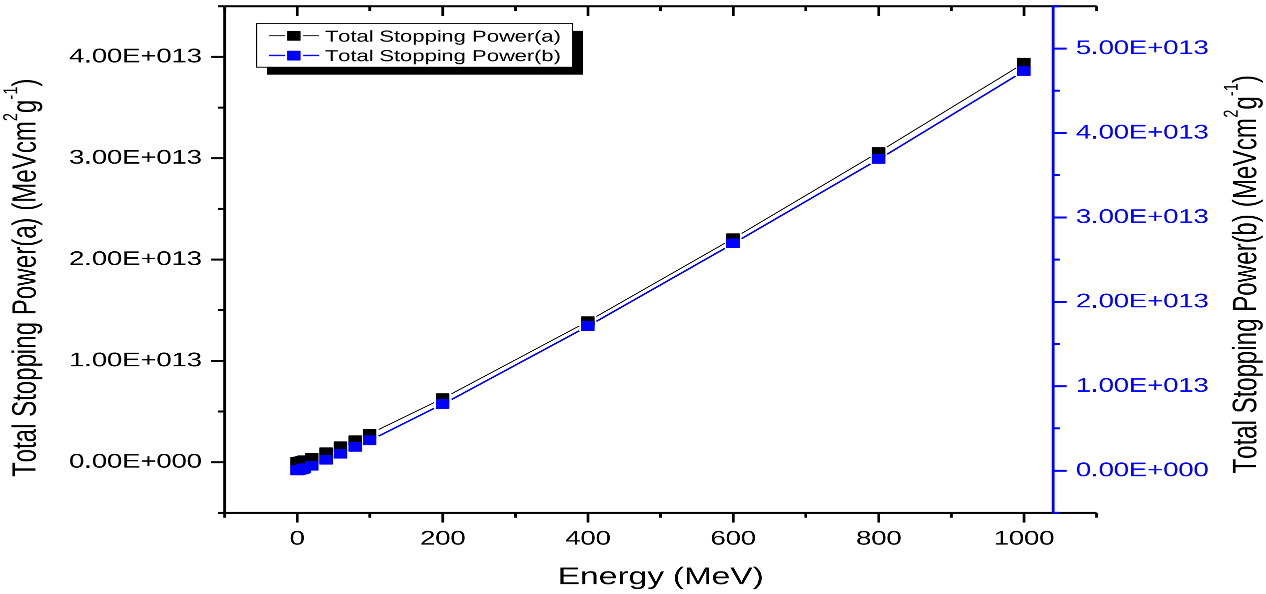

Fig 4: Correlation between electron Total stopping powers in Skeletal Muscle

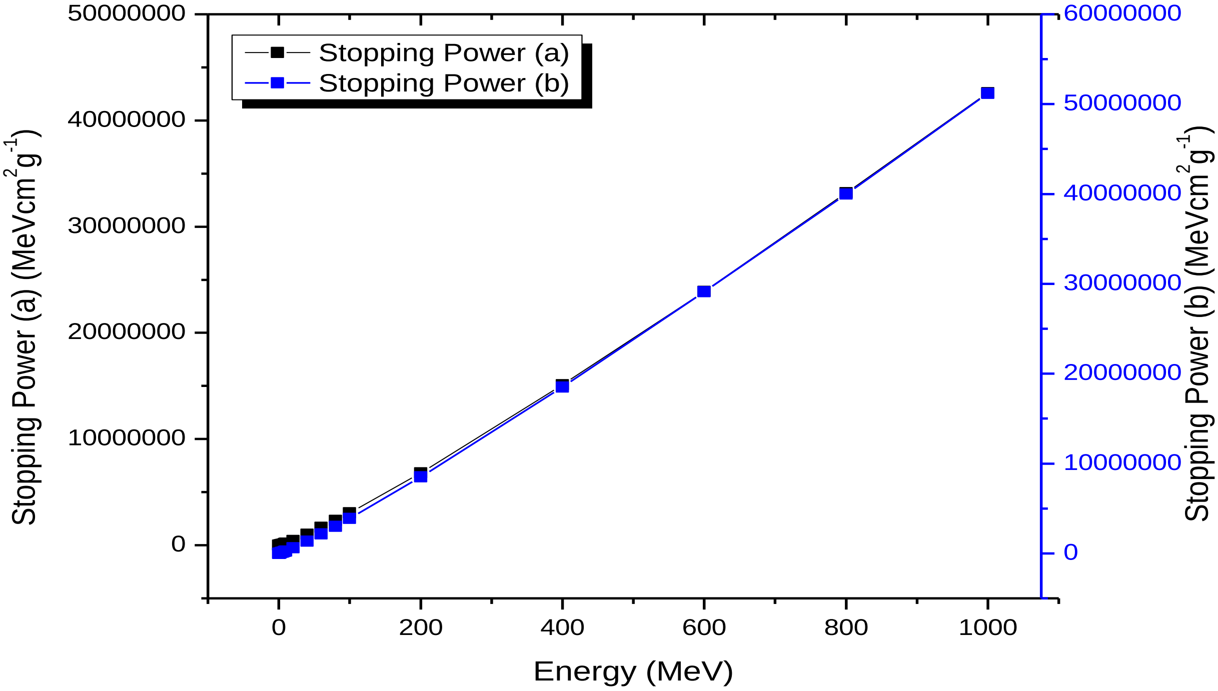

Fig 5: Correlation between electron Total stopping powers in Plastic

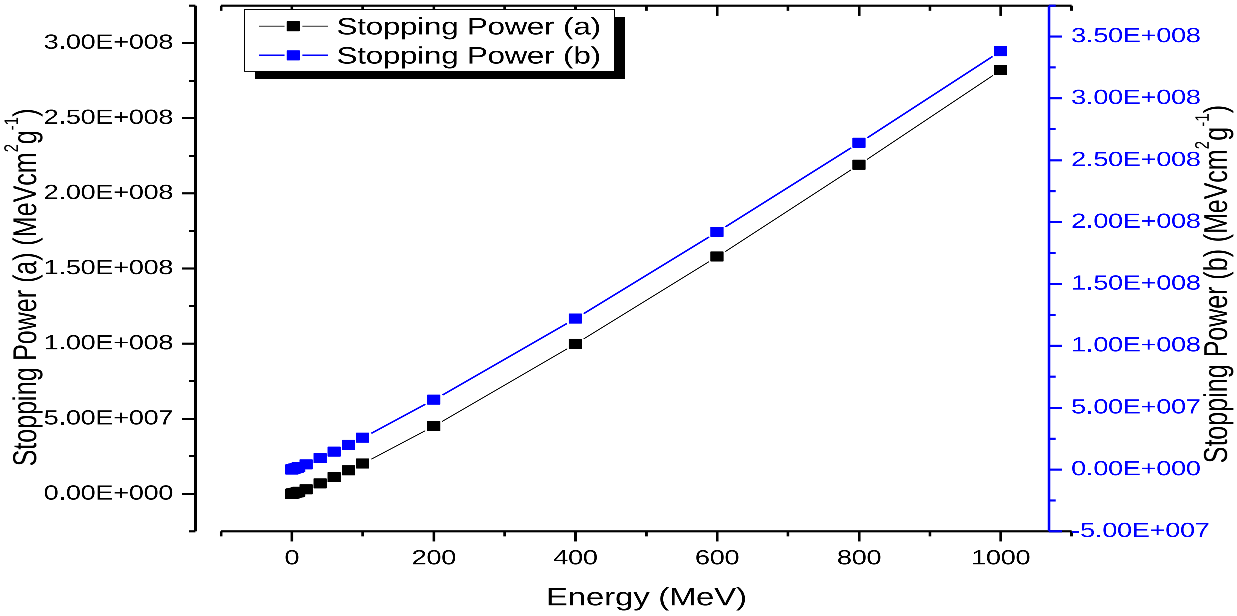

Fig 6: Correlation between electron Total stopping powers in Copper

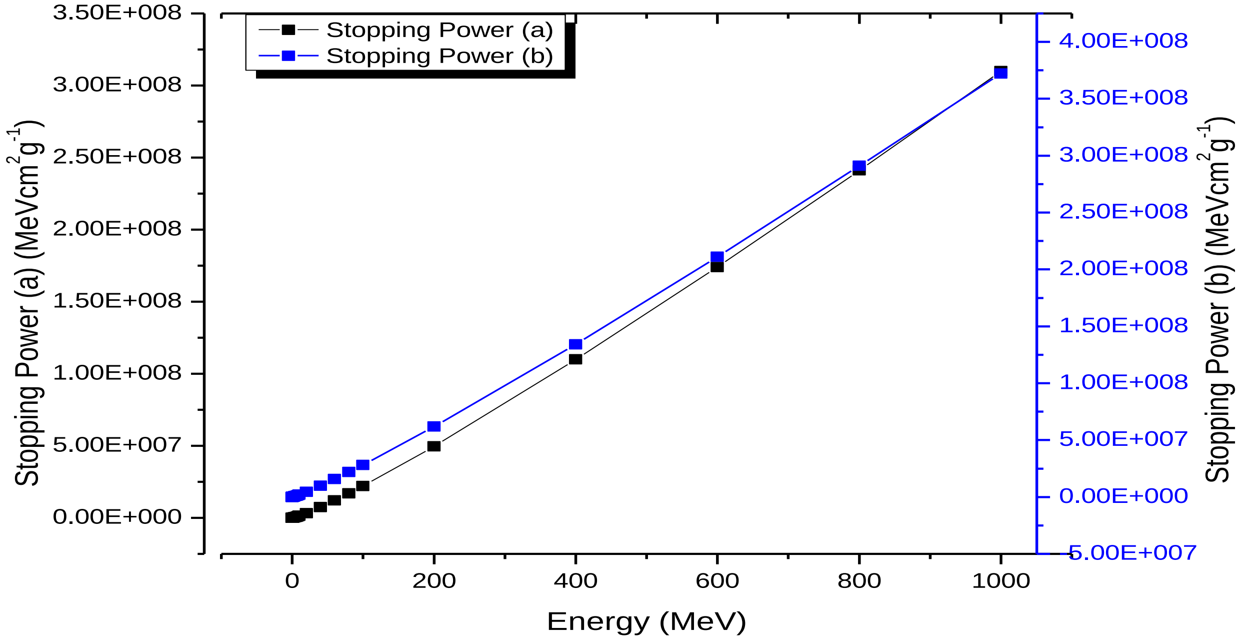

Fig 7: Correlation between electron Total stopping powers in Lead.

4.0. Conclusion

The new mass-energy concept theory, mbc, has been employed in the beth-bloch stopping power formula to calculate the total stopping power of electron in some materials, namely,air, tissue, water,skeletal muscle, plastic, copperand lead within the electron energy range of 0.01MeV to 1000MeV.

The mass-energy formula mc^2 has been over estimated since the speed of electron is below $3x10^8$. Therefore the electron stopping power for low mass density materials: air, tissue, water, skeletal muscle and plastic and such others are lower for the mbc mass-energy formula; while for high mass density materials like copper and lead, the Einstein's mass-energy formula underestimates the electron stopping power because of their high excitation energies.
This non-relativistic mass-energy equivalence will help in measuring the masses of the various particles in low and high energy states to replace the relativistic mass-energy mc^2which results in various applications in nuclear physics and chemistry. The derived universal particle speed constant b, describing the speed of the electron, is more realistic than Dirac value where he found the electron speed is equal to the speed of light [4]

In the historical development of E = mc^2, it is interesting to note that this concept has been evolving continuously. If the concept of Einstein's mass-energy relationship has evolved into many areas of applications, many alternative conceptions would be formed during the last 100 years. This paper has demonstrated some of the controversies surrounding the conceptual development of E = mc^2 and there is the need to pay attention to its inclusion in any curriculum[10].

Recommendation

The new mass – energy concept mbc can be employed in nuclear binding energy and nuclear binding energy calculations for the investigation and interpretation of nuclear structure and nuclear reactions. The universal particle speed constant, b, can be applied in relating the frequency and wavelength of elementary particles.

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