

Theoretical Paradigm: Computational Analysis of Proton Stopping Power in Material Targets using Einstein, Bahjat and New Mass-Energy Concepts



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ABSTRACT

This research study the theoretical Paradigm: Computational Analysis of proton stopping power in materials target such as Air, tissue, water, skeletal, plastic, copper and lead within energy range of 0.001MeV to 0.2MeV. The method employed Einstein mass-energy theory(mc^2), Bahjat mass-energy concept (mbc) and new mass- energy concept (mvc) into the Beth-Bloch Stopping power formula for calculations stopping power of proton in the above mentioned materials target. The graphical extrapolations of stopping power as a function of energy, shows that, the Einstein mass-energy theory has been under estimated and the new mass-energy (mvc) ride between the mc^2 and mbc; also close to mc^2 compared to mbc. In a graphical plot particle speed relative to speed of light (β) as a function of energy also depicted the same characteristics. Since in most literature, the einstein's theory was either over estimate or underestimate nuclear reaction and the new mass-energy concept appeared in between the two theories. Hence, the new mass-energy (mvc) it gives minimal energy loss compare Eintein's and Bahjat Mass-energy theories and it can be use in studying atomic structures as well binding energy of atomic nuclei. The derived universal particle speed constant v , describing the speed of the Proton is more realistic since the proton has mass, hence moves slower than the photon (light).

Keywords:

Proton,
Stopping Power,
Material targets,
Einstein Theory,
Bahjat Energy,
New Mass-energy.

INTRODUCTION

In the history regarding relativistic theory, it was crucial to observed that, the concept has been evolving spontaneously. The Einstein theory for the past ten decades developed from philosophical interpretation, figured out two realities which is mass and energy (Ngari et al., 2024; Long and Chin, 2005). The relativistic mass was interrogated by scientist that led to agreement that increase in mass or energy of a particle with velocity results to internal changes in structure of the particle (Jammer, 2000). Consequently, Einstein's ideology on relativistic mass and the relationship between mass and speed appeared inconsistent, leading to controversy over the interpretation of his statements. Some scholars advocate for the photon's rest mass to be zero, while others argue that its relativistic mass should be defined as the ratio of its energy to the square of the speed of light (Leong and Chin, 2005). The Einstein's theory, has also been criticized for overestimating nuclear energy, prompting the idea of a new conversion factor, contrary from c^2 , for calculating nuclear energy (Bahjat, 2008).The energy loss and stopping power of charged

particles as they crossbeam through matter have been of significant interest for many years, given their broad applicability in nuclear physics (Ahlam and Khalda, 2022). Recently, there has been a growing focus on both experimental and theoretical investigations into the stopping power and range of these charged particles. Numerous theoretical and experimental studies have been conducted (Ahmed et al., 2020). Due to continuous collisions, charged particles experience energy loss (Anthony et al., 2017). The stopping power, which is the rate of energy loss per unit length, depends on the velocity and charge of the incident particles as well properties of the target material. Moreover, accurately understanding and predicting the energy loss of fast ions in metals is essential for various charged particle beam applications, such as material characterization and modification. Recently, modeling the radiosensitization of metal nanoparticles in ion beams has found applications in cancer therapy (Taghreed and Firas, 2019; Isabel et al., 2021). The total stopping power of an electrically charged particle is defined as the sum of its collisional and radiative stopping powers, which are

treated as distinct components. The methods for evaluating these two components differ significantly. Specifically, the energy expended in ionizing and exciting atoms is absorbed in the medium close to the electron's path, while the energy lost as bremsstrahlung radiation can travel far from the track before being absorbed (Barger et al., 1993). Calculations of stopping power predominantly rely on the effective charge and velocity of the ions (Dore et al., 2014). Due to its large areas of application, such as in ion implantation, fundamental particle physics, nuclear physics, radiation damage, radiology (Leong and chi, 2005; Jummer,2000)

Theory

The Conceptual Pattern of Newtonian Mechanics involved kinetic and potential which described laws of motion, the non-relativistic energy was expressed as $E = \frac{mv^2}{2}$ In comparison, Einstein's theory was expressed as $E = mc^2$ (Annamalai and Antonio, 2023). In general, mass is made of several forms of materials that occupy space. Since light possesses no mass nor volume, its speed, about 2.99×10^8 m/s, surpasses that of any solid object (Annamalai, 2022). The Einstein mass-energy theory is crucial to the idea of relativistic energy within the context of special relativity, where relativistic momentum is connected to the motion of particles with speeds approaching the speed of light (Perez and Ribisi, 2022).

The Concept of Mass- Energy Theory Derived from Newtonian Mechanics

According to Annamalai (2023a) Newton's second law was mathematically expressed as

$$F = \frac{dp}{dt} = \frac{d(mv)}{dt} = m \frac{dv}{dt} + v \frac{dm}{dt} \tag{1}$$

$$dK = dw = Fds \tag{2}$$

The following equation is found by substituting equation (1) for F in equation (2).

$$dK = Fds = \left(m \frac{dv}{dt} + v \frac{dm}{dt} \right) ds \tag{3}$$

The derivative of equation (3) is taken with respect to time (t)

$$dK = Fds = m \frac{ds}{dt} dv + v \frac{ds}{dt} dm \tag{4}$$

where velocity is given as

$$\frac{ds}{dt} = v \tag{5}$$

Considering $c^2 dm$ which prompt to the idea of changeable mass as it occurs at high speed. Also, $c^2 dm$ is equivalent to the kinetic energy (Annamalai, 2023a).

$$dK = mvdv + v^2 dm \tag{6}$$

which implies

$$dK = \text{Kinetic energy} \tag{7}$$

$$c^2 dm = mvdv + v^2 dm \tag{8}$$

Equation (8) yields the following outcome when the subject of the relation is made $\frac{dm}{m}$

$$\frac{dm}{m} = \frac{vdv}{c^2 - v^2} \tag{9}$$

The integral of equation (9) is:

$$\int_{m_0}^m \frac{dm}{m} = \int_0^v \frac{v}{c^2 - v^2} dv \tag{10}$$

$$[\ln(m)]_{m_0}^m = -\frac{1}{2} [\ln(c^2 - v^2)]_0^v \tag{11}$$

$$\ln m - \ln m_0 = -\frac{1}{2} \ln(c^2 - v^2) + \frac{1}{2} \ln c^2 \tag{12}$$

$$\ln \frac{m}{m_0} = \frac{1}{2} \ln \frac{c^2}{c^2 - v^2} \tag{13}$$

$$\frac{m}{m_0} = \sqrt{\frac{c^2}{c^2 - v^2}} \tag{14}$$

$$\frac{m}{m_0} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{15}$$

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{16}$$

Where the following parameters are defined as follows: m = the relativistic mass, m_0 = the particle rest mass, v = the particle velocity when in motion, and c = speed of light (Annamalai, 2023g).

Momentum Relation is given as in the Following

$$P = mv \tag{17}$$

Equation (16) when substituted into equation (17) gives

$$P = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{18}$$

,substituting equation (16) into Einstein's Theory

$$E = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{19}$$

By squaring both sides of equation (19) and simplifying, the following equations results:

$$E^2 = \frac{m_0^2 c^4}{1 - \frac{v^2}{c^2}} \tag{20}$$

$$E^2 = \frac{m_0^2 c^2 (v^2 - v^2 + c^2)}{1 - \frac{v^2}{c^2}} \tag{21}$$

$$E^2 = \frac{m_0^2 c^2 v^2 - m_0^2 c^2 v^2 + m_0^2 c^4}{1 - \frac{v^2}{c^2}} \tag{22}$$

By simplifying equation (22), the following is obtained

$$E^2 = \left(\frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} \right)^2 c^2 + \frac{m_0^2 c^2 (c^2 - v^2)}{c^2} \tag{23}$$

By employing equation (18) for momentum into (23), the following equation is obtained:

$$E^2 = P^2 c^2 + m_0^2 c^4 \tag{24}$$

The particle rest energy is given as $E = m_0 c^2$ and the momentum $P = 0$, provided the particles are at rest.

Currently accepted knowledge states that Newton's second law of motion is the source of relativistic mass, momentum, and energy.

Newtonian relativistic Mass-Energy Equivalence ($E=mc^2$)

By employing equation (2.16) and by squaring the both side, the following equation is obtained

$$m^2 = \frac{m_0^2}{1 - \frac{v^2}{c^2}} \tag{25}$$

$$m^2(c^2 - v^2) = m_0^2 c^2 \tag{26}$$

where, $m_0^2 c^2$ is particle rest mass energy

$$m^2 c^2 - m^2 v^2 = m_0^2 c^2 \tag{27}$$

By differentiating equation (27) with respect to time, we get

$$2mc^2 \frac{dm}{dt} - 2mv \frac{d(mv)}{dt} = 0 \tag{28}$$

From equation (28), the following equation was obtained:

$$c^2 \frac{dm}{dt} = v \frac{d(mv)}{dt} \tag{29}$$

$$\frac{dE}{dt} = Fv = v \frac{d(mv)}{dt} = c^2 \frac{dm}{dt} \tag{30}$$

$$dE = c^2 dm \tag{31}$$

The particle kinetic energy K was obtained as follows:

$$\int_0^K dK = \int_{m_0}^m c^2 dm \tag{32}$$

$$K = c^2(m - m_0) \tag{33}$$

The sum of the particle's kinetic energy and the rest mass energy $m_0 c^2$ is its total energy

Total Energy (E) = Kinetic Energy (K) + Rest Mass-Energy $m_0 c^2$

$$E = c^2(m - m_0) + m_0 c^2 \tag{34}$$

Hence

$$E = mc^2 \tag{35}$$

Bahjat Theory of Mass-Energy Concept

Bahjat theory discovered his Mass - Energy relation as in the following equation (Bahjat, 2008)

$$E = mbc \tag{36}$$

where b stand for speed with am magnitude of 0.6037970064×10^8 m/s

Bethe-Bloch Model for Stopping Power

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{4\pi Z^2 N_A Z\rho}{mc^2 \beta^2 A} \left[\ln\left(\frac{2mc^2 \beta^2}{I}\right) - \ln(1-\beta^2) - \beta^2 \right]$$

$$\tag{El-Ghoshal, 2017) \tag{37}$$

The parameter $-dE/dx$ is known as the stopping power, the negative sign indicate loss of energy, e is the electron charge, m is the mass of the 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 expression given in equation (1) was resolved into equation (2) and (3) for the case of electron(El-Ghoshal, 2017) .

MATERIALS AND METHODS

The Method

The method glance at both Einstein and Bahjat Mass-energy theories as given in equation (35) and (36) in deriving new mass-energy relation $E=mc^2$ where v is obtained as 1.801898475×10^8 m/s. This is achieved through the application of Plank's radiation law, Energy-frequency relation ($E=h/\lambda$), Blackbody Energy-temperature relation ($E=KT_{Blackbody}$), Wein's displacement relation ($\lambda=b/T_{Blackbody}$), Particle momentum relation ($P=mc$), velocity-wavelength relation ($c=f\lambda$) and Beth- bloch stopping power formula

Derivation of New Mass- Energy ($E = mvc$)

From the Plank's law of Radiation which is express as in the following equation

$$U(\lambda) = \frac{8\pi hc}{\lambda^5} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-1} \tag{38}$$

$$\text{But } \left[\frac{dU}{d\lambda} \right]_{Max} = 0 \tag{39}$$

$$\frac{dU}{d\lambda} = U \frac{dv}{d\lambda} + V \frac{du}{d\lambda} = 0 \tag{40}$$

$$\frac{8\pi hc}{\lambda^5} \times \frac{hc}{\lambda^2 K_B T} e^{\frac{hc}{\lambda K_B T}} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-2} + \left[-\frac{40\pi hc}{\lambda^6} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-1} \right] = 0 \tag{41}$$

$$\frac{8\pi h^2 c^2}{\lambda^7 K_B T} e^{\frac{hc}{\lambda K_B T}} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-2} - \frac{40\pi hc}{\lambda^6} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-1} = 0 \tag{42}$$

$$\frac{8\pi hc}{\lambda^6} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-1} \left[\frac{hc}{\lambda K_B T} e^{\frac{hc}{\lambda K_B T}} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-1} - 5 \right] = 0 \tag{43}$$

$$\frac{8\pi hc}{\lambda^6} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-1} = 0 \text{ or } \left[\frac{hc}{\lambda K_B T} e^{\frac{hc}{\lambda K_B T}} \left[e^{\frac{hc}{\lambda K_B T}} - 1 \right]^{-1} - 5 \right] = 0 \tag{44}$$

$$\text{Let } \frac{hc}{\lambda K_B T} = x \tag{45}$$

$$\left[x e^x \left[e^x - 1 \right]^{-1} - 5 \right] = 0 \tag{46}$$

$$e^x [x-5] + 5 = 0 \tag{47}$$

The above equation is the form of transcendental which the solution for the trivial function is deduce graphically as in the following

The Graphical Solution of the Transcendental Equation

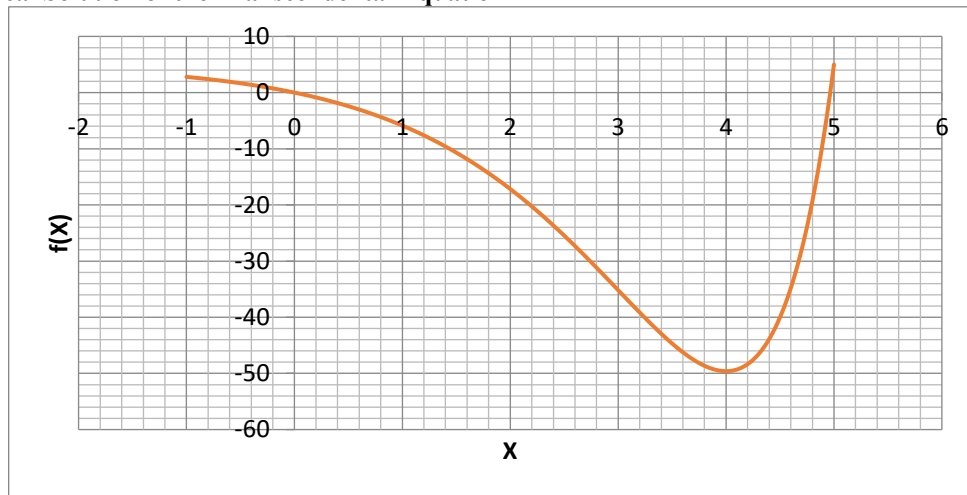


Figure 1: The Graphical Solution of the Transcendental Equation

Figure 1: Shows the graphical plot of $f(x)=e^x(x-5)+5$ and a point on the x-axis clearly indicate two intercepted points which signifies the values of the trivial function x, where $x=0$ and $x=4.965$

From equation (45)

$$\lambda_{Max} = \frac{hc}{xk_B T} = \frac{b}{T} \tag{48}$$

From Wiens wave length and temperature relation

$$T = \frac{b}{\lambda_{Max}} \tag{49}$$

Substituting (49) into Energy and Temperature relation as given in the following equation

$$E = kT \tag{50}$$

$$E = K \frac{b}{\lambda_{Max}} \tag{51}$$

From De broglie relation given as in the following

$$\lambda_{Max} = \frac{h}{P} \tag{52}$$

Substituting (52) into (51) where $P=mc$

$$E = \frac{kb}{h} mc \tag{53}$$

Since $\left(\frac{kb}{h}\right)$ is a minimum velocity and c is the maximum velocity of a particle at maximum wavelength, the average velocity of a particle is obtained by summing equation (35) and (53) as follow

$$E = \frac{\frac{kb}{h}mc + mc^2}{2} \tag{54}$$

$$E = \frac{\left(\frac{kb}{h} + c\right)mc}{2} \tag{55}$$

Where the new mass-energy converting factor v is deduced from equation (55) as

$$\frac{\frac{kb}{h} + c}{2} = v \tag{56}$$

The above constants in equation (56) have their numerical values as:

Boltzmann constant, $K = 1.3806488 \times 10^{-23} J/K$

Weins displacement constant, $b = 2.8977685 \times 10^{-3} mK$,

Planks constant, $h = 6.62606957 \times 10^{-34} Js$ and

speed of light, $c = 3 \times 10^8 m/s$,

When substituted into equation (56) gives:

$$v = 1.801898475 \times 10^8 m/s \tag{57}$$

Hence the new mass-energy relation is

$$E = mvc \tag{58}$$

The Bethe-Bloch formula has the following full expression as given in equation (37)

(a) Using Eienstein Energy mc^2

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{4\pi Z^2 N_A Z\rho}{mc^2\beta^2 A} \left[\ln\left(\frac{2mc^2\beta^2}{I}\right) - \ln(1-\beta^2) - \beta^2 \right] \tag{59}$$

(b) Using Bahjat Energy mbc

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{4\pi Z^2 N_A Z\rho}{mbc\beta^2 A} \left[\ln\left(\frac{2mbc\beta^2}{I}\right) - \ln(1-\beta^2) - \beta^2 \right] \tag{60}$$

(c) Using New Mass-Energy mvc

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{4\pi Z^2 N_A Z\rho}{mvc\beta^2 A} \left[\ln\left(\frac{2mvc\beta^2}{I}\right) - \ln(1-\beta^2) - \beta^2 \right] \tag{61}$$

Equation (59),(60) and (61) are stopping power models Using Einstein's, Bahjat and New mass-energy concepts use in computations of Proton Stopping powers in air, tissue, water, plastic, copper and lead

RESULTS AND DISCUSSION

Table 1: Mean Excitation Energy in Air, Tissue, Water, Skeletal, Muscle, Plastic, Copper and Lead

| S/N | Material | I (EV) | Density P (G/M ³) | Z/A | N = N _A PZ/A (Electron/M ³) |
|-----|----------|--------|-------------------------------|-------|--|
| 1 | Air | 85.7 | 0.00129 | 0.499 | 3.88 × 10 ²⁰ |
| 2 | Tissue | 63.2 | 0.92 | 0.558 | 3.09 × 10 ²³ |
| 3 | Water | 75 | 1.00 | 0.555 | 3.34 × 10 ²³ |
| 4 | Skeleton | 75.3 | 1.04 | 0.549 | 3.44 × 10 ²³ |
| 5 | Plastic | 65.1 | 1.127 | 0.549 | 3.73 × 10 ²³ |
| 6 | Copper | 322 | 8.960 | 0.456 | 2.46 × 10 ²⁴ |
| 7 | Lead | 823 | 11.35 | 0.396 | 2.70 × 10 ²⁴ |

The table above consist of the parameter used in bethe bloch formula for computation Proton stopping power.

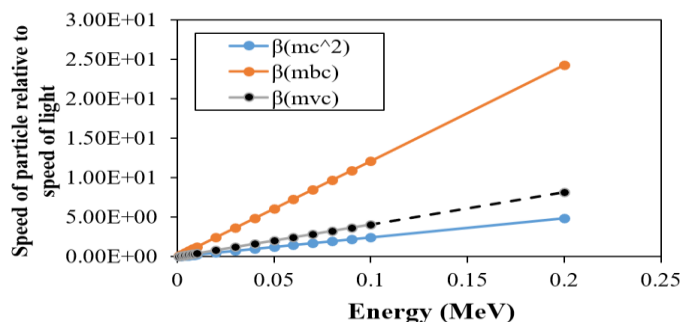
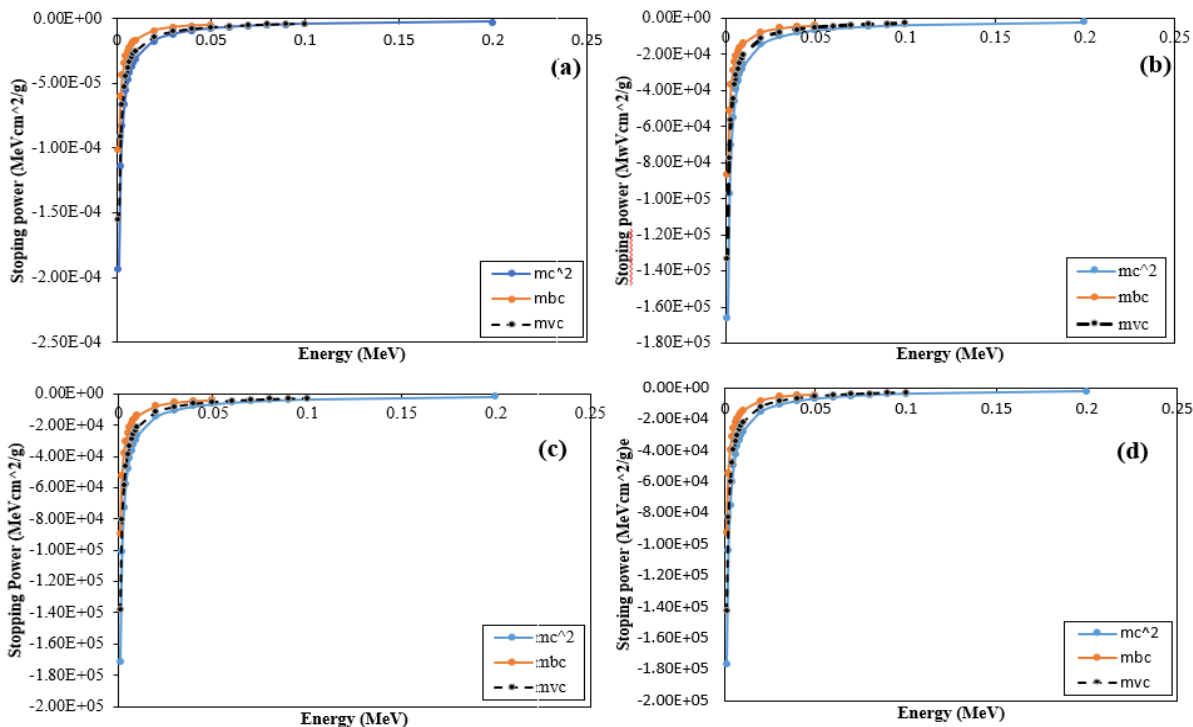


Figure 2: Graph of Speed of Particle Relative to Speed of Light (β) as a Function of Energy

This graphical extrapolation of speed of particle relative to the speed of light (β) as a function of Energy using Eientein's (mc^2), Bahjat (mbc) and new mass-energy concept (mvc). The bahjat is over estimated and the

Eientein is underestimated while The new mass-energy concept ride in between and close to that of Eientein (mc^2).



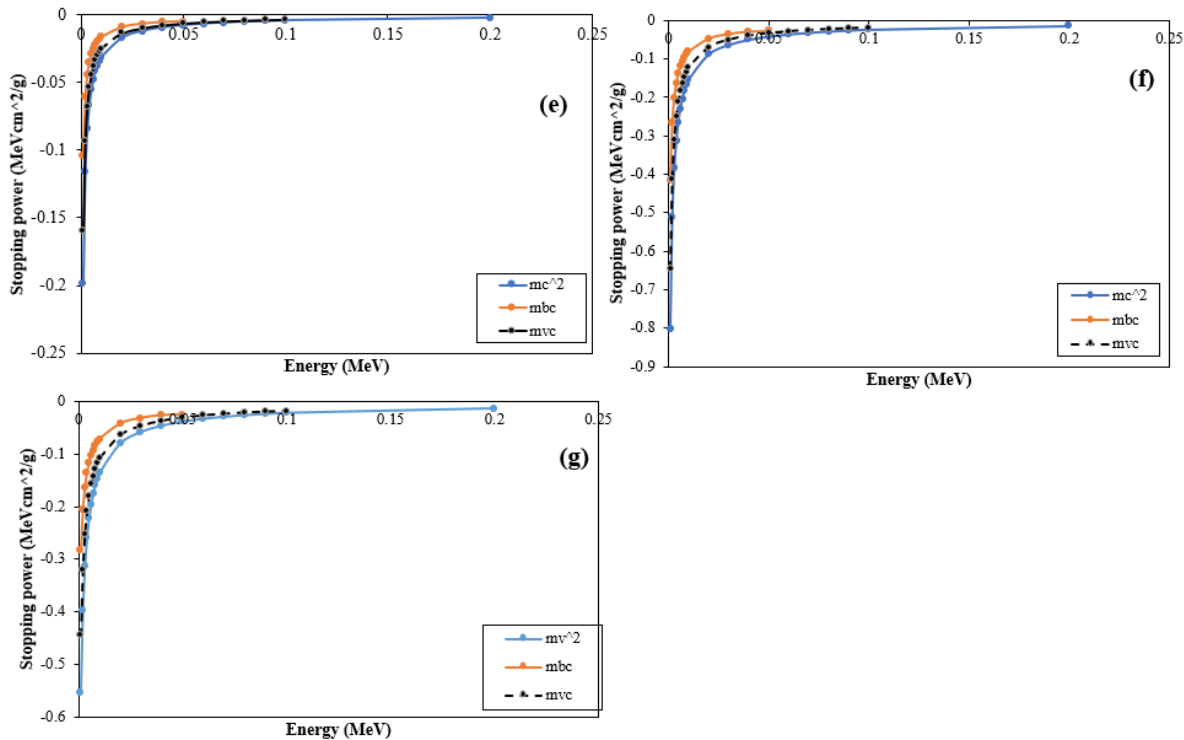


Figure 3: Stopping Power of Proton in Air(a), Tissue(b), Water(c), Skeletal(d), Plastic(e), Copper (f) and Lead (g)

Discussion

Over the years, it was reported that Einstein theory ($E=mc^2$) over estimate nuclear reactions (Bahjat, 2008). The new mass-energy concept ($E=mvc$) was applied on electron stopping power which resulted to a minimal energy lost compared to Einsteins theory ($E=mc^2$) and Bahjat energy relation ($E=mbc$) (Ngari et al., 2023). Subsequently, this research applied the new mass-energy concept $E=mvc$ on proton stopping power in materials targets such as air(a), tissue(b), water(c),skeletal(d), plastic(e), copper (f)and lead(g) comparative with Einstein's mass-energy theory $E=mc^2$ and bahjat mass-energy relation $E=mbc$. The results, depicted that, the Einstein relativistic Mass-Energy (mc^2) underestimate the studies and Bahjat Mass-energy concept (mbc) is overestimated while The new mass-energy (mvc) gives a minimal energy lost This observation is as a result disparity in their energy converting factors c^2 , bc and vc .

CONCLUSION

The energy loss per unit length (stopping power) is a point of concern and this paradigmatic shit in the Proton stopping power results obtained using the new mass-energy concept (mvc) is neither over estimated nor underestimated, it falls between the Einstein and Bahjat theories , as it did not solely rely on speed of light. Additionally, these results surpass the Bahjat mass-energy relation due to difference in the energy conversion

factor. It is therefore crucial to look into the new relativistic mass-energy concept in studying the interpretation of nuclear structure and the energy of particles that are relatively massive.

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