Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v32i4.2023.129
Volume 32(4). December 2023

Application of a New Mass-Energy Concept in the Computation of Atomic Nuclear Masses

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ABSTRACT

In most literatures and scientific extrapolations, the Bethe-Weizsacker's mass formula is dependent on Einstein's relativistic mass-energy theory for calculations of nuclear masses, but the relativistic energy converting factor (speed of light) is only attributed to massless particle. Therefore, the method employed involves the conversion of the binding energy fitting coefficients by krane from mega electron volt (MeV) to unified atomic mass unit (u) using Einstein relativistic mass-energy theory, Bahjat mass-energy relation (mbc) and our new mass-energy concept(mvc). A close correlation can be observed between the calculated masses of light, medium and heavy nuclei using the relativistic mass-energy theory (mc^2), our new mass energy concept (mvc) and the experimentally measured mass. The Bahjat mass-energy relation (mbc) is underestimated compared to our new mass energy concept. Therefore, any particle with mass greater than zero would travel with speed less than the speed of light. Hence the relation, $E = mc^2$, needs to be modified. It would therefore be more precise to apply the mass energy concept, E = mvc, for a mass particle. This is the reason why the Beth-Weizsacker's semi empirical mass formula shows a closer result to the experimental results, for masses of nuclei, when computation is done with our new mass -energy concept.

Keywords:
Einstein(mc^2),
Bahjat (mbc),
New mass-energy concept(mvc),
Krane fitting coefficient,
Weizsacker,
Experimental-mass.

INTRODUCTION

Mass is one of the most fundamental properties of a nuclei and it predicts the quantity of atomic nuclei that exist in nature Mumpower, *et al.*, 2016 and Cowan. *et al*., 2021. Mass formula provides theoretical predictions concerning a number of features of nuclei and their behaviour Chowdhury and Basu,, 2004.

In nuclear physics, mass is mainly quantified by two elementary particles protons (Z) and neutrons (N). Recently, the nucleus of an atom can be measured with high degree of accuracy in nuclear laboratories. However, from theories formulae for calculating nuclear masses are now common, the Bethe and Weizsacker's formula the dominant formula. Ngari and Ngadda, 2018. It was developed based on liquid drop model which assumes the nucleus as a liquid drop together with associated properties like binding energy (BE) of the nucleus which consists of Volume Term (the interaction of nucleons with adjacent nucleons regardless of decrease interaction of surface nucleons); Surface Term (the effect of the decrease in interaction of surface nucleons); Coulomb Term (the interaction of coulomb repulsion among protons); Asymmetry Term (different amount of energy in equal and unequal models of proton and neutron numbers); and Parity Term (nuclides with even atomic number and odd neutron number or odd atomic number and even neutron number are generally less stable than even-even nuclides, and thus the even-odd and odd-even are assigned zero to the pairing term) Vahid *et al.*, 2017.

Weizsacker semi-empirical mass formula depends on speed of light for computation of nuclear masses, and massive particles moves slower compared to speed of light. Therefore, there is need to apply new mass-energy concept for computation of atomic nuclear mass. Hence, need for the research.

Nuclear Mass Model

High precision mass measurement with relative uncertainties of $\frac{\delta m}{m} \leq 10^{-7}$ provides input for nuclear structure or nuclear astrophysics studies Lunney *et al.*, 2003. Mass data can be used to test the predictive power of mass model or to deduce input parameters for empirical mass formular and to predict masses of unmeasured nuclides.

The mass measurement of nuclei is of paramount importance due to the fact that binding energy depends on the mass. The mass of a nucleus, as a whole, with nucleons is lower than the sum of the masses of its N neutrons and Z protons. This mass defect is directly linked to the binding energy by Einstein's Mass-energy relation Mumpower *et al.,* 2016.

The Liquid Drop Model

The model assumed the atomic nucleus as incompressible liquid drop with the following assumptions:

i. The nucleus is spherical and consist of incompressible matter so that, the radius $R = r_O A^{1/3}$ Vahid *et al.,* 2017. With the exception of small regions where deformation from sphere is significant. These regions generally occur in the areas far from proton and neutron magic numbers. In the instant where the deformation is small or non – existence, the radius closely follows the equation, where $r_0 = 1.2\ fm$. The importance of accuracy in the value of r_0 will be considered in the determination of the coulomb term theoretically. However, evidence does not strongly suggest a value in the region$(1.23 fm)$ Hugh and Roger, 2012 and $(1.25 fm)$ Dejager *et al.*, 1974.

ii. The nuclear density is constant with respect to varying radius, neutron (N) and proton (Z) numbers, thus the nuclear matter is incompressible. This is true in the central nuclear region where there is approximately uniform density which taper off with increasing radius leading to an apparent skin effect. The nuclear radius is defined as the measure of size of atom Egfer, 1974.

iii. The nucleons have a short-range force of attraction, thus only strongly attract their nearest neighbor. In essence this is also believed true however; if this was absolutely correct then point (ii) would be contradicted. By comparing the density of large nucleus with that of a small one, we would expect the larger to be more tightly bound due to the purely attractive force acting within it, thus have a higher density. In reality there is a repulsive force that acts over a short range Vahid *et al.*, 2017.

The Bethe Weizsacker Semi-Empirical mass formula

The Bethe – Weizsacker's formula also known as semi empirical mass formular used to estimate the atomic mass via its nucleon number. It is also derived on two bases (theory and empirical measurement). The theory involved liquid drop model which explained the binding energy terms fitting coefficients such as volume term, a_V; the surface term, a_S; the Coulomb term, a_c; the asymmetry term, a_{asy} and the pairing term, a_p Vahid *et al.,* 2017.

$$M(A,Z) = (ZM_p + (A-Z)M_n - B_E)/C^2 \quad (1)$$

Where the binding energy,

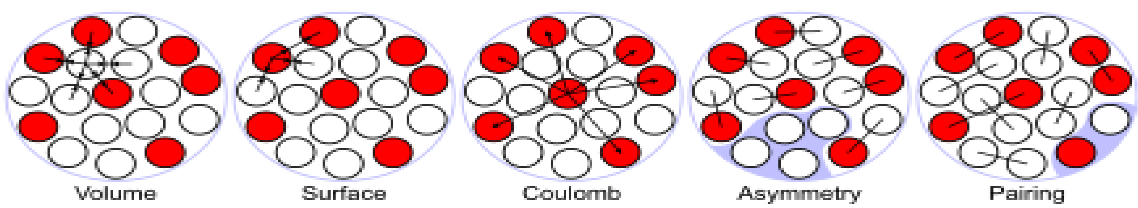
$$B_E = a_V A - a_S A^{2/3} - a_c Z^2 A^{-1/3} - a_{asy}(A - 2Z)^2 A^{-1} \pm a_P A^{-1/2} \quad (2)$$

Substituting equation (2) in to (1) we obtain the Bethe-Weizsacker semi-empirical mass formula Weizsacker, 1934.

$$M(A,Z) = (ZM_P + (A-Z)M_n - a_V A + a_S A^{2/3} + a_c Z^2 A^{-1/3} + a_{asy}(A-2Z)^2 A^{-1} \pm a_p A^{-1/2})/c^2 \quad (3)$$

where $M_P = Massofproton$; $M_n = Massofneutron$; $A = Massnumber$;and Z = proton number

Pictorial view of the interactions in the binding energy terms



Vahid *et al.,* 2017.

The Binding energy fitting coefficients mentioned above were calculated Krane, 1987.

MATERIALS AND METHODS

In order to compare the empirically calculated nuclear mass and experimental mass, we first convert the binding energy fitting coefficients by krane from mega electron volt (MeV) to unified atomic mass unit (u) using Einstein relativistic mass-energy theory, Bahjat mass-energy relation $(mbc)$and the new mass-energy concept(mvc) Ngari *et. al.*, 2023. given in table 1. Secondly, these concepts will be introduced independently into Bethe-weizsacker's semi empirical mass formula given by equation (3) to replace mc^2 as expressed in the following equation. Lastly, the masses of light, medium and heavy nuclei were computed using computer program which would employ Microsoft Excel and origin 8.5 for graphical analysis.

$$M(A,Z) = (ZM_P + (A-Z)M_n - a_V A + a_S A^{2/3} + a_c Z^2 A^{-1/3} + a_{asy}(A-2Z)^2 A^{-1} \pm a_p A^{-1/2})/bc \quad (4)$$

$$M(A,Z) = (ZM_P + (A-Z)M_n - a_V A + a_S A^{2/3} + a_c Z^2 A^{-1/3} + a_{asy}(A-2Z)^2 A^{-1} \pm a_p A^{-1/2})/vc \quad (5)$$

Table 1: The semi empirical mass fitting coefficients by Krane

Binding Energy Coefficient	Krane (MeV)	mc^2 (u)	mbc (u)	mvc (u)
a_v	15.5	0.01664	0.08262	0.027657
a_s	16.8	0.018035	0.089547	0.029977
a_c	0.72	0.000773	0.003838	0.001285
a_{asy}	23	0.024691	0.122597	0.041039
a_p	34	0.0365	0.18123	0.060667

Table 1 contains the binding energy fitting coefficients by Krane using relativistic mass – energy concept (mc^2), Bahjat mass – energy concept (mbc) and our new mass-energy concept(mvc)

RESULT AND DISCUSSION

The computed results of light, medium, heavy and experimental masses (u) as a function of atomic number (Z) are graphically presented in Figures 1, 2 and 3.

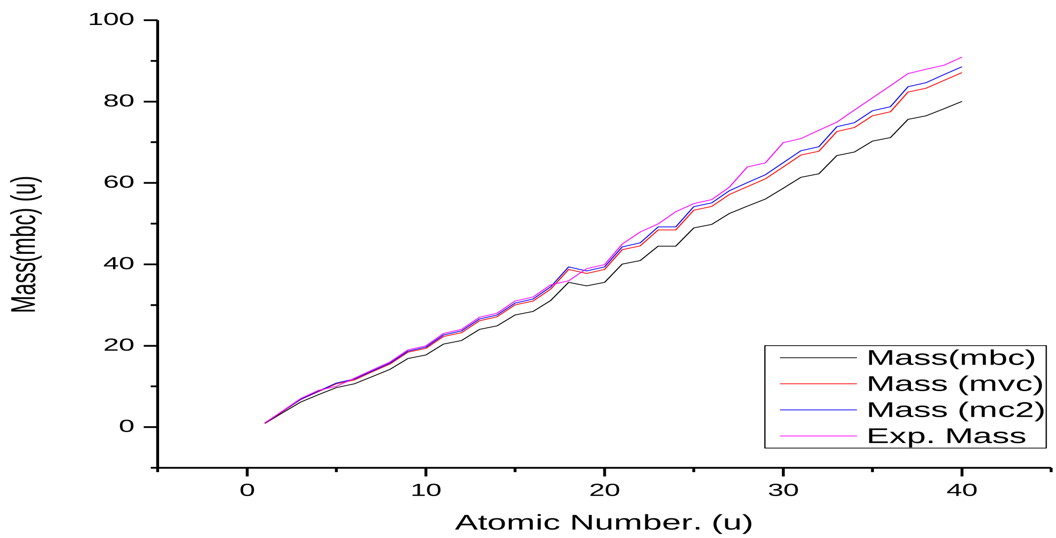


Figure 1: Graph of calculated and experimental mass of light atomic nuclei

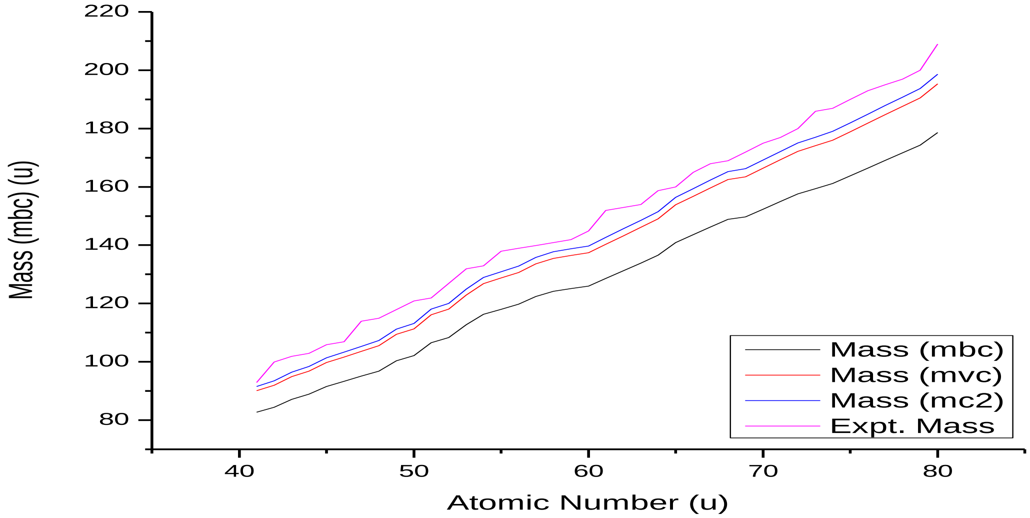


Figure 2: Graph of calculated and experimental mass of medium sized atomic nuclei

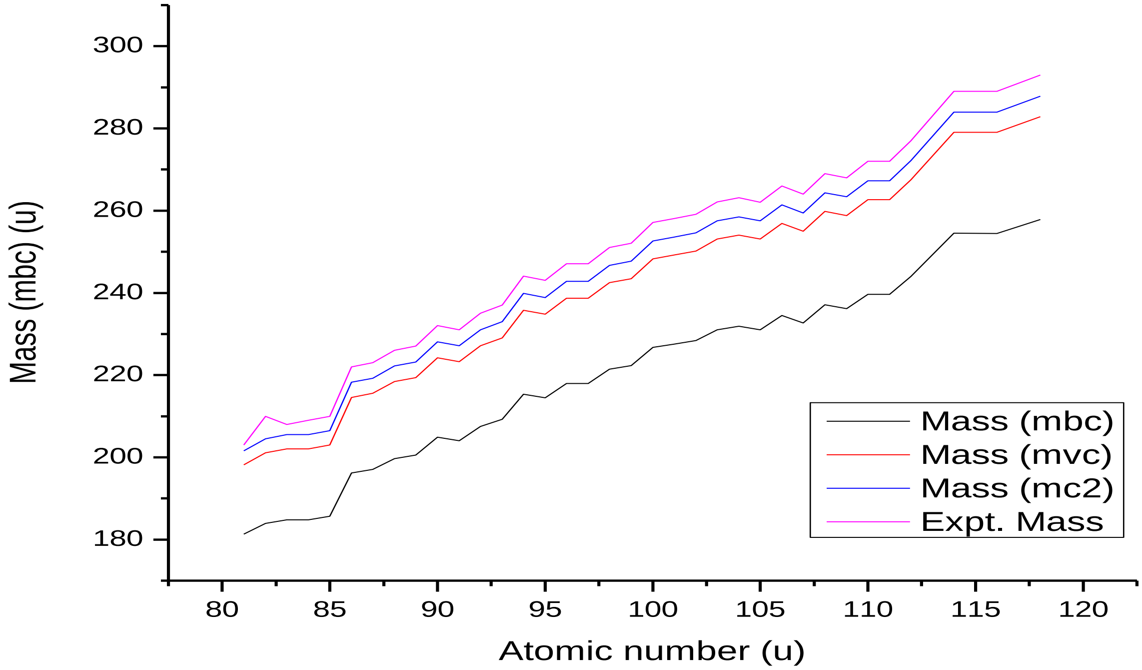


Figure 3: Graph of calculated and experimental mass of large atomic nuclei

Discussion

From the results of light, medium and heavy nuclei presented in the figures above, a close correlation can be observed between the calculated masses of light, medium and heavy nuclei using the relativistic mass-energy relation (mc^2), our new mass-energy concept (mvc) and the experimentally measured mass. The Bahjat mass-energy relation (mbc) is underestimated compared to our new mass energy concept (mvc) due to the effect of it mass-energy converting factor (b).

CONCLUSION

Einstein's mass energy relation, $E = mc^2$, applies to particles with mass, m, greater than zero. However the speed of light, c, applies to only photons which are massless. Therefore, any particle with mass greater than zero would travel with speed less than the speed of light. Hence the relation, $E = mc^2$, needs to be modified. It would therefore be more precise to apply the mass energy concept, $E = mvc$, for a mass particle. This is the reason why the Beth-Weizsacker's semi empirical mass formula shows a closer result to the experimental results, for masses of nuclei, when computation is done with the new mass energy concept.

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