Universal equality of masses of nucleons and binding energy of the nucleus

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Abstract: There are two inherent observations: firstly, masses of nucleons are fundamental constants, *i.e.*, they are the same universally (inside and outside the nucleus in all cases); and secondly, nuclei possess Binding Energy (BE) (Δmc^2) owing to a mass defect. To explain these observations, in the case of the deuteron (BE = 2.2244 MeV), the mass defect of nucleons must be 0.002388 amu or about 0.118 54% of the mass of nucleons, *i.e.,* nucleons must be lighter in the nucleus. This is not experimentally justified. If the generalised equation $\Delta E = Ac^2\Delta m$ is applied, then it explains both observations simultaneously, *i.e.,* the equality of masses of nuclei (assuming an infinitesimally small mass defect) and the BE. According to $\Delta E = Ac^2\Delta m$, even with an infinitesimally small mass defect (2.388×10^{-4} amu, for example), the BE of the deuteron can be 2.2244 MeV owing to the presence of the conversion factor *A*.

Keywords: mass defect; binding energy; BE; deuteron.

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Biographical notes: Ajay Sharma obtained his MSc in Physics from PAU Ludhiana, Punjab, India in 1985. He then joined DAV College Chandigarh as a Lecturer in Physics. He has published a large number of articles dealing with basic laws, especially on critical analyses of Einstein's September 1905 paper. In some papers he has highlighted some inconsistencies in Einstein's derivation of $E = mc^2$ and suggested a new equation, $\Delta E = Ac^2\Delta m$. He has been invited to over 55 international conferences; he presented his work in England in 2005 and in the USA in 2006. He wrote the book *100 Years of* $E = mc^2$.

1 Decrease in masses of proton and neutron in deuteron nucleus

In experimental and theoretical nuclear physics, the masses of nucleons (protons and neutrons) are fundamental physical constants in the category of atomic and nuclear constants, and the Binding Energy (BE, energy required to break the nucleus) is an inherent property of all nuclei. Also, it is equally true that all the mass-energy interconversions are universally explained on the basis of $E = \Delta mc^2$, where Δmc^2 is the mass defect:

mass defect = mass of nucleons outside nucleus – mass of nucleons inside nucleus. (1)

This aspect is critically discussed with reference to the deuteron, which contains just one neutron and one proton.

- The mass of a proton has been experimentally measured to be equal to 1.672 621 $\times 10^{-27}$ kg (1.007 276 u or 938.272029 MeV) and is the same in all cases. Also, the mass of a neutron is 1.674 927 $\times 10^{-27}$ kg (1.008 664 amu or 939.565 360 MeV).
- The BE of the deuteron has been measured experimentally by various methods (Greene *et al*., 1986; Chupp *et al*., 1961; Kessler *et al*., 1999) and has been found to be 2.2244 MeV (1 amu = 931.494 MeV, 1 amu = 1.660 5381 $\times 10^{-27}$ kg), which is equivalent to 0.002 388 amu (3.984 $\times 10^{-30}$ kg) on the basis of $\Delta E = \Delta mc^2$, *i.e.*, the mass of nucleons is converted into energy.

2 Decrease in mass of nucleons in nucleus is not justified

The phenomena of the universal equality of masses of nucleons and the origin of the BE of nuclei have been studied critically and quantitatively (Sharma, 2005; 2006a; 2006c). The BE of the deuteron is experimentally observed as 2.2244 MeV; according to $\Delta E = \Delta mc^2$ it is equal to the mass defect 0.002 388 amu. This means that in the nucleus of deuterium, the mass 0.002 388 amu (of the proton and neutron) is converted into BE.

The mass defect, *i.e.*, 0.002 388 amu, is comparable with the sum of the masses of the neutron and proton (2.015 94 amu); the masses must decrease in the nucleus considerably, *i.e.*, by 0.118 45% (compared with the mass in the free state). In deuterons there are only protons and neutrons, hence theoretically the decrease in mass or mass defect of 0.002 388 amu is only at the cost of the mass of the proton (M_p) and the mass of the neutron (M_n). The mass of the proton is 1.007276 amu; if the decrease in the mass of the proton is half the mass defect (0.002 388 amu), *i.e.*, 0.001 194 amu (which contributes towards the BE of deuterium), then theoretically the mass of the proton in the nucleus must be 1.006 082 amu (1.670 64 $\times 10^{-27}$ kg) and the decrease in the mass of the proton must be 0.1185%. Also, the mass of the neutron is 1.008 664 amu; if the decrease in the mass of the neutron is half the mass defect, *i.e.*, 0.001 194 amu, then the mass of the neutron in the nucleus must be 1.007 47 amu (1.672 94 $\times 10^{-27}$ kg), and the decrease in mass is also 0.1185%.

In a similar way the theoretical decrease in the mass of nucleons in other nuclei can also be estimated. The greater the value of the BE, the greater would be the decrease in the mass of nucleons in the nucleus. The BE of ^{235}U (atomic mass = 235.0439 amu) is 1783.87 MeV or 1.915 amu, thus the theoretical decrease in the mass of each nucleon is nearly 0.8%. Further, the BEs in the cases of ^{35}Cl and ^{56}Fe are 298.3 MeV and 492.26 MeV, which are equivalent to mass defects 0.320 23 amu and 0.528 46 amu, respectively. Thus, theoretically, there must be decreases in the masses of nucleons in ^{35}Cl and ^{56}Fe of 0.91% and 0.94%, respectively. In the simple case of hydrogen, both the mass defect and the BE are zero, as this nucleus contains only one proton. Likewise, the decrease in the mass of nucleons when they form a nucleus can be calculated for other nuclei as well.

Table 1 The universal equality of the masses of protons and neutrons is not justified when BE is calculated on the basis of $E = \Delta mc^2$

Sr. no.	*Characteristic*	${}_1H^1$	${}_1H^2$	${}_{17}Cl^{35}$	Fe^{56}	${}_{92}U^{235}$
1	BE (MeV)	0	2.2244	298.3	492.26	1783.87
2	Mass defect (BE/c^2)/amu	0	2.388×10^{-3}	0.320 23	0.528 46	1.915
3	Decrease in mass per nucleon/amu	0	1.194×10^{-3}	9.149×10^{-3}	9.436×10^{-3}	8.15×10^{-3}
4	M_p and M_n in nucleus	$M_p = 1.007\,276$	$M_p = 1.006\,082$ $M_n = 1.007\,47$	$M_p = 0.998\,127$ $M_n = 0.999\,513$	$M_p = 0.997\,84$ $M_n = 0.999\,225$	$M_p = 0.999\,1276$ $M_n = 1.000\,512$
5	Percentage decrease in M_p	0	0.1185	0.9082	0.9367	0.8091
6	Percentage decrease in M_n	0	0.1183	0.9070	0.9354	0.808
7	Universal equality of masses of M_p and M_n	Obeyed	Not obeyed	Not obeyed	Not obeyed	Not obeyed

These theoretical predictions from $\Delta E = \Delta mc^2$ are not consistent with observations or experimental findings (the masses of nucleons are universally the same, *i.e.*, inside and outside in all nuclei, and regarded as fundamental physical constants). The decreases in the masses of the neutron and proton in various elements, to explain the values of BE on the basis of $\Delta E = \Delta mc^2$, are shown in Table 1.

3 $E = \Delta mc^2$, binding energy and mass of nucleons in deuteron

If the masses of nucleons remain the same universally (a fundamental idea used in all aspects of experimental and theoretical nuclear physics), *i.e.*, the mass defect Δm is zero, then according to $\Delta E = \Delta mc^2$ the BE is also zero:

$$\text{Binding Energy (BE)} = \text{mass defect } (\Delta m)c^2 = 0. \quad (1)$$

Thus the universal equality of masses of protons and neutrons (meaning $\Delta m = 0$) implies that the mass defect must be zero theoretically, hence also BE = 0. If the BE is zero then the nucleus will be unstable, hence this is not experimentally justified. The masses of protons and neutrons are the same inside and outside the nucleus, as has been experimentally confirmed (Beiser, 1987).

When a gamma ray photon of energy 2.2244 MeV hits a deuteron (the BE of the deuteron is 2.2244 MeV), then the deuteron is split up and a proton and a neutron are emitted. The masses of the released proton and neutron are the same as the usual masses, *i.e.*, 1.007 276 amu and 1.008 662 amu, respectively.

The masses of the proton and neutron are never less in the nucleus, *i.e.*, 1.006 082 amu and 1.007 47 amu as theoretically predicted by $\Delta E = \Delta mc^2$ to explain the BE. No external energy is provided by the gamma ray photon to increase the mass of the proton and neutron inside the nucleus. If the masses of the proton and neutron are less in the nucleus, then lighter protons and neutrons must be emitted. But the masses of the emitted proton and neutron are the usual masses. Whatever the energy of the gamma ray photon, it is provided to dissociate the BE of deuteron, as both are exactly equal, *i.e.*, 2.2244 MeV each. Thus the mass defect and the BE both must be zero, as the masses of the protons and neutrons are equal both outside and inside the nucleus.

According to $\Delta E = \Delta mc^2$, the BE of the nucleus can never originate without annihilation of an adequate mass of nucleons. If the mass defect Δm is zero (masses of nucleons are the same inside and outside the nucleus), then the BE is also zero, implying instability of nuclei, which is never justified. The question, then, is, what is the source of BE on the basis of $\Delta E = \Delta mc^2$?

Thus the application of $\Delta E = Ac^2\Delta m$ can be speculated (on an *ad hoc* basis) in this regard, *i.e.*, to simultaneously explain the BE and the mass of nucleons in the nucleus. Consequently, the generalised mass-energy equation implies that for even the annihilation of an incalculable mass defect (this assumption is for obeying the universal equality of protons and neutrons), a BE equal to 2.2244 MeV (3.965×10^{-13} J) is feasible owing to the presence of the conversion factor A. Let us assume that, in this case, the mass defect is 2.388×10^{-14} amu or 3.965×10^{-41} kg and that, owing to the higher value of the proportionality coefficient, the BE can be 2.2244 MeV. Thus there is consistency between experimentally observed facts (BE and equality of masses of nucleons) and theoretical predictions based upon $\Delta E = Ac^2\Delta m$.

4 Explanation on the basis of $\Delta E = Ac^2\Delta m$

Einstein's September 1905 derivation of the mass-energy interconversion equation (Einstein, 1905b) has been critically analysed by the author (Sharma, 2003; 2004a–b; 2006a–b; 2007), and it was found that this derivation is true under special conditions only (for certain values of parameters, not for all values of involved parameters). In this paper, firstly, Einstein (1905b) derived under special conditions the light energy-mass interconversion equation, *i.e.*:

$$\Delta L = \Delta mc^2. \tag{2}$$

Equation (3) is based on relativistic variation of light energy, which was given by Einstein (1905a) in his June 1905 paper as:

$$l^* = l\,[1 - v/c\,\cos\phi\,]/[(1 - v^2/c^2)^{1/2}] \tag{3}$$

where:

l^* = energy measured in a moving frame
l = energy emitted by the body in a rest frame
ϕ = angle at which the light ray is emitted
v = relative velocity between the two frames.

Equation (4) is purposely mentioned here, as Einstein derived Equation (3) using it for light energy only, but arbitrarily replaced light energy L by energy E (any type of energy) and proposed Equation (5), *i.e.*:

$$\Delta E = \Delta mc^2. \tag{4}$$

Further, Einstein maintained that $\Delta E = \Delta mc^2$ holds for all perceivable energies, *e.g.*, heat energy, chemical energy, nuclear energy, magnetic energy, electrical energy, sound energy, energy emitted in the form of invisible radiation, energy emitted as cosmological and astrophysical energy, *etc*. However, in Einstein's derivation there is no mathematical basis to account for all the energies for which the equation is applied.

In view of the theoretical situation, the author (Sharma, 2003; 2004a–b; 2006a–b; 2007) has derived the generalised mass-energy interconversion equation, *i.e.*:

$$\Delta E = Ac^2\Delta m \tag{5}$$

specifically for all energies by an independent method, where A is a coefficient of proportionality. Like many other coefficients of proportionality in the existing literature, the value of A depends on the inherent characteristic conditions of the process. It can be equal to, less than or greater than 1. Thus, according to $\Delta E = Ac^2\Delta m$, *like* Einstein's equation mass is converted into energy, but *unlike* Einstein's equation the conversion factor is not always c^2. Thus, according to $\Delta E = Ac^2\Delta m$, the energy emitted can be less than, equal to or greater than $\Delta E = \Delta mc^2$, as the interconversion of mass and energy is a bizarre process right from chemical reactions to heavenly phenomena governing the origin and development of the universe.

5 $\Delta E = Ac^2\Delta m$ implies that a smaller mass defect can give the binding energy 2.2244 MeV

The equality of the masses of protons and neutrons inside and outside the nucleus implies that the mass defect is too small to be measured by any means. Only then are these masses fundamental physical constants. Let us propose that the mass defect in this regard is 2.388×10^{-14} amu, or 3.965×10^{-41} kg; if so, then the masses of nucleons inside and outside the nucleus are equal or the difference is too small to be measured. According to the generalised form of the mass-energy interconversion equation, for annihilation of an infinitesimally small mass, a large amount of energy can be emitted, *i.e.*, the conversion factor is much higher than c^2. Now, applying the equation $\Delta E = Ac^2\Delta m$ under this condition, the value of A can be determined as (with BE = 2.2244 MeV = 3.965×10^{-13} J, and $\Delta m = 2.388 \times 10^{-14}$ amu = 3.965×10^{-41} J):

$$A = \Delta E/c^2\Delta m = [3.965 \times 10^{-13}]/[9 \times 10^{16} \times 3.965 \times 10^{-41}] = 1.11 \times 10^{11}. \quad (6)$$

Thus, in this case, we have:

$$\Delta E = Ac^2\Delta m = 1.11 \times 10^{11}\ c^2\Delta m. \quad (7)$$

The value of the conversion coefficient (A) is similar to the coefficients of proportionality in von Weizsacker's semi-empirical formula (Beiser, 1987) for BE (associated with Bohr's Liquid Drop Model).

Thus we find that the masses of the neutron and proton are the same inside and outside the nucleus, as the mass defect is 2.388×10^{-14} amu or 3.965×10^{-41} kg, which is incalculable. Corresponding to this mass defect, the mass of the proton, 1.007 274 amu, will decrease by the incalculable amount 1.195×10^{-14} amu. The case of the neutron is similar. Thus the masses of the nucleons are the same inside and outside the nucleus; and in this particular case, for the annihilation of a negligible mass defect, more energy is emitted than is predicted by $\Delta E = \Delta mc^2$. According to $\Delta E = Ac^2\Delta m$, however, the mass defect 3.984×10^{-41} kg can explain the BE equal to 2.2244 MeV if A is 1.11×10^{11}. Thus the generalised equation explains both mysteries, *i.e.*, the universal equality of the masses of nucleons and the BE of the nucleus, 2.2244 MeV. The decreases in the masses of the neutron and proton in various elements, to explain the values of BE on the basis of $\Delta E = Ac^2\Delta m$, are shown in Table 2.

In addition to this, Equation (6) is also capable of explaining the following existing observations:

- It has been through experimental observation (Bakhoum, 2002; Hambsch *et al.*, 1989; Thiereus *et al.*, 1981) over three decades that the total kinetic energy of fission fragments of ^{235}U or ^{239}Pu has been found to be 20–60 MeV less than the Q-value (200 MeV) predicted by $\Delta E = \Delta mc^2$. If the value of energy observed is 175 MeV, then it can be explained with a value of A equal to 0.875 in $\Delta E = \mathrm{A}c^2\Delta m$.
- The mass of the particle Ds (2317), discovered at SLAC (Palano *et al.*, 2003), is lower than current estimates based on $\Delta E = \Delta mc^2$. It can be explained with a value of A greater than 1 in the generalised equation, *i.e.*, $\Delta E = Ac^2\Delta m$.

Table 2 The universal equality of the masses of protons and neutrons is justified when BE is calculated on the basis of $\Delta E = Ac^2\Delta m$ ($A = 10^{10}$)

Sr. no.	*Characteristic*	$_1H^1$	$_1H^2$	$_{17}Cl^{35}$	Fe^{56}	$_{92}U^{235}$
1	BE (MeV)	0	2.2244	298.3	492.26	1783.87
2	Mass defect (BE/c^2) in amu	0	2.388×10^{-3}	$0.320\,23 \times 10^{-11}$	0.528 46	1.915
3	Decrease in mass per nucleon (amu)	0	1.194×10^{-3} or 1.982×10^{-40} kg	9.149×10^{-3} or 15.187×10^{-40} kg	9.436×10^{-3} or 15.663×10^{-40} kg	8.15×10^{-3} or 13.529×10^{-40} kg
4	M_p and M_n in nucleus	$M_p = 1.007\,276$	Virtually the same	Virtually the same	Virtually the same	Virtually the same
5	Percentage decrease in M_p	0	1.185×10^{-11}	9.082×10^{-11}	9.367×10^{-11}	8.091×10^{-11}
6	Percentage decrease in M_n	0	1.183×10^{-11}	9.070×10^{-11}	9.354×10^{-11}	8.08×10^{-11}
7	Universal equality of masses of M_p and M_n	Obeyed	Obeyed	Obeyed	Obeyed	Obeyed

Hence, according to the generalised equation, *i.e.*, $\Delta E = Ac^2\Delta m$, the masses of protons and neutrons are the same inside and outside the nucleus; and the BE for the deuteron is the same as experimentally observed, *i.e.*, 2.2244 MeV. In this case the conversion factor A is exceptionally greater than 1, and thus the results are consistent with observations. As newer and newer phenomena in such cases are being discovered, in such phenomena the equation $\Delta E = Ac^2\Delta m$ can be discussed critically.

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