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A Theoretical Verification of Invalidity of the Law of Conservation of Mass: The Cases of Nuclear Species and Nuclear Processes

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ABSTRACT

The law of conservation of mass which suggests the absoluteness of mass by stating that the mass can never be created nor destroyed nor changed even at nuclear species level and during nuclear processes (nuclear reactions, radioactive decays, etc.), is no longer founded. Of course, within some problem domain, the amount of mass remains constant-mass is neither created nor destroyed. This seems quite obvious, as long as we are not talking about nuclear species or very exotic physics problems and processes. When we move a solid object the object retains its shape, density, and volume. On the other hand, in another domain, the result of the law of conservation of mass is quite not the same. It is found that the rest mass of nuclear species is measurably smaller than the sum of the rest masses of its constituent protons and neutrons. Mass is no longer considered unchangeable in this domain. Besides, the law of conservation of mass is proved to be invalid in basic nuclear processes like nuclear decays and nuclear reactions. Therefore, the aim of this article is to discuss some problem domain where the law of conservation of mass is not valid and along the way to reveal that the absoluteness of mass is recently not acceptable.

Keywords: *Mass, Law of conservation of mass, Nuclear species, Nuclear processes*

INTRODUCTION

At the beginning of the 20th century, the notion of mass underwent a radical revision. Mass lost its absoluteness. One of the striking results of Einstein's theory of relativity is that mass and energy are equivalent and convertible one into the other. Equivalence of the mass and energy is described by Einstein's famous formula $E = mc^2$. In words, energy equals mass multiplied by the speed of light squared. Because the speed of light is a very large number, the formula implies that any small amount of matter contains a very large amount of energy. The mass of an object was seen to be equivalent to energy, to be interconvertible with energy, and to increase significantly at exceedingly high speeds near that of light. The total energy of an object was understood to comprise its rest mass as well as its increase of mass caused by increase in kinetic energy [1,2,3].

In special theory of relativity certain types of matter may be created or destroyed, but in all of these processes, the mass and energy associated with such matter remains unchanged in quantity. It was found the rest mass of an atomic nucleus is measurably smaller than the sum of the rest masses of its constituent protons and neutrons. Mass was no longer considered unchangeable in the closed system. The difference is a measure of the nuclear binding energy which holds the nucleus together. Furthermore, the nuclear binding energy is the energy required to break up the nucleus into its separate nucleons or this can be expressed as the energy released when the nucleus is formed from separate nucleons and is equal to the decrease in potential nuclear energy of the nucleons when they come together. According to the Einstein relationship ($E = mc^2$) this binding energy is proportional to this mass difference and it is known as the mass defect [4,5].

In general, the conservation of mass is a fundamental concept of physics along with the conservation of energy and the conservation of momentum. Within some problem domain, the amount of mass remains constant-mass is neither created nor destroyed. This seems quite obvious, as long as we are not talking about nuclear species or very exotic physics problems including nuclear decays and nuclear reactions. The mass of any object can be determined by multiplying the volume of the object by the density of the object. When we move a solid object the object retains its shape, density, and volume. The mass of the object, therefore, remains a constant between two states. For the obvious reason, mass may be absolute for this kind of matter [6,7].

On the other hand, nuclear species(nuclides), which are made up of protons and neutrons, have unique nature and characteristics. Moreover, nuclides are made up of neutrons and protons, but the mass of a nuclide is not the same as the sum of the mass of the neutrons and protons of which it consists. The mass of a nuclide is less than the sum of the masses of the protons and neutrons of which it is made up. The difference in the masses is referred to as the mass defect. In other words, the principle of conservation of mass, which states that "mass can never be changed", is not valid for nuclear species and any nuclear processes. Hence, the law of conservation of mass which suggests the absoluteness of mass by stating that the mass can never be created nor destroyed nor changed at all even at a level of nuclear species and during any nuclear processes (nuclear reactions and nuclear decays), is unfounded. To this end, it is possible to conclude that mass is not always conserved but it can only be approximately conserved [1,2]. Accordingly, the objective of this article is to reveal that the law of conservation of mass which suggests the absoluteness of mass is no longer true.

In the following sections, we will further summarize the historical developments of the concept of conservation of mass, and we will discuss the relationship between binding energy and mass defect.

Historical developments of the concept of conservation of mass

The concept of conservation of mass has gone through different historical developments. It is summarized as follows:

Ancient Times	The ancient Greeks proposed the idea that the total amount of matter in the universe is constant.

1748 AD	The principle of conservation of mass was first outlined by Mikhail Lomonosov in 1748. Suggested the law of conservation of mass to be always conserved. Conjectured mass can always never be created nor destroyed.
Late 18th Century	The law of conservation of matter (or the principle of mass/matter conservation) as a fundamental principle of physics was discovered in by Antoine Lavoisier in the late 18th century. It was of great importance in progressing from alchemy to modern chemistry. It also considered mass as absolute at all level of matters. In other words, it saw the law of conservation of energy to be satisfied at any level of particles.
1905	In special theory of relativity certain types of matter may be created or destroyed, but in all of these processes, the mass and energy associated with such matter remains unchanged in quantity. It was found the rest mass of an atomic nucleus is measurably smaller than the sum of the rest masses of its constituent protons, neutrons and electrons. Mass lost its absoluteness.
Late 20th Century	Reiterated that the principle of conservation of mass is only approximately valid. It is not valid for the masses of nuclides and their constituents, Nuclear processes and other exotic particles. The result was observed in various phenomena(nuclear decays, nuclear reactions, etc.) and advancement of technologies including nuclear reactor involving fission reactions.
Recent	Invalidity of the conservation of mass has widely been theoretically proved in various processes like Nuclear reaction, Nuclear fission and fusion, and practically observed in technologies. This further fortifies that mass can only be approximately conserved.

Nuclear Binding Energy Vs. Mass Defect

The relationship between binding energy and mass defect is given by Einstein's equation [3,4]

$$E_b = \Delta mc^2 \qquad .... (1)$$

where

$$\Delta m = (A - Z)m_n + Zm_p - M_N \; ....(2)$$

and where Δm is mass defect, M_N is the mass of a nuclide, m_n is the mass of a neutron, m_p is the mass of a proton, Z is proton number or atomic number, A is nucleon number or mass number. If we know the total binding energy of a nucleus, and the number of nucleons, we can work out the binding energy per nucleon, which is the average energy needed to remove each nucleon.

Verifying Invalidity of conservation of mass

Furthermore, the aim of this article is to discuss some problem domain where the law of conservation of mass is not valid and along the way to reveal that the absoluteness of mass is recently not acceptable. In this section, we consider some segments of problem domain which support and vivify the very objective of this article. This can be done by considering the following segments identified as "through the masses of the nuclides and their constituents: by calculating mass defects/mass differences of nuclides" and "through different nuclear processes".

(I) Through the masses of the nuclides and their constituents: by calculating mass defects/mass differences of nuclides

This can convincingly be shown by considering the number of cases as follows [8,9]:

Case 1: Mass defect of a ^{63}Cu

To verify the invalidity of mass, in this case, it is possible to calculate the mass defect of a ^{63}Cu nucleus where the actual mass of ^{63}Cu in its nuclear ground state from the mass data is given to be **62.91367 u.**

Clearly, ^{63}Cu nucleus has 29 protons and also has (63 – 29) = 34 neutrons.

Again, from the mass data the mass of a proton is **1.00728 u** and a neutron is 1**.00867 u.**

The combined mass is: **29 protons x (1.00728 u/proton) + 34 neutrons x (1.00867 u/neutron) = 63.50590 u.** Here, we can obviously see that the sum of the masses of constituent protons and neutrons is calculated to be greater than the mass of ^{63}Cu which they make up or the mass of ^{63}Cu is less than the sum of masses of the constituent protons and neutrons of which it is made up i.e. 63.50590 u> 62.91367 u. Hence, the mass defect or mass difference is **Δm = 63.50590 u – 62.91367 u = 0.59223 u.**

Furthermore, converting the mass defect into energy (nuclear binding energy) i.e.

(0.59223 u/nucleus) x (1.6606 x 10^{-27} kg/u) = 9.8346 x 10^{-28} kg/nucleus

Then, the binding energy can also be calculated as follows

$\Delta E = \Delta mc^2$

ΔE = (9.8346 x 10^{-28} kg/nucleus) x (2.9979 x 10^8 m/s)^2 = 8.8387 x 10^{-11} J/nucleus

Case 2: Mass defect of the reactor core

The mass defect of the 3000MW$_{th}$ reactor core after one year of operation can also be calculated for further proof of invalidity of conservation of mass.

It is known the average recoverable energy per fission is about 200 MeV, being the total energy minus the energy of the energy of antineutrinos that are radiated away.

The reaction rate per entire 3000MW$_{th}$ reactor core is about 9.33×10^{19} fissions / second.

The overall energy release in the units of joules is:

200×10^6 (eV) x 1.602×10^{-19} (J/eV) x 9.33×10^{19} (s^{-1}) x 31.5×10^6 (seconds in year) = 9.4×10^{16} J/year

The mass defect is calculated as:

$\Delta m = \Delta E/c^2$

Δm = 9.4×10^{16} / (2.9979 x 10^8)^2 = 1.046 kg

That means in a typical 3000MWth reactor core about 1 kilogram of matter is converted into pure energy which is violation of conservation of mass. It is noted that, a typical annual uranium load for a 3000MWth reactor core is about 20 tonnes of enriched uranium (i.e. about 22.7 tonnes of UO_2). Entire reactor core may contain about 80 tonnes of enriched uranium.

The mass defect of reactor core can also be calculated directly from the Einstein relationship ($E = mc^2$) as:

$\Delta m = \Delta E/c^2$

Δm = 3000×10^6 (W = J/s) x 31.5×10^6 (seconds in year) / (2.9979 x 10^8)^2 = 1.051 kg, which is approximately the same value.

Case 3: Mass defect of ^{12}C

The actual mass of ^{12}C in its nuclear ground state from the mass data is given to be exactly **12.00 u**. On the other hand, ^{12}C nucleus has 6 protons and also (12-6) = 6 neutrons and from the mass data the mass of a proton is **1.00728 u** and a neutron is **1.00867 u.** However, the combined mass is: **6 protons x (1.00728 u/proton) + 6 neutrons x (1.00867 u/neutron) = 12.0957 u.** Here, we can strikingly see that the sum of the masses of constituent protons and neutrons is calculated to be greater than the mass of ^{12}C which they make up or the mass of ^{12}C is less than the sum of masses of the constituent protons and neutrons of which it is made up i.e**. 12.0957 u> 12.00 u.** Hence, the mass defect or mass difference is **Δm = 12.0957 u – 12.00 u = 0.0957 u.**

This case also vividly verify that conservation of mass is not valid particularly when it comes to the masses of nuclides and their constituents(protons + neutrons).

Case 4: Mass defect of ^{16}O

The standard mass of ^{16}O in its nuclear ground state from the mass data is given to be exactly **15.9949 u.** On the other hand, ^{16}O nucleus has 8 protons and also (16-8) = 8 neutrons and from the mass data the mass of a proton is **1.00728 u** and a neutron is **1.00867 u.** However, the combined mass is: **8 protons x (1.00728 u/proton) + 8 neutrons x (1.00867 u/neutron) = 16.1276 u.** Here, we can strikingly see that the sum of the masses of constituent protons and neutrons is calculated to be greater than the mass of ^{16}O which they make up or the mass of ^{16}O is less than the sum of masses of the constituent protons and neutrons of which it is made up i.e. **16.1276 u> 15.9949 u.** Hence, the mass defect or mass difference is **Δm = 16.1276 u – 15.9949 u = 0.1327 u.**

This case also conclusively verifies that conservation of mass is not valid particularly when it comes to the masses of all nuclides and their constituents (protons + neutrons).

In general, the invalidity of conservation of mass works for all nuclear species at all energy states. This is to say for all nuclear species the mass of the nuclide is not equal to the sum of the masses of protons and neutrons of which it is made up i.e. The sum of the masses of the protons and neutrons is always greater than the mass of the nuclide which they make up. Therefore, the notion that "matter is always conserved" is not valid for nuclear species [13].

(II) Through different nuclear processes

Furthermore, it is also possible to present established facts and evidences in the way of reaffirming and reasserting the previous point concluding that conservation of mass/matter is not valid under the following nuclear processes (nuclear reactions and nuclear decays).

1) Nuclear reactions

Nuclear reactions are generally taken to be reactions in which particles interact with nuclides and end up giving rise to nuclides and particles. Generally, the principle of conservation of mass is not satisfied in the processes of nuclear reactions. This can be explained and shown under the following typical classifications of nuclear reaction (i.e. nuclear fission and nuclear fusion) [1,2,3].

a) Nuclear fission

During the nuclear splitting or fission, some of the mass of the nucleus gets converted into huge amounts of energy and thus this mass is removed from the total mass of the original particles, and the mass is missing in the resulting nucleus. The nuclear binding energies are enormous; they are of the order of a million times greater than the electron binding energies of atoms [2,5].

Generally, in both chemical and nuclear reactions, some conversion between rest mass and energy occurs, so that the products generally have smaller or greater mass than the reactants. Therefore, the new conservation principle is the conservation of mass-energy. In this process the mass difference is converted to energy and emitted as energy of disintegration [6].

For example, we can consider the following fission reaction:

$$^{235}_{92}U \; + \; ^{1}_{0}n \; \rightarrow \; ^{144}_{56}Ba \; + \; ^{90}_{36}Kr \; + \; 2^{1}_{0}n$$

Masses: 235.118 + 1.009 → 143.881 + 89.947 + 2.018

Sum: 236.127 amu → 235.846 amu

As it can obviously be seen from this fission reaction that the sum of the masses in the entrance channel(236.127 amu) is greater than the sum of the masses in the exit channel(235.846 amu). That means, the conservation of mass/matter is apparently violated. However, the missing mass is converted and emitted as disintegration energy in exit channel. Therefore, the notion suggesting mass/matter can never be destroyed, is not valid in fission reactions.

b) Nuclear fusion

During the nuclear mashing or fusion, just similar to nuclear fission, some of the mass of the nucleus gets converted into huge amounts of energy and thus this mass is removed from the total mass of the original particles, and the mass is missing in the resulting nucleus. The nuclear binding energies are enormous, they are of the order of a million times greater than the electron binding energies of atoms. Here, also it is possible to consider typical example of nuclear fusion reaction and fortify that the total mass is not conserved in the process[10,11].

For example, among the fusion reactions that occur in stars is:

$$^{3}_{2}He + ^{3}_{2}He \;\rightarrow\; ^{4}_{2}He + ^{1}_{1}H + ^{1}_{1}H$$

Masses: 3.016029+3.016029 → 4.002603+1.007825+1.007825

Sum: 6.032058 amu → 6.018253 amu

From this reaction scheme and representation of masses data , it is highly fortified that the fraction of total mass gets destroyed**.** Because the masses in the exit channel is added to be less than the sum of the masses in entrance channel**,** this fusion reaction is strikingly against the principle of conservation of mass which states that "mass/matter can never be destroyed"**.**

2) Nuclear Decay

Nuclear decay is the spontaneous transformation of the atomic nucleus, leading to a change in the composition and/or internal energy of the nucleus, in general. Generally, the principle of conservation of mass is not valid in the process of nuclear decay. This can be explained and shown under the following typical conceptual segments of nuclear decay (i.e. matter-antimatter creation and matter-antimatter annihilation) [1,3,8].

a) Matter- antimatter creation

Matter- Antimatter creation occurs naturally in high-energy processes involving cosmic rays, and also in high-energy experiments in accelerators in Earth. High-energy cosmic rays impacting Earth's atmosphere (or any other matter in the Solar System) produce minute quantities of antiparticles in the resulting particle jets, which are immediately annihilated by contact with nearby matter. The presence of the resulting antimatter is detectable by the two gamma rays (with 511 keV) produced every time positrons annihilate with nearby matter [12].

Antimatter creation is also very common in nuclear decay of many isotopes. Let assume a decay of potassium-40. Naturally occurring potassium is composed of three isotopes, of which ^{40}K is radioactive. Traces of ^{40}K are found in all potassium, and it is the most common radioisotope in the human body. ^{40}K is a radioactive isotope of potassium which has a very long half-life of 1.251×10^{9} years and undergoes both types of beta decay [13].

- About 89.28% of the time (10.72% is by electron capture), it decays to calcium-40 (^{40}Ca) with emission of a beta particle (β^-, an electron) with a maximum energy of 1.33 MeV and an antineutrino, which is an antiparticle to the neutrino.
- Very rarely (0.001% of the time) it will decay to ^{40}Ar by emitting a positron (β+) and a neutrino [1].

Another very interesting source of antimatter is, in fact, a nuclear reactor. Nuclear reactors are the major source of human- generated antineutrinos. This is due to the fact that antineutrinos are produced in a negative beta decay. In a nuclear reactor occurs especially the β- decay, because the common feature of the fission fragments is in an excess of neutrinos. Billions of solar neutrinos per second pass (mostly without any interaction) through every square centimeter ($\sim 6 \times 10^{10}$) on the Earth's surface and antineutrino radiation is by no means dangerous. This shows that matter can be created [11].
Finally, the fact is that creation of antimatter is much more common, than it may seem, which further backs up the aforementioned point.
Moreover, In January 2011, research by the American Astronomical Society discovered antimatter **(**positrons**)** originating above thunderstorm clouds. It is suggested that these positrons are formed in terrestrial gamma-ray flashes (TGF). These positrons are produced in gamma-ray flashes created by electrons accelerated by strong electric fields in the clouds. TGFs are brief bursts occurring inside thunderstorms and associated with lightning. The streams of positrons and electrons collide higher in the atmosphere to generate more gamma rays. About 500 TGFs may occur every day worldwide, but mostly go undetected. Therefore, it is possible to say that matter can only be approximately conserved, because there are many cases where matter can be created including antimatter [13].

b) Matter- antimatter annihilation

When a positron (antimatter particle) comes to rest, it interacts with an electron, resulting in the annihilation of the both particles and the complete conversion of their rest mass to pure energy in the form of two oppositely directed 0.511 MeV photons [14].
As was written, a particle and its antiparticle have the same mass as one another, but opposite electric charge, and other differences in quantum numbers. That means a proton has positive charge while an antiproton has negative charge and therefore they attract each other. A collision between any particle and its antiparticle partner is known to lead to their mutual annihilation**.** Since matter and antimatter carry an immense amount of energy (due to $E = mc^2$), their mutual annihilation is associated with production of intense photons (gamma rays), neutrinos, and sometimes less-massive particle–antiparticle pairs[2,3].
One of best known processes is electron-positron annihilation. Electron–positron annihilation occurs when a negatively charged electron and a positively charged positron collide. When a low-energy electron annihilates a low-energy positron (antiparticle of electron), they can only produce two or more photons (gamma rays). The production of only one photon is forbidden because of conservation of linear momentum and total energy. The production of another particle is also forbidden because of both particles (electron-positron) together do not carry enough mass-energy to produce heavier particles. When an electron and a positron collide, they annihilate resulting in the complete conversion of their rest mass to pure energy (according to the $E=mc^2$ formula) in the form of two oppositely directed 0.511 MeV gamma rays (photons) [2].

$$\mathbf{e^- + e^+ \rightarrow \gamma + \gamma \ (2x\ 0.511\ MeV)}$$

This reaction clearly indicates that total mass is annihilated or destroyed. Therefore, this is also another process whereby the conservation of mass is verified to be unsatisfied.
However, this process satisfies the following conservation laws:

- Conservation of electric charge. The net charge before and after is zero.
- Conservation of linear momentum and total energy. T
- Conservation of angular momentum.

Conclusively, the principle of conservation of mass (i.e. mass/matter can never be created or annihilated), is not satisfied in the domain of nuclear species and nuclear processes including nuclear reactions(nuclear fissions, nuclear fusions, etc), nuclear decays(matter-antimatter creation, matter-antimatter annihilation, etc).

CONCLUSION

In general, from striking reality and substantiated facts presented through this article, it is clear that mass is no longer considered absolute and the law of conservation of mass is also not valid at all level of matters. Moreover, mass may be absolute and the law of conservation of mass may be purely valid at some problem domain but the absoluteness of mass and validity of the law of conservation of mass are no longer satisfied for another problem domain. Therefore, as per the objective of this article, absoluteness of mass and validity of law of conservation of mass are proved to be no longer real at subatomic particles another exotic physics problems. It is shown that the rest mass of nuclear species is measurably smaller than the sum of the rest masses of its constituent protons and neutrons. Mass is proved to be no longer considered unchangeable in this domain. Besides, the law of conservation of mass is proved to be invalid in basic nuclear processes like nuclear decays and nuclear reactions.

REFERENCES

1. Lilley J., Nuclear Physics: Principles and Applications, John Wiley, (2001).
2. Samuel S. M. Wong, Introductory Nuclear Physics, University of Toronto, (2005).
3. Kenneth S. Krane, Introductory Nuclear Physics, 3rd Edition, Wiley, (Nov 1987).
4. Basdevant, Jean-Louis et al., Fundamentals in Nuclear Physics, From Nuclear Structure to Cosmology, (2005).
5. Blatt, J.M., Weisskopf, V.F., Theoretical Nuclear Physics, (1952).
6. Takigawa, Noboru et al., Fundamentals of Nuclear Physics, (2017).
7. David Griffiths, Introduction to Elementary Particles, 2nd, Revised Edition, (1983).
8. A. Das and T. Ferbel, Introduction to Nuclear and Particle Physics, (Dec 2003).
9. Introduction to High Energy Physics, 4th Edition, by Donald H. Perkins.
10. Modern Atomic and Nuclear Physics, Jan 2010, by Fujia Yang, Joseph Hamilton, World Scientific. pp.
11. Nuclear Physics- Exploiting the Heart of the matter, National Research Council of the National Academies, Physics (2010).
12. http://www.journaloftheoretics.com/Links/Papers/APRLE.pdf.
13. https://www.quora.com/Is-the-law-on-the-conservation-of-matter-wrong-because-antimatter-can-destroy-matter.
14. Laurent Canetti et al., Matter and antimatter in the universe, New Journal of Physics, (2012), 14(3): 1.

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