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MASS-ENERGY EQUIVALENCE NOT EXPERIMENTALLY VERIFIED.

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ABSTRACT. The notion of mass-energy equivalence and its mathematical expression through the famous equation $E = mc^2$ predates Einstein when he introduced special relativity in 1905. It has to be noted that $E = mc^2$ has no rigorous theoretical basis; it is only a pure hypothesis not related to any physical theory. The thesis of this paper is that there is no incontrovertible experimental verification of mass-energy equivalence. The Year_Of_Physics_2005 'Direct Test Of $E = mc^2$' published in Nature 2005 [4] claims a verification of the equation to an accuracy of 0.00004%. The experimenters misunderstood the very nature of the experiment that they carried out. It was not a verification of $E = mc^2$, but just another experiment to deduce the mass of the neutron. To date, we have not measured the true mass of the neutron to any degree of accuracy; we only have a deduced estimate of the neutron mass based on the mass-energy equivalence of $E = mc^2$.

1. INTRODUCTION

The notion of mass-energy equivalence in modern physics is that nature provides for the mutual convertibility between mass and energy under the right conditions. The quantitative conversion is with the famous equation $E = mc^2$. This equation has two parts: the kinetic energy part given by $E = (\frac{1}{\sqrt{1 - v^2/c^2}} - 1)m_0c^2$ and the rest-energy part given by $E = m_0c^2$; m_0 being the invariant rest-mass of particles (The author has an unpublished paper that details why the kinetic energy part is invalid [1]). When we discuss mass-equivalence and $E = mc^2$, we are concerned only with the equivalence between rest mass and energy. The notion of $E = m_0c^2$ predates Einstein when he introduced special relativity in 1905. The discovery of the equation was credited to him as he probably made the most detailed analysis of it through his later papers. It has to be noted that $E = m_0c^2$ has no rigorous theoretical foundation based on any physics; it is still only a hypothesis - a pure hypothesis. It has no relation to any physical theory; it is not even remotely related to the special theory of

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relativity. The textbooks and the literature in physics have given various phenomena and experiments to be proofs of mass-energy equivalence of $E = mc^2$. Experiments have even been done that supposedly verified the equation to a very high degree of accuracy [4]. It is presented here that it is not so. The phenomena and the the experiments provided are not without serious issues. The following sections will show the arguments in details.

2. Proofs Of E=mc^2

2.1. **Pair Production.** Pair production is the hypothesis that pure light energy - or light photons - may convert to matter through the creation of a particle and its anti-particle. In 1933, Patrick Blackett discovered the pair production of the electron positron (through high energy radiation) within the cloud chamber he invented. Ever since, such pair productions have been taken as proof of mass-energy equivalence. It is shown here that such pair production does not constitute an incontrovertible proof. There are three strong arguments against it:

(1) Pair production cannot take place in a vacuum: The textbooks always point to a reason why pair production fails to take place in the vacuum - that mass-energy conservation and momentum conservation cannot both be satisfied at the same time in vacuum. So pair production needs to be within the 'vicinity' of a nucleus of an atom in order that the nucleus would help to carry away some momentum. It is easily shown why energy and momentum conservation cannot be satisfied at the same time in vacuum. Consider the hypothetical conversion of a photon to an electron positron pair in vacuum:

$$h\nu \rightarrow e^- + e^+ \tag{1}$$

A light photon has energy $E = h\nu$ where h is the planck constant, ν the frequency of the photon. The photon has linear momentum given by: $p = E/c$ where c is the speed of light. In order for momentum conservation, the particle pair have to take line paths that is a plane together with the direction of the photon; the particles must also make the same angle θ with the photon axis and have equal velocity v. For mass-energy conservation:

$$E = h\nu = 2m_ec^2 + m_ev^2 \tag{2}$$

For momentum conservation along the photon direction:

$$p = E/c = 2m_evcos\theta \tag{3}$$

Eliminating E and m_e from (2) and (3) above, we have:

$$v^2 - 2cvcos\theta + 2c^2 = 0 \tag{4}$$

It is easily seen through inspection that (4) cannot be satisfied for any small value of $v < c$ and any angle θ. This proves that pair production of interaction (1) cannot occur in the *'empty-space'* of vacuum without violating either energy conservation or momentum conservation.

The region of *'empty-space'* ends only when we enter the *'space'* of matter; i.e. when we enter into the nucleons - a proton or a neutron. So what it means is that pair production may only happen when light strikes a nucleon. It is for this reason that the typical electron positron pair production only occurs in a cloud chamber or a bubble chamber that contains a vapor or a liquid material such as within a bubble chamber with liquid hydrogen[6]:

$$h\nu + p^+ \to p^+ + e^- + e^+ \tag{5}$$

When a high energy $\gamma\text{-}ray$ hits a proton (a nucleus of hydrogen), a pair of electron positron appears. A light photon has energy $E = h\nu$ where h is the plancks constant, ν the frequency of the photon. A mere inspection of (5) clearly shows it is not anything like a *'transmutation'* of a pure photon to an electron and a positron. It clearly is a proton emitting a electron positron pair 'under_the_right' conditions - when it absorbs a high energy photon. We have to take it that we have not much knowledge yet of a classical proton and how such an interaction occur. It is simplistic just to take the energy part and label it as conversion of pure radiation energy to mass downgrading the proton's participation as just merely to being a *'momentum-carrier'*.

(2) Creation of electric charges in the universe: The interaction involves creation of additional negative charges and positive charges in the universe. That the pair production here not only involves mass-energy conversion, but also causes an appearance of an amount of negative charge in the universe - 'out_of_emptiness'. Similarly, an amount of positive charge too appears in the universe 'out_of_emptiness'. Just because the electron charge is an infinitesimal amount does not mean such a creation of charge could be ignored in the pair production process. It could well be of great significance as to the true nature of the interaction.

(3) Creation of a full particle: Pair production creates only full elementary particles such as the electron, proton and their antiparticles. In the most common nuclear interactions where mass-energy conversion applies, there are no creation of full particles; the number of nucleons are unchanged. The mass changes before and after the interactions are only due to mass

defects. Take the interaction of the 1932 Cockroft and Dalton experiment:

$$p^{+} +_{3}^{7} Li \rightarrow 2\,_{2}^{4}He \tag{6}$$

It is the first historical transmutation of matter. A high energy proton collided with lithium resulting in two nuclei of helium. The mass-energy conversion is due only to the mass defects between the initial and the final constituent particles. Such interactions are the most common of mass-energy conversion and an ideal interaction as an experimental proof is most convincing if it is one of such interaction type.

2.2. **Pair Annihilation.** The textbooks and the physics literature too would point to particle anti-particle mutual annihilation to be proof of mass-energy equivalence. A detailed study by Ling Jun Wang[2] shows that it also could not be taken to be incontrovertible proof of mass-energy equivalence.

Quoting from section IX, Annihilation Of Mass Into Energy:

> *The inverse of the pair-production is the annihilation of a particle-antiparticle pair into pure energy. In annihilation,all masses are lost. There is simply no experimental evidence whatsoever that could show the annihilation of particles. The annihilation of particle-antiparticle is simply a theoretical prescription...We simply do not have a solid experiment that provides evidence of annihilation beyond reasonable doubt.*

The analysis of Wang may be accepted unless there is strong counter-arguments against it.

2.3. **1932 Cockcroft And Walton Experiment.** Cockcroft and Walton are credited with the first experimental verification of mass-energy equivalence. They achieved the first transmutation of matter when they bombarded $^{7}_{3}$Li with accelerated protons:

$$p^{+} +_{3}^{7} Li \rightarrow 2\,_{2}^{4}He \tag{7}$$

The sum of the rest masses of the proton and Lithium was greater than that of the two alpha-particles; an amount of 0.0154 amu of mass ‘disappeared’ after the reaction. They estimated the initial kinetic energy of the reactants to be 125 KeV and the total kinetic energy of the final alpha-particles to be 17.2 MeV. As the amount of lost mass of 0.0154 amu is equivalent to 14.3 MeV, they concluded that mass-energy equivalence of $E = mc^2$ to be verified within experimental errors.

As pointed out by Ajay Sharma [3], using the latest mass of the proton, alpha-particle and Litium-7 gives an error close to 10%. This 1932 experiment did not have the accuracy to be offered as an experimental proof of $E = mc^2$. Nonetheless - as noted earlier - this reaction is ideal for an experiment to resolve the question of mass-energy equivalence. What is needed is a repeat of the experiment to a high enough accuracy. Unfortunately, no one to date has repeated this experiment as a verification of $E = mc^2$.

2.4. **2005 Direct Test Of E=mc^2.** In the *'Year_Of_Physics_2005'*, four physicists from the MIT, NIST and the Institute Laue Langevin, Genoble, France (ILL) conducted an experiment that was entitled *'Direct Test Of E=mc^2'* [4]. It gave the accuracy of the result as: $1-\triangle(mc^2)/E$ $= -1.4 \pm 4.4 \times 10^{-7}$ or accurate to 0.00004%. With this degree of accuracy, such an experiment would indeed put to rest any doubts about the hypothesis of mass-energy equivalence given precisely by $E = mc2$. Unfortunately - and rather incomprehensible - the experimenters had a critical misunderstanding of their very own experiment. The experiment was not an experiment that verified mass-energy equivalence, but rather an experiment to deduce the mass of the neutron based on the assumption of $E = mc^2$. We will see why.

Their experiment was based on neutron capture by an element resulting in the next higher isotope of the element accompanied by $\gamma\text{-}rays$. The change in the rest mass of the element's nucleus was measured and the energy of the emitted rays were also measured. They computed the rest mass of the neutron and the nucleus less the rest mass of the resulting nucleus. The result is compared to the radiated energy as a test of $E = mc^2$. They did experiments on sulphur(S) and silicon(Si):

$$\begin{aligned} n + {}^{32}S &\rightarrow {}^{33}S + \gamma\text{-}ray \\ n + {}^{28}Si &\rightarrow {}^{29}Si + \gamma\text{-}ray \end{aligned} \tag{8}$$

The $\gamma\text{-}ray$ was emitted as the new isotope returns from an excited state to its ground state. The error equation of mass-energy equivalence would be (for sulphur):

$$error\text{-}estimate = 1 - \frac{\triangle(mass(neutron) + mass({}^{32}S) - mass({}^{33}S))c^2}{E\text{-}\gamma\text{-}ray} \tag{9}$$

The error was found to be within 0.00004%.

The experiment could have been a landmark experimental verification of $E = mc^2$ had we have an accurate measured value for the mass of the neutron needed in the equation (9) above. As will be explained in the later sections, to date, we have not found a way to measure the mass of the neutron. Without an independently measured mass of the neutron, the above cannot be a valid experiment to verify mass-energy equivalence. Rather, the experiment may just be another experiment to deduce the mass of the neutron. Rearranging equation (9) assuming equality:

$$mass(neutron) = mass({}^{33}S) - mass({}^{32}S) + (E\text{-}\gamma\text{-}ray)/c^2 \tag{10}$$

The right_hand_side of the above equation may be computed with the measured values from the experiment. So, the experiment is just another experiment to deduce the mass of the neutron using a different reaction.

The detail calculations as given in the original published paper [4] starts with this equation:

$$\begin{aligned} &\triangle\, Mc^2 = (M[^AX] - M[^{A+1}X] + M[D] - M[H])c^2 \\ &= 10^3 N_A h(f_{A+1} - f_D) mol AMU kg_{-1} \end{aligned} \tag{11}$$

where $\triangle M$ is the experimentally determined mass difference (mass of neutron + mass(X) less mass(X+1)) of the reaction; "the Avogadro constant N_A relates the measured mass M[X] in unified atomic mass units(AMU) to its mass in kilograms m[X]"; h = planck constant; M[D] = deuteron mass; M[H] = proton mass; f_{A+1} is the measured frequency giving the energy of the γ-ray; f_D is the frequency giving the energy of the γ-ray relating to an outside experiment for the binding energy of the deuteron. From equation (11) above, we have (using m[]) for kg:

$$(m[D] - m[H]) + hf_D/c^2 = m[^{A+1}X] - m[^AX] + hf_{A+1}/c^2 \tag{12}$$

Both sides of the equation above represent the mass of the neutron; the left side is from the outside experiment [5] to deduce the neutron mass from its measured binding energy; the right side is for the deduction from the current experiment. For the current experiment, we have:

$$m[neutron] = m[^{A+1}X] - m[^AX] + hf_{A+1}/c^2 \tag{13}$$

As all the terms in the right side of the above equation are available as measured quantities of the experiment, we could deduce the mass of the neutron. Thus eliminating the unnecessary introduction of the binding energy of the deuteron into the experiment, the true nature of the experiment is revealed.

3. We have Yet To Measure The Mass Of The Neutron

Through the collaboration of the international scientific community, we have data for the various universal physical constants determined by the various laboratories around the world. As examples, we have the atomic masses for the fundamental particles, atoms and the molecules. The table below show some masses from the US National Institute of Standards and Technology (NIST):

Particle/atom	Mass(u)
electron	5.485 799 090 70 x 10^{-4}
proton/^{1}H	1.007 276 466 879
deuteron/^{2}H	2.013 553 212 745
neutron	1.008 664 915 88
alpha-particle/^{4}He	4.001 506 179 127
Carbon-12	12(exact)
Lithium-7	7.016 003 436 6

The above are examples of the precisions that are achievable today for some experimental values.

From around the 1900, various scientists (such as J.J. Thomson) pioneered the technique of mass spectrometry that enables charged particles like the electron, the proton and other charged ions of atoms and molecules to be measured. It makes use of the fact that a moving charged particle is deflected from a straight path when injected into a magnetic field; if the magnetic field is uniform, the particle will trace out a circle whose radius is dependent on the magnetic field strength B, its mass m and its speed v. By measuring the radii for two particles and together with the other measured variables, the relative atomic masses may be calculated. If the mass of one particle is known, the other may be determined. So mass spectrometry is the equivalent of the weighing scales for measuring mass of macroscopic body. A technique, the 'ion-mass-spectrometry', with much greater accuracy is now available using the Penning trap to measure relative atomic masses of charged particles and ions [8, 9].

Although atomic masses may be measured to a very high degree of accuracy, the unfortunate aspect is that only charged particles and ions may be measured. Current mass measurement techniques cannot be used to measure any uncharged particle; e.g. the neutron. But then, why is that NIST gives the mass of the neutron to an accuracy comparable to that of the proton? There is actually a real issue in the figure 2.013 553 212 745u for the mass of the neutron that has not been acknowledged. The current accepted value of the neutron mass is not a measured mass in the sense that the other atomic masses are directly measured values such as the electron, the proton.

> ***To date, we do not know the true mass of the neutron to any degree of accuracy.***

3.1. **Neutron Mass And The 1934 Chadwick Experiment.** The neutron was discovered by Sir James Chadwick in 1932. In 1934, he and Maurice Goldhaber[7] made the first determination of the neutron mass that was accurate enough to decide that the neutron was indeed a new neutral particle within the nucleus; there was no free electrons within the nucleus of an atom. Their method was by determining the minimum gamma-ray energy required to disintegrate the deuteron; Chadwick and Goldhaber were able to constrain the binding energy of the deuteron within a range. They then made use of the mass-energy equivalence of $E = mc^2$ to arrive at a mass difference which was used to compute the mass of the neutron; this was done despite the fact there was no experimental verification for the mass-energy equivalence hypothesis at the time - it probably was the only way to have an estimate of the neutron mass that must await a verification of $E = mc^2$ in the future. Through further arguments, they made an estimate of the correct binding energy to be 1.8 MeV giving the neutron an estimated mass of 1.0081 amu. The accepted mass of the neutron today is still based on a similar method that Chadwick used - by assuming the correctness of mass-energy equivalence of $E = mc^2$ using an accurate measured value of the binding energy of the deuteron [5].

4. Conclusion

To date, the notion of mass-energy equivalence and its mathematical expression in $E = mc^2$ cannot be said to have been experimentally verified beyond reasonable doubt. Although the physics community has been using the neutron mass as if it has been measured to the same degree of accuracy as with the directly measured mass of the proton, it is not correct. We only have a deduced estimate value of the neutron mass by assuming the correctness of mass-energy equivalence of $E = mc^2$.

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