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Challenges in Interpreting Mass Energy Relationship as per Modern view; the case of Wolaita Sodo University Physics Community

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ABSTRACT

The mass-energy relationship, $\mathrm{E{=}mc^2}$ which was proposed by Einstein in 1905 under his Special Relativity Theory has removed the barrier between matter and energy. However, it was traditionally set to have had incorrect interpretation in many books. Such interpretation includes 1) mass is variant 2) mass is completely equivalent to energy 3) mass can be converted in to energy and 4) mass(inertia) is conserved because mass equals energy divided by c^2, and energy is always conserved. More recently, the new view has followed to indicate conceptual interpretation that contradicts the above one. Though this new conceptual interpretation has widely been accepted as correct representation of $\mathrm{E{=}mc^2}$, it is remaining puzzle to large number of the students amid the old view is still drastically persisting through books. The very limited internet access is another challenge that exacerbates this situation. Accordingly, this article provides mass-energy related interpretation in the domain of modern view. It also examines misconceptions that have been inherited from aforementioned challenge. In addition, this article identifies issues and proposes solutions and suggestions that are helpful to create conducive environment in introducing correct interpretation of $E{=}mc^2$ to students.

Keywords: *modern view, mass-energy relationship,* $E{=}mc^2$

INTRODUCTION

The Einstein's general mass-energy related view has been developed in association with his Special Relativity Theory. His idea of the "relativistic mass" that was introduced in 1905 considers mass as a variant or a velocity dependent quantity, which increases with velocity. The Einstein's concept of mass-energy relationship that was proposed in the same year also depicts mass and energy as two forms of the same thing by asserting "mass is completely equivalent to energy" in reference to his famous equation, $\mathrm{E{=}mc^2}$ from which he also explained the relation between mass and energy as "mass can be converted in to energy" [1],[3]. These conceptual segments i.e. "relativistic mass" and "mass-energy equivalence" situating in the realm of Einstein's overall mass-energy related view have been the most prominent in Special Relativity Theory and yet widely familiar in many textbooks and references persistently. Perhaps, many related conceptual segments have also been endorsed by many Physicists in their attempts of explaining mass-energy relationship by using Einstein's view as premise. For example, Hobson(2003) proposed the conservation of mass from the Einstein's relation as "It is true that matter (rest-mass) is not always conserved. But mass (inertia) is always conserved, because mass equals energy divided by c^2, and energy is always conserved" [1].

Nevertheless, regardless of the Einstein's view or related interpretations endorsed by different Physicists or popular philosophical discussions otherwise, mass and energy are not two forms of the same thing according to modern interpretation of mass-energy relationship, $E{=}mc^2$. Instead, under the modern domain, the concept of energy momentum 4-vector suggests another interpretation of $E{=}mc^2$ which contradicts the idea of Einstein's mass-energy equivalence. Hence, energy momentum 4-vector implies that mass is not completely equivalent to energy[2],[3],[9]. Modern view also underlines that to consider mass as variant or velocity dependent quantity in Special Relativity Theory is a misconception. This implies that mass is invariant quantity and so it does not depend on velocity [3],[4],[10].With regard to mass conservation, modern concept explains that there is only one mass in Special Relativity Theory and mass can only be approximately conserved, depending on the system chosen whereas energy can always be conserved in any system [3],[4]. Besides, this concept rejects the idea of conversion of mass into energy by proposing the interpretation of $E{=}mc^2$ as "mass is a property that all energy exhibits"[13].

In general, the above paragraph implies that the modern view of $E{=}mc^2$ basically contradicts the idea of relativistic mass and interpretation of $E{=}mc^2$ highlighted in paragraph1 as 1) mass is variant 2) mass is completely equivalent to energy 3) mass can be converted in to energy 4) mass(inertia) is conserved because mass equals energy divided by c^2, and energy is always conserved. Nowadays, the view proposed under second paragraph as a whole has widely been accepted as the only correct conceptual representation of $E{=}mc^2$ [2],[3],[4],[13]. However, this concept of $E{=}mc^2$ has still been remaining puzzle to many students I have asked for and spoken to. The main challenge that has been casting shadow on the effort of students toward being familiar with this modern view arises from the fact whereas vast number of books that are accessible to them still persistently using the traditional view highlighted in paragraph1. The objective existence of this challenge can be shown as a testament by the following survey I have conducted in Ethiopia ,this year. In this survey of more than 20 textbooks, and more than 25 reference books, all books(textbooks and reference books) use the term "relativistic mass", or the term "mass" which may vary with velocity, that is, they are holding still incorrect representations of old view. These books are also found to interpret $\mathrm{E = mc^2}$ exactly in the same way highlighted in paragraph1, which is misinterpretation according to modern view. Another yet challenging issue that have driven me toward writing this article is having known the very limited internet access in Ethiopian Universities may have exceptionally been hampering the knowledge progress of the students and teachers on this scale of limiting them from coping with modern physics theories, knowledge and recent developments in the field. Perhaps the most disturbing fact is that the situation is worse when students are continuing to misrepresent mass and misinterpret E=mc^2 due to lack of due sources.

In easing all these existing and potentially obstructing challenges, I believe that the following summary would be differently relevant to the Physics community of Ethiopian Universities. It may also be helpful to those who are not fully cognizant of the difference between traditional and modern view of mass-energy relationship by addressing some confusing and contentious issues they may have faced. Ultimately, this summary may help students and teachers to cope with modern view of E=mc^2 in general. Besides, it may also encouraging me if I will be able come out in triumph in embodying the text. Misconceptions, suggestions toward fulfillment of correct interpretations and solutions are discussed.

II. Modern view of mass-energy relationship, E=mc^2

Here under, I give concise summary of modern view of mass-energy relationship, E=mc^2 by comparing and contrasting it with old view which interprets E=mc^2 in Special Relativity Theory as 1) mass is variant 2) mass is completely equivalent to energy 3) mass can be converted in to energy 4) mass(inertia) is conserved because mass equals energy divided by c^2, and energy is always conserved. Ultimately, this summary unveils the whole picture of modern view of E=mc^2 through explaining all its conceptual segments one by one in the following manner.

1. Mass does not increase with speed-mass is not variant

When the particle moves with different velocities, there is no change in the internal structure of the particle. It is meaningful to define a mass which is invariant in all inertial frame of reference. Mass means invariant mass. Mass does not increase with speed, even though energy does [2],[3],[4]. The concept of "relativistic mass", which increases with speed, is no longer used in physics and there are no longer prominent defenders of its use. The use of "relativistic mass" should be restricted to historical references, not used to explain physical phenomena. The term "relativistic mass" can be easily seen to be inconsistent. For example, one cannot observe changes in the mass of an object as a function of the speed of an observer relative to the object (to make it clearer, as it does not matter who is considered to be at rest). So, if a fast rocket passes near you and someone in there looks at you, you will not increase your mass. In other words, you will not become a black-hole if you move fast enough. The Newtonian physics $p = mv$ momentum equation, cited in the past as a motivation to use relativistic mass, is invalid in special relativity. The association of "relativistic mass" with gravitational effects is fundamentally incorrect; for example the gravitational attraction between the photon and a large mass (the Sun) is determined by their energy-momentum tensors, not just by their energies. Relativistic mass also makes the increase of energy of an object with velocity or momentum to be connected with some change in internal structure of the object that would increase its mass, which change cannot be observed [5],[6],[7],[11],[12].

2. Mass is only approximately conserved

According to modern view of mass-energy relationship, an isolated (free) system can reduce or increase its mass by internal mass energy conversion. For example, mass is not conserved when an isolated body (in a system considered large enough to be closed) emits a photon, or undergoes nuclear fission or fusion. However, an isolated (free) system cannot reduce or increase its energy by internal mass energy conversion. Two different isolated systems, with the same energy content, can have different invariant masses. For example, a system of two photons can be massless or have an invariant mass up to 2E/c^2, where E is each photon's energy (assumed equal), as a function of relative momentum orientation for the photons. So, in such a system, independently of the energy content being held constant at $2E$, the invariant mass may vary from zero to $2E/c^2$ [8],[9].The term "rest energy" is used for the energy content E_0 of a body that is 1) isolated (free), and 2) at rest relative to the observer. Due to the special relativity theory mass-energy equivalence, the rest energy corresponds to the mass $m = E_0 /c^2$ (this equation cannot be applied to a photon). In general (including photons), the invariant mass is given by the energy-momentum relation $(mc^2)^2 = E^2 - (pc)^2$. If conditions (1) and (2) apply, then the invariant mass is equal to the rest mass. If the isolated (free) condition no longer applies (e.g., the body is placed near another body) for a body originally with rest mass m, its invariant mass will be less than m [3],[4].

3. Mass is the property that all energy exhibits

To demonstrate that the concept of total mass energy conversion is not correct, it is very appropriate to consider the mass difference between hydrogen atom and its constituent particles as an example. It is known that the hydrogen atom has less mass than combined masses of proton and electron that make it up. The extra mass comes from the sum of potential energy(E_p) between electron and proton and the kinetic energy(E_K) of electron in atom through the mass energy relationship, $m_{extra} = \frac{E}{c^2}$, where $E = E_p + E_K < 0$, i.e. potential energy(E_p) between proton and electron is negative and kinetic energy of electron is always positive. The sum of potential energy and kinetic energy still comes out negative because potential energy is large enough to make the total sum negative. With this premise, we can clearly see that E is exhibited from the hydrogen atom as a result of the sum of potential energy between electron and proton and kinetic energy of electron. Generally, we can deduce that this energy is exhibited around the mass of hydrogen atom and inter converted to m_{extra} but it is not as a result of total conversion of mass of the hydrogen atom in to it. On the other hand, m_{extra} is ridiculously very small when compared to the mass of hydrogen atom and very difficult to practically detect it. This tells us that the idea of "the total mass conversion" is incorrect but rather it can be correctly pronounced as mass is a property that all energy exhibits. The mass difference implies that the conservation of mass is only approximately valid [13],[2].

4. Mass is not completely equivalent to energy

By summing up all the above explanations about mass and energy relationship we can simply conceive that mass and energy are not two natures of the same thing. Mass is an invariant and is not conserved in isolated(free) systems; while energy is not an invariant, and is conserved in isolated (free) systems. Moreover, with the discovery of the Special Relativity Theory, energy was found to be one component of an energy-momentum 4-vector. Each of the four components (one of energy and three of momentum) of this vector is separately conserved in any given inertial reference frame. But mass is scalar(magnitude of energy-momentum 4-vector) and is not conserved in every inertial reference frame. We can further infer the factuality of the above arguments by considering the mass data assigned to a photon in conventional textbooks. Accordingly, since photon is massless there is no frame in which photon is at rest which implies no frame in which the momentum of a photon is zero. Therefore the photon has energy

$E = pc$, where p is the photon's momentum and c is the speed of light. From this we can clearly see that energy appears as more fundamental quantity; while there is massless energy(a photon), there is no energyless mass. Conversely, while an energy does indeed correspond to any mass, the opposite is not true as mass does not correspond to every energy (a photon)[1],[3],[9].

The above summaries can explicitly indicate and represent a brief modern and correct interpretation of concept of mass-energy relationship, $E = mc^2$. Though another similar correct interpretations are available on internet vastly, students and teachers are continue to explain mass-energy concept depending on old view. With the attainment of internet, the concepts can be clear, and the knowledge could be even wider and deeper. Can teachers keep up to date with the new knowledge? Would not the students of the new generation gain access of the internet easily keep up to date with latest knowledge? Will the students be able to answer all the questions related to mass-energy relationship concept? What are the main misconception when students respond to mass-energy relationship related questions?

III. Misconceptions associated to modern interpretation of $E=mc^2$

In my attempt to address the main possible misconceptions regarding to modern view of $E = mc^2$, I set the following mass-energy concept related questions and examine its outcome. Besides, these are questions which even different physics teachers may give or accept different answers under unfulfilled conditions like this article concerned with. Here are the questions:

Question 1: According to modern view of mass- energy relationship a nuclear power station differs from one burning coal or oil as it converts mass into energy according to the law $E = mc^2$.

A. True B. False

I set this "true-false" question to 120 undergraduate university physics students from fresh man to third year, only 13 students recognized it as false. From a small number of post graduate students, 65% of them accepted the statement as true. About 90% of answer given by undergraduate students to this question shows us that there is clear misconception in interpreting mass-energy relationship as per modern view. It is clear that they mimicked the traditional view -"mass converted in to energy" and applying it in answering this question.

Question 2: According to modern interpretation of $E = mc^2$, during the radioactive decay, which of the conservation laws is/are conserved?

A. Mass B. Energy C. Momentum

The decay of a radioactive nuclide may be represented by the equation

$$^{220}_{86}Rn \rightarrow {}^{216}_{84}Po + \alpha$$

State and explain whether mass is conserved in this decay.

Regarding to this question , about 3/4th of the students gave the answer that mass is conserved during this decay. The rests have had no any idea about it and failed to respond any of the other answer.

Actually, whether conservation of mass is conserved or not conserved we are not sure because conservation of mass depends on the system chosen. However, it is expected that more students or even teachers will add up the masses and conclude that the sum of masses after decay is less than before. Hence, their answer is simply mass is not conserved. One possible reason is they view energy and mass as separate entities. Besides, they would also explain that the "conservation of mass" is only approximately true.

Question 3: What will happen when you raise a book by a height of 1 metre according to modern interpretation of mass-energy relationship?

A. There is no change in mass in the book

B. There is an increase in mass in the book.

C. There is a decrease in mass in the book.

D. Not sure.

Question No. 3 is also interesting as some physics students and teachers felt that it seems somewhat strange that the mass of the book would change with the change in potential energy of the book. We expect the most common answer is "There is no change in mass in the book." Many physics teachers and students may choose this because they reason that there is simply no change in the quantity of matter though there is change in potential energy. However, with contrary to this expectation, considerable number of students and few post graduate students responded : There is an increase in mass of the block.

They may have applied the concept of equivalence of mass and energy to deduce that the change in energy corresponded to a change in mass. Since the mass gained potential energy, so ultimately mass should get increased.

V. Solutions and Suggestions

I suggest that there are a number of issues which universities and experts need to be working on in introducing this modern view of mass-energy relationship, $E = mc^2$ to their respective students and teachers in the effort of subsuming it in to their curriculum.

1. Supplying books (Universities): Supplying adequate books that use modern interpretation of $E = mc^2$ in quality and quantity can give students and teachers the chance of comparing and contrasting it with traditional view of mass-energy concept. Since students are already more familiar with the traditional view of mass-energy concept, they can apply it as introduction to shortly get familiar with modern view of mass-energy concept without facing appreciable difficulties in understanding the differences between the two. In addition to becoming familiar with new concept or knowledge, introducing modern interpretation of mass-energy relationship through supplying of adequate books that use modern view can help students develop their further ability of examining the whole(traditional and modern) context of $E = mc^2$. Eventually, students may identify the conceptual limitations associated with traditional view of $E = mc^2$ and they may grasp the conceptual sophistication in modern view of $E = mc^2$ in broad and deep senses.

2. Boosting internet coverage and accessibility(Universities): Internet is the main provider of various journal articles on various titles and contexts with new results and interpretations. Indeed, many websites are relentlessly releasing a large numbers of latest books and journal articles which are priceless in value and scope. Considerable numbers of books and journal articles which give the broader overview on modern mass-energy relationship can also freely be available on internet. However, different articles may explain mass-energy relationship, $E = mc^2$ in many alternatives. This is because mass is characterized by its deeper and broader concept. This typical characteristics of mass may seem to be challenging yet it can be helpful to students and teachers in paving the way for them toward fuller and deeper knowledge on the whole context of mass-energy concept.

In general, in providing numerous articles and many books that accompany modern view of mass-energy interpretation internet plays indispensible role and share. Therefore, working on coverage and accessibility of internet can eventually help to solve misconceptions and knowledge limits of students and teachers with regard to the modern interpretation of $E = mc^2$. Furthermore, reliable internet access and coverage can effectively remove the curtain disguising the whole picture of recent mass-energy concept. For example one frequently-asked question in Physics is the mass of photon. Most teachers might follow the conventional textbooks' explanation that mass of light is zero. But on internet we can find the new experimental limit on photon mass, less than 1×10^{-51} gm or 6×10^{-17}eV. Providing sufficient internet coverage and accessibility is the solution in helping ease mass-energy related misunderstandings and knowledge limits in this regard, and ultimately can help students and teachers to fully understand scientific progress on conceptual development of mass-energy relationship, $E = mc^2$.

3. Providing trainings for teachers(experts): Inexperienced teachers who are unfamiliar with modern concept of $E = mc^2$ may have many difficulties in coping with it. Therefore, effective teacher training helps teachers to be aware about the modern interpretation of $E = mc^2$ and helps prepare even for another related challenges. While teacher training and student teaching won't completely prepare teachers for every issue they will face, it can help them feel more confident about many common problems that arise for teachers each day. Without this background, teachers might feel like failures and eventually give up. Thus, providing adequate trainings for teachers on modern interpretations of $E = mc^2$ can further be helpful in introducing it by filling the possible skill gaps and knowledge limits of teachers on mass-energy related concepts as a whole.

Besides, effective teacher training on modern interpretation of $E = mc^2$ will address teachers burnout regarding to those who are somehow little familiar and so confused with modern view of $E = mc^2$ but seek additional help. First, it helps inexperienced teachers to understand what can lead to teacher burnout. In some cases, this is just the stress of daily teaching. However, it can also be caused by not being able to introduce the new concepts of like $E = mc^2$and methods of teaching enough. Teacher training programs that focus on the modern interpretation of $E = mc^2$ can help students learn about its correct interpretation in avoiding misconceptions inherited from traditional view.

Another yet challenge that can necessitate effective training of teachers is the nature of the concept of mass. The concept of mass is not as simple as it seems. Though we may commonly consider mass as "quantity of matter", some physicists prefer mass like Wilczek (2004), as "unitary irreducible representations of the Poincaré group in Hilbert Space". There are many other conceptual meanings of mass too. For example regarding to "velocity dependent mass" teachers may develop how to conceptualize in demystifying mass does not increase due to the increase in velocity. (If you imagine you are moving with the same velocity as the particle, then you might consider that there is no change in the internal structure of the particle.) Conceptual challenge can be solved through effective trainings of teachers. Subsequently, this may build confidence of teachers in playing their part toward introducing this modern interpretation of $E = mc^2$ to their students in turn.

4. Nurturing research(Universities): Acquisition of knew knowledge about modern interpretation of $E = mc^2$ may also most likely be achievable through nurturing of fundamental research on the area of mass-energy related concept. The ultimate goal is change or the improvement of the problematic situation by introducing the results about modern interpretation of $E = mc^2$ to the due audiences(students). This can help students in comparing and contrasting it with traditional interpretation of $E = mc^2$ and eventually be door opener in examining additional facts behind $E = mc^2$. To achieve realize this fundamental goal or benefit of research to this particular issue, universities need to create conducive environment by considering the nurturing of research on the modern view of mass-energy related titles. Furthermore, the more the teachers practice or study the modern interpretation of mass- energy relationship, $E = mc^2$ the more they vigorously get introduced to it.

These all are the possible solutions for the persisting challenges that have been putting setback on the progress of students toward understanding of modern interpretation of $E = mc^2$. As I mentioned through, this solutions are relevant to those students who are still familiar with only old interpretation of $E = mc^2$ (traditional view). On the basis of this challenge, this article suggests the achievable way of becoming familiar with modern interpretation of $E = mc^2$. On the other hand, it is cognizable that there are also challenges that may come as result of overwhelming alternatives from the whole picture of mass-energy relationship on other sides whereby many books and internet are explaining $E = mc^2$ in different ways, which is nether the focus of this article nor the present issue.

VI. CONCLUSION

In the conceptual advancement of $E = mc^2$, it is important to note that the concept of $E = mc^2$ has been continuously evolving in reaching to its current phase of modern conceptual interpretation. However, many students have been having greater dispute to keep up to date with modern interpretation of $E = mc^2$ due to two main challenges which are unattainability of internet and unavailability of books that use this interpretation. These persisting challenges have been putting setback on the progress of students toward understanding of modern interpretation of $E = mc^2$.

The challenges related with scarcity of latest sources(books, internet) have made the students to be misled in understanding the modern interpretation $E = mc^2$. The problem of misconceptions that has been seen from the side of students has been inherited from these challenges. I hope this paper has demonstrated challenges induced misconceptions to modern view of $E = mc^2$. Universities need to work toward effectively introducing modern interpretation of $E = mc^2$ by taking the mentioned solutions and suggestions in to account.

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