EXTENDED ESSAY

Research Question

How did Albert Einstein Changed the Definition of Mass

From Newtonian Mechanic

Subject: Physics

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Table of Contents

INTRODUCTION

Our understanding of mass concept in science has changed over time which started with Sir Isaac Newton's theories and later Albert Einstein's ideas. During the 17th century, Newtonian mechanics introduced concepts like force, inertia, and mass to explain how objects move.[1] While in the 20th century, Einstein's theory of relativity completely transformed our understanding of space-time relationships and the nature of mass in physics.[2] This research aims to explore how the development of physics changed our understanding of matter and energy.

PERSONAL ENGAGEMENT

Since middle school I knew I was fascinated by science in general however I also could not break away from mathematics and complex equations. That's the reason I wanted to do my extended essay in theoretical physics. I wanted to observe how a thought process and equations create a life different from the reality we are used to.

BACKGROUND

The modern comprehension of the concept of mass relates back to Isaac Newton's Law of Motion alongside with the scientific advancements made in the past centuries. In ancient times, societies like Egypt and Greece established a fundamental understanding of weight and mass.[3] However since they did not have precise measurement devices, people were not able to take a certain grasp on concepts of weight, volume, and most importantly mass. Therefore, Isaac Newton introduced a mass definition within his laws of motion we still use today.[4] Regardless of external forces or location within space-time, mass was a constant term that was crucial for calculating the force/acceleration ratio until the 20th century. However, the concept of mass underwent an immense change with Einstein's Theory of Relativity in 1905. Among his many discoveries, he proposed an interchangeable dynamic called mass-energy equivalence, revealing new insights into how mass correlates to energy. He also brought a new understanding of mass by suggesting that mass is not constant and has a relativistic characteristic. Such realizations led to major developments that significantly changed our understanding of matter and energy.[5]

METHODOLOGY

Since this thesis is theoretical, second-hand data will be used rather than experiments. The methodology will involve three main approaches: Literature Review, Historical Analysis, and Comparative Analysis.

Literature Review

A detailed review of various sources, including books, articles, and scientific papers, will explore Newtonian mechanics, Einstein's theory of relativity, and the evolution of the concept of mass. This thorough examination will provide a comprehensive understanding of the research topic.

Historical Analysis

The evolution of Newtonian mechanics and Einstein's advancements in physics will be studied via written textbooks and papers. Einstein's articles on special and general relativity will be analyzed to understand how he questioned the notion of mass.

Comparative Analysis

This method aims to investigate how the definition of mass differs when viewed through both Newtonian Mechanics and Einstein's Theory of Relativity which allows me to have a detailed analysis.

ANALYSIS

Mass in Newtonian Mechanic 1

1.1 Newton's Definition of Mass

The principle of mass conversion asserts that the mass of an object remains constant. This strengthens the hypothesis that the total mass is the sum of each mass of the particles when the particles get together.[6] Mass, a fundamental property inherent in all matter, serves as a quantitative measure of inertia.[7] Inertia is the resistance to the change in speed or position when the body of an object is exposed to external forces. In other words, the response against the forces increases as the mass decreases according to the definition of inertia. In the early 1900s, this realization led researchers to incorporate mass as a reliable measurement of inertia. [8] A deeper understanding of Newton's definition of mass is underlain by the concepts of absolute time and space, wherein he declared the existence of absolute space as a vast space covered by objects. He defined space as independent of external factors and as always, the same and immovable.[9] Newton's understanding of mass was based on the assumption of Euclidean space, in which particles were considered mathematical points with a fixed positive number called "mass". Mass was defined as a unit and was viewed as an innate property of particles. It served as a means of comparison and played a crucial role in measuring inertia.[10] Assigning a value or establishing a means of comparison is necessary for assigning significance to any physical quantity, including mass. For example, the concept of temperature evolved through numerous experiments on thermal equilibrium, leading to its definition and the development of measurement devices. Similarly, mass, as the amount of matter, is imprecise, and the concept of inertial mass emerged as a more precise measure of inertia. Inertial mass became a means to compare the resistance to acceleration, where more mass implies more resistance to acceleration. On the other hand, gravitational mass symbolizes the influence exerted by gravity and is identical to weight, the gravitational force between an object and the Earth. The gravitational mass establishes the strength of gravity connecting an object and the Earth. Experimental results showed that inertial and gravitational mass have identical results despite their conceptual differences.[11] After carefully examining Newton's Principia, Newton is often credited with introducing the concept of mass and its different appearances as inertial and gravitational mass. He did not view mass as a simple property but as a measurable quantity of matter. Newton's teachings do not show any explicit or implicit distinction between the "inertial" and "gravitational" characteristics of matter. Thus, while Einstein's work demonstrated the equivalence of these concepts, it can be argued that Newton's teachings already encompassed the interconnectedness of mass.[12]

2.2 Ernst Mach's Definition of Mass

Ernst Mach, a renowned physicist and philosopher, offered a unique definition of mass that challenged prevailing materialist views.[13] He rejected the idea of mass as a measure of matter, focusing instead on observable kinematic properties. Using Newton's laws of motion, Mach proposed that bodies have equal mass if they produce equal and opposite accelerations when interacting. This kinetic approach to mass redefined its understanding during his time. He formulated a definition: bodies are of equal mass if they produce equal and opposite accelerations when they act upon each other.[14]

$$m1\times \overrightarrow{OP}1'' = -m\times\overrightarrow{OP}2'' \quad \text{[13]} \qquad 1.2.1$$

In this example, Mach derived Equation 1.2.1 to highlight the relationship between the masses and accelerations of the two particles in an isolated system. According to the equation, if we multiply the mass of particle 1 (referred to as "$m1$") by its acceleration (represented as $OP1''$ we obtain the result as multiplying the mass of particle 2 (called "$m2$") by its acceleration (labelled as $OP2''$). This equation is based on the principle of motion that states the forces between two particles are equal in magnitude but opposite in direction.

$m1 \times \overrightarrow{OP}1'' =$force on the particle P1 due to the particle P2

Which is also equal to;

$=-$force on the particle P2 due to the particle P1 because of the third law of motion,

$= -m2 \times \overrightarrow{OP}2''$ since the particles form an "isolated" system.

Therefore;

$m1 \times \overrightarrow{OP}1'' = -m2 \times \overrightarrow{OP}2''$ or

$$\frac{m1}{m2} = \frac{-\overrightarrow{OP}2''}{\overrightarrow{OP}1''} \quad 1.2.2$$

[15]

Mach's equation links masses to the accelerations they produce when interacting. He defined the mass as "ratio of two particles as the negative inverse ratio of their mutual accelerations", considering it a constant.[16] However, equation 1.2.2 fails in non-inertial frames of reference as accelerations change. If we call the acceleration of particles 1 and 2 on the accelerated frame of reference with an acceleration a, $a1$, and $a2$, respectively, the ratio that Mach suggested that this ratio was constant changes.

$$a1' = \overrightarrow{OP}1'' + a \quad 1.2.3$$

$$a2' = \overrightarrow{OP}2'' - a \quad 1.2.4$$

In that case, the ratio of the acceleration which should also give the mass ratio of the particles becomes:

$$\frac{a1}{a2} = \frac{1-\frac{a}{\overrightarrow{OP}1''}}{1+\frac{a}{\overrightarrow{OP}2''}} \times \frac{\overrightarrow{OP}1''}{\overrightarrow{OP}2''} \quad 1.2.5$$

Ernst Mach's equation 1.2.5 sets limitations on equation 1.2.1 since mass remains constant regardless of reference frame. While less accurate than the Newton-Euler theory, [17] Mach's theories stirred debate and altered our understanding of mass, in particular inspiring Albert Einstein's theory of relativity. Mach's criticism of mass as a measure of matter quantity, and his emphasis on its relations, inspired Einstein's ideas. Einstein recognised the significance of Mach's approach. He included it into his own concept. According to this concept, mass is an indicator of an object's energy capacity rather than its physical properties. Mach's ideas have had a long-term impact on the development of physics and our knowledge of mass.[18]

Einstein's Definition of Mass 2

2.1 Relativistic Mass

Einstein's revolutionary ideas reformed our understanding of relativity and mass [19], growing the principles of relative motion and questioning the theories of absolute space and time. [20] His studies broke new ground on these subjects, elucidating the nature of motion and the theory of relativity.[21] Einstein explored the behaviour of light and thus discovered that light travels at a constant speed and that physical laws apply universally in frames of reference experiencing no acceleration.[20] Moreover, Einstein's studies defied the concept of the ether as a medium for electromagnetic wave propagation.[21] These pioneering ideas not only put an end to the theory of a preferred frame of reference but continue to shape modern physics and change our understanding of the universe as well.

One of the most significant differences Einstein made about classical physics is the concept of mass. Relativistic mass is a concept that emerges within the context of relativity. In relativity, it is proposed that mass is not a constant quantity but varies with the velocity of an object. The term "mass" represented by m refers to the mass of an object from the perspective of an observer in motion to that object. And there is the rest mass, an object's mass at rest, denoted as $m0$. The equation gives the relationship between relativistic mass and rest mass:

$$m = \gamma \times m0 \quad 2.1.1$$

where γ is the Lorentz factor, which depends on the velocity of the object relative to the observer. The Lorentz factor is given by:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad 2.1.2$$

Where v is the velocity of the object and c is the speed of light.

To delve deeper, let us consider an elastic collision involving two masses, with velocities u and $-u$, moving in opposite directions within the S' frame of a reference frame which is moving with the velocity v according to the S frame. We will denote the velocities in the S frame as $u1$ and $u2$. Despite the equality of velocities in the S' frame, this equivalence does not hold in the S frame. Nevertheless, following the law of conservation of linear momentum, we found a crucial relation in mass. Let's also call the mass of the first particle in the S frame m1 and the mass of the second particle $m2$. When doing this thought process, we consider assuming mass changes by observing from another frame of reference. However, even with this assumption, if we stick to the conservation of linear momentum, we can establish the following relationship:

$$m1 \times u1 + m2 \times u = (m1 + m2) \times v \qquad 2.1.3$$

Equation 2.1.3 signifies that from the perspective of the S' observer, the entire system is at rest. The two masses, with equal values, approach each other, implying that the system's centre of mass is not in motion. Nevertheless, once we observe this collision from an S frame observer's standpoint, the entire system (S' frame) appears to move with a specific velocity, v. This observation underscores that linear momentum conservation, in this scenario, manifests as the sum of the momenta of the two particles equalling the product of the sum of their masses and the velocity.

$$= m1\frac{u+v}{1+\frac{u\times v}{c^2}} + m2\frac{u+v}{1+\frac{u\times v}{c^2}} = (m1 + m2) \times v$$

$$m1\frac{u+v}{1+\frac{u\times v}{cc^2}} - m1 \times v = m2 \times v - m2\frac{-u+v}{1-\frac{u\times v}{c^2}}$$

$$= m1\frac{u-\frac{u\times v}{c^2}}{1+\frac{v\times u}{c^2}} = m2\frac{u-\frac{u\times v}{c^2}}{1-\frac{v\times u}{c^2}}$$

$$\frac{m1}{m2} = \frac{\left[\left(u-\frac{v\times u}{c^2}\right)\times\left(1+\frac{v\times u}{c^2}\right)\right]}{\left[\left(u-\frac{v\times u}{c^2}\right)\times\left(1-\frac{v\times u}{c^2}\right)\right]}$$

$$= \frac{\left(1+\frac{v\times u}{c^2}\right)}{\left(1-\frac{v\times u}{c^2}\right)} \qquad 2.1.4$$

As this collision continues, an interesting relationship between the two masses appears. Initially, it was mentioned that both masses appear equal from the perspective of a specific observer. However, it is essential to emphasise that this equality holds only for this observer, the one at rest in the S' frame. This equality cannot be imposed for the other observer that is in relative motion, as the velocities of the two particles could differ, subsequently affecting the masses. To explore the relativistic mass further, a different mathematical approach is required. We can expand the equation $1 - \frac{u1^2}{c^2}$. As we continue, it becomes clear that modifying how we express the equation is crucial in figuring out the relationship between the masses and their velocities for observers in distinct frames of reference.

$$1 - \frac{u1^2}{c^2} = 1 - \frac{1}{c^2} \times \left(\frac{u+v}{1+\frac{u\times v}{c^2}}\right)^2$$

$$= \left[1 - \frac{1}{c} \times \left(\frac{u+v}{1+\frac{u\times v}{c^2}}\right)\right] \times \left[1 + \frac{1}{c} \times \left(\frac{u+v}{1+\frac{u\times v}{c^2}}\right)\right]$$

$$= \frac{1}{c} \times \left[c - \left(\frac{u+v}{1+\frac{u\times v}{c^2}}\right)\right] \times \frac{1}{c} \times \left[c + \left(\frac{u+v}{1+\frac{u\times v}{c^2}}\right)\right]$$

$$= \frac{1}{c^2} \times \left[\frac{c+\frac{u\times v}{c}-u-v}{1+\frac{u\times v}{c^2}}\right] \times \left[\frac{c+\frac{u\times v}{c}+u+v}{1+\frac{u\times v}{c^2}}\right]$$

$$= \frac{1}{c^2} \times \left[\frac{c\times(1-\frac{v}{c})-u\times(1-\frac{v}{c})}{1+\frac{u\times v}{c^2}}\right] \times \left[\frac{c\times\left(1+\frac{v}{c}\right)+u\times(1+\frac{v}{c})}{1+\frac{u\times v}{c^2}}\right]$$

$$= \frac{1}{c^2} \times \left[\frac{(c-u)\times(1-\frac{v}{c})}{1+\frac{u\times v}{c^2}}\right] \times \left[\frac{(c+u)\times(1+\frac{v}{c})}{1+\frac{u\times v}{c^2}}\right] = \frac{1}{c^2} \times \left[\frac{(c^2-u^2)\times(1-\frac{v^2}{c^2})}{(1+\frac{u\times v}{c^2})^2}\right]$$

$$= 1 - \frac{u1^2}{c^2} = \frac{(1-\frac{v^2}{c^2})\times(1-\frac{u^2}{c^2})}{(1+\frac{u\times v}{c^2})^2} \qquad 2.1.5$$

Similarly for $u2$;

$$= 1 - \frac{u2^2}{c^2} = \frac{(1-\frac{v^2}{c^2})\times(1-\frac{u^2}{c^2})}{(1-\frac{u\times v}{c^2})^2} \qquad 2.1.6$$

Equation 2.1.5/Equation 2.1.6

$$= \frac{1-\frac{u2^2}{c^2}}{1-\frac{u1^2}{c^2}} = \frac{\left[\frac{\left(1-\frac{v^2}{c^2}\right)\times\left(1-\frac{u^2}{c^2}\right)}{\left(1-\frac{u\times v}{c^2}\right)^2}\right]}{\left[\frac{\left(1-\frac{v^2}{c^2}\right)\times\left(1-\frac{u^2}{c^2}\right)}{\left(1+\frac{u\times v}{c^2}\right)^2}\right]}$$

$$= (\frac{1+\frac{u\times v}{c^2}}{1-\frac{u\times v}{c^2}})^2$$

$$\sqrt{\left(\frac{1-\frac{u2^2}{c^2}}{1-\frac{u1^2}{c^2}}\right)} = (\frac{1+\frac{u\times v}{c^2}}{1-\frac{u\times v}{c^2}}) \qquad 2.1.7$$

Compare 3.4 and 3.7

$$\frac{m1}{m2} = \sqrt{\frac{1-\frac{u2^2}{c^2}}{1-\frac{u1^2}{c^2}}} \qquad 2.1.8$$

Equation 2.1.8 is critical in understanding this relationship since it shows how the masses in the S frame are related to their velocities. Now, let's consider a situation where an observer in the S frame perceives $m2$, as be at rest. In this perspective, the velocity $u2$ becomes zero for that observer. This scenario allows us to re-evaluate the relationship between masses m1 and $m2$,

$m2 = m0$ (rest mass)

Then, $u2 = 0$

Therefore, we can rename the terms

$$m1 = m$$

$$u1 = v$$

If we substitute equation 2.1.8 with these things, then simply equation 2.1.8 becomes;

$$\frac{m1}{m2} = \frac{m}{m0} = \sqrt{\left(\frac{1-\frac{0^2}{c^2}}{1-\frac{v^2}{c^2}}\right)}$$

Therefore, $\frac{m}{m0} = \sqrt{\frac{1}{1-\frac{v^2}{c^2}}}$

profound observation emerges from our exploration. When a measurement is conducted on a particle at rest, we ascertain its intrinsic rest mass ($m0$) – an inherent property unaffected by its motion. On the other hand, when we measure the mass of a moving particle and denote it as "m," we encounter the concept of relativistic mass.

$$m = \left(\frac{m0}{\sqrt{1 - \frac{v^2}{c^2}}} \right) \qquad 2.1.9$$

Delving deeper into relativistic physics, this relationship helps us understand how mass changes as an object's velocity deviates from rest.[22]

It is essential to note that the object itself does not feel the mass increase, similar to how it does not experience time dilation in Special Relativity. Instead, the mass increase is apparent to an external observer, making it "relative" and dependent on the frame of reference used. For an external, stationary observer, the faster the object moves, the more energy is needed. This leads the observer to infer that the object's mass has increased because it resists acceleration. In relativity, the idea of increase carries implications per Einstein's theory. It highlights that mass is not a property but depends on the observer's perspective.

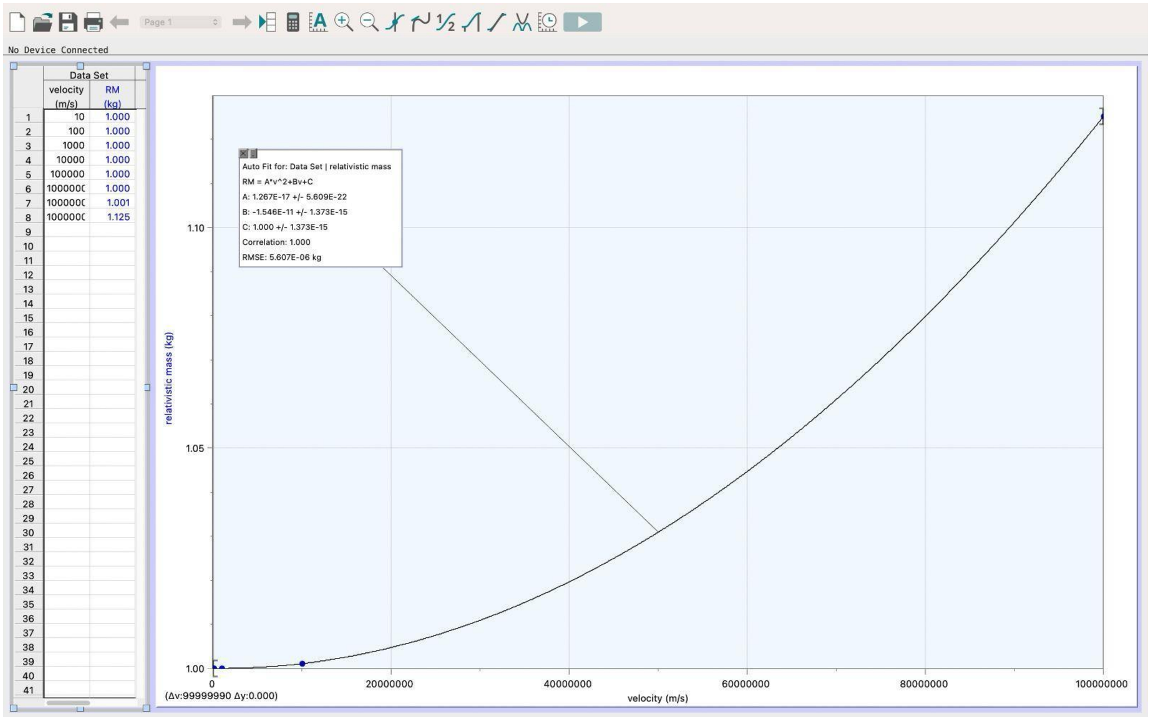
Table 1: The change in mass of a unit body with the velocity of that body

velocity(m/s)	rest mass(kg)	relativistic mass(kg)
10ˆ1	1.000	1.000
10ˆ2	1.000	1.000
10ˆ3	1.000	1.000
10ˆ4	1.000	1.000
10ˆ5	1.000	1.000
10ˆ6	1.000	1.000
10ˆ7	1.000	1.001
10ˆ8	1.000	1.125

As it is shown at the table above if we increase the velocity of a unit mass with the mass of the body also increases. This increase can be mathematically explained by the equation 2.1.9

Below is the graph for the Table 1 data to illustrate the change better.

Graph 1: The change in mass of a unit body with the velocity of that body



The y-axis represents the object's rest mass, set to 1 kg, while the x-axis denotes its velocity. From this graph, we can observe that at velocities such as 10ˆ7m/s and 10ˆ8 m/s, there is a change in mass compared to the rest mass (m0). However, the first six data are linear for 4 significant figures As the velocity increases to 10ˆ7 m/s, there is a deviation in mass from the rest mass, although it remains relatively close. This demonstrates that as an object approaches to the speed of light, its velocity starts to impact its mass. Once the velocity reaches 10ˆ8 m/s, the difference from the rest mass becomes more prominent. The mass is now noticeably larger than the rest, indicating that these effects become increasingly significant as the object accelerates. This behaviour aligns with the principles of the mass equation, which suggests that as velocity increases the relativistic mass approaches infinity when nearing the speed of light.

2.2 Mass-Energy Equivalence

The exploration of mass and its relationship with an object's velocity has led physicists to delve deeper into the nature of mass within the context of dynamics. However, this pursuit ultimately resulted in a transformation of our understanding of the connection between mass and energy. In 1905 Albert Einstein presented his insight in the form of the theory of mass energy equivalence symbolized by the equation $E=m\times c^2$. This equation shows that mass and energy are not separate concepts but interlinked, highlighting their potential for conversion between one another.[23] Recognizing mass (relativistic or rest mass) as a form of energy changed physics. This leads us to modern physics, where we explore interactions, between mass, and energy.

The fundamental equation for mass-energy equivalence is,

$$E = \gamma \times m0 \times c^2 = \gamma \times E0, \qquad 2.2.1$$

The equation states that mass is a type of energy. When multiplied by the speed of light squared, even a small mass equals an immense quantity of energy. This relationship combines the concepts of mass and energy, demonstrating the enormous energy placed within matter. This concept shows a closed box that emits electromagnetic radiation from one end. This radiation transfers energy and momentum, causing the box to rebound. The radiation is absorbed at the opposite end, counteracting the box's recoil and bringing it back to rest. When radiation passes through a box, it moves a distance "s". To keep the system's centre of mass fixed, radiation must have moved mass from the emission end to the absorption end. For simplicity, we take the box's sides to be massless and its ends to have mass M each. The centre of mass is located in the centre of the box, so it means center of mass has a distance of

½L from both ends. An electromagnetic radiation with energy E carries momentum Ec and, according to hypothesis, has a mass of "m". When radiation is emitted, the box's mass is now

$$M - m$$

with the velocity v. Additionally, due to the principle of conservation of momentum,

$$Pbox = P\ radiation$$

$$(M - m) \times v = \frac{E}{c}$$

And so the velocity of the box when it is coming back is

$$v = \frac{E}{(M-m)\times c} \approx \frac{E}{M\times c}$$

Because the mass "m" is significantly smaller than "M," the time "t" it takes for the box to move is the same as the time it takes for the radiation to travel to the opposite end of the box, which is "L" metres away. Thus, "t" can be written as $t = \frac{L}{C}$." During the time "t," the box moves to the left by;

$$s = v \times t = \frac{E}{M\times c^2}$$

When the box comes to a stop, the mass of the left end becomes $½M - m$, while the mass of the right one becomes $½M - m$. This is due to the change in mass "m" associated with the energy "E" of radiation. To keep the centre of mass in its original location,

$$(½M - m) \times (½L + s) = (½M + m) \times (½L - s)$$

Or

$$m = \frac{M\times s}{L}$$

Inserting the value of the displacement s,

$$m = \frac{E}{c^2} \quad 2.2.2$$

[25]

Equation 2.2.2 can be used to compute the quantity of mass that corresponds to a given energy E. In our derivation, we assumed that the box behaved like a rigid body, which means that when radiation is released, the whole box begins to move. It stops when the radiation is absorbed. However, nothing actually meets these exact standards. For instance, because radiation travels at the speed of light, it will arrive at the right end of the box before the box ever begins to move. When we consider the speed of elastic waves within the box ,which is slower relative to speed of light, and perform a more capacious calculation, we get the same result (equation 2.2.1). The version of the equation states that if energy is removed from the body as a result of such a conversion, the body's rest mass will decrease because they are directly proportional.

Comparison

Newton's concept of mass was deeply about absolute space and particles as mathematical points with a constant positive value of mass. This notion enabled the establishment of inertial mass, which served as a means of comparison, allowing physicists to measure the amount of inertia different objects have. Additionally, Newton's concept of gravitational mass—the force of attraction between an object and the Earth—yielded identical results to inertial mass despite their different conceptual origins. However, Ernst Mach challenged usual materialist views and presented a unique perspective on mass. Mach rejected the idea of mass as an inherent measure of matter and instead focused on observable kinematic properties. Thus, Mach's equation linked masses to the accelerations they produced during their interaction. However, Mach's ideas faced limitations in non-inertial frames of reference, where accelerations could change, undermining the concept's universality. Even though it was a dead end for Mach, his perspective inspired Albert Einstein, who used the limitations and expand upon these ideas. In his theory of relativity, Einstein proposed a revolutionary concept of mass-energy equivalence, represented by the iconic equation $E=mc^2$. This equation revealed that mass and energy were profoundly interconnected, and mass could be considered a form of energy. Consequently, relativistic mass became a part of the framework falsifying the constant characteristic of mass. Einstein enlightened modern physics by suggesting that mass increases as velocity increases.

CONCLUSION

Albert Einstein's redefinition of the essence of mass, transformed our understanding from the limitations of Newtonian mechanics to the discovery of the dynamics of relativity. His theories introduced the concept of relativistic mass and revealed the profound interconnection between mass and energy. Einstein's change of understanding of such a deep concept taught me that I should look at things from a different perspective. This research also helped me develop a new mindset toward science and knowledge. It created a perception about whether there is a full certainty we can attain at all. The general agreement is that scientific methods offer the most reliable information to acquire the truth. Nonetheless, as it can be seen here even the most precise concept that all scientists once accepted as the truth may encounter a loss of accuracy as time progresses.

Further Research

- Equation $E = m \times c^2$ can be used in the development of nuclear physics. We can explore how the energy that is released from mass can be used in nuclear fusion.
- In this thesis, we mentioned the theoretical side of the mass but some real-life experiments explain how mass increases with velocity. By conducting those experiments, we can have a better understanding of the notion of mass.
- In Einstein’s theory of relativity, there are also relatively new concepts like time dilation and length contraction. We can find a connection between these concepts and relativistic mass.
- Investigating the correlation between quantum mechanics and the energy-mass equivalence can help develop a bridge between small and massive particles.

Strengths

- This thesis touches multiple discipline like particle physics, astrophysics and philosophy which can contribute to a more inclusive understanding of how mass changed throughout the years.
- Einstein’s theories can be applied in modern technologies and space engineering. This theoretical analysis has practical implications in real life. This makes the research relevant to our world right now.
- This thesis enables us to convey a very complex subject to a wider readership. The thesis's simple explanation of Newton's laws and theories such as relativity is an educational benefit.

Weaknesses

- Since this thesis has a limited word count, not all topics may have been looked at in the same depth. Therefore, each aspect cannot be explored in sufficient detail.
- Even though the language that is used is pretty simple the topic is still pretty complex for the general reader. This can cause a vagueness in understanding.
- Since it is a theoretical concept we analysed the empirical part is a little weak. There are obviously some practical experiments that can be used, but it mostly relies on thought processes which can weaken the scientific precision.

REFERENCES

1. NASA Glenn Research Center. (2023, August 7). *Newton's Laws of Motion | Glenn Research Center | NASA*. Glenn Research Center | NASA. https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/#:~:text=Sir%20Isaac%20Newton%20worked%20in,of%20motion%2C%20Newton%20revolutionized%20science
2. Stein, V. (2022, February 1). *Einstein's theory of special relativity*. Space.com. https://www.space.com/36273-theory-special-relativity.html
3. Egypt, W. a. T. U. O. M. I. A. (2023, October 1). *What are the units of measurement in ancient Egypt?* What Are the Units of Measurement in Ancient Egypt? https://www.youregypttours.com/en/egypt-tours-blog/weights-in-ancient-egypt
4. *READ: Isaac Newton (article) | The Big Bang | Khan Academy*. (n.d.). Khan Academy. https://www.khanacademy.org/humanities/big-history-project/big-bang/how-did-big-bang-change/a/isaac-newton
5. Studocu. (n.d.). *General Physics III (PHY-2040) Lecture 5 - Mass-energy equivalence - Mass-energy equivalence - Studocu*. https://www.studocu.com/en-us/document/prince-georges-community-college/general-physics-iii/general-physics-iii-phy-2040-lecture-5-mass-energy-equivalence/53483854
6. Encyclopædia Britannica, inc. (n.d.). *Conservation of mass*. Encyclopædia Britannica. https://www.britannica.com/science/conservation-of-mass
7. The Editors of Encyclopaedia Britannica. (2023, December 24). *Mass | Definition, Units, & Facts*. Encyclopedia Britannica. https://www.britannica.com/science/mass-physics

8. The Editors of Encyclopaedia Britannica. (2023b, December 24). *Mass | Definition, Units, & Facts*. Encyclopedia Britannica. https://www.britannica.com/science/mass-physics#:~:text=The%20greater%20the%20mass%20of,%C3%97%2010%E2%88%9234%20joule%20second
9. Gould, J.A. (1962). The Existence of Absolute Space, *62*,101.
10. Pendse, C. (1937). LXXXVII. A note on the definition and determination of mass in Newtonian Mechanics. *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science*, *24*(164), 1012–1022. https://doi.org/10.1080/14786443708565160
11. Khan Academy. (2021, July 14). *Inertial Mass vs. Gravitational Mass | Circular motion and gravitation | AP Physics 1 | Khan Academy* [Video]. YouTube. https://www.youtube.com/watch?v=Ws3yB3QsKY4
12. *11. Ed Dellian, Newton on Mass and Force: A Comment on Max Jammer's Concepts of Mass (1961; 2000) - Physics Essays Publication*. (n.d.). https://physicsessays.org/browse-journal-2/product/1002-11-ed-dellian-newton-on-mass-and-force-a-comment-on-max-jammer-s-concepts-of-mass-1961-2000.html
13. Famous Scientists. (2017, November 19). *Ernst Mach - Biography, facts and pictures*. https://www.famousscientists.org/ernst-mach/
14. https://www.jstor.org/stable/23917954?seq=5
15. Pendse, C. (1937b). LXXXVII. A note on the definition and determination of mass in Newtonian Mechanics. *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science*, *24*(164), 1012–1022. https://doi.org/10.1080/14786443708565160

16. Banks, E. (2003). Mach's definitions of mass and Inertia. In *The Western Ontario series in philosophy of science* (pp. 193–208). https://doi.org/10.1007/978-94-017-0175-4_13
17. Bunge, M. (1966). Mach's critique of Newtonian mechanics. *American Journal of Physics*, *34*(7), 585–596. https://doi.org/10.1119/1.1973119
18. Wåhlin, Lars. (2002). Einstein's Special Relativity Theory and Mach's Principle, 5-6.
19. Admin. (2022, August 10). *Galilean Transformation - Galilean Relativity, Limitations, FAQs*. BYJUS. https://byjus.com/physics/galilean-transformation/#:~:text=It%20is%20fundamentally%20applicable%20in,near%20the%20speed%20of%20light
20. Halliday, D., Resnick, R., & Walker, J. (2013). *Fundamentals of Physics*. John Wiley & Sons, p. 1117
21. Serway, R. A., & Jewett, J. W. (2003). *Physics for Scientists and Engineers* (6th ed.), p. 1249.
22. For the Love of Physics. (2021, July 2). *What is Relativistic mass? & DERIVATION (variation of mass with velocity)* [Video]. YouTube. https://www.youtube.com/watch?v=YaaiPQ_nlyM
23. *The Equivalence of mass and Energy (Stanford Encyclopedia of Philosophy)*. (2019, August 15). https://plato.stanford.edu/entries/equivME/
24. Beiser, A. (2003). *Concepts of modern Physics*. McGraw-Hill Science, Engineering & Mathematics, p.22-32.