Abstract
The negative mass concept does not exist in modern physics as Newton's second law creates a paradigm in which negative mass should accelerate in the opposite direction to the applied force. However, some recent theories propose that antimatter generates repulsive forces when interacting with matter, which is not taken into account by Newton's gravitational law.

By changing Newton’s second law equation, to allow the existence of negative mass, this repulsive gravitational behavior can be easily achieved using Newton's gravitational equation, if we consider that antimatter body mass values are negative.

It also enables us to define a new mass conservation principle, valid for processes involving generation and annihilation of matter/antimatter particles.

It may seem daring to want to change Newton’s second law that is over three hundred years old, but, if in fact, matter repels antimatter, considering only positive masses, it is Newton's own gravitational law that cannot be applied and therefore must be modified when dealing with antimatter.

So, if we need to change one of Newton's laws in order to adapt it to physical reality, generated by the existence of antimatter, this author believes that this change should be made in the most elegant way.

One such way is by defining that antimatter bodies have negative mass.

Another way is by considering that the inertial mass of antimatter bodies is different to their gravitational mass.

Indexing terms/Keywords
Antimatter repulsion, gravitational law, negative mass.

Academic Discipline and Sub-Disciplines
Classical mechanics, Quantum mechanics, Relativity and Cosmology

SUBJECT CLASSIFICATION
Physics Classification

TYPE (METHOD/APPROACH)
Theoretical Analysis of matter/antimatter repulsion model in the context of the Newton's laws.

INTRODUCTION
In 2011, Italian physicist Massimo Villata [1], proposed a new model where matter can exert a repulsive force on antimatter, creating a framework similar to that which occurs with electric charges, as shown in Figure 1.

In a recent paper [2] Villata writes:

Now we are confronted with two independent developments of general relativity, the Kerr metric and the theory of CPT gravity, which both predict this gravitational repulsion, in perfect consistency between them. If repulsive gravity between matter and antimatter is concerned, this discovery will represent a historic breakthrough dense with consequences. As shown in [3,4], it can explain many of the currently most debated mysteries in physics and cosmology, such as dark energy and dark matter and the cosmic asymmetry between matter and antimatter.
In addition to Villata’s work, the repulsion behavior of matter/antimatter has also been predicted in the work of this author [5,6], where an alternative model to the Higgs field mass generation mechanism, based on a dipole wave pressure model, is presented.

Furthermore, this author has presented a cosmological model [7], where the galaxy’s matter is generated in the vicinity of black holes made up of antimatter that repel matter particles.

Regardless of these theories, the fact is that in a few years, the gravitational behavior of antimatter will be clarified by ongoing experiments that are being developed at CERN, such as AEGIS [8], ALPHA [9] and GBAR [10,11].

The fundamental question of the gravitational behavior of antimatter is still, until today, addressed in differing theories, but only experiments can give us a definitive answer.

And what if the results from these experiments, after the passing of many years, show us that, in fact, matter repels antimatter?

Must we wait all this time in order to be concerned with the consequences of this fact?

This author believes that if matter does repel antimatter, these results will give us some deep implications for modern physics that can be seen from now on.

For example, Newton’s gravitational law is not able to explain repulsion forces arising between matter and antimatter bodies. So, this law must be modified in order to also be valid for antimatter.

A simple option would be to use a variation on Newton’s gravitational equation (for example, with a negative sign), only being applied to the interaction of matter with antimatter.

On the other hand, if we make an analogy using electrical charges, as presented in Figure 1, the behavior of the repulsion and attraction forces are given by one simple equation (Coulomb’s law), that determines the directions of each force as a function of electrical charge signs.

Similarly, if we consider that antimatter has a negative mass, then Newton’s gravitational law also gives us the direction of each force as a function of mass signs.

This analogy becomes more important when we observe that electrical charges always come in pairs, which also occurs with matter and antimatter particles. As positive electrical charges can cancel out negative ones, the total electrical charge in the universe tends to be null. Thus, if we consider that positive matter mass cancels out negative antimatter mass, the total mass in the universe also tends to be zero.

It should be noted, that for electrical charges, positive and negative values were defined in an arbitrary manner. Similarly, we can consider that matter has negative mass and antimatter has positive mass, which shows that these signs only make sense within the context of two elements that can cancel each other out. This is radically different from a case where the sign used entails a physical connection, as in the case of a negative acceleration that indicates a slowing down process or a negative balance in a bank account that is indicative of a financial problem.

**BREAKING THE NEGATIVE MASS PARADIGM**

Currently, the negative mass concept can be considered ridiculous, as based on Newton’s second law, a body with negative mass should accelerate in the opposite direction to an applied force.

Nevertheless, if we need to change Newton’s gravitational law to accommodate the gravitational behavior of antimatter, would it not be easier to change Newton’s second law to allow the existence of negative masses?
In addition, why should Newton's second law be valid for antimatter, if, when in Newton's lifetime, no one had the slightest idea of the existence of antimatter?

This author believes that to deal with antimatter, Newton's second law should be modified to:

\[ \vec{F} = |m| \vec{a} \]  \hspace{1cm} (1)

Where the \(|m|\) term indicates the application of module function, for the mass in consideration.

Using this new formula the acceleration is always in the direction of the applied force, even if the mass is negative.

Therefore, all formulas that use mass as a parameter must be adapted to deal with the negative mass associated with antimatter. For example, the kinetic energy equation should also use mass module function:

\[ E = \frac{|m|v^2}{2} \] \hspace{1cm} (2)

So the only formula that should consider a negative sign, associated with antimatter mass, is Newton's gravitational law:

\[ F = \frac{m_1 m_2 G}{d^2} \] \hspace{1cm} (3)

If we use negative mass (relating to antimatter bodies) in equation (3), the behavior of the forces presented in figure 1 is naturally obtained. This is because for two bodies of antimatter, the multiplication of negative signs produces a positive force. And so, the repulsion force that appears between different types of bodies (matter and antimatter) comes from the negative value of the antimatter body mass.

**INERTIAL MASS AND GRAVITATIONAL MASS**

Current physics models consider that there are two types of mass (inertial mass and gravitational mass) and one of the still unresolved mysteries of modern physics is the fact that these two masses have the same value.

However, when physicists consider that inertial mass is equal to gravitational mass, they use a single symbol to represent these two types of mass and do not make a distinction between them.

Observing the proposal presented above (that antimatter has negative mass), we can also consider an alternative path in which the gravitational mass of antimatter is different to its inertial mass.

In this case, inertial mass is always positive (for both matter and antimatter) and gravitational mass is positive for matter and negative for antimatter.

And so, the two types of mass are no longer equal, being connected by the following equation:

\[ m_{\text{inertial}} = |m_{\text{gravitational}}| \] \hspace{1cm} (4)

In this way, we can consider that most equations that now deal with generic mass, in fact, are using inertial mass, which is always positive.

For only a few specific equations, such as Newton's gravitational law, we must use gravitational mass, considering a negative value for the case of bodies made up of antimatter.

And so, Newton's laws do not need to be modified, but it is necessary to identify which type of mass (inertial or gravitational) should be applied in each case.

**MASS CONSERVATION PRINCIPLE**

The use of a negative mass value associated with antimatter bodies enables Newton's gravitational law to deal with antimatter.

In addition, it has the advantage of generating a mass conservation principle, which can be applied to interactions between matter and antimatter particles.

In Figure 2, for example, two high energy photons interact, generating matter and antimatter particles. Considering that the two particle masses are always positive, this system's total mass changes from a null value (before the photons interact) to a positive value, which is equal to the sum of each particle's mass.

However, if we consider that antimatter has a negative mass, this system's total mass will always be null, because the mass of the antimatter particle plus the mass of the matter particle is also equal to zero.
Therefore, in the case of the collision of the two particles (causing their annihilation), presented in Figure 3, this system’s total mass is always zero if we also consider that the antimatter particle has a negative mass.

In both the above figures, Einstein’s energy conservation law is maintained, as we must use the value of inertial mass (that is always positive) or consider the mass module function (if we do not distinguish between inertial and gravitational mass) in Einstein’s matter energy equation:

\[ E = |mc^2| \]  

It should be noted that the mass conservation principle is a “weak principle”, as equation (5) shows us that the application of energy to one particle (for example, by increasing its speed) will change its mass.

So, in the case of figure 2, if we accelerate the antimatter particle, its mass tends to increase (thus, becoming more negative) and the total mass of the system is no longer zero, instead becoming a negative value.

However, knowing that time also runs more “slowly” for particles moving at high speed, using one concept of mass/time density (mass value in relation to time flow), it can be proved that this density value is not affected by the particle’s speed or by the presence of gravitational fields.

And so, it is possible to obtain a strong mass/time density conservation principle, which points to the fact that for every matter’s mass in our universe, there is an equal amount of antimatter mass. And so, the universe’s total mass/time density value is always equal to zero.

This position reinforces the question: Where is this antimatter?

For this author, the most obvious answer is that the supermassive black holes (that exist in the center of each galaxy) are made up of antimatter [7].

CONCLUSION

If in a few years, the experiments being carried out at CERN have shown that antimatter presents a repulsive force regarding matter, as shown in figure 1, Newton’s gravitational law will cease to be valid.

Although there are alternative ways to explain this phenomenon, through the general theory of relativity and Ker’s law for black holes in rotation, as shown in detail in the work of Villata [1,2], should we then rule out the possibility of more simple explanations?

Should we explain to young people learning about physics that Newton's gravitational law is not valid for interaction between matter and antimatter particles?

For this author, the answer to this question is NO!

The concept that antimatter has a negative mass is highly intuitive and leads to a mass conservation principle, which is quite interesting when studying matter/antimatter particle interactions.
This author believes that, until today, the negative mass concept has not been applied to antimatter, as it hits head-on with Newton’s second law.

However, why should Newton’s laws work perfectly for antimatter, if Newton himself never even imagined that antimatter could exist?

If we must choose between changing Newton’s second law or his gravitational law, which one should remain unchanged?

The fact is that Newton’s second law generates the concept of inertial mass while his gravitational law creates the concept of gravitational mass. And so, if we let go of the idea that these two types of mass must be the same, we can easily accept that the gravitational mass of antimatter is negative and that its inertial mass is positive, thus solving the problem!

We can always use positive mass values for formulas linked to the inertial mass concept and use the negative mass values for antimatter bodies in formulas associated with gravitational mass.

And so, a very simple explanation, to the behavior of forces present in figure 1, is to consider that antimatter has a negative mass that physics students can easily understand. This means that Newton’s gravitational law can be easily applied to predict the behavior of the gravitational forces that appear between matter/antimatter bodies, in the same way that Coulomb’s Law can be used to predict forces between electrons and protons.

But, for this to occur, modern physicists must break the paradigm that there is no negative mass!

Despite the fact that inertial mass is always positive, this author believes that the experiments with antimatter will show that the gravitational mass of antimatter has a negative value.

REFERENCES