A Space-Time Formalism with Negative Mass to describe Antimatter and Dark Energy

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Abstract

A space-time formalism is proposed in which anti-matter has negative mass and moves forward in time but backwards in proper time. By redefining and generalizing relativistic expressions including relativistic energy, momentum and the stress energy tensor it is shown that it is agreement will all current experimental data. This theory predicts that anti-matter generates an anti-gravitational field. This would make anti-matter a candidate for dark energy, because it explains why no anti-matter stars would be able to form, so it is dark and distributed, it can explain the accelerated expansion of the universe and also resolve the vacuum energy problem. It is predicted that anti-matter repels both matter and anti-matter, but because both follow geodesics, the strongest gravitational field will determine the direction of a particle. So this theory predicts that on Earth anti-matter particles will fall down, but that anti-matter will gravitationally repel other anti-matter. It is proposed to experimentally test this.

Anti-Matter with Negative Mass

If we rewrite the line-element of special relativity

$$c^2 d\tau^2 = c^2 dt^2 - dx^2 - dy^2 - dz^2 \tag{1}$$

into

$$c^2 dt^2 = c^2 d\tau^2 + dx^2 + dy^2 + dz^2 \tag{2}$$

we can use that do define space-propertime. With space-propertime we mean a space with the usual three spatial dimensions x,y,z and with c times the proper-time τ ($c\tau$) as a fourth dimension. The length of a path or worldline of a particle through the four-dimensional space-propertime is then equal to ct (if it started at $t = 0$), which means it is a measure of time. We propose to indicate anti-particles moving in space-propertime diagrams by using downward arrows, so anti-particles move forward in time ($dt > 0$), but backwards in proper-time

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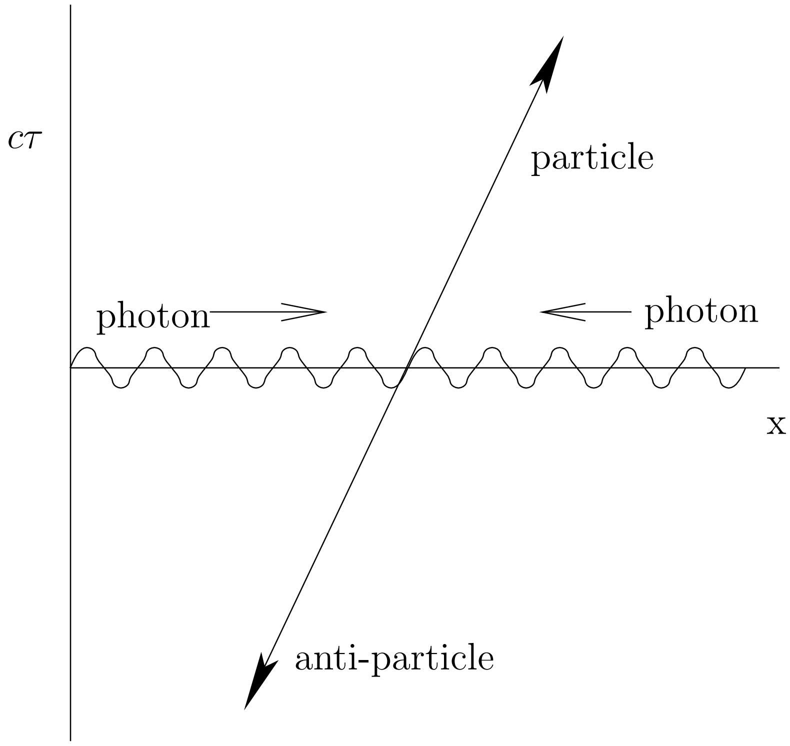
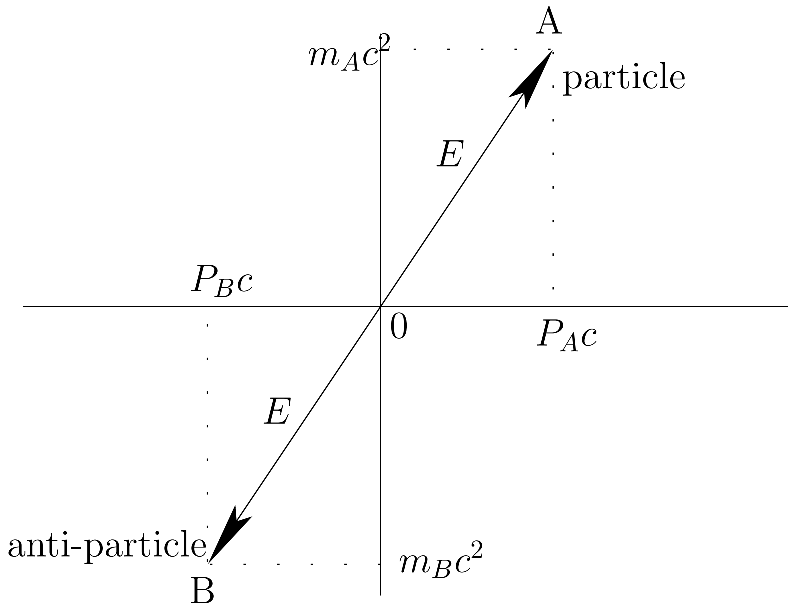
($d\tau < 0$). See [2, 3] for more details. If we use this to describe and visualize interactions between particles we get a kind of Feynman-diagrams in a natural way. As a simple example we describe two colliding photons with equal energy. As a result a particle and antiparticle are formed.



Four-vectors behave and transform in the same way as the space and time-coordinates. We can use this to visualize four-vectors in a similar diagram. To get the diagram for a four-vector we should replace the x,y,z-axis by the spacelike-components of the four-vector. The invariant of the four-vector then becomes the fourth dimension of the diagram (just like $c\tau$). The length of the vector in the diagram will then be equal to the time-like (0-th) component of the four-vector.

We will visualize two energy-momentum four-vectors this way. For the particle and antiparticle from the previous diagram we get



We used the mass as the fourth dimension, because it is the invariant of the energy-momentum four-vector. The fact that we multiplied the axis with c doesn't matter for the diagram, because it is just a constant. We did this so the length of the 4-dimensional vector has the same units as energy. We see that this length is equal to the energy of the particle.

$$E = \sqrt{(mc^2)^2 + (pc)^2} \tag{3}$$

A length of a vector is always positive, and so is energy, but the components can have negative values. We see that the spacelike momentum of the particle and antiparticle is opposite, so the total momentum is zero, just as before the collision. We can use the same argument for the 4th dimension. We could interpret mass as a kind of quantized momentum in the 4th dimension (only values of masses of elementary particles occur). Then it should be opposite for particle and anti-particle because of conservation of momentum in that direction.

Because a massive particle and anti-particle can be formed from massless particles we expect that one of them must have a positive mass and the other negative mass. If we look in our diagram we see that m_B has a negative value. So besides moving in a negative proper-time direction an anti-particle also has a negative mass in our formalism.

Note that the previous formula about energy is still correct. For zero momentum this reduces to

$$E = \sqrt{(mc^2)^2} = \sqrt{m}^2 c^2 = |m|\, c^2 \tag{4}$$

This is the correct formula for matter and anti-matter. Note that this is different from the formula $E = mc^2$. According to our theory of negative mass this famous formula is incorrect, because it is invalid for antimatter. For negative mass this would lead to negative energy, which is incorrect. In our new formula energy is always positive, as expected. Even if we have negative mass.

It's important to also investigate other formulas that depend on the mass m, before we use them with negative masses. As an example we discuss the relativistic expression for energy and momentum.

For momentum this currently is $\vec{p} = \gamma m \vec{v}$. If we measure the velocity $\vec{v}$ of the antiparticle and use a negative mass, the momentum would be in the opposite direction of $\vec{v}$. This is incorrect and therefore we propose a new, more precise definition of momentum, that is also valid for antiparticles.

$$\vec{p} = m\vec{w} = m\frac{d\vec{x}}{d\tau} \tag{5}$$

For particles this is just the same as the normal formula, but for antiparticles we get an extra minus-sign because $d\tau$ is the opposite for anti-particles. This extra minus-sign cancels the minus-sign of the mass. This is the reason we can also write the momentum in the following form

$$\vec{p} = \gamma\, |m|\, \vec{v} \tag{6}$$

We could also see this visually in the diagram, because the projection onto the space-like dimensions is the same for a particle and antiparticle that move in the same direction.

For total energy in Einstein coordinates we also propose a new and more precise definition.

$$E = mc^2 \frac{dt}{d\tau} \tag{7}$$

This is equivalent to the normal formula for particles. For anti-particles an extra minus-sign occurs because of $d\tau$. This minus-sign cancels again with the minus sign of the negative mass, so we can write in general form for particles and anti-particles

$$E = \gamma\, |m|\, c^2 \tag{8}$$

In four-vector notation we can write these new definitions for energy and momentum in one formula. For relativistic coordinates we have

$$p^\mu = m\frac{dx^\mu}{d\tau} = (\gamma\, |m|\, c, \gamma\, |m|\, \vec{v}) = (\gamma\, |m|\, c, \vec{p}) \tag{9}$$

We see that for some things the result is independent of the sign of the mass, but in other areas there is a difference. For example in the Dirac equation it avoids negative energy solutions for anti-particles by giving them a negative mass. Currently two different Dirac equations are used to describe particle and anti-particles. According to Griffiths [6]:

> Notice that whereas the u's (particles) satisfy the momentum space Dirac equation in the form
>
> $$(\gamma^\mu p_\mu - mc)\, u = 0 \tag{10}$$
>
> the v's (anti-particles) obey the equation with the sign of p_μ reversed:
>
> $$(\gamma^\mu p_\mu + mc)\, v = 0 \tag{11}$$

In our formalism we would say that for an anti-particle the sign of the mass is reversed, and not the sign of p_μ. With our new definition of energy-momentum, we noticed that the sign of the momentum four-vector doesn't change if we use a negative mass for an anti-particle in combination with moving backwards in proper time. The energy $E = p_0$ is positive for both matter and antimatter and this solves the sign problem.

We can also check what happens with anti-particles in an electromagnetic field. By expressing the Lorenz Force Law with proper times we see that the negative signs of the proper times and the negative sign of the mass cancel each other again

$$\frac{d^2x^\mu}{d\tau^2} = -\frac{q}{m} F^{\mu\nu} \frac{dx_\nu}{d\tau} \tag{12}$$

So here anti-particles also just behave as if they have positive mass and move forward in proper time. Our definition with negative mass is in agreement and compatible with all those effects.

Anti-Gravitation and Dark Energy

Another area is gravitation. Let us analyze Einstein's theory of gravity

$$G^{\mu\nu} = T^{\mu\nu} \tag{13}$$

with the following stress-energy tensor for dust:

$$T^{\mu\nu} = m \frac{dx^\mu}{d\tau} \frac{dx^\nu}{d\tau} \tag{14}$$

For an anti-particle m is negative and so is $d\tau$. But because $d\tau$ appears twice, it doesn't cancel the minus-sign of the mass now. Bondi [7] already showed that negative mass can be compatible with general relativity. In our theory it is predicted that antimatter has the following anti-gravitational properties: the gravitational field caused by antimatter is repulsive for both matter and other antimatter. It can also explain dark energy. Because antimatter repels everything, it can't form clusters or anti-stars or anti-galaxies and so that explains why it is dark and why it spreads itself. Normal matter gravitationally attracts each other, so they do form stars and galaxies. This also explains why the antimatter and matter are mostly separated in the universe, and why we have much more matter than antimatter in our galaxy (and also because antimatter annihilates with normal matter). This is also why we expect more antimatter between the galaxies. Because antimatter gravitationally repels everything it would also repel those galaxies and this can also explain the acceleration of the expansion of the universe.

This theory also predicts CP violation. As an example consider a neutral meson consisting of a heavy quark (with large positive mass) and a lighter anti-quark (with small negative mass). Then we predict there will be a gravitational attraction between those quarks (not including the other forces). But for the anti-meson there will be a gravitational repulsion between the anti-quark (with big negative mass) and quark (with small positive mass). Although the gravitational force is much weaker than the other forces, it at least shows that such a meson and anti-meson are not exactly identical and this means there is some CP-violation.

Our theory and redefinition and reinterpretation of the stress energy tensor can also solve the vacuum energy problem. Our current best theory and standard model predicts and requires that the vacuum energy in a cubic meter of free space is in the order of 10^{113} Joules. But experimentally it has been estimated to be in the order of 10^{-9} Joules by using the upper limit of the cosmological constant. This last value comes from measuring the global gravitational effects of the vacuum. The calculation with the standard model is related to the quantum fluctuations which create virtual particles. Because of conservation laws these always consist of an equal amount of particles and anti-particles. In our theory the antiparticles have negative mass and generate anti-gravitational fields that cancel all the gravitational fields of the particles, so this is makes it consistent with the experimental measurement. In Einstein's theory of gravity the stress energy tensor is always positive, so then both virtual particles and virtual antiparticles would add to the gravitational field and to the vacuum energy. The new theory of gravity that is proposed here is the same as Einstein's theory, except for the use and interpretation of the stress energy tensor. In our theory it is negative for antimatter.

The gravitational field of matter attracts other matter and antimatter. How does anti-matter move? Let us examine the geodesic equation expressed with proper times.

$$\frac{d^2x^\mu}{d\tau^2} = -\Gamma^\mu_{\nu\rho}\frac{dx^\nu}{d\tau}\frac{dx^\rho}{d\tau} \tag{15}$$

The negative signs of the proper times cancel and no mass appears in this equation. So antiparticles will move along geodesics too. So how anti-matter moves itself depends on the strengths of the gravitational fields. Because the mass of the earth is much larger than that of an antiparticle it is predicted that antimatter will also fall down on earth. To show that our theory cannot only explain existing phenomena, we also give a prediction that can confirm or falsify our theory. It is proposed to measure the gravitational force between neutral anti-matter particles. This is very difficult because the gravitational force is many orders of magnitude weaker relative to the other forces. Einstein's theory predicts that those anti-particles will gravitationally attract, but our theory predicts they will gravitationally repel. Hereby we challenge experimentalists to come up with a smart experiment that could distinguish between these theories.

For more information see [1, 2, 3, 4, 5].

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