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An Exploration of Paradoxes Concerning Space-Time in the Quantum World

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***Abstract*: Space-time, gravity and time dilation are topics that have already been broadly discussed and extensively covered by modern-day and 20th-century physicists. However, these common “macroscopic” parameters have not been as widely researched in the quantum world rather than in the classical physics one. They have been debated, yes, speculations extending even to suggesting a quantum theory of gravity, “connecting” the micro- and macro-parameters together; yet not much definition or concrete knowledge has been acquired in the process of pondering on the all-encompassing topic. This article is written in hopes of expanding some more on this subject, and in it is described the process of how time dilation may not exist in the quantum world, and how some quantum particles may move at speeds faster than light. In the discussion and conclusion block of the paper, a possible implication of the paradoxes discussed will be explored: a quantum theory of gravity will not be possible if we take the information in the previous sections as our basis.**

***Keywords*: Gravity, physics, space-time, theory, time dilation.**

1. Introduction

As it has been said in the abstract, many space-time paradoxes have been explored since Albert Einstein’s four papers published in his *Annus mirabilis* in 1905. The special and general theories of relativity (SR and GR) prompted the discovery of the Einstein-Rosen bridge (how could you get to two far-apart locations in an instant amount of time?) [1], the twin paradox (with the increase in velocity per second squared making for a considerable time dilation between two differently moving “twins”-observers) [2], and the Ehrenfest paradox (where an ideally rigid circumference is rotated around its axis of symmetry, only for it to not stretch out along the direction of its motion, unlike all linearly moving objects. [3] The last phenomenon is quite interesting; the subtle thought experiment yields another argument for the fact that rotating observers don’t follow most commonly taught Euclidean geometry.

2. Macroscopic Paradox: On the Brinks of Space-Time

At the beginning of our exploration spanning the quantum realm to some of the most colossal structures of the Universe, let us venture out into the edges of space-time, right where everything meets nothing. Let us consider the simplest case – a spatially homogenous and isotropic accelerating Universe, consisting of perfect isotropic fluids. Alexander Friedmann first described the abovementioned entity mathematically, creating his eponymous Friedmann equations – a separate case of Einstein’s field equations:

$$\frac{\dot{a}^2+kc^2}{a^2}=\frac{8\pi Gp+\Lambda c^2}{3} \tag{1}$$

and

$$\frac{\ddot{a}}{a}=-\frac{4\pi G}{3}\left(\rho+\frac{3p}{c^2}\right)+\frac{\Lambda c^2}{3} \tag{2}$$

where a is the scale factor, G is the Newtonian constant of gravitation, k is a constant depending on a specific solution, Λ is the cosmological constant, ρ is the volumetric mass density, p is pressure, and c is the speed of light. [4]

One may think that due to SR the edges of the Universe can’t expand past the speed of light; yet current observation seems to defy that hypothesis. At the time of human civilization flourishing, scientists have approximated the rate of expansion of the Universe to be about 69.8 kilometers per second per mega-parsec. [5] However, if we account for recent evidence, [6], “the universe is expanding faster than it should be”. If the acceleration of the Universe isn’t slowing, *or* even if it has been (and has been much bigger before), there is a high possibility that, at some point, its velocity has topped the speed of light. How is that possible?

Critical density depends on time by this formula:

$$\rho_c(t)=\frac{3H^2(t)}{8\pi G} \tag{3}$$

where ρ_c is critical density, $H(t)$ is the Hubble parameter.

$H(t)$ depends on time and velocity/acceleration by the following equation:

$$H(t)=\frac{\vartheta}{r}=\frac{at}{r} \tag{4}$$

where ϑ is the velocity of the object relative to an observer, a is acceleration and r is the distance between the object and the observer.

Connecting (3) and (4) together, we get:

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$$\rho_c(t) = \frac{3H^2(t)}{8\pi G} = \frac{3(\frac{at}{r})^2}{8\pi G} = \frac{3a^2t^2}{8\pi r^2 G} \qquad (5)$$

Plugging in the acceleration of the Universe, 69.8 kilometers per second per mega-parsec, and t=13.8 billion years, we get:

$$\rho_c(t) = \frac{3a^2t^2}{8\pi r^2 G} < 1.$$

This indicates that with this acceleration, the Universe will continue to expand forever and accelerate forever. [7]

And that lays the basis for our macroscopic paradox.

A. Quantum Paradox: Why the Universe is a "Deity" – with a center everywhere

Now in the quantum world, things seem a little bit different. First, we don't take into account the cosmological principle (as we don't analyze the Universe over a large scale); secondly, many of the constants and variables we operated with in *Section A* only apply to macroscopic calculations.

In the quantum world, pieces of space-time are so infinitesimally small that the SR time dilation may be dismissed. Therefore, in the quantum world, time may be regarded as absolute.

It leads to the fact that, as time is absolute at the center of the Universe, "everywhere" in it (on the quantum level) can be the center of the Universe.

But how then do we think about any accelerating edges?

B. Quantum Paradox: Can particles move with speeds more than the speed of light?

1) In which it is hypothesized that velocity is relative

If the speed of light is the limit of "average-sized" objects in classical mechanics, then perhaps it does not reflect the actual speed limit of the object relative to the quantum world.

To possibly predict what this speed would seem like in the quantum world, we may "venture out" onto the edges of the Universe and "move with them"; we will notice that the inner space-time closer to the center of the Universe (and farther from us) would be closer to the speed of light. However, it would look exactly symmetrical to the place we're in right now; at our exact position on Earth in the Milky Way.

So, our place in the Universe may also be moving away from the center of expansion with the speed of light, as described and proved by the current predicted value of the acceleration of the Universe, the Friedmann equations and their derivative (5). But our velocity seems smaller.

Therefore speed, like time, is relative.

2) In which it is concluded that some quantum particles may move with a speed greater than light

We have ventured out to the edges of the Universe. But we haven't delved into the depths of the most minuscule sizes, and haven't moved with them.

Simply using the likeness theory, we may find that some quantum particles are moving at speeds faster than light. Photons and gluons would be. [8]. Perhaps, all the rest of the particles would be moving at speeds more or equal to a certain "minimum" speed – the speed of light. As the Universe's macroscopic space-time moves with speeds seemingly more than the speed of light – relatively to us, the observer – in Section A, the quantum world may have a completely different story. So, in conclusion, this paradox assumes that light is the minimum barrier that quantum particles must overcome to be detectable in the larger classical physics scale.

In quantum terms, there may be particles moving with speeds greater than light.

However, this is simply a paradox.

3. Discussion and Conclusion

We have explored three different paradoxes, including a known macroscopic one and two quantum ones, the latter two expanded on by the author. In closing, I would like to add that one possible implication arises from the pondered upon quantum paradoxes. Consider gravity. Due to excusable time dilation and consequently any significant space-time curvature, it may not exist in the quantum world. Or, it may be too big to be even conceived. It may get weaker as the object of which it is a curvature of gets heavier, or larger. Consequently, the quantum theory of gravity *may* not be possible. But we may need more evidence to confidently prove its impossibility.

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