Quantum Gravity and Einstein's Relativistic Kinetic Energy Formula

The goal of this paper is to highlight the deep connection between Einstein's relativistic kinetic energy formula and two quantum gravity laws' governing their respective domains: black holes and particle physics. It seems this connection leads to a deeper understanding of the nature of the intervening processes.

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1. Introduction

Two salient theories developed during the 20th century – Einstein's theory of General Relativity and the Standard Model (SM) of particle physics, are thought to be two of the best formulations we have to account for a broad spectrum of phenomena. General Relativity is based on the idea that spacetime can be curved by the presence of massive objects such as planets, stars and black holes. Despite General Relativity's effectiveness at describing several astronomical and cosmological phenomena, it cannot predict the correct behaviour of black holes, such as its temperature (Hawking temperature is an approximation [1]). The reason GR fails at the microscopic scale is because it does not incorporate the Heisenberg uncertainty relations or any other uncertainty relations (such as the universal uncertainty principles [2]). The Standard Model of particle physics, on the other hand, is a collection of quantum mechanical theories providing an amazingly accurate description of almost all the microscopic phenomena where the effects of gravity are assumed to be negligible. The Standard Model explains the behaviour of normal matter (visible matter) and three out of the four forces of nature: the electromagnetic force, the weak force and the nuclear force (the combination of the electromagnetic and the weak forces into a single unified theory is known as the electroweak unification). Despite the Standard Model's success at describing the quantum phenomena, it is nevertheless an incomplete theory. This incompleteness is due, at least, to the following reasons: the SM does not include gravity, the SM cannot predict any of the external parameters of the model, the SM does not include any particle that could explain the observed abundance of dark matter (26.8 % or so), the SM does not include any neutrino masses (at least one out of the three types of known neutrinos must have non-zero mass), the SM is based on an incorrect mathematical process called renormalization (infinity minus infinity cannot produce a finite result other than 0), the SM cannot explain quantum entanglement, the SM cannot explain the origin of the mass of the Higgs boson, the SM cannot explain the origin of the masses of black holes, the SM cannot predict the decay rates of some subatomic particles, the SM cannot predict all particles types there exist in the universe, The SM incorrectly predicts that at high energies the probability of scattering a *W* particle off another *W* particle is greater than one, the SM cannot predict the size of the fundamental particles, the SM cannot explain the large imbalance between matter and antimatter of the universe (I proposed two solutions to this problem [3]), etc. Because of the limited (nevertheless remarkable) predicting power of these theories, specially at high energies, a new unified theory is needed if we want a complete account of reality. This unified theory which is supposed to describe the four known forces of nature with unprecedented accuracy, is known as quantum gravity (QG). The task of unifying both gravity and quantum mechanics, however, has proven to be extremely difficult as, at the present time, no "reasonably comprehensive and correct" QG theory has been developed.

In the remainder of this paper I shall compare two quantum gravitational formulas with Einstein's relativistic kinetic energy formula. These formulas represent a tiny part of QG. The nomenclature used in this paper is given in **Appendix 1**.

2. Einstein's Total Relativistic Energy Formula

Let us begin with the Einstein's total relativistic energy formula. This formula is

$$E^2 = p^2 c^2 + m_0^2 c^4 \tag{1.1}$$

The relativistic kinetic energy, *K*, of any particle (massless or massive) is given by

$$K = E - m_0 c^2 \tag{1.2}$$

It is worthwhile to mention that when the rest mass, m_0, of the particle is zero, the kinetic energy, *K*, equals the total relativistic energy, *E*.

From equations (1.1) and (1.2) we can write

$$K = \sqrt{\left(m_0 c^2\right)^2 + \left(p c\right)^2} - m_0 c^2 \tag{1.3}$$

$$K = \sqrt{\left(m_0 c^2\right)^2 \left[1 + \frac{(p c)^2}{\left(m_0 c^2\right)^2}\right]} - m_0 c^2 \tag{1.4}$$

Finally

$$K = m_0 c^2 \left[\sqrt{1 + \left(\frac{p c}{m_0 c^2}\right)^2} - 1\right] \tag{1.5}$$

or

$$K = m_0 c^2 \left(\sqrt{1 + \frac{p^2}{m_0^2 c^2}} - 1 \right) \quad (1.6a)$$

This equation may be written in terms of *beta* [see **Appendix 2**, eq. (A2.5)] as follows

$$K = m_0 c^2 \left(\sqrt{1 + \frac{\beta^2}{1 - \beta^2}} - 1 \right) \quad (1.6b)$$

Equations (1.6) are two equivalent forms of writing Einstein's relativistic kinetic energy formula. The reason I have chosen to write the kinetic energy formula this way, is to compare it, later on, with two quantum gravitational formulas.

3. Quantum Gravitational Formulas

The two quantum gravitational formulas I shall compare with Einstein's relativistic kinetic energy law belong to two different levels of reality: the macroscopic level and the microscopic level. These formulas are

(1) **At the macroscopic level**: The formula for the black hole temperature
(2) **At the microscopic level**: The "Alpha-23" formula for the mass of the electron

I shall analyse these formulas in two separate subsections (the formulas used in this subsection are given in **Appendix 2**):

3.1 Macroscopic Level: The Quantum Gravitational Formula for the Black Hole Temperature

In 2014 I published an article on black holes [1]. In that article I derived the thermodynamic properties of black holes - temperature and entropy - from the universal uncertainty principle [2]. I found that the black hole temperature was given by equation (Reference [1]: Eq. 4.15):

$$T = \frac{T_H}{8\sqrt{\pi}} \left(\sqrt{\frac{k_B}{S_{BH}} + 64\pi} - \sqrt{\frac{k_B}{S_{BH}}} \right) \quad (3.1.1)$$

This equation can be rewritten as

$$T = \frac{T_H}{8\sqrt{\pi}} \sqrt{\frac{k_B}{S_{BH}}} \left(\sqrt{1 + \frac{64\pi S_{BH}}{k_B}} - 1 \right) \quad (3.1.2)$$

The energy of a photon that escapes from a black hole into empty space due to Hawking radiation is given by formula (Reference [4]: Eq. 5.1) from the paper entitled: *The Temperature of a System as a Function of the Multiplicity and its Rate of Change* [4]. Because the rest mass of photon is thought to be zero, the total relativistic energy of the photon is equal to its relativistic kinetic energy, $K_{escaping\,\gamma}$. Thus we can write

$$E_{escaping\,\gamma} = K_{escaping\,\gamma} = k_B T \tag{3.1.3}$$

$$E_{escaping\,\gamma} = K_{escaping\,\gamma} = \frac{T_H k_B}{8\sqrt{\pi}}\sqrt{\frac{k_B}{S_{BH}}}\left(\sqrt{1+\frac{64\pi S_{BH}}{k_B}}-1\right) \tag{3.1.4}$$

The above equation has got the form of Einstein's kinetic energy formula - equation (1.6).

(3.2) Microscopic Level: The Quantum Gravitational "Alpha-23" Formula for the Mass of the Electron

The "Alpha-23" Formula for the Mass of the Electron [5] is given by

$$m_e = \frac{m_p^2}{4\alpha^6 M_P}\left(\sqrt{1+\frac{4e^2\alpha^{23}M_P}{\pi\epsilon_0 G m_p^3}}-1\right) \tag{3.2.1}$$

If we multiply both sides of this formula by, c^2 , we get the electron rest energy

$$m_e c^2 = \frac{m_p^2 c^2}{4\alpha^6 M_P}\left(\sqrt{1+\frac{4e^2\alpha^{23}M_P}{\pi\epsilon_0 G m_p^3}}-1\right) \tag{3.2.2}$$

One more time the above equation has got the form of Einstein's kinetic energy formula - equation (1.6).

4. Summary

Table 1 shows the two formulas: (3.1.4) and (3.2.2) for comparison purposes. It is worthwhile to observe that these formulas are very similar to Einstein's relativistic kinetic energy equation. The reason for this will be discussed in section 5 and is also explained in the last column of the table.

Field	**Quantum Gravity Formulas**	**Physical Meaning**
Special Relativity	(Reference Formulas) Einstein's relativistic kinetic energy formula $$K = m_0 c^2 \left(\sqrt{1 + \frac{p^2}{m_0^2 c^2}} - 1 \right) \quad (1.6a)$$ or, equivalently $$K = m_0 c^2 \left(\sqrt{1 + \frac{\beta^2}{1-\beta^2}} - 1 \right) \quad (1.6b)$$ Note that the ratio $\frac{p^2}{m_0^2 c^2} = \frac{\beta^2}{1-\beta^2}$ is dimensionless	Relativistic kinetic energy of a body or a particle
Black Holes (macroscopic level)	Energy (either kinetic or total) of a photon "emitted" by a black hole due to Hawking radiation. Eq. (3.1.4) $$K_{escaping\,\gamma} = \frac{T_H k_B}{8\sqrt{\pi}} \sqrt{\frac{k_B}{S_{BH}}} \left(\sqrt{1 + \frac{64\,\pi\, S_{BH}}{k_B}} - 1 \right)$$ Note that the ratio $\frac{64\,\pi\, S_{BH}}{k_B}$ is dimensionless	The formula suggests that the temperature of a black hole originates from a dynamic unknown quantum gravitational process
Particle Physics (microscopic level)	Rest energy of the electron. Eq. (3.2.2) $$m_e c^2 = \frac{m_p^2 c^2}{4\alpha^6 M_P} \left(\sqrt{1 + \frac{4 e^2 \alpha^{23} M_P}{\pi \epsilon_0 G m_p^3}} - 1 \right)$$ Note that the ratio $\frac{4 e^2 \alpha^{23} M_P}{\pi \epsilon_0 G m_p^3}$ is dimensionless	The formula suggests that the rest mass of the electron originates from a dynamic quantum gravitational process. Possibly the Brout-Englert-Higgs mechanism.

Table 1: Two energy formulas (second and third row) that are very similar to Einstein's relativistic kinetic energy formula shown on the first row.

5. Conclusions

In summary, the similarity of the above quantum gravitational formulas: (3.1.4) and (3.2.2) with Einstein's relativistic kinetic energy formula are profound: it suggests that these formulas describe dynamic processes in their respective domains.

The following formulas:

$$\text{(a)} \quad K_{escaping\,\gamma} = \frac{T_H k_B}{8\sqrt{\pi}} \sqrt{\frac{k_B}{S_{BH}}} \left(\sqrt{1 + \frac{64\pi S_{BH}}{k_B}} - 1 \right)$$

may be interpreted as evidence of a dynamic processes taking place inside a black hole.

$$\text{(b)} \quad m_e c^2 = \frac{m_p^2 c^2}{4\alpha^6 M_P} \left(\sqrt{1 + \frac{4 e^2 \alpha^{23} M_P}{\pi \epsilon_0 G m_p^3}} - 1 \right)$$

may be interpreted as evidence of a dynamic processes that may give rise to the mass of the electron.

In the case of the black hole, the temperature formula seems to describe an unknown dynamic process occurring inside the black hole. This conclusion is totally reasonable since, in classical physics, the temperature of a system is an indication of the motion of the molecules inside a container filled with gas. Thus the fact that a black hole has got a temperature means that there must be a dynamic process inside. This, in turn, suggests a black hole has a structure, whose nature is still unknown. However, according to my general quantum gravitational theory of black holes, a black hole can have not only positive temperatures but also negative absolute temperatures. And even zero absolute temperature (See preliminary results in [1]). This means that the structure of a black hole must be very different to that of any other known cosmic object. In the case of the electron rest mass, the process that originates this mass is likely to be a dynamic process as well. In this is so, the process must be the Brout-Englert-Higgs mechanism (also known as the Higgs mechanism) which is due to the Higgs field. According to the Higgs mechanism, particles (such as electrons) acquire their masses through interactions with the Higgs particle. However the dominant source from which the Higgs particle acquires its mass is yet unknown. Since the Higgs particle was discovered in 2012 by CERN's scientists, the formula for the mass of the electron discussed in this paper is in agreement, from a qualitative point of view, at least, with the Standard Model. Finally, it should be emphasized that the SM does not include gravity in its formulation. In contrast, the above formula for the mass of the electron [Eq. (3.2.1)] includes the famous Newton's gravitational constant, *G,* and therefore it accounts for gravity. Finally, is worthwhile to emphasize that this formula, along with the formula for the temperature of a black hole, are two examples of quantum gravity's laws.

Appendix 1
Nomenclature

The following are the symbols, abbreviations and terminology used in this paper

Symbols

E = total relativistic energy
K = relativistic kinetic energy
p = relativistic momentum of a body or particle ($p = m\,v$)
v = velocity of a body or particle
β = ratio between the velocity of a body, v, to the speed of light, c
m = relativistic mass of a body or particle
m_0 = rest mass of a body or particle
m_e = electron rest mass
m_p = proton rest mass
M_p = Planck mass
α = fine-structure constant, electromagnetic coupling constant, atomic structure constant [6].
c = speed of light in vacuum
h = Planck's constant
$\hbar$ = reduced Planck's constant
G = Newton's gravitational constant
e = elementary electric charge
ϵ_0 = permittivity of vacuum
T = black hole temperature
T_H = Hawking's black hole temperature (approximation)
A_H = black hole's event horizon area (area of a sphere)
k_B = Boltzmann's constant
$E_{escaping\,\gamma}$ = total or kinetic energy of the escaping photon

Appendix 2
Formulas

1. Hawking temperature

$$T_H = \frac{hc^3}{16\pi^2 k_B G M} \tag{A2.1}$$

2. Berkenstein-Hawking black hole entropy

$$S_{BH} = \frac{k_B c^3 A_H}{4\hbar G} \tag{A2.2}$$

3. Planck mass

$$M_P = \sqrt{\frac{h\,c}{2\,\pi\,G}} \tag{A2.3}$$

4. Fine-structure constant, electromagnetic coupling constant or atomic structure constant [6].

$$\alpha = \frac{e^2}{2\,\epsilon_0 h\,c} \tag{A2.4}$$

5. Beta

$$\beta = \frac{v}{c} \tag{A2.5}$$

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