The Special Quantum Gravitational Theory of Black Holes (Wormholes and Cosmic Time Machines)

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Abstract

The present research is concerned with the problem of finding a quantum gravitational description applicable to all phenomena including black holes. Thus, this paper introduces the universal uncertainty principle which is an extension of Heisenberg uncertainty relations. While this universal principle includes the Planck length (as the minimum length with physical meaning) and the zero point momentum due to the quantum fluctuations of empty space, the effects of the latter are neglected. This approach predicts the two thermodynamics properties of black holes: temperature and entropy. The general equation for the temperature of the black hole shows a surprising result: the temperature depends not only on the mass of the black hole but also on its radius. Therefore this formulation desagrees with Hawking's theory which claims that the temperature of the black hole does not depend on its radius. However, the impact of the radius of the black hole on its temperature is relatively significant for radii smaller or equal than 3 times the Planck length only. Finally, the black hole's entropy law emerges naturally from this formulation without needing the inclusion of additional postulates. The entropy law derived in this paper fully agrees with the Berkenstein-Hawking's entropy formula and except for the Schwarzschild radius formula, this formulation does not use any other equations derived from general relativity. The preliminary results of the general quantum gravitational theory of black holes is given in section 5.

Keywords: *quantum fluctuations, zero point energy, zero point momentum, event horizon, entropy, virtual photon, Hawking radiation, Boltzmann constant, Schwarzchild radius, wave-packet, wormhole, time machine.*

1. Introduction

The idea that the black hole entropy depends on the area of the event horizon of the black hole was proposed by J. D. Berkenstein in 1972. In 1974 Stephen Hawking proposed an evaporation mechanism [1] by which a black hole can radiate energy into space through the emission of photons originated near the event horizon. This along with the Berkenstein-Hawking’s formula of the black hole entropy was a great milestone in understanding how these mysterious celestial objects could behave.

The quantum fluctuations of the vacuum produce pairs of virtual particles and anti-particles around the black hole (in fact these pairs are created everywhere in empty space). If one of these pairs turns out to be two photons and if the pair is close enough to the event horizon of the black hole, one of the virtual photons can be absorbed by the hole and the other one can escape to infinity and become real. The absorbed photon, with an assumed negative energy, would reduce the mass of the black hole by a tiny amount. Eventually, if the black hole is unable to absorbe positive energy from its surroundings to compensate the loss, it should simply vanish. This evaporation process is known as *Hawking radiation*. The detection of this radiation is extremely difficult due to the relatively slow rate of emission. This explains why this radiation has not been observed yet. The next section explains the cornerstone of this theory: *the universal uncertainty principle* [2]. The preliminary results of the general quantum gravitational theory of black holes is given in section 5.

2. The Universal Uncertainty Principle

The principle introduced in this paper is an extension of the Heisenberg uncertainty principle [3]. This principle includes three different effects:

a) ***vacuum effects****. These effects are due to the quantum fluctuations of empty space (the energy of empty space is also known as the zero point energy),*
b) ***gravitational effects****. These effects are due to the strong gravitational field surrounding the black hole (due to this the de Broglie law does not hold) and are taken into account through the Schwarzschild radius.*
c) ***quantum gravitational effects****. These effects are taken into account through the Planck length.*

To differentiate this principle from other generalized principles I shall call it the *Universal Uncertainty Principle* (UUP). The expression that defines this principle is

$$\Delta p \Delta x \geq \sqrt{\left(\frac{h}{4\pi}\right)^2 - \frac{h}{8\pi} P_Z (\Delta x \pm L_Z) - \frac{h}{8\pi} (\Delta p \pm P_Z) L_L} \tag{2.1}$$

$$\Delta p \Delta x \geq \sqrt{\left(\frac{\hbar}{2}\right)^2 - \frac{\hbar}{4} P_Z (\Delta x \pm L_Z) - \frac{\hbar}{4} (\Delta p \pm P_Z) L_L} \tag{2.2}$$

If we neglect P_Z then inequation (2.1) reduces to

$$\Delta p \Delta x \geq \sqrt{\left(\frac{h}{4\pi}\right)^2 - \frac{h}{8\pi} \Delta p L_Z} \tag{2.3}$$

$$\Delta p \Delta x \geq \sqrt{\left(\frac{\hbar}{2}\right)^2 - \frac{\hbar}{4} \Delta p L_Z} \tag{2.4}$$

This is the relation we shall use in this formulation.

The variables used in relations (2.1), (2.2), (2.3) and (2.4) are:

Δp = Uncertainty in the momentum of a particle due to its wave nature (wave-packet representing the particle). This uncertainty does not include the uncertainty P_Z in the momentum due to the quantum fluctuations of space-time.

Δx = Uncertainty in the position of the particle due to the wave-packet representing the particle. This uncertainty does not include the uncertainty L_Z in the position due to the quantum fluctuations of space-time.

L_Z = Uncertainty in the position of the particle due to the quantum fluctuations of space-time. This uncertainty does not include the uncertainty Δx due to the wave-packet representing the particle. The minimum value of this uncertainty cannot be measured experimentally with the present technology. Further, it seems logical to assume that this uncertainty is identical to the Planck length L_P. However, these two lengths could be different but the difference should not be significant.

P_Z = Uncertainty in the momentum of a particle due to to the quantum fluctuations of space-time (uncertainty due to the zero point momentum). This uncertainty does not include the uncertainty Δp in the momentum due to the wave nature of the wave-packet representing the particle. We shall neglect the effects of P_Z in this formulation. On way of extending this principle to include the zero point momentum (or zero point energy if the temporal form of the uncertainty principle is used) is to use the Schwinger formulation.

For more information about the UUP see reference [2] and **Appendix 1**.

3. Black Hole Temperature

Let us consider a black hole of radius R_S and mass *M*. Let's assume that a pair of virtual photons is created near the event horizon (at P1) due to the quantum fluctuations of empty space. Let us also assume that one of the photons of this pair (an anti-photon) is absorbed by the black hole while the other one (a photon) escapes to space and thus becomes real (see Fig 1).

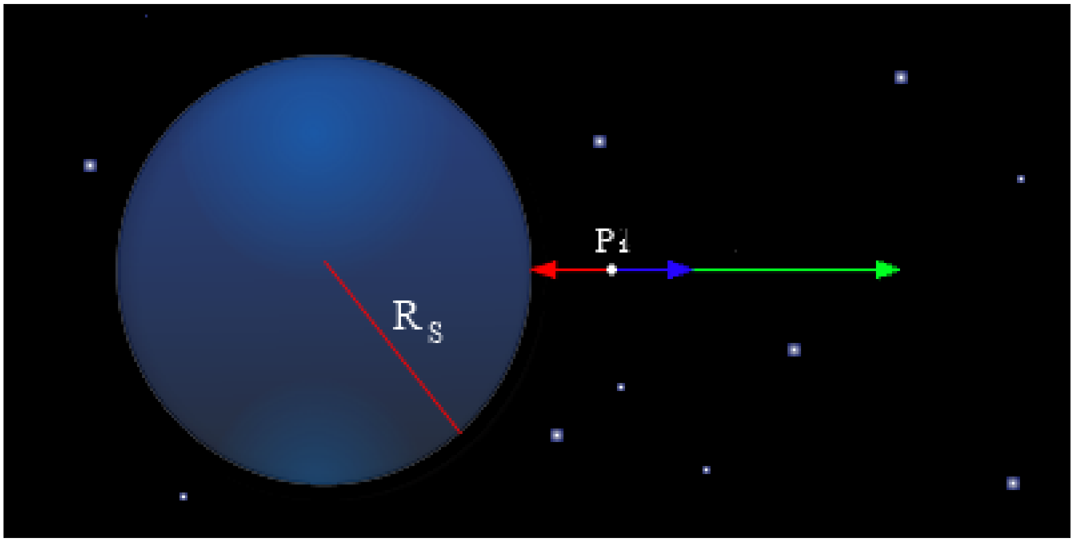


Fig 1: The blue sphere represents a black hole of radius R_S *. A pair of virtual photons is created near a black hole's event horizon due to the quantum fluctuations of the vacuum. The point of creation is labeled as* P_1 *. One of the photons (red arrow) of the pair is absorbed by the black hole while the other one (blue arrow) escapes to space and becomes real (green arrow). This evaporation mechanism was proposed by Hawking and is known as Hawking radiation.*

According to general relativity, the Schwarzchild radius of this black hole is

$$R_S = \frac{2GM}{c^2} \qquad (3.1)$$

Equation (3.1) leads to

$$c^2 = \frac{2GM}{R} \qquad (3.2)$$

In order to simplify the equations I shall use R instead of R_S . Let's multiply both sides of equation (3.1) by the equivalent mass m_v of the virtual photon that becomes real (from now on I shall call it "the escaping photon"). Because this photon becomes real all the laws of physics that apply to real photons will apply to this photon. However, there is one exception: *the de Broglie law*. Because of the extremely intense gravitational fields produced by the black hole this law does not hold for photons absorbed by the black hole's event horizon (surface of a sphere of radius R). On the other hand, the de Broglie law holds for Hydrogen atoms because, in comparison with black holes, the gravitational force between the proton and the electron is very weak. This is explained in more detail below.

$$m_v c^2 = \frac{2GMm_v}{R} \qquad (3.3)$$

But according to Einstein

$$E_v = m_v c^2 \tag{3.4}$$

$$E_v = hf \tag{3.5}$$

Where E_v is the total relativistic energy of the escaping photon. From equations (3.3), (3.4) and (3.5) we have

$$\frac{2GM\,m_v}{R} = h\,f \tag{3.6}$$

Solving this equation for m_v we obtain

$$m_v = \left(\frac{hR}{2GM}\right) f \tag{3.7}$$

The condition that the black holes imposes on the absorbed photon is that the wavelength of the photon must be roughly the size of the black hole. This is because if the wavelength of the photon is too short the photon will be absorbed by the quantum fluctuation of the vacuum surrounding the photon before it gets the chance to go through the event horizon of the black hole, and if, on the other hand, the wavelength of the photon is too long, the photon will miss out the black hole entirely. Thus the uncertainty in the position of the absorbed photon, due to its wave nature, is

$$\Delta x = 2\pi\; R \tag{3.8}$$

In order to simplify the equations we shall substitute Δx with a, thus

$$a \equiv \Delta x \tag{3.9}$$

Because the black hole forces the photon to have only one wavelength (the wavelength must be exactly the size of the circumference that results from slicing the black hole along any great circle. Virtual photons with any other wavelengths will not be absorbed by the black hole because if this wavelength is too short they will be absorbed by the quantum field around the black hole and if the wavelength is too long they will tunnel through the hole). Because of the intense gravitational fields, the momentum of the photon will be related to the wavelength through the universal uncertainty principle and not through the de Broglie law (you can develop an identical theory from the Heisenberg uncertainty principle $\Delta p \Delta x \geq h/4\pi$ to see that the de Broglie law: $p_v = h/2\pi\; R$ will not produce the correct relationship for the black hole temperature. In other words the de Broglie equation does not hold for black holes. The correct relationship is: $p_v = h/8\pi^{\,2} R$ which is derived from the Heisenberg uncertainty principle. In this formulation we use equation (3.11) instead (see below). Therefore we shall substitute Δp with p_v, thus

$$\Delta p = p_v \tag{3.10}$$

Substituting into equation (2.3) we obtain

$$p_v a \geq \sqrt{\left(\frac{h}{4\pi}\right)^2 - \frac{h}{8\pi} p_v L_Z} \tag{3.11}$$

If we square both sides of the above inequation we get

$$p_v^2 a^2 \geq \left(\frac{h}{4\pi}\right)^2 - \frac{h}{8\pi} p_v L_Z \tag{3.12}$$

Rearranging the terms and substituting the inequality with an equality sign lead us to a second degree equation that can be easily solved

$$a^2 p_v^2 + \frac{h L_Z}{8\pi} p_v - \left(\frac{h}{4\pi}\right)^2 = 0 \tag{3.13}$$

The coefficients of this equation are

$$A = a^2 \tag{3.14}$$

$$B = \frac{h L_Z}{8\pi} \tag{3.15}$$

$$C = -\left(\frac{h}{4\pi}\right)^2 \tag{3.16}$$

And the solution to this equation is

$$p_v = \frac{-\frac{h L_Z}{4\pi} \pm \sqrt{\left(\frac{h L_Z}{8\pi}\right)^2 + 4a^2\left(\frac{h}{4\pi}\right)^2}}{2a^2} \tag{3.17}$$

We shall neglect the negative square root

$$p_v = \frac{1}{2a^2}\left[\sqrt{\left(\frac{h L_Z}{8\pi}\right)^2 + 4a^2\left(\frac{h}{4\pi}\right)^2} - \frac{h L_Z}{4\pi}\right] \tag{3.18}$$

$$p_v = \frac{1}{2(2\pi\ R)^2}\left[\sqrt{\left(\frac{hL_Z}{8\pi}\right)^2 + 4(2\pi R)^2\left(\frac{h}{4\pi}\right)^2} - \frac{hL_Z}{4\pi}\right] \tag{3.19}$$

$$p_v = \frac{1}{8\pi^2 R^2}\left[\sqrt{\frac{h^2 L_Z^2}{64\pi^2} + h^2 R^2} - \frac{hL_Z}{4\pi}\right] \tag{3.20}$$

$$p_v = \frac{1}{8\pi^2 R^2}\left[\sqrt{\frac{h^2 R^2}{64\pi}\left(\frac{L_Z^2}{\pi\ R^2} + 64\pi\right)} - \frac{hL_Z}{4\pi}\right] \tag{3.21}$$

$$p_v = \frac{1}{8\pi^2 R^2}\left(\frac{hR}{8\sqrt{\pi}}\sqrt{\frac{L_Z^2}{\pi\ R^2} + 64\pi} - \frac{hL_Z}{4\pi}\right) \tag{3.22}$$

$$p_v = \frac{h}{64\pi^2\sqrt{\pi}\ R}\left(\sqrt{\frac{L_Z^2}{\pi\ R^2} + 64\pi} - \frac{L_Z}{\sqrt{\pi}\ R}\right) \tag{3.23}$$

According to Einstein the energy of a photon is

$$p_v c = h f \tag{3.24}$$

Hence

$$f = \frac{c}{h} p_v \tag{3.25}$$

Substituting f in equation (3.7) with the value obtained from equation (3.24) gives

$$m_v = \left(\frac{hR}{2GM}\right)\left(\frac{c}{h} p_v\right) = \left(\frac{Rc}{2GM}\right) p_v \tag{3.26}$$

Multiplying both sides by c^2 we get

$$m_v c^2 = \left(\frac{Rc^3}{2GM}\right) p_v \tag{3.27}$$

Considering that the energy E_v of the escaping photon is proportional to the absolute temperature T of the black hole we can write

$$E_v = k_B T \tag{3.28}$$

Hence

$$T = \frac{E_v}{k_B} \tag{3.29}$$

Substituting E_v in equation (3.28) with the right hand side of equation (3.26) gives

$$T = \left(\frac{Rc^3}{2k_B GM} \right) p_v \tag{3.30}$$

Substituting p_v in equation (3.29) with the right hand side of equation (3.22) produces

$$T = \left(\frac{Rc^3}{2k_B GM} \right) \frac{h}{64\pi^2 \sqrt{\pi}\, R} \left(\sqrt{\frac{L_Z^2}{\pi R^2} + 64\pi} - \frac{L_Z}{\sqrt{\pi}\, R} \right) \tag{3.31}$$

which can be re-written as

$$T = \left(\frac{1}{8\sqrt{\pi}} \right) \left(\frac{hc^3}{16\pi^2 k_B GM} \right) \left(\sqrt{\frac{L_Z^2}{\pi R^2} + 64\pi} - \frac{L_Z}{\sqrt{\pi}\, R} \right) \tag{3.32}$$

We recognize the second factor of equation (3.32) as the Hawking temperature, T_H. Thus we write

$$T_H = \frac{hc^3}{16\pi^2 k_B GM} \qquad \text{(Hawking temperature)} \tag{3.33}$$

Now we shall assume that the Planck length L_P is the minimum length with physical meaning. Thus we shall make two changes to equation (3.32) a) we shall substitute the zero point energy's length, L_Z, with the Planck length, L_P; and b) we shall substitute the second factor with T_H. With these two changes equation (3.32) transforms into

$$T = \frac{T_H}{8\sqrt{\pi}} \left(\sqrt{\frac{L_P^2}{\pi R^2} + 64\pi} - \frac{L_P}{\sqrt{\pi}\, R} \right) \qquad \text{(Black hole temperature)} \tag{3.34}$$

This is the equation for the black hole temperature in terms of the Hawking temperature. Thus this theory allow us to make the following prediction:

Prediction 1

The black hole temperature depends on both the mass M and the radius R of the black hole.

The values of the ratio, T/T_H , are tabulated on Table 1 for different values of the ratio: R/L_P . The relative error is shown on the last column as a percentage

Black hole radius / Planck length $\frac{R}{L_P}$	**Black hole Temperature / Hawking temperature** $\frac{T}{T_H}$	**Relative error (percentage)** $100\times\left(\frac{T_H - T}{T_H}\right)$
1	0.9610	3.8998
2	0.9803	1.9697
3	0.9868	1.3175
4	0.9901	0.9898
5	0.9921	0.7926
6	0.9934	0.6610
7	0.9943	0.5668
8	0.9950	0.4961
9	0.9956	0.4411
10	0.9960	0.3971
20	0.9980	0.1988
30	0.9987	0.1325
40	0.9990	0.0994
50	0.9992	0.0796
60	0.9993	0.0663
70	0.9994	0.0568
80	0.9995	0.0497
90	0.9996	0.0442
100	0.999602	0.0398
1 000	0.9999602	0.00398
10 000	0.99999602	0.000398
100 000	0.999999602	0.0000398
1 000 000	0.9999999602	0.00000398

TABLE 1: *This table shows that the actual temperature T predicted by equation (3.34) is smaller than the corresponding temperatures* (T_H) *predicted by the Hawking equation.*

From the above table we see that the temperature T predicted by equation (3.34) is smaller than the corresponding temperatures predicted by the Hawking equation (3.33). We also see that the maximum relative error is about 4 % and occurs for black holes of the size of the Planck length ($R = L_P$). For black holes whose radii R are greater than $3\,L_P$ the relative error is less than 1 %. Thus we conclude that the impact of the black hole radius on the temperature is insignificant for black holes of radii greater than $3\,L_P$. However we have to keep in mind that, despite the very similar numerical results, this quantum gravitational model is conceptually very different to Hawking's formulation. The main barrier to Hawking's theory is that it is a conventional relativistic approach which does not consider any generalized uncertainty principle. On the other hand the cornerstone of this formulation is the universal uncertainty principle (UUP). As a result, this theory yields a more general and accurate formula for the temperature of the black hole.

Now let us return to equation (3.34) and let us take the limit of T when L_P tends to zero. This gives

$$\lim_{L_P \to 0} T = \frac{T_{BH}}{8\sqrt{\pi}} \sqrt{64\pi} \tag{3.35}$$

$$\lim_{L_P \to 0} T = T_{BH} \tag{3.36}$$

Then we find that

Prediction 2
The Hawking temperature is a special case of the general formula of the black hole temperature when the Planck length is zero

If we take the limit when the radius tends to infinity we obtain

$$\lim_{R \to \infty} T = \frac{T_H}{8\sqrt{\pi}} \sqrt{64\pi} = T_H \tag{3.37}$$

Then we can claim that

Prediction 3
The Hawking temperature is a special case of the general formula of the black hole temperature when the radius of the black hole is infinite.

4. Black Hole Entropy

In this section we shall analyze equation (3.34) more closely. We notice that the ratio $L_P^2 / \pi R^2$ is dimensionless, thus we define the dimensionless parameter ρ , whose physical meaning we intend to find, as

$$\rho \equiv \frac{L_P^2}{\pi R^2} \tag{4.1}$$

In order to find the physical meaning of ρ we turn our attention to equation (3.34) where we substitute $L_P^2 / \pi R^2$ with ρ. This gives

$$T = \frac{T_H}{8\sqrt{\pi}} \left(\sqrt{\rho + 64\pi} - \sqrt{\rho} \right) \tag{4.2}$$

Now let us consider the definition of the Planck length L_P:

$$L_P \equiv \sqrt{\frac{hG}{2\pi\ c^3}} \tag{4.3}$$

Hence

$$L_P^2 = \frac{hG}{2\pi\ c^3} = \frac{\hbar G}{c^3} \tag{4.4}$$

Now we substitute L_P^2 in equation (4.1) with the value obtained in (4.4). This gives

$$\rho = \frac{\hbar G}{c^3}\frac{1}{\pi\ R^2} \tag{4.5}$$

Multiplying the second side by 4/4 yields

$$\rho = \frac{4\hbar G}{c^3}\frac{1}{4\pi\ R^2} \tag{4.6}$$

We recognize the denominator $4\pi\ R^2$ of the second factor as the area of a sphere of radius *R*. This sphere is, by definition, the event horizon of the black hole. The area of the event horizon is

$$A_H = 4\pi\ R^2 \tag{4.7}$$

Where

$A_H =$ area of the event horizon (Area of the sphere of radius R)

Then we write the parameter ρ in terms of the area of the event horizon

$$\rho = \frac{4\hbar G}{c^3 A_H} \tag{4.8}$$

Now we consider the following two limits

$$\lim_{R\to\infty}\left(\frac{1}{\rho}\right) = \lim_{R\to\infty}\left(\frac{\pi\ R^2}{L_P^2}\right) = \infty \tag{4.9}$$

$$\lim_{R \to L_P}\left(\frac{1}{\rho}\right) = \lim_{R \to L_P}\left(\frac{\pi\ R^2}{L_P^2}\right) = \pi \tag{4.10}$$

Because the possible values of $1/\rho$ are between π (minimum) and ∞ (maximum), we can define this thermodynamic property as a quantity proportional to the entropy S of the black hole (it cannot be the black hole temperature because: [a] the units do not represent a temperature and [b] we have already found the relationship for the temperature). Since the entropy has units of $J\,/\,^0K$ while $1/\rho$ is dimensionless, the proportionality constant must be the inverse of the Boltzmann's constant, k_B. Then we write

$$\frac{1}{\rho} = \frac{S}{k_B} \tag{4.11}$$

Where

S = entropy of the black hole
k_B = Boltzmann's constant

Hence

$$S = \frac{k_B}{\rho} \tag{4.12}$$

Thus we have found the physical meaning of the variable ρ : this variable is inversely proportional to the entropy of the black hole. From equations (4.8) and (4.12) we can write:

$$S = \left(\frac{k_B c^3}{4\hbar G}\right) A_H \tag{4.13}$$

We recognize this formula as the famous Berkenstein-Hawking black hole entropy S_{BH}. Then we write

$$S_{BH} = \frac{k_B c^3 A_H}{4\hbar G} \qquad \text{(Berkenstein-Hawking black hole entropy)} \tag{4.14}$$

This result confirms that the second order uncertainty principle we have adopted in this theory provides the correct description of nature. Then we make the fourth prediction of this theory:

Prediction 4

The Berkenstein-Hawking entropy formula of the Black hole is a direct consequence of the universal uncertainty principle used in this theory.

Finally we express the equation of the black hole temperature (either equation 3.34 or equation 4.2) as a function of the Berkenstein-Hawking entropy, S_{BH}. This yields the following equation

$$T = \frac{T_H}{8\sqrt{\pi}} \left(\sqrt{\frac{k_B}{S_{BH}} + 64\pi} - \sqrt{\frac{k_B}{S_{BH}}} \right) \qquad (4.15)$$

Thus, the temperature of the black hole depends on its entropy. Because

$$\sqrt{\frac{k_B}{S_{BH}} + 64\pi} > \sqrt{\frac{k_B}{S_{BH}}} \qquad (4.16)$$

we deduce that the temperature of the black hole is always grater than zero. In the light of the general theory, this conclusion is false as we shall see in the next section.

5. The General Quantum Gravitational Theory of Black Holes:

(Preliminary Results)

The theory presented in the previous sections is the *special quantum gravitational theory of black holes*. I have also developed another theory which I called the *general quantum gravitational theory of black holes.* This theory takes into account the uncertainty in the momentum of a particle, P_Z , due to to the quantum fluctuations of space-time. Because P_Z is a function of time we can write

$$P_Z = P_Z(t) \qquad (4.17)$$

According to the *general theory,* the general formula for the black hole temperature, *T*, turns out to be:

$$T = \frac{T_H}{8\sqrt{\pi}} \left\{ \sqrt{\frac{L_P^2}{\pi R^2} + 64\pi - \frac{(16\pi)^2}{h} P_Z(t)(\pi R + L_P)} - \frac{L_P}{\sqrt{\pi} R} \right\} \qquad (4.18\text{ a})$$

which can also be written in terms of the black hole entropy as follows

$$T = \frac{T_H}{8\sqrt{\pi}}\left\{\sqrt{\frac{k_B}{S_{BH}} + 64\pi - \frac{(16\pi)^2\sqrt{\pi}}{h}P_Z(t)L_P\left(\sqrt{\frac{S_{BH}}{k_B}} + \frac{\sqrt{\pi}}{\pi}\right)} - \sqrt{\frac{k_B}{S_{BH}}}\right\} \qquad (4.18\ \text{b})$$

Equation (4.18 a) indicates that the temperature of the black hole can be either positive, zero or negative.

Table 2 summarizes the preliminary results of the general theory

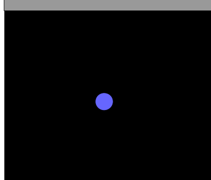
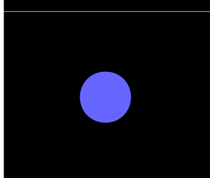
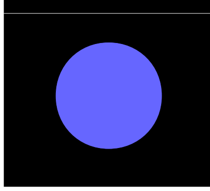
Conceptual graphics only (Not to scale)	Black hole radius (Condition) (If the radius of the black hole satisfies this condition then the sign of its temperature is given by the corresponding row of column 4)	Black hole radius (Approximate condition) $(L_P = 0)$	Sign of the black hole temperature T (see equations 4.18 a or 4.18 b)
	$R_S < \frac{\hbar}{2\pi P_Z(t)} - \frac{L_P}{\pi}$ (c.1)	$R_S < \frac{\hbar}{2\pi P_Z(t)}$	**positive**
	$R_S = \frac{\hbar}{2\pi P_Z(t)} - \frac{L_P}{\pi}$ (c.2)	$R_S \simeq \frac{\hbar}{2\pi P_Z(t)}$	**zero**
	$R_S > \frac{\hbar}{2\pi P_Z(t)} - \frac{L_P}{\pi}$ (c.3)	$R_S > \frac{\hbar}{2\pi P_Z(t)}$	**negative**

TABLE 2: *This table shows the preliminary results of the general quantum gravitational theory of black holes.*

Before we continue we need to define the following concepts:

Definition of Positive Energy Black Holes

A positive energy black hole is a black hole whose temperature *T* is positive. “Normal black holes” are positive energy black holes.

Definition of Negative Energy Black Holes

A negative energy black hole is a black hole whose temperature *T* is negative.

Thus black holes come in types: positive energy black holes and negative energy black holes.

Definition of Local Wormhole

A local wormhole is a *negative energy black hole* that connects to a different place (and in general also time) in our own universe. Whether these objects can be used as a transportation means of matter (or anti-matter) is unclear.

Definition of Non-Local Wormhole

A non-local wormhole is a *negative energy black hole* that connects to a different universe (parallel universe). Whether these objects can be used as a transportation means of matter (or anti-matter) is unclear.

It is worthy to remark that the difference between local and non-local wormholes is the "physical jurisdiction".

Definition of Cosmic Time Machines

Cosmic time machines are *negative energy black holes* that can transport particles/anti-particles and other bodies either forward in time or back in time. The transportation mechanism can be used to transport matter (or anti-matter), without alterations, to another time. The transportation mechanism takes place within our own universe. We can think of cosmic time machines as a special case of local wormholes.

In the case of zero temperature the black hole can become an intermittent wormhole (or intermittent cosmic time machine):

Definition of Intermittent Wormhole

For a given size of the Schwarzschild radius, a black hole can have a zero temperature for a relatively brief period of time. Because of the random nature of $P_Z(t)$, the temperature of this black hole will fluctuate between positive and negative values [see equations (c.1), (c.2) and (c.3)]. Therefore the energy of the black hole will also fluctuate between positive and negative values. This means that the black hole will behave as an *intermittent wormhole* (or as an *intermittent time machine*). In other words, the black hole will behave sometimes as a *wormhole/time machine* and sometimes as a *normal black hole*.

A normal black hole can become an intermittent wormhole by absorbing material from its surroundings. For example, a *positive energy black hole* that has absorbed enough negative energy from its surroundings could become a *negative energy black hole* so that it will comply with condition (c.3) on permanent basis. This black hole will stop being a normal black hole to become a wormhole or a cosmic time machine for the rest of its lifetime (provided the conditions do not change). On the other hand, an intermittent wormhole can become a permanent normal black hole by absorbing material from its surroundings. For example, a *negative energy black hole* that has absorbed enough positive energy from its surroundings could become a permanent *positive energy black hole* so that it will comply with condition (c.1) on permanent basis. This black hole will stop being a wormhole or a cosmic time machine and it will become a normal black hole for the rest of its lifetime (provided the conditions do not change).

It is important to clarify the physical meaning of negative energy. The concept of negative energy used in this paper is not to be confused with gravitational potential energy which is also "negative". However the type of negative energy I refer to in this paper involves remarkable properties which are absent in the definition of gravitational potential energy. Thus, I shall used these properties to define negative energy as follows

Definition of Negative Energy

An entity (particle or object) with negative energy:

a) can travel backward in time (in this case the entities are anti-particles), or
b) and its counterpart (positive energy particle) will annihilate when they are in contact (in this case the entities are anti-particles - see **Appendix 2**), or
c) can connect to another place and time in our universe (in this case the entities are negative energy black holes) and/or
d) can connect to parallel universes (in this case the entities are negative energy black holes).
e) is the cause of the expansion of the universe (in this case the entity is the energy of the vacuum or cosmological constant also known as dark energy).

The Casimir effect [4, 5] provides the experimental evidence of the existence of negative energy density between two uncharged conducting plates placed a very short distance apart.

Difference between Negative Energy Entities

While anti-particles possess the same negative energy at all times, the content of negative energy of negative energy black holes can change over time. Thus a black hole can have, for example, a content of -10^{100} Joules at a given time and -10^{120} Joules sometime later.

Thus, in the light of the preliminary results of the general quantum gravitational theory of black holes we can make the following predictions:

Prediction 5

Black holes are wormholes and/or cosmic time machines.

Prediction 6

There exist intermittent temperature black holes and non-intermittent temperature black holes.

An ***intermittent temperature black hole*** *is a black hole whose temperature fluctuate from positive to negative and viceversa in a relatively short period of time.*

A ***non-intermittent temperature black hole*** *is a black hole whose temperature is either positive or negative but it does not fluctuate between positive and negative values.*

I shall publish a new paper with the full details of the general formulation in the future.

6. Conclusions

In summary, the *special quantum gravitational theory of black holes* predicts that

- the black hole temperature depends on both the mass *M* and the radius *R* of the black hole. The impact of the black hole radius on the temperature is, in general, numerically insignificant. However this prediction marks a huge conceptual gap between this theory and Hawking's formulation.

- the Hawking temperature is a special case of the more general formulation presented here.

- the black hole's entropy law (The Berkenstein-Hawking entropy) can be derived from the universal uncertainty principle without using general relativity (except for the Schwarzschild radius formula).

The general quantum gravitational theory of black holes contemplates the possibility of the existence of two types of black holes: positive energy black holes and negative energy black holes. Natural wormholes and cosmic time-machines are negative energy black holes. These objects connect two different regions of space-time by creating a curved space-time shortcut which allows the movement of objects from one place to another without the necessity of travelling the normal distance between the two points. Another novel aspect of the general theory is that it contemplates the existence of intermittent wormholes and intermittent cosmic time machines. Thus, the general formulation predicts that

- negative energy black holes are both wormholes and cosmic time machines.

Finally I shall remark that the black hole entropy obtained through these formulations (both the special and the general formulations) agrees with the Berkenstein-Hawking's formula. In addition, the black hole entropy emerges naturally from the present formulation without making any additional assumptions and without adding new postulates. This is an indication of the predicting potential and correctness of the two theories presented in this paper.

Appendix 1
Verification

I shall show that

(a) when $P_Z = 0$ and $L_Z = 0$ the principle reduces to $\Delta p \Delta x \geq h/4\pi$
(b) when $\Delta p = 0$ and $\Delta x = 0$ the principle reduces to $P_Z L_Z \geq h/4\pi$

(a) If $P_Z = 0$ and $L_Z = 0$ inequation (2.1) reduces to

$$\Delta p \Delta x \geq \sqrt{\left(\frac{h}{4\pi}\right)^2 - 0 - 0}$$

$$\Delta p \Delta x \geq \frac{h}{4\pi}$$

$$\Delta p \Delta x \geq \frac{\hbar}{2}$$ Heisenberg uncertainty principle

Which is the famous Heisenberg uncertainty principle (space-momentum Heisenberg uncertainty relation).

(b) If $\Delta p = 0$ and $\Delta x = 0$ inequation (2.1) reduces to

$$0 \geq \sqrt{\left(\frac{h}{4\pi}\right)^2 - \frac{h}{8\pi} P_Z (0 + L_Z) - \frac{h}{8\pi} (0 + P_Z) L_L}$$

$$0 \geq \sqrt{\left(\frac{h}{4\pi}\right)^2 - \frac{h}{8\pi} P_Z L_Z - \frac{h}{8\pi} P_Z L_L}$$

$$0 \geq \sqrt{\left(\frac{h}{4\pi}\right)^2 - \frac{h}{4\pi} P_Z L_Z}$$

$$0 \geq \left(\frac{h}{4\pi}\right)^2 - \frac{h}{4\pi} P_Z L_Z$$

$$\frac{h}{4\pi} P_Z L_Z \geq \left(\frac{h}{4\pi}\right)^2$$

$$P_Z L_Z \geq \frac{h}{4\pi}$$

$$P_Z L_Z \geq \frac{\hbar}{2} \qquad \text{“Planck uncertainty relation”}$$

Because Heisenberg did not include P_Z and L_Z in his relations, we could call the last expression the “Planck uncertainty relation”.

Appendix 2
Negative Energy

Let us consider the Einstein's formula for the total relativistic energy

$$E = \pm\sqrt{(pc)^2 + (m_0 c^2)^2}$$

where

p = relativistic momentum
m = relativistic mass
m_0 = rest mass
c = speed of light in vacuum

There are two cases:

a) for particles (e.g. electrons) both the mass and the energy are positive:

$$E = +\sqrt{(pc)^2 + (m_0 c^2)^2}$$

b) for anti-particles (e.g. positrons) the mass is positive and the energy negative:

$$E = -\sqrt{(pc)^2 + (m_0 c^2)^2}$$

According to Feynman, particles move forward in time, while anti-particles move backward in time. I shall generalize Feynman's idea by saying that particles made of positive energy (normal matter) moves forward in time, while particles made of negative energy (anti-matter) move backward in time.

Notes

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