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Theoretical Investigation of Gravitational Effect on Effective Mass of Electromagnetic Wave

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***Abstract**: This paper proposes that the effective mass of an electromagnetic wave is not zero and further points out that an electromagnetic wave undergoes a frequency shift in a gravitational field only if its effective mass varies with gravity. Based on proposed model, mass of an electromagnetic wave of frequency f is given by formula $m = 7.36\text{x}10^{-51} f$. This new understanding can be helpful for the analysis of mass, linear momentum, force, frequency, wavelength and energy of electromagnetic waves inside the gravitational field namely at Schwarzschild radius, black hole and so on. A key point of this work is that the gravitational redshift effect can be explained more directly based on the variation of the proposed mass of the electromagnetic wave inside the gravitational field.*

***Keywords:** Theoretical Cosmology, Gravitational Redshift, Theory of Relativity, Schwarzschild Radius.*

I. INTRODUCTION

The study of various influences of gravity on the electromagnetic waves such as change in frequency and wavelength have been receiving astonishing attention from researchers as the results of its various applications in the area of astrophysical investigation such as the analysis of black holes, stars, and other celestial bodies [1]. Einstein developed the theoretical analysis of red-shift derivation in his famous paper on general relativity [2], following his concept, different valuable studies on the theme of gravitational effect on light have been conducted and published by different researchers up to these days [3]. John Earman and Clark Glymour gave a formal redshift derivation in [4]. Also from experimental observations, it was known that electromagnetic waves can undergo a frequency shift in the presence of a gravitational field [5]. This phenomenon was called the "gravitational red-shift effect" [6]. This effect was thought to be due to space-time distortion as predicted from general relativity [7]. Work interpreted the gravitational redshift as the gravitational time dilation [8]. Gravitational redshift can also be interpreted as the consequences of the mass energy [9] equivalence and conservation of energy [10]. Paper [11] entails the relativistic mechanics to describe the phenomenon of redshift and to show the variation of mass inside the gravitational field [12].

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Articles presents research that relate the special theory of relativity with De-Broglie wavelength of a particle and electric permittivity and magnetic permeability of electromagnetic wave [13]. Also, modified Newton's second law of motion by developing the novel formula of linear momentum, force and kinetic energy [14]. Papers present the original derivations of the Lorentz transformations in three-dimensional space [15]. There are numerous publications conducted on theory of relativity with a universal frame of reference and all possible experiments to falsify these theories were conducted in [16]. Furthermore [17], has used the measurement of gravitational redshift to theoretically predict the various criteria for a body to be inside the black hole [18]. Because of the theoretical importance of gravitational redshift effect [19], we would like to conduct a wider investigation of its physical basis [20]. It is a well-known fact that an electromagnetic wave can be quantized as a photon [21], which acts as a particle in several ways [22]. Such a particle will have a certain effective mass [23]. Based on this proposed mass of EM waves [24], we will show the gravitational red shift and further calculate the different conditions for EM waves to be inside the black hole [25].

This paper is arranged as follows: the theoretical formalism to find the mass of an electromagnetic wave based on quantum and relativistic energy is meticulously presented in the next Section II [26]. Furthermore, variation of the calculated mass of EM waves with gravity is demonstrated [27]. The results and discussions are presented in Section III. This section discusses change of various physical parameters namely mass, linear momentum, force, energy, frequency and wavelength of EM waves inside the gravitational field. The summary and concluding remarks are given in the final Section IV [28].

II. THEORETICAL FRAMEWORK

A. Mass of Electromagnetic Wave

Consider an electromagnetic wave of frequency f. Then the energy of EM wave from quantum expression is given by,

$$E = hf \quad \ldots \quad (1)$$

Where $h = 6.626\text{x}10^{-34}$JS is the Planck's constant. On the other hand, let m be the equivalent mass of the EM wave, then its energy from relativistic expression is given by,

$$E = mc^2 \quad \ldots \quad (2)$$

Where $c = 3\text{x}10^8$m/s is the speed of light in vacuum.
From equation (1) and (2), we have

$$mc^2 = hf$$

$$\text{or,} \quad m = \frac{h}{c^2} f \quad \ldots \quad (3)$$

Putting the value of constants

c and h in above equation,
we get,

$$\text{or,} \quad m = \frac{6.626\text{x}10^{-34}}{(3\text{x}10^{8})^{2}} f$$

$$\text{or,} \quad m = 7.36\text{x}10^{-51} f \quad \ldots \quad (4)$$

This equation shows that mass of an EM wave totally depends on its frequency. Thus, mass of different EM waves calculated using equation (4) for different frequencies are summarized in Table- I.

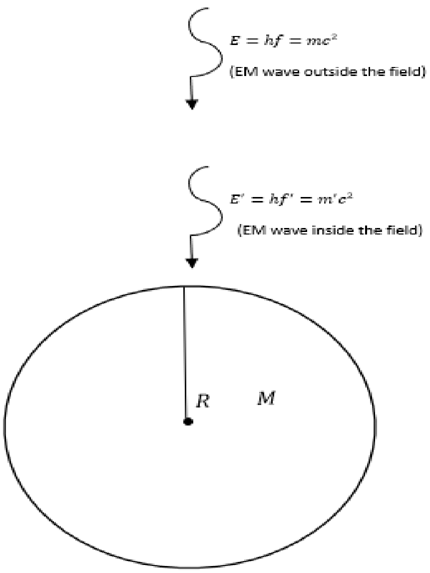
Table 1: Effective Mass of EM Waves

EM Waves	Approximated Frequency(f)	Mass ($m = 7.3555\text{x}10^{-51} f$)
Radio	$3\text{x}10^{7}$ Hz	$m = 7.3555\text{x}10^{-51} \times 3\text{x}10^{7}$ $m = 2.2\text{x}10^{-43}$ kg
Microwave	$3\text{x}10^{10}$ Hz	$m = 7.3555\text{x}10^{-51} \times 3\text{x}10^{10}$ $m = 2.2\text{x}10^{-40}$ kg
Infrared	$3\text{x}10^{11}$ Hz	$m = 7.3555\text{x}10^{-51} \times 3\text{x}10^{11}$ $m = 2.2\text{x}10^{-39}$ kg
Visible Light	$3\text{x}10^{13}$ Hz	$m = 7.3555\text{x}10^{-51} \times 3\text{x}10^{13}$ $m = 2.2\text{x}10^{-37}$ kg
Ultraviolet	$3\text{x}10^{15}$ Hz	$m = 7.3555\text{x}10^{-51} \times 3\text{x}10^{15}$ $m = 2.2\text{x}10^{-35}$ kg
X-Ray	$3\text{x}10^{17}$ Hz	$m = 7.3555\text{x}10^{-51} \times 3\text{x}10^{17}$ $m = 2.2\text{x}10^{-33}$ kg
Gamma Ray	$3\text{x}10^{20}$ Hz	$m = 7.3555\text{x}10^{-51} \times 3\text{x}10^{20}$ $m = 2.2\text{x}10^{-30}$ kg

B. Mass of EM Wave and Gravity

The effective mass of an EM wave of frequency f can be written from equation (3) as follows.

$$m = \frac{h}{c^2} f$$



[Fig.1: An EM Wave Falling in Gravitational Field]

Let this EM wave falls on a gravitational field and as we know, an EM wave falling in a gravitational field gains the potential energy as shown in Figure 1. This gain in potential energy is manifested as increase in frequency from f to f'. The potential energy experienced by EM wave at surface of the star of mass M and radius R is given by the expression,

$$V(x) = \frac{GMm}{R} \quad \ldots \quad (5)$$

Putting the value of m from equation (3) we get,

$$V(x) = \frac{GMhf}{Rc^2} \quad \ldots \quad (6)$$

Now, total energy of the EM wave inside the gravitational field is given by,

E' = Initial energy + Potential energy

$$\text{or,} \quad hf' = E + V(x)$$

Using equations (1) and (6) we get,

$$\text{or,} \quad hf' = hf + \frac{2GM\,\text{hf}}{RC^2}$$

$$\text{or,} \quad hf' = hf\left(1 + \frac{GM}{RC^2}\right)$$

$$\text{or,} \quad f' = f\left(1 + \frac{GM}{RC^2}\right) \quad \ldots \quad (7)$$

This equation presents the frequency of EM wave inside the gravitational field and it is well understood fact in each scientific literature such as in general relativity. On the basis of general relativity, the frequency of an electromagnetic radiation is assumed to be change depending on the strength of gravitational field and this phenomenon can be easily analyzed by using equation (7). When frequency of EM wave changes from f to f', the mass of EM wave must be changed from m to m'. Hence, we can write,

Relativistic energy = Quantum energy

$$\text{or,} \quad m'c^2 = hf'$$

$$\text{or,} \quad m' = \frac{h}{c^2} f' \quad \ldots \quad (8)$$

Substituting the value of f' into above equation (8) from equation (7) we get,

$$\text{or,} \quad m' = \frac{h}{c^2} f \left(1 + \frac{GM}{RC^2}\right)$$

Using the equation (3) we get,

$$\text{or,} \quad m' = m\left(1 + \frac{GM}{RC^2}\right) \quad \ldots \quad (9)$$

This equation clearly shows that mass of EM wave gradually changes when it falls inside gravitational field. Therefore, it should be remembered that mass of EM wave exists and it always

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varies in gravitational field similar to the variation of frequency in a gravitational field. We will deeply analyze this phenomenon using Schrodinger's equation in upcoming section.

III. RESULTS AND DISCUSSIONS

The one-dimensional time-dependent Schrodinger's equation is given by,

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2} + V(x)\Psi \quad \dots \quad (10)$$

For a free particle, the potential energy $V(x) = 0$ and let $\Psi = Ae^{\frac{i}{\hbar}(px-Et)}$ represents the wave function for free particle (outside the gravitational field) of mass m, momentum p and energy E. Hence equation (10) reduces to,

$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\Psi}{\partial x^2}$$

or, $$i\hbar\frac{\partial}{\partial t}\left(Ae^{\frac{i}{\hbar}(px-Et)}\right) = -\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\left(Ae^{\frac{i}{\hbar}(px-Et)}\right)$$

or, $$-i^2EAe^{\frac{i}{\hbar}(px-Et)} = \frac{p^2}{2m}Ae^{\frac{i}{\hbar}(px-Et)}$$

or, $$EAe^{\frac{i}{\hbar}(px-Et)} = \frac{p^2}{2m}Ae^{\frac{i}{\hbar}(px-Et)}$$

or, $$E\Psi = \frac{p^2}{2m}\Psi$$

or, $$\left(E - \frac{p^2}{2m}\right)\Psi = 0$$

The wavefunction Ψ can't be zero i.e., $\Psi \neq 0$. Hence,

$$E - \frac{p^2}{2m} = 0$$

or, $$E = \frac{p^2}{2m}$$

or, $$E = hf = \frac{p^2}{2m} \quad \dots \quad (11)$$

This equation relates energy $E = hf$ of an EM wave, which is outside the gravitational field, with its mass m and momentum p. If this EM wave falls in a gravitational field, then its frequency changes from f to f' and mass from m to m'. Therefore, energy of EM wave must be changed from $E = hf = mc^2$ to $E' = hf' = m'c^2$. Hence, equation (11) for an EM wave falling in gravitational field becomes,

$$E' = hf' = \frac{p'^2}{2m'} \quad \dots \quad (12)$$

This equation relates energy $E' = hf'$ of an EM wave, which is inside the gravitational field, with its mass m' and momentum p'. From above mathematical discussion, it should be inferred that an EM wave of initial energy $E = hf = mc^2$ falls into the gravitational field and it gains the potential energy. As a result, its energy changes to $E' = hf' = m'c^2$. Hence, in mathematical form,

$$E' = E + V(x)$$

Using equation (11) and (12) we get,

or, $$\frac{p'^2}{2m'} = \frac{p^2}{2m} + V(x)$$

or, $$\frac{(m'c)^2}{2m'} = \frac{(mc)^2}{2m} + V(x)$$

or, $$\frac{m'c^2}{2} = \frac{mc^2}{2} + V(x)$$

or, $$m' = m + \frac{2V(x)}{c^2}$$

or, $$\frac{m'}{m} = 1 + \frac{2V(x)}{mc^2}$$

or, $$\frac{m'}{m} - 1 = \frac{2V(x)}{mc^2}$$

Putting the value of $V(x)$ from equation (5) we get,

or, $$\frac{m'}{m} - 1 = \frac{2GMm}{mRc^2}$$

or, $$\frac{m'}{m} - 1 = \frac{2GM}{Rc^2}$$

or, $$\frac{m'}{m} - 1 = \frac{2GMR}{R^2c^2}$$

or, $$\frac{m'}{m} - 1 = \frac{2gR}{c^2}$$

or, $$\frac{m'}{m} - 1 = \frac{v^2}{c^2} \quad \dots \quad (13)$$

Where $v = \sqrt{2gR}$ be escape velocity of a star having radius R and acceleration due to gravity g. Further solving above equation, we get,

$$\frac{m'}{m} = 1 + \frac{v^2}{c^2}$$

or, $$m' = m\left(1 + \frac{v^2}{c^2}\right) \quad \dots \quad (14)$$

Here, this equation relates the mass of EM wave (m') inside the gravitational field with mass of EM wave outside the field (m). This equation is completely true because it generates exactly same shift in frequency as discussed below. Putting the value of m' from equation (8) we get,

or, $$\frac{h}{c^2}f' = m\left(1 + \frac{v^2}{c^2}\right)$$

or, $$f' = \frac{c^2}{h}m\left(1 + \frac{v^2}{c^2}\right)$$

Also, Putting the value of m from equation (3) we get,

or, $$f' = \frac{c^2}{h}\frac{h}{c^2}f\left(1 + \frac{v^2}{c^2}\right)$$

or, $$f' = f\left(1 + \frac{v^2}{c^2}\right) \quad \dots \quad (15)$$

This change in frequency due gravitational field is in completely agree with ordinary frequency shift.

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Hence, change in frequency (15) takes place only if change of mass in the gravitational field takes place as discussed in equation (14). Also, using the relation $f = \frac{c}{\lambda}$ and $f' = \frac{c}{\lambda'}$ in equation (15) we get,

or, $$\frac{c}{\lambda'} = \frac{c}{\lambda}\left(1+\frac{v^2}{c^2}\right)$$

or, $$\lambda = \lambda'\left(1+\frac{v^2}{c^2}\right)$$

or, $$\lambda' = \frac{\lambda}{1+\frac{v^2}{c^2}} \quad \ldots \quad (16)$$

This change in wavelength due gravitational field is completely in agree with ordinary wavelength shift. From equations (15) and (16), it is clear that variation of frequency and wavelength under the gravity is properly satisfied when mass variation formula (14) is employed. Therefore, frequency and wavelength of EM wave change if and only if mass of EM wave changes in gravitational field. Also, from the definition of de Broglie wavelength,

$$\lambda = \frac{h}{p} \text{ and } \lambda' = \frac{h}{p'} \quad \ldots \quad (17)$$

Using equation (17) into equation (16) we get,

or, $$\frac{h}{p'} = \frac{h}{\left(1+\frac{v^2}{c^2}\right)p}$$

or, $$p' = p\left(1+\frac{v^2}{c^2}\right) \quad \ldots \quad (18)$$

Here, this equation relates the linear momentum of EM wave (p') inside the gravitational field with linear momentum of EM wave outside the field (p). Further, differentiating equation (18) with respect to time we get,

or, $$\frac{dp'}{dt} = \frac{dp}{dt}\left(1+\frac{v^2}{c^2}\right)$$

Since velocity of light c and escape velocity of gravitational field v are the constant parameters.

or, $$F' = F\left(1+\frac{v^2}{c^2}\right) \quad \ldots \quad (19)$$

Where $F' = \frac{dp'}{dt}$ and $F = \frac{dp}{dt}$ represent the force on EM wave inside and outside the gravitational field respectively. This equation (20) states that the force acting upon EM wave inside the gravitational field (F') is equal to $\left(1+\frac{v^2}{c^2}\right)$ times of the force (F) acting outside of the gravitational field. If ds be the displacement of the EM wave then work done by the force given by equation (19) can be calculated as follows:

or, $$\frac{dp'}{dt}ds = \frac{dp}{dt}ds\left(1+\frac{v^2}{c^2}\right)$$

or, $$\frac{ds}{dt}dp' = \frac{ds}{dt}dp\left(1+\frac{v^2}{c^2}\right)$$

For EM wave, rate of change of displacement i.e., velocity is equal to velocity of light c. Hence, velocity $= \frac{ds}{dt} = c$. Now, above equation reduces to,

or, $$c\,dp' = c\,dp\left(1+\frac{v^2}{c^2}\right)$$

Removing derivative from both sides we get,

or, $$cp' = cp\left(1+\frac{v^2}{c^2}\right)$$

Putting value of momentum $p' = m'c$ and $p = mc$ we get,

or, $$m'c^2 = mc^2\left(1+\frac{v^2}{c^2}\right)$$

or, $$E' = E\left(1+\frac{v^2}{c^2}\right)$$

We can also achieve exactly same formula from equation (15) as discussed below. Rewriting equation (15) we get,

$$f' = f\left(1+\frac{v^2}{c^2}\right)$$

Multiplying by h on both sides,

or, $$hf' = hf\left(1+\frac{v^2}{c^2}\right)$$

or, $$E' = E\left(1+\frac{v^2}{c^2}\right) \quad \ldots \quad (20)$$

Where $E' = hf'$ and $E = hf$ represent the energy of EM wave inside and outside the gravitational field. Therefore, equation (20) points out that energy of EM wave inside the gravitational field (E') is equal to $\left(1+\frac{v^2}{c^2}\right)$ times of the initial energy (E) i.e., energy of the EM wave outside of the gravitational field.

As we typically know that a gravitational field is said to be black hole if its escape velocity (v) is greater than velocity of light (c). Mathematically,

$$v > c$$

or, $$v^2 > c^2$$

or, $$\frac{v^2}{c^2} > 1 \quad \ldots \quad (21)$$

Equation (21) represents the required condition for a gravitational field to be a black hole. Putting the value of $\frac{v^2}{c^2}$ from equation (13) we get,

or, $$\frac{m'}{m} - 1 > 1$$

or, $$\frac{m'}{m} > 2$$

or, $$m' > 2m \quad \ldots \quad (22)$$

Therefore, this equation tells that a gravitational field is said to be a blackhole if the mass of an EM wave inside the gravitational field is greater than two times of its initial mass i.e., mass of EM wave outside the gravitation field (m). In order to calculate the criteria in terms of frequency for an EM wave to be inside a black hole, let consider equation (15),

or, $$f' = f\left(1+\frac{v^2}{c^2}\right)$$

or, $$\frac{f'}{f} - 1 = \frac{v^2}{c^2} \quad \ldots \quad (23)$$

Using the criteria (21) for a particle to be inside black hole, above equation (23) becomes,

or, $$\frac{f'}{f} - 1 > 1$$

or, $$\frac{f'}{f} > 2$$

or, $$f' > 2f \quad \ldots \quad (24)$$

Therefore, this equation tells that a gravitational field

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is said to be a blackhole if the frequency of an EM wave inside the gravitational field is greater than two times of its initial frequency i.e., frequency of EM wave outside the gravitation field (f). Multiplying by h on both sides of equation (24) we get,

or, $$hf' > 2hf$$

or, $$E' > 2E \quad \ldots \quad (25)$$

Therefore, this equation tells that a gravitational field is said to be a blackhole if the energy of an EM wave inside the gravitational field is greater than two times of its initial energy i.e., energy of EM wave outside the gravitation field (E). Further, solving above equation (24) we get,

or, $$\frac{1}{2f} > \frac{1}{f'}$$

or, $$\frac{c}{2f} > \frac{c}{f'}$$

or, $$\frac{\lambda}{2} > \lambda' \quad \ldots \quad (26)$$

Therefore, this equation tells that a gravitational field is said to be a blackhole if the wavelength of an EM wave inside the gravitational field is less than half of its initial wavelength i.e., wavelength of EM wave outside the gravitation field (λ). Also, from the definition of de Broglie wavelength,

$$\lambda = \frac{h}{p} \text{ and } \lambda' = \frac{h}{p'} \quad \ldots \quad (27)$$

Using equation (27) in equation (26) we get,

or, $$\frac{h}{2p} > \frac{h}{p'}$$

or, $$p' > 2p \quad \ldots \quad (28)$$

Therefore, this equation tells that a gravitational field is said to be a blackhole if the linear momentum of an EM wave inside the gravitational field is greater than two times of its initial linear momentum i.e., momentum of EM wave outside the gravitation field (p). Also, from equation (19) we have,

$$F' = F\left(1 + \frac{v^2}{c^2}\right)$$

or, $$\frac{F'}{F} = 1 + \frac{v^2}{c^2}$$

or, $$\frac{F'}{F} - 1 = \frac{v^2}{c^2} \quad \ldots \quad (29)$$

Putting this value of $\frac{v^2}{c^2}$ in equation (21) we get,

$$\frac{F'}{F} - 1 > 1$$

or, $$\frac{F'}{F} > 2$$

or, $$F' > 2F \quad \ldots \quad (30)$$

Therefore, this equation states that a gravitational field is said to be a blackhole if the force acting on the EM wave is greater than two times of its initial force i.e., force on EM wave acting outside the gravitation field (F). Also, the Schwarzschild radius of the body of mass M is defined as

$$R = \frac{2GM}{c^2}$$

or, $$c^2 = \frac{2GM}{R}$$

or, $$c^2 = \frac{2GMR}{R^2}$$

or, $$c^2 = 2gR$$

or, $$c^2 = v^2$$

or, $$\frac{v^2}{c^2} = 1 \quad \ldots \quad (31)$$

Where $v = \sqrt{2gR}$ represents the escape velocity. Equation (31) tells that escape velocity of a gravitational field is equal to velocity of light at Schwarzschild radius. Substituting the value of $\frac{v^2}{c^2}$ from equation (13) we get,

or, $$\frac{m'}{m} - 1 = 1$$

or, $$\frac{m'}{m} = 2$$

or, $$m' = 2m \quad \ldots \quad (32)$$

Therefore, this equation tells that mass of EM wave inside the gravitational field is equal to two times of its initial mass (m) at Schwarzschild radius. In order to calculate the criteria in terms of frequency for an EM wave to be at Schwarzschild radius, let Substituting the value of $\frac{v^2}{c^2}$ from equation (23) into equation (31) we get,

or, $$\frac{f'}{f} - 1 = 1$$

or, $$\frac{f'}{f} = 2$$

or, $$f' = 2f \quad \ldots \quad (33)$$

Therefore, this equation tells that frequency of EM wave inside the gravitational field is equal to two times of its initial frequency (f) at Schwarzschild radius. Multiplying by h on both sides of equation (33) we get,

$$hf' = 2hf$$

or, $$E' = 2E \quad \ldots \quad (34)$$

Therefore, this equation tells that energy of EM wave inside the gravitational field is equal to two times of its initial energy (E) at Schwarzschild radius. Further, solving above equation (33) we get,

or, $$\frac{1}{2f} = \frac{1}{f'}$$

or, $$\frac{c}{2f} = \frac{c}{f'}$$

or, $$\frac{\lambda}{2} = \lambda' \quad \ldots \quad (35)$$

Therefore, this equation tells that wavelength of EM wave inside the gravitational field is equal to half of its initial wavelength (λ) at Schwarzschild radius. Also, from the definition of de Broglie wavelength,

$$\lambda = \frac{h}{p} \text{ and } \lambda' = \frac{h}{p'} \quad \ldots \quad (36)$$

Using equation (36) in equation (35) we get,

or, $$\frac{h}{2p} = \frac{h}{p'}$$

or, $$p' = 2p \quad \ldots \quad (37)$$

Therefore, this equation tells that linear momentum of EM wave inside the gravitational field is equal to two times of its initial momentum (p) at Schwarzschild radius.

Also, putting this value of $\frac{v^2}{c^2}$ from equation (29) into equation (31) we get,

$$\frac{F'}{F} - 1 = 1$$

or, $$\frac{F'}{F} = 2$$

or, $$F' = 2F \quad \ldots \quad (38)$$

Therefore, this equation tells that the force acting on the EM wave is equal to two times of its initial force (F) at Schwarzschild radius. The mass, linear momentum, energy, frequency, wavelength and force experienced by EM wave inside the gravitational field is meticulously presented in Table- II.

Table 2: Measurement of Physical Quantities Inside the Gravitational Field

Physical Quantities Related to EM Wave	Gravitational field (Escape Velocity v)	Black Hole ($v \geq c$)	Schwarzschild Radius ($v = c$)
Mass	From equation (14) $m' = m\left(1+\frac{v^2}{c^2}\right)$	From equation (22) $m' > 2m$	From equation (32) $m' = 2m$
Frequency	From equation (15) $f' = f\left(1+\frac{v^2}{c^2}\right)$	From equation (24) $f' > 2f$	From equation (33) $f' = 2f$
Wavelength	From equation (16) $\lambda' = \frac{\lambda}{1+\frac{v^2}{c^2}}$	From equation (26) $\frac{\lambda}{2} > \lambda'$	From equation (35) $\frac{\lambda}{2} = \lambda'$
Momentum	From equation (18) $p' = p\left(1+\frac{v^2}{c^2}\right)$	From equation (28) $p' > 2p$	From equation (37) $p' = 2p$
Force	From equation (19) $F' = F\left(1+\frac{v^2}{c^2}\right)$	From equation (30) $F' > 2F$	From equation (38) $m' = 2m$
Energy	From equation (20) $E' = E\left(1+\frac{v^2}{c^2}\right)$	From equation (25) $E' > 2E$	From equation (34) $E' = 2E$

IV. CONCLUSION

The new understanding presented in this paper has several interesting implications. Firstly, one can greatly calculate the mass of all EM waves as discussed in Table- I. In addition to this, the variation of mass of EM waves with gravity can be calculated by using the formula presented in equation (14). Furthermore, based on our proposed model, one can apply the gravitational redshift effect of EM waves to conduct the studies for the analysis of mass, linear momentum, force, energy, frequency and wavelength of EM waves within the gravitational field as discussed in Table- II. To the best of our knowledge, this is the first study regarding the variation of effective mass of electromagnetic waves inside the gravitational field. Henceforth, this study could be a milestone for further investigations of astrophysical phenomena based on the variation of proposed mass of EM waves in the gravitational field.

DECLARATION STATEMENT

I must verify the accuracy of the following information as the article's author.

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- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
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- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
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Chandra Bahadur Khadka is a theoretical physicist at Tribhuvan University in Nepal, where he is currently working in Einstein's relativity theory. Most importantly, for the first time in physics, the form of the Lorentz transformation equations in the three dimensions of space, which are considered as the backbone of special theory of relativity, were invented by Chandra Bahadur Khadka, see:

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