Ing. Stefano Quattrini
Via Jesi 54 60126
ANCONA, ITALY
stequat@libero.it

ANCONA, 04/12/2013

"QUANTA ET INERTIA"

THE GRAVITATIONAL RED-SHIFT

INTERPRETATION

ABSTRACT

The gravitational red-shift is said to be the cornerstone of the General Relativity theory of Albert Einstein. The frequency shift of photons in a gravitational field, was certified as a verified phenomenon in the HARVARD TOWER EXPERIMENTS. The **interpretation of the gravitational red shift as the variation of the energy of the quanta was supported by Prof. RICHARD P. FEYNMAN and other scientists**. It will be shown that the energy exchange with the space-time represents the "only explanation" of the phenomenon of the quanta frequency shift, although the accredited theory relegates it as a direct consequence of time dilation between the emitter and the observer in a gravitational field. An experiment is proposed and a theoretical demonstration is given in order to open a window on the actual nature of the Gravitational red-shift. A generalization is proposed of the **frequency shift of photons, resulting in the differences of potential of mechanical energy between the emitter and the observer**, excluding the effects of time dilation between them.

INTRODUCTION

The experiments of POUND-REBKA (1960) and POUND-SNIDER (1964) (the PRS experiments) showed the presence of the **frequency-shift of electromagnetic radiation** according to the values predicted by the theory. Prof. **Richard P. Feynman** in the second half of the last century, wrote (*2)**:** " a photon of frequency $\boldsymbol{v_o}$ *has the energy* $E_o = h\boldsymbol{v_o}$. In falling the distance H it will gain an additional energy $\left(\frac{\boldsymbol{hv_o}}{\boldsymbol{c^2}}\ \boldsymbol{gH}\right)$".

Muller et al: "we first note that no experiment is sensitive to the absolute potential U. When two similar clocks at rest in the laboratory frame are compared in a classical red-shift test, their frequency difference $\boldsymbol{\Delta U = gh + o(h^2)}$ where $\mathbf{g} = \boldsymbol{\nabla U}$, the gravitational acceleration in the laboratory frame, h is the clock's separation, c is the velocity of light, therefore **classical red shift are sensitive to g, not to the absolute value of U**, just like interferometry red-shift tests". Many authors refer to the potential $\phi = -\frac{\mathrm{GM}}{\mathrm{r}}$ *in the time dilation relation***.** This formulation is not correct, since only differences of potentials are defined. The potential ϕ is determined only defining a reference potential (p. e. $\phi_\infty = 0$). **The question whether the shift is a result of the propagation is left open by Dicke.**

In another article) an alternative to the HARVARD TOWER setup was proposed. Doubts were raised on the possibility of finding places on Earth (depressions) at different gravitational potential with no time-shift.
A different, simpler and more feasible set up is proposed in this article, in order to cancel out the time-shift between the reference systems without using any uncommon configuration. The time delay between the emitter of the radiation and the observer gets minimized, having the observer and emitter, over the sea surface level, a gravitational potential difference, being valid the Schwartzshild approximated solution of General Relativity.
In order to perform such a **time-shift cancellation**, a system, exploiting the effect of time dilation of **a moving observer**, will be adopted. The idea is to nullify the effect of gravitational time-shift on clocks using the opposite effect of inertial time-shift. In order to **minimize the Doppler effects** on frequencies due to reference systems speed, the experiment setup is designed to use trajectories of photons normal to the direction of motion of the reference systems.

GRAVITATIONAL AND INERTIAL TIME DILATION BETWEEN TWO REFERENCE SYSTEMS

According to the General Relativity theory the **Schwartzshild line element ds** of the curved space-time, solution of the Einstein Field equations, in **a weak gravitational field**, of a non-rotating massive spherically-symmetric object of mass M, in spherical coordinates is

$ds = f\left(c, G, M, dr, dt, d\theta, d\varphi, r, \quad \theta\right)$ $where$ M $\left(\frac{\boldsymbol{M}}{\boldsymbol{r}} << \frac{\boldsymbol{c^2}}{\boldsymbol{2G}}\right)$

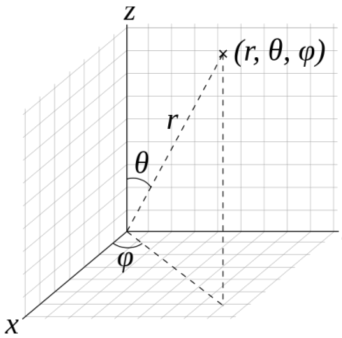


Figure 1

$$\boldsymbol{ds^2 = \left(1 - \frac{2GM}{rc^2}\right) c^2 dt^2 - [\left(1 - \frac{2GM}{rc^2}\right)^{-1} dr^2 + r^2(\sin^2\theta\, d\varphi^2 + d\theta^2)\,]}$$

Being $ds^2 = c^2 d\tau^2$

$$c^2 d\tau^2 = c^2\left(1 - \frac{2GM}{rc^2}\right) dt^2 - \left(1 - \frac{2GM}{rc^2}\right)^{-1} dr^2 - r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)$$

The **differential proper time of a reference system** respect to the measured local "dt" is expressed as

$$d\tau^2 = \left(1 - \frac{2GM}{rc^2}\right) dt^2 - \frac{\left(1 - \frac{2GM}{rc^2}\right)^{-1}}{c^2} dr^2 - \frac{r^2}{c^2} * (d\theta^2 + \sin^2\theta\, d\varphi^2)$$

For a body moving in a circular path over the surface of the mass M : $r = cte \rightarrow dr \quad = 0$; $\theta = cte \rightarrow d\theta \quad = 0$ → $d\tau^2 = \left(1 - \frac{2GM}{rc^2}\right) dt^2 - \frac{r^2}{c^2} * (\sin^2\theta\, d\varphi^2)$; with constant speed $\omega \rightarrow d\varphi = \omega dt$

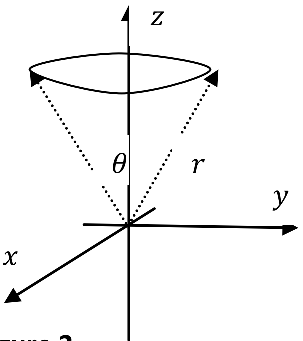


Figure 2

$$d\tau^2 = \left(1 - \frac{2GM}{rc^2}\right) dt^2 - (r^2 \sin^2\theta(\,\omega^2 dt^2)/c^2$$

$$\boldsymbol{d\tau \;\; = dt\sqrt{1 - \frac{2GM}{rc^2} - \frac{(\sin^2\theta\, r^2\omega^2)}{c^2}}\;\; ; \; d\tau \;\; < dt}$$

This expression represents the **differential time dilation** between proper times for a circular moving **reference system A** $(\boldsymbol{dt})$ in a gravitational field in comparison with a non rotating **reference system B** $(\boldsymbol{d\tau})$ at arbitrary distance from the mass M **.**

Let T_A be the proper time interval between two events at $R_A > R$ distance from the center of a massive object M and T_B be the proper time between the same events at a large R_B arbitrary distance.

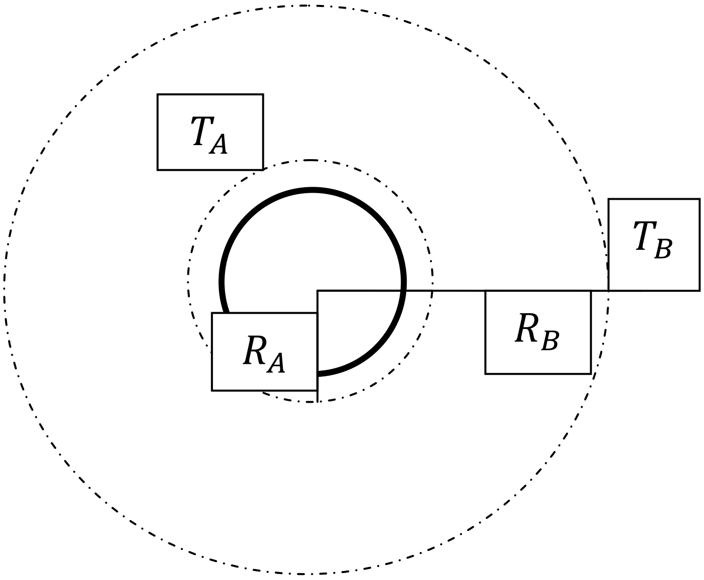
$$T_B = T_A\sqrt{1 - \frac{2GM}{c^2 R_A} - \frac{({R_A}^2\omega^2 \sin^2\theta\,)}{c^2}} \quad \text{--------}\rightarrow T_B < T_A$$

The gravitational term is $\frac{2GM}{R_A c^2}$, $the\ inertial\ \ term\ is$ $\frac{({R_A}^2\omega^2\sin^2\theta\,)}{c^2}$.

${R_A}^2\omega^2\sin^2\theta$ is the velocity of an object rotating with ω speed around an axis with radius $r_c = R_A\sin \quad \theta$.

THE GRAVITATIONAL TIME DILATION:

Figure 3



Neglecting the inertial term the previous relation between intervals of proper times becomes

$T_A = \frac{T_B}{\sqrt{1-\frac{2GM}{c^2 R_A}}}$ With R_B→infinity. with $\frac{M}{RB} < \frac{M}{RA} \le \frac{c^2}{2G}$;

$T_A > T_B$ time dilation of A ; ⊠= $\sqrt{1-\frac{2GM}{c^2 R_A}} < 1$ RA→infinity , ⊠→ 1 , $T_A \dashrightarrow T_B$

in the case $R_B > R_A$ is small ; $\boldsymbol{T_A} = \frac{\sqrt{\mathbf{1}-\frac{\mathbf{2GM}}{c^2 R_B}}}{\sqrt{\mathbf{1}-\frac{\mathbf{2GM}}{c^2 R_A}}} \boldsymbol{T_B}\ with$ $\frac{M}{R_B} < \frac{M}{RA} \le \frac{c^2}{2G}$

THE INERTIAL TIME DILATION:

Let T_A be the proper time between two events in **A,** T_B be the proper time between the same events, ***v*** is the relative velocity between A and B moving . B is time delayed, the time of the observer results contracted (**now B is moving, instead of A compared to the preceding description**).

$$T_A = T_B\sqrt{1 - \frac{({R_B}^2 \omega^2 \sin^2\theta)}{c^2}}\ ;\ R_B \sin\ \ \theta = r_c;\ \mathrm{v} = r_c\ \ \omega\ \ ;\ T_A = T_B\sqrt{1 - \frac{(v^2)}{c^2}}$$

From the **Lorentz factor** in the particular theory of Relativity similar results are found

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\ \ ;\gamma > 1;\quad \boldsymbol{T_A}\mathbf{=1}/\ \gamma * \boldsymbol{T_B} \rightarrow \quad \boldsymbol{T_A}\mathbf{=}\sqrt{1-\frac{v^2}{c^2}} * \boldsymbol{T_B} \Rightarrow \quad \boldsymbol{T_B} > \boldsymbol{T_A}$$

THE PROPOSED EXPERIMENT SETUP

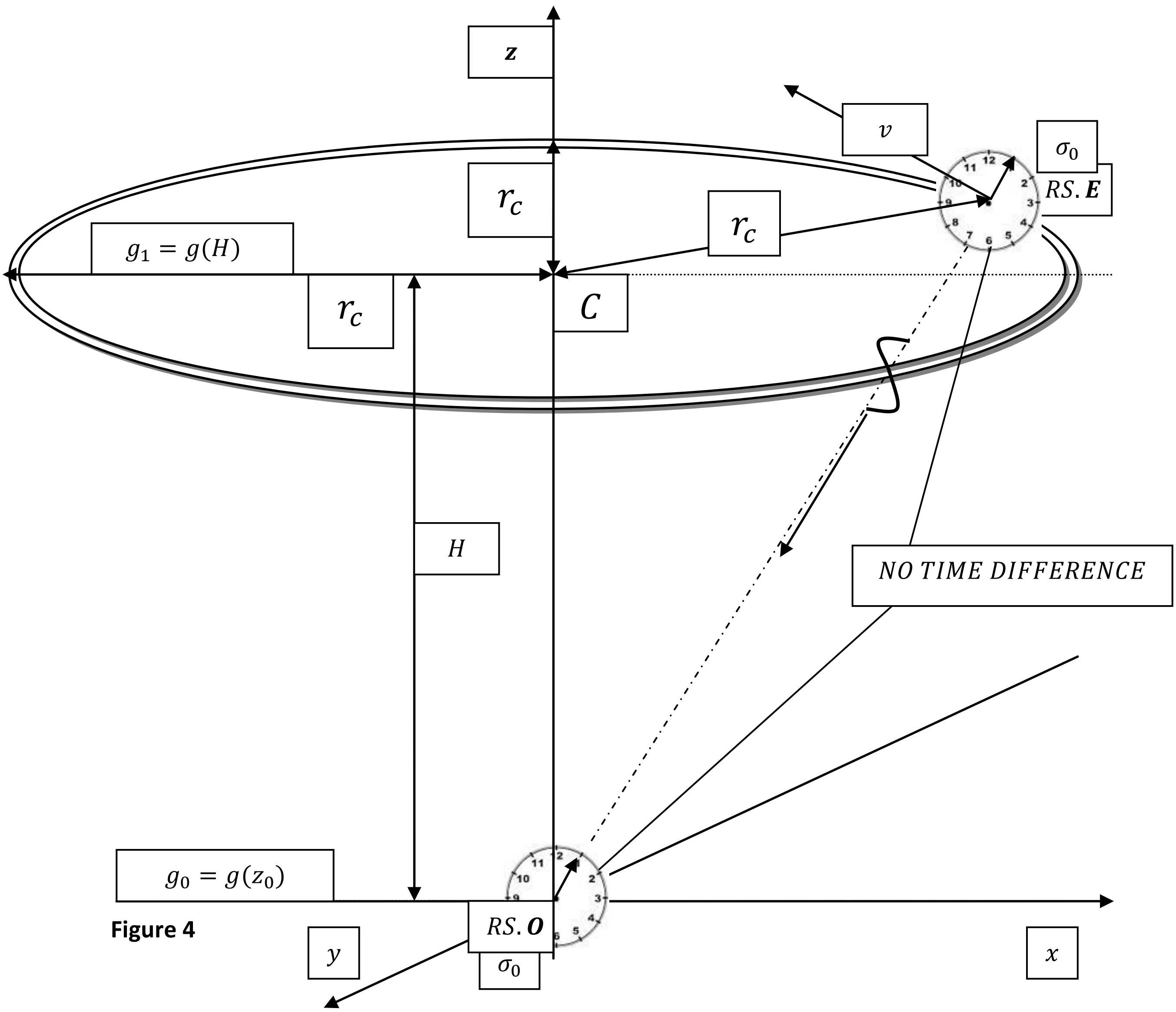


Figure 4

Let **O** (observer) and **E** (emitter) be two Reference Systems. Let **O** be the still reference system. Let **E** being bounded to travel with ***v*** velocity relative to **O** in **a thin circular guide of radius** r_C being the circle parallel to the ground and centered in **C** at height H with the normal trough C passing also through **O .**

THE DOPPLER EFFECT MINIMISATION

Hasselkamp, Mondry, and Scharmann [14] measured the Doppler shift from a source moving at right angles to the line of sight, the transverse Doppler shift: $fdetectd \triangleq frest * (1 - \frac{v}{c}\cos\varphi) * \mathbf{1}/\gamma$

For $\boldsymbol{\varphi}$ **= 90° (cos**$\boldsymbol{\varphi}$ **= 0) this reduces to** $f_{\text{detected}} = f_{\text{rest}} * 1/\gamma$ **, thus there should be no transverse Doppler shift** due to the angle, and the lower frequency of the moving source can be attributed to the time dilation effect alone. According to Freidman and Novik [5], the transverse Doppler Shift with emitter moving perpendicular to the radiation beam can result **not null experimentally only because the amplitude of the absorber and emitter window** have small but finite dimensions. Though **in order to be detectable, the velocity of E must be at least 100 m/s**.

TIME-SHIFT CANCELLATION BETWEEN REFERENCE SYSTEMS

The idea is to **minimize the time difference between two reference systems** at different potentials by moving the reference system E respect to the mass M with speed v, and by making O be steady with M. Being E at height H respect to O, E has a faster time beat than O due to gravitational time delay. By increasing its speed, the time beat in E will get slower till it will compensate the gravitational time delay of O.

Two methods will be applied giving virtually the same results:

a) Using the inertial and gravitational time dilation from general relativity :

$$\boldsymbol{T_o} = \frac{\sqrt{1-\frac{2GM}{c^2R_e}-\frac{v^2}{c^2}}}{\sqrt{1-\frac{2GM}{c^2R_O}}}\,\boldsymbol{T_e};\ \boldsymbol{T_o} = \boldsymbol{T_e} \rightarrow \quad \frac{\sqrt{1-\frac{2GM}{c^2R_e}-\frac{v^2}{c^2}}}{\sqrt{1-\frac{2GM}{c^2R_O}}} = \mathbf{1};\ \frac{1-\frac{2GM}{c^2R_e}-\frac{v^2}{c^2}}{1-\frac{2GM}{c^2R_O}} = \mathbf{1}$$

with $\boldsymbol{R0} = \boldsymbol{R}$ and $\boldsymbol{Re} = \boldsymbol{R} + \boldsymbol{H}$; $\boldsymbol{H} > 0$; $k = \frac{2GM}{c^2}$; $\frac{M}{R+H} < \frac{M}{R} \leq \frac{c^2}{2G}$; v<<c

$$-\frac{2GM}{c^2R_e} - \frac{v^2}{c^2} = -\frac{2GM}{c^2R_O} \rightarrow \frac{2GM}{c^2R_O} - \frac{2GM}{c^2R_e} = \frac{v^2}{c^2};\quad \sqrt{2GM\left(\frac{1}{R} - \frac{1}{R+H}\right)} = v$$

$$\boldsymbol{v} = \sqrt{2GM_T\frac{H}{R_T(R_{T+H})}} \text{ -> } \mathrm{H} << \boldsymbol{R_T} \qquad \boldsymbol{v} = \frac{\mathbf{1}}{\boldsymbol{R_T}} * \sqrt{\mathbf{2}\boldsymbol{GM_T}\mathbf{H}}$$

b) Applying the INERTIAL Lorentz factor: $\boldsymbol{T_e} = \gamma * \boldsymbol{T_o}$ and the gravitational one $\boldsymbol{T_o} = \frac{\sqrt{1-\frac{2GM}{c^2Re}}}{\sqrt{1-\frac{2GM}{c^2R0}}}\,\boldsymbol{T_e}$;

$$\boldsymbol{T_o} = \frac{\sqrt{1-\frac{2GM}{c^2R_e}}}{\sqrt{1-\frac{2GM}{c^2R_O}}} * \gamma\,\boldsymbol{T_e};\quad \frac{\sqrt{1-\frac{2GM}{c^2Re}}}{\sqrt{1-\frac{2GM}{c^2R0}}} * \gamma = 1$$

; with $\boldsymbol{R0} = \boldsymbol{R}$ and $\boldsymbol{Re} = \boldsymbol{R} + \boldsymbol{H}$; $\boldsymbol{H} > 0$; $k = \frac{2GM}{c^2}$;

$\frac{M}{R+H} < \frac{M}{R} \leq \frac{c^2}{2G}$; v<<c; $\frac{\sqrt{1-\frac{k}{(R+H)}}}{\sqrt{1-\frac{k}{R}}}\,\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = 1$ -> $\frac{1-\frac{k}{(R+H)}}{1-\frac{k}{R}} = 1 - \frac{v^2}{c^2}$ ->

$$v = c * \sqrt{1 - \frac{\mathrm{R(R+H-k)}}{\mathrm{(R+H)(R-k)}}} = c * \sqrt{\frac{\mathrm{kH}}{\mathrm{R^2-Rk+HR-kH}}} =; c * \sqrt{\frac{\frac{2GM}{c^2}\mathrm{H}}{\mathrm{R^2-R}\frac{2GM}{c^2}\mathrm{+HR-}\frac{2GM}{c^2}\mathrm{H}}} = c * \sqrt{\frac{2GM\mathrm{H}}{c^2\mathrm{R^2-R}2GM+c^2\mathrm{HR}-2GM\mathrm{H}}}$$

for H<<R

$\boldsymbol{c}^2\mathrm{R}^2 \gg \boldsymbol{c}^2\mathrm{HR}$, $\mathrm{R}\mathbf{2}\boldsymbol{GM} \gg \mathbf{2}\boldsymbol{GM}\mathrm{H}$

Being $\frac{M_T}{R_T} \ll \frac{c^2}{2G}$ -> $\boldsymbol{c}^2\mathrm{R}^2 \gg 2\mathrm{G}\,R_TM_T$, $\quad v \triangleq \boldsymbol{C} * \sqrt{\frac{\mathbf{2}\boldsymbol{GM_T}\mathrm{H}}{\boldsymbol{c}^2{R_T}^2}} = \frac{\mathbf{1}}{\boldsymbol{R_T}} * \sqrt{\mathbf{2}\boldsymbol{GM_T}\mathbf{H}}$

In both cases $v \triangleq \frac{1}{6*10^6} * \sqrt{2(6{,}6 * 10^{-11} * 6 * 10^{24}H)} = \frac{1}{6*10^6} * \sqrt{(7{,}2 * 10^{14}H)} = \frac{5}{3} * \sqrt{(7{,}2 * H)}$, $\quad \boldsymbol{H} = \mathbf{22}\ \boldsymbol{m} \rightarrow \quad \boldsymbol{v} = \mathbf{20{,}9}\ \left[\frac{\boldsymbol{m}}{\boldsymbol{s}}\right]$ a couple of values are proposed minimizing also the secondary Doppler effects $r_c = 20m : the\ \ acceleration\ is\ |a| = \frac{v^2}{r_c} = 21{,}84\ m/s^2$

From the Schwartzshild solution a direct dependency of time delay on local acceleration doesn't appear, the numerical values are proposed only to stress the feasibility of the experiment. Partial compensations between the two effects have been registered in experiments of National Physical Laboratory[6].

THE THEOREM

This exposition is a thought experiment, doesn't want to suggest the real experiment but applies the conservation principles in order to indicate the nature of the frequency shift, in a similar fashion Prof. Richard Feynman did in his lectures.

Let' consider a **generic g (z) continuous function** with z real (as in the figure 2), representing the gravitational field defined. It is known that the gravitational field of a mass M is a monotonous function in open space where Z is the distance from the center of mass M, so $g \quad (\boldsymbol{z}) = \frac{\boldsymbol{GM}}{\boldsymbol{z^2}} + \boldsymbol{o^2}$ **is . Being E** the rotating reference system (**along the circumference having radius r_C) with speed** $\boldsymbol{v} = \frac{1}{R_T} * \sqrt{2GM_T\mathrm{H}}$ **respect to O,** σ_0 the time shift between them, is minimized, where **H > 0 is the distance between the parallel planes passing through O and E.** Being minimized the time delay difference between O and E, it is a good approximation to consider the same measure of the energy in each reference system.

Let's consider an **atom T of rest mass $\boldsymbol{m_o}$** ,in its ground state (not excited) in E. The atom T is brought **from E to O** letting out, its Potential energy and kinetic energy.

$$\boldsymbol{\Delta U(E,O) = U(E) - U(O) = m_o\, g_x H + \tfrac{1}{2} m_o v^2 - U(O)} \quad \textbf{(U(O) = 0)} \rightarrow \boldsymbol{\Delta U(E,O) = \ m_o g_x H + \tfrac{1}{2} m_o v^2}.$$

For the "first mean value theorem for integration", it is in fact possible to find a **suitable average value** $\boldsymbol{g_x} = g(\boldsymbol{\alpha})$ of a continuous real function g(y) in an interval of real numbers (a, b) where $\alpha \in$ (a, b), such that the definite integral in (a, b), is equal to the $\boldsymbol{g_x}$ value, times the distance H of (a, b) . This implies that $\boldsymbol{\Delta U(A,B) = \ m g_x H}$ **with a generic m** (provided that gravity field doesn't affect the variation of mass itself) ***no other hypotheses*** *are required,* ***not even*** *the m << M (mass of Earth) approximation or H<<R (radius of Earth) used elsewhere.*

Let's now assume to be true the generally accepted viewpoint. **HYPOTHESYS: "energy of photons is NOT ALTERED climbing up a potential well"**

A **round trip of the atom and radiation** top-> bottom→ top: E→O→E, is considered.

1) **Top to bottom: E→O** (T arrives in O from E and then is excited by the photon emitted from E)

   A photon of energy $\boldsymbol{hv_o}$ is generated in E and directed to O**.** Being no time difference between O and E, and **considering also the HYPOTHESYS,** the photon is unaltered by the transition from E to O. The external energies to produce the state in O would be:

   $$\boldsymbol{\Delta E(E,O) + \ E_{\mathrm{ph}} = \ m_o g_x H + \tfrac{1}{2} m_o v^2 + hv_o}$$

   The atom **T** goes O then already in O receives the photon $\boldsymbol{hv_o}$, gets excited by the photon**,** becomes **T'** having mass, **from Einstein special relativity**, $\boldsymbol{m_e}$ **=** $\boldsymbol{(m_o + hv_o/c^2)}$**.**

2) **Bottom to top: O → E (**the excited atom is lifted and brought back to the emitter and emits back the photon)

   T' atom has to get energy for the transition from O to E equal to its gravitational potential energy and kinetic energy in order to follow the emitter:

$\boldsymbol{\Delta E(O,E)} = \boldsymbol{(m_o + h\nu_o/c^2)^* \, g_x * H + \frac{1}{2}(m_o + h\nu_o/c^2)v^2;}$ In E again, the atom emits the photon, T'→T, $h\nu_o$ is given back; $\boldsymbol{\Delta E(O,E) + E_{\mathrm{ph}}} = \boldsymbol{\left(m_o + \frac{h\nu_o}{c^2}\right) * \, g_x * H + \frac{1}{2}\left(m_o + \frac{h\nu_o}{c^2}\right)v^2 + h\nu_o;}$

The I/O ENERGY balance or the **total energy difference in the round trip for the E and O system is**:
$\boldsymbol{\Delta E_{\mathrm{tot}}} = \boldsymbol{\Delta E(E,O) + E_{\mathrm{ph}} - \left(\Delta E(O,E) + E_{\mathrm{ph}}\right)};$

$$m_o g_x H + \frac{1}{2} m_o v^2 + h\nu_o - \left[\left(m_o + \frac{h\nu_o}{c^2}\right) g_x H + \frac{1}{2}\left(m_o + \frac{h\nu_o}{c^2}\right) v^2 + h\nu_o\right] = -\left(\frac{h\nu_o}{c^2}\right)\left(\frac{1}{2} v^2 + g_x H\right) < 0$$

Starting from E by combining atom and radiation in O, going back and emitting the photon, from the excited atom, **the system results deprived of** $|\Delta E_{\mathrm{tot}}| = \left(\frac{h\nu_o}{c^2}\right)\left(\frac{1}{2} v^2 + g_x H\right)$ **; THIS CONFIGURES A VIOLATION OF THE ENERGY CONSERVATION LAW;**

Proof by contradiction: by holding true the **HYPOTHESYS:** "energy of photons is NOT ALTERED climbing up a potential well", the conservation of energy law gets contradicted (EMILY NOETHER's Theorem about continuous symmetry of space-time, 1918) hence "**energy of photons is ALTERED climbing up a potential well**", **is PROVED to be true.**

Admitting the photon's red-shift being an apparent effect only due to different curvature of the space-time fabric in observer and emitter reference systems, altering the perception of the frequencies observed, **no difference in the curvature of ST would bring no distortion of frequencies. The consequence of the last admission turns, as previously shown, in an evident violation of the energy conservation law**. Only admitting that the photon $\boldsymbol{h\nu_o}$ gains energy by going into a potential well, the energy $\boldsymbol{U_{ph}} = \left(\frac{h\nu_o}{c^2}\right)\left(\frac{1}{2} v^2 + g_x H\right)$ is added to the photon descending the "potential well" complying with energy conservation. So it seems **reasonable to admit** as stressed by Feynman $\boldsymbol{m_{ph}} = \left(\frac{h\nu_o}{c^2}\right)$ **as being the "inertial-gravitational mass" of the photon** $\boldsymbol{h\nu_o}$**, "not the rest mass"**. The "rest mass" of photons **can't be defined is impossible to be measured is a ill posed problem, it's not even possible to consider it null.**

CONCLUSIONS

The generally accepted view point brings to a contradiction of the conservation principles.

An experimental verification of the illustrated theoretical result, according to the suggested setup, is strongly required. The experiment similar to the HARVARD TOWER one, would consist in measuring the blue shift originated by a gamma ray of a reference frequency emitted by the moving emitter E , observed in O with a higher frequency in a lower gravitational potential, as already described. The energy difference between emitter and observer should be $\boldsymbol{\Delta E_{\mathrm{ph}}} = \left(\frac{h\nu_o}{c^2}\right)\left(\frac{1}{R_T^2} G M_T \mathrm{H} + g_x H\right) = \boldsymbol{2 * \left(\frac{h\nu_o}{c^2}\right)(g_x H)}$

The frequency blue shift should be double the value found in Pound and Rebka's experiment, or better, **double the value of the Gravitational frequency shift alone.**

In the case the presence of such blue shift is verified experimentally, it would certify that the frequency shift is not due to time dilation of the reference systems directly but it is the global property of the action of a "multitude of clocks" summed along the path of the quantum between the two reference systems.

The photon emitted from E will be observed frequency shifted in O being in between a difference of potential energy and "zero" time dilation. By applying correctly the theorems, the theory suggests that a blue shift, in the conditions described, should be found experimentally, consisting of two terms, gravitational and inertial. **The phenomenon of frequency shift should depend on the way quanta propagate** in the space between the reference systems not directly on time differences or local space-time warp between them.

The experiment would **confirm also the equivalence principle**, attributing to the gravitational acceleration and the centripetal acceleration the same effects. It would connect directly in free space the local space time warp effects to the local accelerations related to the local energy content of the space time itself (EINSTEIN STRESS TENSOR), and not related directly to the generic gravitational "potential energy" being a quantity not defined unless defining a arbitrary reference value. The experiment **would certify the presence of the energy exchange between QUANTA and SPACE-TIME through the INERTIA mediation (HIGGS FIELD?) crossing differences of potential of mechanical energy**.

BIBLIOGRAPHY

[1] **APPARENT WEIGHT OF PHOTONS** R. V. Pound and G. A. Rebka, Jr. Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts (1960) http://prl.aps.org/pdf/PRL/v4/i7/p337_1

[2] **The Feynman Physics Lectures, "Curved space",** Volume 2 Chapter 42 paragraph 6 (1963-1965) **Richard Feynman**

[3] **THE MEANING OF RELATIVITY** (Princeton university press, Princeton, N.J.) (1921-1955) **Albert Einstein**

[4] **ON THE INTERPRETATION OF THE REDSHIFT IN A STATIC GRAVITATIONAL FIELD (1999)** L.B. OKUN , K.G. SELIVANOV ,V.L. TELEGDI .**http://arxiv.org/pdf/physics/9907017.pdf**

[5] **Testing Einstein's time dilation under acceleration using Mossbauer spectroscopy (2012)** Yaakov Friedman and Israel Nowik Jerusalem College of Technology **http://arxiv.org/pdf/1206.3107v1.pdf**

[6] **National Physical Laboratory:** Einstein News from the National Physical Laboratory http://www.npl.co.uk/upload/pdf/metromnia_issue18.pdf

[7] **POUND REBKA SNIDER EXP** http://www.mrelativity.net/papers/29/gtr_tests_pound_rebka.pdf

[8] **Effect of gravity on gamma radiation** (1965).Phys. Rev. 140, 788–803, Robert V. Pound and Joseph L. Snider

[9] **Course of theoretical physics 1, Mechanics, 3rd edition**. Lev D. Landau and Jewgeni M. Lifshitz

[10] **Modern Infinitesimal Analysis Applied to the Physical Metric dS and a Theoretical Verification of a Time-dilation Conjecture (2008)** Robert A. Hermann http://arxiv.org/pdf/0802.1809v1.pdf

[11] **Closing a window for massive photon** Sergio A. Hojman* and Benjamin Koch* (2013) **http://arxiv.org/pdf/1209.4907v2.pdf**

[12] **On the gravitational Redshift (2012)** Klaus Wilhelm, Bhola N. Dwived http://arxiv.org/pdf/1307.0274v1.

[13] **Direct observation of the transversal Doppler-shift** (1979) Springer Verlag, D. Hasselkamp, E. Mondry,A. Scharmann

[14] **ACTUAL WEIGHT OF PHOTONS OR OPTICAL ILLUSION** Stefano Quattrini (nov 2013) https://www.academia.edu/5170031/ON_THE_HARVARD_TOWER_EXPERIMENTS_INTERPRETATIONS_ACTUAL_WEIGHT_OF_PHOTONS_OR_OPTICAL_ILLUSION