"SPEED OF CLOCKS IN A GRAVITATIONAL FIELD" A FEYNMAN'S LECTURE REVISITED

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"SPEED OF CLOCKS IN A GRAVITATIONAL FIELD"

A FEYNMAN'S LECTURE REVISITED

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ABSTRACT

R.P. Feynman introduced in one of his lectures on physics[2],[14], the Universality of clock rates (UCR) , the gravitational potential energy of photons and the phenomenon of gravitational redshift. His reasoning was very similar to the Einstein's in his first papers [5] some years before his GR theory, few authors nowadays consider valid this point of view. Several authors [4], firmly denied the possibility of gravitational potential energy of photons, supported also by the experimental evidence of the GP-A experiment review [15]. The Feynman's lecture will be revisited according to the correct approach based on the tested General Relativity clock theory [3],[4],[13].

INTRODUCTION

Richard P. Feynman in his lectures on physics 1962-1965 wrote [2],[14]**:** " *a photon of frequency* $v_{\boldsymbol{o}}$ *has the energy* $E_o = hv_{\boldsymbol{o}}$ *. Since the energy* E_o *has a gravitational mass* $\frac{E_o}{c^2}$ *, the photon has a mass* $\frac{hv_o}{c^2}$ *(not rest mass), in falling the distance H it will gain an additional energy* $\frac{hv_o}{c^2}\ gH$".

In the Feynman's lectures of Gravitation [6] :"*further evidence comes from the fact that light falls in a gravitational field by an amount which is given by our theory*". Feynman wrote [6 p. 65]: "*the frequency shift is implicit in the experimental results of Eötvös, gravity forces are proportional to the energy content, thus the frequency shift corresponds to the gravitational energy of the photon energy*" and "*It is obvious that the frequency shift is required by energy conservation*".

In the preface of Feynman's book on gravitation [6] p. XXXIV by Brian Hatfield, mid 90's talking about Quantum gravity, it is reported : "*Eötvös experiment and recent refinements empirically indicate that gravity does couple to energy content of objects, hence things like photons should be affected by gravity* ".

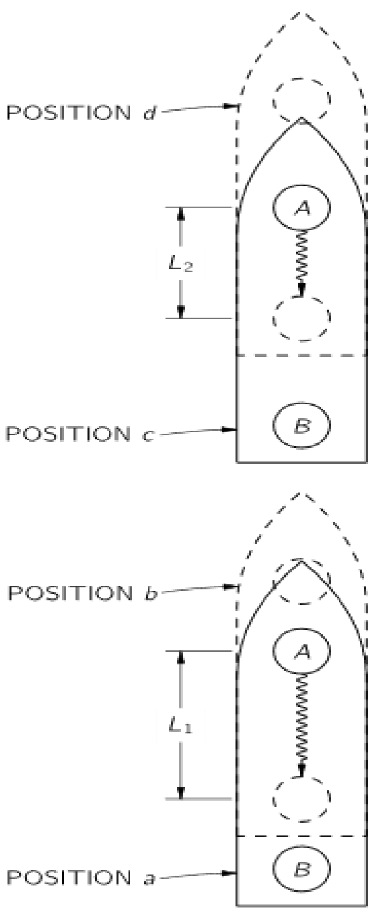
L.B. Okun , K.G. Selivanov ,V.L. Telegdi in 1999 [4] stressed the fact that the verified Einstein clock hypothesis reduces the photon energy loss as an apparent, relative phenomenon [4]: "The blue shift of clocks with height has thus been exhibited as an absolute phenomenon. One sees once over again that the explanation of the gravitational red shift in terms of a naïve attraction of the photon by the earth is wrong".

Roger Penrose in his preface of 1999 to the book "Six not so easy pieces" by Richard Feynman extracted from Feynman's Lectures, didn't make any comment about the presence of the gravitational potential energy of photons.

The experiment of Vessot and Levine et. al, Gravity probe-A, representing a test of General Relativity theory, is the key to understand the phenomenon. The paragraph written in the Feynman's lecture "speed of clocks in a gravitational field"[14] , will be reviewed in order to point out the critical points and the actual differences between the old and the new point of view.

“SPEED OF CLOCKS IN A GRAVITATIONAL FIELD”, REVISITED

FIRST PART



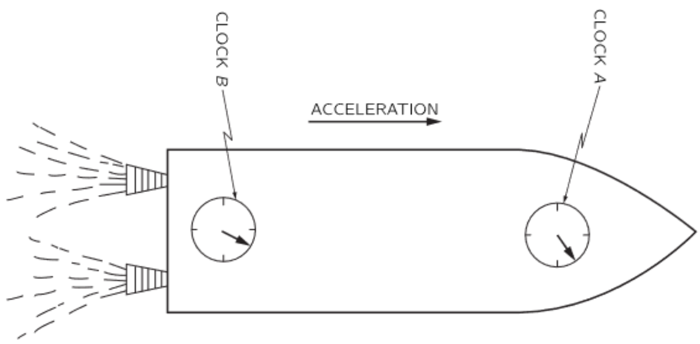
Feynman: “*Now suppose you are in a rocket ship which is accelerating. Accelerating with respect to what? Let’s just say that its engines are on and generating a thrust so that it is not coasting in a free fall. Also imagine that you are way out in empty space so that there are practically no gravitational forces on the ship*”.
Flat space-time condition of the space ship.

Feynman: “*Suppose we put a clock at the “head” of the rocket ship—that is, at the “front” end—and we put another identical clock at the “tail,” as in. Let’s call the two clocks A and B . If we compare these two clocks when the ship is accelerating, the clock at the head seems to run fast relative to the one at the tail. To see that, imagine that the front clock emits a flash of light each second, and that you are sitting at the tail comparing the arrival of the light flashes with the ticks of clock B*”.

The head clock “appears” to run faster. The frequency of photons, incoming from the clock A, gets higher for the classical Doppler effect.

Feynman: ”*So when the signals arrive at B , the ship has increased its velocity by gH/c . The receiver always has this velocity with respect to the emitter at the instant the signal left it. So this is the velocity we should use in the Doppler shift formula, Eq. (42.4). Assuming that the acceleration and the length of the ship are small enough that this velocity is much smaller than c , we can neglect the term in v^2 /c^2 . We have that ω=ω0 (1+gH/c^2).* “

By considering low speeds, the relation above reports the frequency of photons, changed by the classical Doppler effect relation, during their free path towards the relative moving observer.



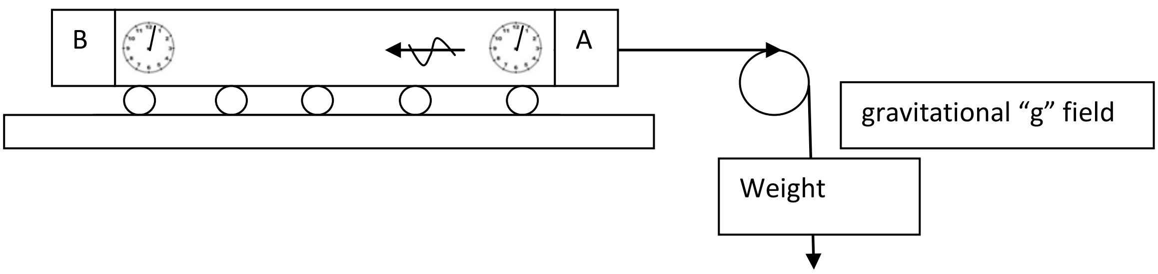
Feynman: *” So for the two clocks in the spaceship we have the relation: (Rate at the receiver)=(Rate of emission)(1+gH/c^2) where H is the height of the emitter above the receiver. From the equivalence principle the same result must hold for two clocks separated by the height H in a gravitational field with the free fall acceleration g .*”

It is the case to distinguish carefully between frequencies of clocks and photons. The frequency of photons is certainly altered by the Doppler effect due to acceleration, since the classical Doppler effect is a tested phenomenon on radiation, related to energy exchange. According to the last sentence of Feynman the difference of clock rates is supposed to be of (*1+gH/c^2)* in the space ship. This "detail" has never been tested so far due also to lack of technology (only since 2005 it is possible to perform such experiment). According to this configuration and to what was affirmed before by Feynman, the clock A should tick faster than B during the pull of the rope, not only perceived to beat faster from B.

Feynman: "*If they didn't, you would be able to tell the difference between a gravitational field and an accelerating reference system. The idea that time can vary from place to place is a difficult one, but it is the idea Einstein used, and it is correct—believe it or not*".
The second sentence complies with the UCR. The first is related to EEP.
An interpretation of the principle of equivalence requires that, if this redshift is observed in an experiment performed under conditions of uniform acceleration in the absence of gravitational fields, then the same redshift must be observed by an experiment performed under conditions where there is a uniform gravitational field, but no acceleration. All occurs, but for completely different reasons: energy difference of photons due to classical Doppler (acceleration without gravitation), frequency difference perceived due to local space-time curvature (gravitational potential). In the case of the rocket there is an actual energy variation of photons and an apparent clock-rate difference. In the case of the gravitational field there is an actual clock-rate difference and an apparent energy variation of photons.

The equivalence principle tested in the *Eötvös* -Dicke experiment, does not include weighting of radiant energy. It is verified though that clock-rates differ for that amount in a gravitational field.
The clock hypothesis was tested [14] and it is the only actual reason why the clocks run different times at different gravitational potentials. Even if the values of the redshift calculated with the preceding relation are in agreement with the values of the Harward Towers experiments [1],[5], this is not sufficient to affirm that the equivalence principle can be extended to radiation.
We will consider the coincidence in the values of the frequency variation of photons with constant cinematic acceleration (classical Doppler effect) and the clock frequency variation in a static gravitational potential with the same static acceleration. It regards, as specified in [4], the necessary energy gap for the photon in order to be absorbed at a higher gravitational potential by the same type of atom emitters situated at a lower gravitational potential. Free-energy should gravitate like tied-energy in order to get that effect on photons. This is disproved also by the revisistation of the "Gravity probe A" experiment [14].

Let's consider the following configuration, equivalent to the rocket in free space. A wagon, containing the clocks, connected with a metal wire to a big weight (the figure below was made by the author):



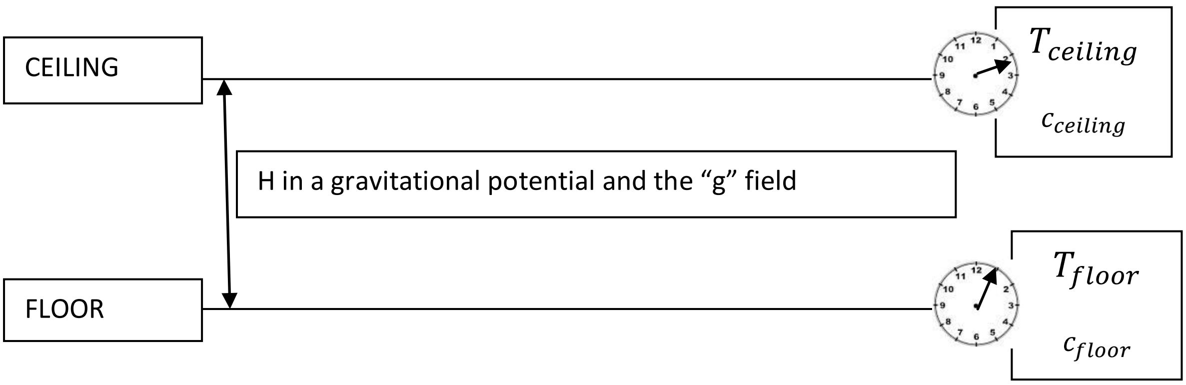
In this situation (as for the rocket in free space) there is constant acceleration in one direction, with photons going in the opposite direction. Since the curvature of ST of the two clocks does not change (same gravitational potential and same speed), no "real" delay of clocks can be present, in compliance with the tested clock hypothesis. The signal coming from A to B will be seen raised in frequency, but this doesn't have anything to do with the relative times of the clocks, it is due only to the classical Doppler effect.

SECOND PART

Feynman: *"This is such an important idea we would like to demonstrate that it also follows from another law of physics—from the conservation of energy.*
We know that the gravitational force on an object is proportional to its mass M, which is related to its total internal energy E by $M=E/c^2$. For instance, the masses of nuclei determined from the energies of nuclear reactions which transmute one nucleus into another agree with the masses obtained from atomic weights.".
This is in compliance with the Eötvös -DICKE experiment and special relativity.

Feynman: " *Now think of an atom which has a lowest energy state of total energy E_0 and a higher energy state E_1 , and which can go from the state E_1 to the state E_0 by emitting light. The frequency ν of the light will be given by $h\nu = E_1 - E_0$*" .
This is in compliance with the quantum physics experiments.

Feynman: "*Now suppose we have such an atom in the state E_1 sitting on the floor, and we carry it from the floor to the height H . To do that we must do some work in carrying the mass $m_1 = E_1/c^2$ up against the gravitational force. The amount of work done is $E_1/c^2 * gH$*":
This is in compliance with mechanical energy theorem and the special relativity (the figure below was made by the author).



Feynman: "*Then we let the atom emit a photon and go into the lower energy state E_o . Afterward we carry the atom back to the floor. On the return trip the mass is E_o/c^2 ; we get back the energy $(E_o/c^2) * gH$*".

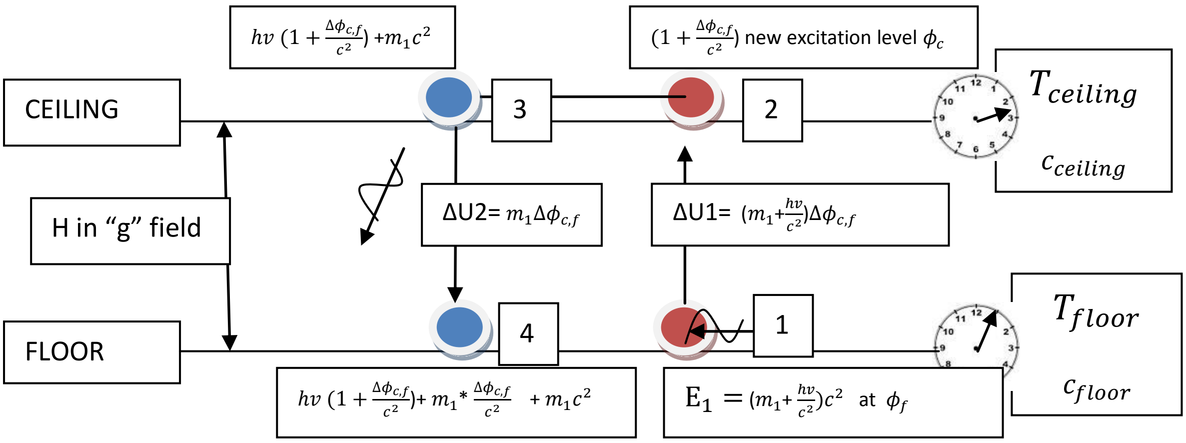
As seen before, the time rate of the ceiling clock is faster than the bottom clock, this by itself should make some differences. The speed of light is "c" if measured in any reference frame in empty space, but it is relative, it is variable in a gravitational potential as tested in experiments [3],[10].
When the atom is excited by the photon at lower gravitational potential, the speed of light is c_{floor}, when the photon is emitted it does it from $c_{ceiling}$. This means that it is quite reasonable to expect some changes.

Feynman: "*If energy is conserved, the energy we end up with at the floor must be greater than we started with by just the work we have done. Namely, we must have that $E_{ph} + E_0 = E_1 + \Delta U$, $E_{ph} = (E_1 - E_0) + \Delta U$. It must be that the photon does not arrive at the floor with just the energy $E_1 - E_0$ it started with, but with a little more energy. Otherwise some energy would have been lost. If we substitute in Eq 42.11 the ΔU we got in Eq. 42.12 we get that the photon arrives at the floor with the energy $E_{ph} = (E_1 - E_0) * (1 + gHc^2)$* "

Feynman referred to the Harvard Tower experiments [1],[5] to show that the redshift just explained was a verified phenomenon. According to Feynman, in order to be compliant with the Noether's theorem of energy conservation, it is necessary that the photon exchanges energy with the gravitational field. This would be correct under the assumption that different space-time curvature had the same influence onto both matter and radiation.
Okun et al. [4] described the crucial part of the Harvard Tower experiments**:** "The red shift was compensated through the Doppler effect, by slowly moving the absorber and thereby restoring the resonant absorption". The energy exchange due to the doppler effect, occurred during the experiment compensated the higher energy absorption/emission (nuclear) level, due to gravitational potential energy difference between the source and the observer. $\boldsymbol{E_{level}}(\phi_{ceiling}) = \boldsymbol{E_{level}}(\phi_{floor})(1+\frac{\Delta\phi_{c,f}}{c^2})$.

THE ALTERNATIVE EXPLANATION, ENERGY CONSERVATION IN COMPLIANCE WITH GR

1) Now think of an atom A which has a lowest energy state of total energy E_0 and a higher energy state E_1 , and which can go from the state E_1 to the state E_0 . The frequency ν of the radiation will be given by $\mathrm{E}_{phf} = h\nu = \mathrm{E}_1 - \mathrm{E}_0$, at the floor level.
2) Now suppose we have such an atom A in the state E_1 sitting on the floor, and we carry it from the floor to the height H . To do that we must do some work in carrying the mass $\mathrm{m}_1 = \frac{\mathrm{E}_1}{c^2}$ up against the gravitational force. The amount of work done is $\Delta U = \frac{\mathrm{E}_1}{c^2} g^*H = \mathrm{E}_1 \frac{\Delta\phi_{c,f}}{c^2}$;
3) Then we let the atom A, having now an energy excitation gap of $(1+\frac{\Delta\phi_{c,f}}{c^2})$ at the ceiling level respect to the floor, emit a photon and go into the lower energy state E_0 . The photon emitted is $\mathrm{E}_{phc} = h\nu(1+\frac{\Delta\phi_{c,f}}{c^2})$, the mass of A is $\frac{\mathrm{E}_0}{c^2}$.
4) Afterward we carry the atom A back to the floor we get back the gravitational potential energy $\mathrm{E}_0 \frac{\Delta\phi_{c,f}}{c^2}$ (the Figure below was made by the author).



The energy is conserved:

ΔE_{TOT} = - [E(A) excited at floor]– [bring A excited to ceiling] + [photon emitted at ceiling]+ [E(A) not excited] + [bring A not excited to floor].

$\Delta E_{TOT} = -(m_1c^2 + h\nu) - (m_1+\frac{h\nu}{c^2})\,\Delta\phi_{c,f} + h\nu\,(1+\frac{\Delta\phi_{c,f}}{c^2}) + m_1c^2 + m_1\Delta\phi_{c,f} = -h\nu - (m_1+\frac{h\nu}{c^2})\,\Delta\phi_{c,f} + h\nu\,(1+\frac{\Delta\phi_{c,f}}{c^2}) + m_1\Delta\phi_{c,f} =$

$-(m_1+\frac{h\nu}{c^2})\,\Delta\phi_{c,f} + h\nu\,(\frac{\Delta\phi_{c,f}}{c^2}) + m_1\Delta\phi_{c,f} = 0$

The shifting of absoption/emission levels complies with the energy conservation. Photons climbing a gravitational potential, will find the same types of atoms they departed from as if they posess an higher energy level of excitation. The atom lifted up in a gravitational potential has to have its energy levels lifted up by the quantity $\frac{\Delta\phi_{c,f}}{c^2}$ **.** Same atoms have different behaviors at different gravitational potentials. According to GR it has to be that space-time curvature blue-shifts the energy levels of the atoms , according to $gHc^2 = \frac{\Delta\phi_{c,f}}{c^2} > 0$.

Feynman:"*The same result can be obtained in still another way. A photon of frequency ωo has the energy E 0 =ℏωo. Since the energy Eo has the gravitational mass Eo /c^2 the photon has a mass (not rest mass) ℏωo /c^2 , and is "attracted" by the earth. In falling the distance H it will gain an additional energy (ℏωo /c 2)gH , so it arrives with the energy E=ℏωo*(1+gHc^2).*
But its frequency after the fall is E/ℏ, giving again the result in Eq. (42.5). Our ideas about relativity, quantum physics, and energy conservation all fit together only if Einstein's predictions about clocks in a gravitational field are right."

a) From "GRAVITY PROBE A" experiment it is possible to deduce that photons don't lose energy in a gravitational field, or rather no energy exchange occur between quanta and space-time in a gravitational potential.
b) As far as "light" is concerned, it doesn't feel the time, ds^2 = 0 [3], confirmed by the gravitational lensing effect based on such equation. So it is inappropriate to treat photons as massive objects. The approximated conversion factor, radiant to tied energy is (1+/- $\frac{\Delta\phi_{c,f}}{c^2}$).
c) The contribution of length variation in a gravitational potential results the same for tied-energy and free-energy, no difference rises for this reason. On the contrary the contribution of time variation factor for free energy is unitary, while for matter-energy it is (1+/- $\frac{\Delta\phi_{c,f}}{c^2}$).

The GR point of view [4] complies, applying the time dilation factor, with the clock hypothesis and the energy conservation and the speed of light variation in a gravitational field, making fit together General Relativity and quantum physics.

It is possible to have a grasp on the phenomenon of the energy levels shift, reasoning only with the variable speed of light. Processes go faster in zones with a faster speed of light: incoming photons generated in a slower light speed zone are seen as having a lower frequency. It is a sort of sampling mechanism: what is generated from a lower bit rate, is perceived relatively slower from a higher bit rate. What defines the bit rate is the light speed which totally determines the speed of the energy exchanges.

CONCLUSIONS

Feynman’s lectures contain a debated issue which could have been solved earlier, carefully analyzing the experiment of 1976 [12] . The compliance with General Relativity and the experiments excludes the extension of the equivalence principle to free energy, and excludes the existance of the gravitational potential energy of photons, any relativistic or gravitational mass of photons.
A photon does not have a gravitational mass, a rest mass or a “relativistic” mass. Only when detected a mass appears but it isn’t then a photon anymore, it is the principle of quantum physics. The inertial mass is measurable transforming a pure energy timeless entity with “c” speed, into something else massive not necessarily moving and subjected to time, according to special relativity and quantum physics. Only conservation principles and gravitational lensing can suggest that photons posess a momentum while travelling.

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