AIRBORNE COMPARISONS OF AN ULTRA-STABLE QUARTZ OSCILLATOR WITH A H-MASER AS ANOTHER POSSIBLE VALIDATION OF GENERAL RELATIVITY

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Abstract

According to general relativity, frequency gravitational shifts are the consequence of time retardation in the vicinity of massive bodies. Time retardation must cause the same relative shifts of frequencies for oscillators of all types.

According to the quasi-Newtonian approach, frequency gravitational shifts are caused by changes in parameters of oscillators: near a massive body the effective mass of classical oscillators is increased, and the energy levels of quantum oscillators are lowered. Thus, gravitational shifts in the cases of classical and quantum oscillators have different natures, and the shift predicted in the classical case are half the shift in the quantum case, which in a linear approximation coincides with the prediction of general relativity.

Note that both general relativity and the quasi-Newtonian approach agree with the experiments performed so far: gravitational effects are tiny, and they have only been observed with the help of precise quantum oscillators. But recently an ultra-stable quartz; i.e., classical, oscillator became available.

It would be of interest to compare a quartz oscillator with a quantum frequency standard onboard a plane, searching for a variation of their frequency difference which is correlated with a change in altitude. According to general relativity, the difference in their gravitational shifts should be equal to zero. According to the quasi-Newtonian approach, a 20-km change in altitude should cause an effect on the order of 1.1×10^{-12}. It could be detected by an ultra-stable quartz oscillator and by a transportable H-maser for averaging times of about 10 s with the sampling time, i.e., the period of altitude change is several minutes long.

An absence of difference in gravitational relative shifts of frequencies of quartz and hydrogen standards could be treated as an additional argument in favor of time retardation in the vicinity of massive bodies.

According to the general relativity, frequency gravitational shifts are the consequence of time retardation in the vicinity of massive bodies. Time retardation must cause the same relative shifts of frequencies for oscillators of all types, in particular, for both quantum and classical oscillators.

According to the quasi-Newtonian approach [1], frequency gravitational shifts are caused by changes in physical parameters of oscillators: in accordance with fundamental laws of conservation, near a massive body the effective mass of classical oscillator is increased, and the energy levels of quantum oscillator are lowered. Thus, gravitational shifts in the cases of classical and quantum oscillators are of different nature, and the shift predicted in the classical case is half the shift in the quantum case, which in linear approximation coincides with the prediction of general relativity.

Note that both the general relativity and our quasi-Newtonian approach agree with the experiments performed so far: frequency gravitational shifts are tiny, and they have only been observed with the help of precise quantum oscillators. But recently ultra-stable quartz, i.e., classical, oscillators, sensitive to gravitational shifts, have become available. The research of a question of whether gravitational relative shifts of frequencies of classical and quantum oscillators are the same, i.e., whether the correspondence principle is valid for gravitational shifts of frequency, would be of considerable interest, as a possibility to obtain another experimental validation of the general relativity.

Let us briefly present theoretical conclusions of the quasi-Newtonian approach. We regard the classical oscillator as a mass that is affected, while being driven off the equilibrium state, by a reverting force of purely electromagnetic nature (we don't discuss oscillators with gravity contribution to the reverting force, e.g., mathematical pendulum or elliptic-orbit satellite, because their frequencies don't depend on the mass oscillating). The classical oscillator effective mass μ_{eff} dependence on the distance R to the center of a massive body of mass M looks like

$$\mu_{eff}(R) = \mu_0\left(1 + \frac{GM}{Rc^2}\right), \tag{1}$$

where G is the gravitational constant, c is the light-speed, and the lower index "zero" means the parameter value at infinity. For all classical oscillators with the proper frequency ω being the reciprocal of the square root of mass, the Eq.(1) gives us in linear approximation

$$\omega(R) = \omega_0\left(1 - \frac{1}{2}\frac{GM}{Rc^2}\right). \tag{2}$$

In the case of a quartz oscillator, the increase of the molecules' effective masses near massive body, in accordance with Eq.(1), results in a decrease of velocity of elastic deformations, and, hence, in a decrease of oscillation frequency, as described by the Eq.(2).

As for a quantum oscillator, its energy levels are the binding energies, supporting the substance structure. For any binding energy E, i.e., for any energy level of quantum oscillator, we have got in linear approximation

$$E(R) = E_0\left(1 - \frac{GM}{Rc^2}\right). \tag{3}$$

Using the well-known Planck formula, we immediately obtain the following expression for the quantum oscillator frequency:

$$f(R) = f_0\left(1 - \frac{GM}{Rc^2}\right). \tag{4}$$

It can be seen that the frequency decrease near a massive body, described by Eq.(4), agrees with that declared by the general relativity.

As follows from Eqs.(2) and (4), the gravitational slowing of rate of the "classical" clock is half that one of the "quantum" clock. If one tries to reveal this difference by comparing the classical and quantum clocks, sited in different gravitational potentials, some problems may arise with the results' interpretation, in view of the features of electromagnetic radiation propagation in changing gravitational potential. Indeed, the general relativity claims that, firstly, identical clocks, sited in different potentials, have different rates, and, secondly, the frequency of light, propagating in changing potential, changes also [2]; the relative values of these two effects are the same, being, near the Earth surface, equal to $g\Delta h / c^2$, where g is the free-fall acceleration, and Δh is the height gain. If so, in all the experiments on gravitational "red shift" detection there would be observed a double effect, comparing with that being indeed observed. For example, Pound and Rebka, who have extracted elegantly the effect of $g\Delta h / c^2$ value with the help of Mossbauer spectroscopy [3], believed that it was the frequency shift obtained by gamma quanta moving vertically that has been measured. However, these authors did not take into account that if a source and an absorber are sited at different heights, their resonant lines have a corresponding mutual shift also. Strictly speaking, the Pound and Rebka's setup did not permit one to make a conclusion about the origin of the effect measured: whether it was a consequence of the source and absorber lines' mutual shift, or a consequence of frequency shift of gamma quanta moved vertically. But subsequent experiments with a transportable atomic clock, including air transportation of the clock, beginning with Hafele and Keating experiment [4], and also the clock operation on the board of numerous satellites, convince us that the gravitational mutual shift ($g\Delta h / c^2$) of frequencies of quantum oscillators, forming the substance structure, takes place: the upper clock runs faster than the lower one. Then it should be accepted that the gravitational "red shift" observed is completely explained by the gravitational mutual shift of frequencies of oscillators in substance, and that light quanta frequencies do not suffer gravitational shift at all. This conclusion agrees with our approach: a light quantum is not a quantum oscillator in the sense described above, and its frequency does not obey the Eq.(4).

In order to eliminate problems connected with comparisons of remote clocks, we propose to compare a quartz oscillator with a quantum standard of frequency on board a plane, searching for variation of their frequency difference correlated with change in altitude. Note that in addition to the true gravitational shift of frequency, which is the same for quartz oscillators of all types, there exist another altitude-dependent effect, caused by the gravity force influence on stress, and, hence, on elastic properties of quartz. This effect is varied, depending on the device construction, oscillation mode used, etc., so the oscillator must be pre-calibrated properly. As for the difference in gravitational shifts for the quartz and the quantum standards, the general relativity predicts this difference to be equal to zero. On the contrary, according to the quasi-Newtonian approach, the 20-km change in altitude would cause an effect of half the shift for the quantum standard, i.e., of order of $1.1 \cdot 10^{-12}$. It can be detected by an ultra-stable quartz oscillator [5] and by a transportable H-maser "Sapphir" [6] for averaging times of about 10 s with the sampling time, i.e., period of altitude change, being several minutes long, that is possible by gentle diving. When planning the experiment, it should be also taken into account that kinetic shifts of frequencies of quartz oscillator and H-maser, that are proportional to the square of their velocity in the geocentric non-rotating frame of reference, can also be not the same; the question of frequency kinetic shift for a quantum oscillator is discussed in [7].

The absence of difference in the gravitational shifts of frequencies of quartz and hydrogen standards could be treated as an additional argument in favor of time retardation in the vicinity of massive bodies.

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