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Red shift atomic and nuclear levels and the problem of energy spectrum shift of photons (γ-quanta) in the gravitational field

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Abstract. It is shown, that the radiation spectrum (or energy levels) of atoms (or nuclei) in the gravitational field has a red shift since the effective mass of radiating electrons (or nucleons) changes in this field. This red shift is equal to the red shift of the radiation spectrum in the gravitational field measured in existing experiments. The same shift must arise when the photon (or γ quantum) is passing through the gravitational field if it participates in gravitational interactions. The absence of the double effect in the experiments means that photons (or γ quanta) are passing through the gravitational field without interactions.

1 Introduction

Interpretation of the results of measurements of the radiation spectrum shift of photons (γ quanta) in the gravitational field [1-2] was discussed in works [3-5]. From the general point of view the shift of the radiation spectrum can be caused by:

a) Changing of the radiating spectrum of atoms because of influence of the gravitational field on the characteristics of the radiating particle;

b) Changing of the photons (or γ - quanta) spectrum while their passing through the gravitational field for their interactions;

c) The contribution of these both cases.

2 Red Shift Atomic (or Nuclei) Levels in the Gravitational Field

The influence of the gravitational field on atomic radiations can occur:

1) Because of the influence of the gravitational field on the radiating electron, rotating around a nucleus. In this case we must take into account the contribution of the change of gravitational field $\varphi(r)$ on atomic distances a:

$$\Delta\varphi(r) = \varphi(r+a) - \varphi(r) \simeq a\frac{\partial\varphi}{\partial r}\mid_r . \qquad (1)$$

It is obvious, that in weak gravitational fields this contribution can be neglected.

2) Because of the change of effective mass of radiating electron (or nucleon) in the gravitational field with potential $\varphi(r)$ in point r. A free electron (or nucleon) has mass m.

It is well known, that electron connected in the atom loses a part of mass Δm (defect of mass) which is equal to the energy of connection $\Delta E = \Delta mc^2$. It is a consequence of the law of the energy conservation. The same situation takes place, in a much more degree, in strong interactions, i.e. nucleus with nuclear number A consisting of Z protons and N neutrons has a defect of mass ΔM, which is equal to the energy of connection of protons and neutrons E_{int}: $\Delta M = E_{int}$.

Similarly to electromagnetic and strong interactions the gravitational interaction, which is an attracted one, will cause changing of the masses determined by the gravitational field with potential $\varphi(r)$ in the point r where the particle (electron or nucleon) is located. Then the law of conservation of the energy can be written in the following form:

$$m_{eff}c^2 = mc^2 - \mid E_{int} \mid, \qquad (2)$$

where

$$E_{int} = m\varphi(r), \qquad \varphi(r) = -(MG)/r,$$

where G- gravitational constant, M - mass of the attracting system (Earth). The Eq.(2) can be written in the following form:

$$\Delta mc^2 = \mid E_{int} \mid = m \mid \varphi(r) \mid, \quad m_{eff} = m - \Delta m,$$

where m_{eff} is mass of electron (or nucleon) connected via gravitational interaction.

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The difference of the gravitational interaction from electromagnetic and strong ones consists in the absence of discrete states and also in impossibility of energy loss while formation of the connected states through this interaction (in electromagnetic interactions it occurs through radiation of photons and in strong interactions - through radiation of hadrons). While formation of the connected states in the gravitational interactions there is a mechanical loss of energy (i.e. through strokes, and in terrestrial experiments with the help of an expenditure of energy, which compensates this defect mass).

So, in the gravitational field with potential $\varphi(r)$ the electron (or nucleon) effective mass m_{eff} is

$$m_{eff} = m(1 + \varphi(r)/c^2), \tag{3}$$

i.e. it decreases by value $m \mid \frac{\varphi(r)}{c^2} \mid$. Then the radiation spectrum (or energy levels) of electron [6] in the gravitational field has the following form:

$$E = \frac{\alpha^2 m_{eff} c^2}{2} \frac{Z^2}{n^2} [1 + \frac{\alpha^2 Z^2}{n} [\frac{1}{(j+1/2)} - \frac{3}{4n}] + ...], \tag{4}$$

where

$$\alpha = \frac{e^2}{4\pi\hbar c}; \qquad n' = 0, 1, 2...;$$

$$j = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}...; \qquad n = n' + j + \frac{1}{2} = 1, 2, 3... \qquad ,$$

and is displaced in the red side by the value ΔE (we suppose, that in E all thin effects connected to the other interactions, except for the gravitational ones, are taken into account):

$$\Delta E/E = \varphi(r)/c^2,$$

Or

$$E = h\nu, \quad \Delta\nu/\nu = \varphi(r)/c^2 = -\Delta\lambda/\lambda. \tag{5}$$

In work [2] the red shift caused by the difference of gravitational potentials on the surface of the Sun and the Earth was measured:

$$\Delta\lambda/\lambda = -(\varphi_{sun} - \varphi_{earth})/c^2,$$

and there was obtained

$$(\Delta\lambda)_{exp}/(\Delta\lambda)_{theor} = 1.01 \pm 0,06.$$

Energy levels of nuclei [7], as well as of atoms are, probably, proportional to the mass of radiating nucleon, therefore nuclear levels also will be displaced in the gravitational field according to the formulae (3) and (5) (it is interesting to note, that if the energy levels of nuclei were back proportional to masses, the red shift and effective masses increase would occur).

¿From (5) we see, that in terrestrial point r_1 with the gravitational potential $\varphi(r_1)$ the level shift is

$$\Delta_1 E/E = \varphi(r_1)/c^2, \tag{6}$$

And in terrestrial point r_2 with the gravitational potential $\varphi(r_2)$ the level shift is

$$\Delta_2 E/E = \varphi(r_2)/c^2, \tag{7}$$

then the difference of the levels in these two points is

$$\Delta_{12} E/E \equiv \Delta_{12}\nu/\nu = (\varphi(r_1) - \varphi(r_2))/c^2 =$$
$$\Delta\varphi/c^2 \equiv (\Delta\varphi)_{theor}/c^2. \tag{8}$$

The experimental results obtained in [1] have shown that in the gravitational field there is a red displacement, by the same value ΔE, determined by expression (8):

$$(\Delta\nu)_{exp}/(\Delta\nu)_{theor} = 1,05 \pm 0,10$$

And

$$\Delta V/2c = (0,9990 \pm 0,0076)\frac{\Delta\varphi}{c^2}.$$

Then, obviously, there is not any contribution remained, which is possible due to the photon (or γ - quantum) interaction with the gravitational field. We shall discuss the influence of the gravitational fields on photon (or γ - quanta) spectra because of their importance for the general relativity theory. Indeed, if photons (or γ - quanta) pass through the gravitational field without any interaction, in analogy with photon in the electrical field, then the deflection of the light beam passing near the Sun is possible to explain only its refraction in the Sun atmosphere. Let us consider this question.

3 Absence of Change of the Spectrum of Photons (or γ - Quanta) due to Their Interaction with the Gravitational Field

If the photon "mass" (further, in this section, we shall mention only photons having in view that γ - quanta behave similarly) is determined by the following expression [8] (see also references in [3-5]):

$$m_{ph} = E_{ph}/c^2 = h\nu/c^2 \tag{9}$$

(it is necessary to note, that the massive particles interact in the gravitational fields through rest masses m but not through $m' = \frac{E}{c^2} = m\gamma$), then while its movement in the gravitational field because of the variety of this field, there should be an interaction. In early interpretation (see references in [5]) it was supposed that the red shift of the photon spectrum occurs in the gravitational field because of this interaction. Then the photon "mass" will vary according to the standard formula:

$$\Delta m'_{ph} = m_{ph}\Delta\varphi/c^2. \tag{10}$$

It is obvious that light velocity c will depend on the gravitational field and $c'(r)$ will have the following form:

$$c'(r) = c/(1 - \varphi(r)/c^2) \simeq c(1 + \varphi(r)/c^2), \tag{11}$$

i.e. in the gravitational field the photon velocity will decrease and the stronger is the field in point r the less is the photon velocity.

If the photon is moving from the point r_1 to the point r_2, the velocity of the light will vary and, accordingly, the spectrum will also vary. Then the frequency of photons changes according to the following expression:

$$\Delta\nu/\nu = (\varphi(r_1) - \varphi(r_2))/c^2 \qquad (12)$$

(we suppose that in the given point the standard ratio is fulfilled between the photon characteristics, taking into account the variation of the light velocity).

¿From the physical point of view it is obvious that – if the photon interacts in the gravitational field, then its velocity, frequency change and it is deflected, i.e. the changing photon characteristics is manifestation of its interaction in the gravitational field. And if the photon does not interact in the gravitational field, then its velocity, frequency does not change and it is not deflected.

As it is already mentioned above, the experimental results obtained in [1, 2] have shown that only the gravitational effect caused by the defect of mass in gravitational field is observed, and the effect caused by the photon interactions in the gravitational field is not observed. In case if the photon interacts with the gravitational field, the double effect should be observed in the experiments (see also [9]).

It is well known, that only massive bodies and particles participate in the Newton theory of gravitation (i.e. body and particle having the rest mass). Since the photons have no rest mass, the usage of the "mass" m_{ph} obtained in the formula (9) is a hypothesis to be checked of. The check has shown (see above) that there are no photons (or γ - quanta) red shift when they are passing through the gravitational field. It is obvious, since they have no rest masses (or a gravitational charge) they cannot participate in the gravitational interactions.

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