Defect Mass in Gravitational Field and Red Shift of Atomic and Nuclear Radiation Spectra

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Abstract

It is shown, that radiation spectrum 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 radiation spectrum in the gravitational field measured in existence experiments. The same shift must arise when the photon (or $\gamma$ quantum) is passing through the gravitational field if it participates in gravitational interactions (photon has no rest mass). The absence of the double effect in the experiments, probably, means that photons (or $\gamma$ quanta) are passing through the gravitational field without interactions.

Key words: gravitational field, red shift, photon, $\gamma$ quantum, defect mass, atomic radiation spectrum, nuclei radiation spectrum, gravitational interaction, rest mass

1 Introduction

In works [1-3] the question on interpretation of the results of measurements of the radiation spectrum of the gravitational field [4] was discussed. From the general point of view shift of the radiation spectrum
can be caused by:

a) With changing of the radiating spectrum because of influence of the gravitational field on the characteristics of the radiating particle;

b) With changing of the photons (or \( \gamma \) - quanta) spectrum while their passing through the gravitational field for their interactions;

c) With the contribution of these both cases.

### 2 Defect of Mass and Red Shift of Spectrum Radiations in Gravitational Field

Influence of the gravitational field on atomic radiations can occur:

1) Because of 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 gravitational field \( \varphi(r) \) on atomic distances \( a \):

\[
\Delta \varphi(r) = \varphi(r + a) - \varphi(r) \simeq a \frac{\partial \varphi}{\partial r} \mid_r .
\]

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 \( \varphi(r) \) in point \( r \). A free electron (or nucleon) has mass \( m \).

It is well known, that electron connected in atom loses a part of mass \( \Delta m \) which is equal to the energy of connection \( \Delta E \) (defect of masses). The same situation takes place, in much more degree, in strong interactions, i.e. nucleus with nuclear number \( A \) consisting of \( Z \) protons and \( N \) neutrons has defect of mass \( \Delta M \), 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 a defect of masses, determined by the gravitational potential \( \varphi(r) \) in the point \( r \) where the particle (electron or nucleon) is located:

\[
E_{\text{int}} = m \varphi(r), \quad \varphi(r) = -\frac{MG}{r},
\]

(2)

where \( G \) - gravitational constant, \( M \) - weight of the attracting system (Earth), and then

\[
\Delta m = | E_{\text{int}} | = m \left| \frac{\varphi(r)}{c^2} \right|.
\]

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 expense of energy, which compensates this defect mass).

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

\[
m_{\text{eff}} = m \left(1 + \frac{\varphi(r)}{c^2}\right),
\]

(3)

i.e. it decreases by value \( m \left| \frac{\varphi(r)}{c^2} \right| \). Then a spectrum of electron radiation [5] in the gravitational field has the following form:

\[
E = \frac{\alpha^2 m_{\text{eff}} c^2 Z^2}{2 n^2} \left[1 + \frac{\alpha^2 Z^2}{n} \left[\frac{1}{(j + 1/2)} - \frac{3}{4n}\right] + \ldots\right],
\]

(4)

where

\[
\alpha = \frac{e^2}{4\pi\hbar c}; \quad n' = 0, 1, 2; \ldots;
\]

\[
j = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}; \ldots; \quad n = n' + j + \frac{1}{2} = 1, 2, 3; \ldots.
\]
and is displaced in the red side on the value \( \Delta E \) (we suppose, that in \( E \) all thin effects connected to the other interactions, except for gravitational ones are taken into account):

\[
\frac{\Delta E}{E} = \frac{\varphi(r)}{c^2},
\]

(5)

Or

\[
\frac{\Delta \nu}{\nu} = \frac{\varphi(r)}{c^2}.
\]

(5')

In work [6] the red shift caused by the difference of gravitational potentials on the surface of the Sun and the Earth was measured:

\[
\frac{\Delta \nu}{\nu} = \frac{\varphi_{\text{sun}} - \varphi_{\text{earth}}}{c^2},
\]

and there was obtained

\[
\frac{(\Delta \nu)_{\text{exp}}}{(\Delta \nu)_{\text{theor}}} = 1.01 \pm 0.06.
\]

Energy levels of nuclei [7], as well as of atoms, 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 violet shift would occur).

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

\[
\frac{\Delta_1 E}{E} = \frac{\varphi(r_1)}{c^2},
\]

(6)

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

\[
\frac{\Delta_2 E}{E} = \frac{\varphi(r_2)}{c^2},
\]

(7)

then the difference of levels in these two points is \( (E = h\nu) \)

\[
\frac{\Delta_{12} E}{E} \equiv \frac{\Delta_{12} \nu}{\nu} = \frac{(\varphi(r_1) - \varphi(r_2))}{c^2} = \frac{\Delta \varphi}{c^2}.
\]

(8)
The experimental results obtained in [4] have shown that in the gravitational field there is a red displacement, by the same value $\Delta E$, determined by expression (8):

$$\frac{\Delta \nu_{\text{exp}}}{\Delta \nu_{\text{theor}}} = 1.05 \pm 0.10$$

And

$$\frac{\Delta V}{2c} = (0.9990 \pm 0.0076) \frac{\Delta \varphi}{c^2}.$$ 

Then, obviously, there does not remain any contribution, which is possible due to the photon (or $\gamma$-quantum) interaction with the gravitational field. We shall discuss the influence of the gravitational fields on photon (or $\gamma$-quanta) spectra because of their importance for the general relativity theory. Indeed, if photons (or $\gamma$-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 Change of the Spectrum of Photons (or $\gamma$-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 $\gamma$-quanta behave similarly) is determined by the following expression [8] (see also references in [1-3]):

$$m_{ph} = \frac{E_{ph}}{c^2}$$

(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 variable of this field, there should be an interaction. In early interpretation (see references in [3]) it was supposed that the red shift of the photon spectrum occurs in the gravitational field because of such interaction. Then the photon mass will vary according to the standard formula:

$$\Delta m_{ph}' = m_{ph} \frac{\Delta \varphi}{c^2}. \quad (10)$$

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

$$c'(r) = \frac{c}{(1 - \frac{\varphi(r)}{c^2})} \approx c(1 + \frac{\varphi(r)}{c^2}), \quad (11)$$

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:

$$\frac{\Delta \nu}{\nu} = \frac{\varphi(r_1) - \varphi(r_2)}{c^2} \quad (12)$$

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

With the physical point of view obviously that – if the photon interacts in the gravitational field then its velocity, frequency change and it is deflected 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 [4, 6] 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). It is clear, that this question requires to be studied.

It is well known, that only massive bodies and particles participate in the Newton theory of gravitation (i.e. body and particle having 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 check of. The check has shown (see above) that, probably, there are no photons (or $\gamma$ - quanta) red shift when they are passing through the gravitational field. It is clear since they have no rest masses. In this case there is a question: How there can the deflection of photons appear in the gravitational field, if they do not participate in these interactions? It is clear, that this problem requires a solution in the experimental aspect. Let’s note, that the given question was discussed in work [9] (see also references in [9]).

4 Conclusion

It was shown, that radiation spectrum 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 radiation spectrum in the gravitational field measured in existence experiments. The same shift must arise when the photon (or $\gamma$ quantum) is passing through the gravitational field if it participates in gravitational interactions (photon has no rest mass). The absence of the double effect in the experiments, probably, means that photons (or $\gamma$ quanta) are passing through the gravitational field without interactions.

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