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# Gravitational Interaction between Photons

Fran De Aquino

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Recently, it has been reported an experiment where a very weak laser beam passes through a dense cloud of *ultracold rubidium atoms*. Under these circumstances, it was observed that the photons bound together in pairs or triplets, suggesting an unexpected *attractive* interaction between them. Here, it is shown that mentioned interaction can be related to the *gravitational interaction*.

**Key words:** Interaction Gravitational, Casimir Force, Interaction between Photons.

## 1. Introduction

In a paper recently published in *Science* [1], researchers have reported that when they have put a very weak laser beam through a dense cloud of *ultracold rubidium atoms* (as a *quantum nonlinear medium*), the photons bound together in pairs or triplets, suggesting an unexpected *attractive* interaction between them.

Here, it is shown that mentioned interaction is related to the *gravitational interaction*.

## 2. Theory

I have show in the *Mathematical Foundations of the Relativistic Theory of Quantum Gravity* [2] that, by combination of Gravitation and the *Uncertainty principle* it is possible to derive the expression for the *Casimir force*. The starting point is the expression of correlation between gravitational mass  $m_g$  and *rest* inertial mass,  $m_{i0}$ , obtained in the mentioned paper, i.e.,

$$\chi = \frac{m_g}{m_{i0}} = \left\{ 1 - 2 \left[ \sqrt{1 + \left( \frac{p}{m_{i0}c} \right)^2} - 1 \right] \right\} \quad (1)$$

where  $p$  is the variation in the particle's *kinetic momentum*;  $c$  is the light speed.

Thus, an uncertainty  $\Delta m_{i0}$  in  $m_{i0}$  produces an uncertainty  $\Delta p$  in  $p$  and therefore an uncertainty  $\Delta m_g$  in  $m_g$ , which according to Eq.(1), is given by

$$\Delta m_g = \Delta m_{i0} - 2 \left[ \sqrt{1 + \left( \frac{\Delta p}{\Delta m_{i0}c} \right)^2} - 1 \right] \Delta m_{i0} \quad (2)$$

From the uncertainty principle for position and momentum, we know that the product of the uncertainties of the simultaneously measurable values of the corresponding position and momentum components are at least of the magnitude order of  $\hbar$ , i.e.,

$$\Delta p \Delta r \sim \hbar$$

Substitution of  $\Delta p \sim \hbar / \Delta r$  into (2) yields

$$\Delta m_g = \Delta m_i - 2 \left[ \sqrt{1 + \left( \frac{\hbar / \Delta m_i c}{\Delta r} \right)^2} - 1 \right] \Delta m_i \quad (3)$$

Therefore if

$$\Delta r \ll \frac{\hbar}{\Delta m_i c} \quad (4)$$

Then the expression (3) reduces to:

$$\Delta m_g \cong - \frac{2\hbar}{\Delta r c} \quad (5)$$

Note that  $\Delta m_g$  does not depend on  $m_g$ .

Consequently, an uncertainty  $\Delta F$  in the gravitational force  $F = -G m_g m'_g / r^2$ , will be given by

$$\begin{aligned} \Delta F &= -G \frac{\Delta m_g \Delta m'_g}{(\Delta r)^2} = \\ &= - \left[ \frac{2}{\pi (\Delta r)^2} \right] \frac{hc}{(\Delta r)^2} \left( \frac{G\hbar}{c^3} \right) \end{aligned} \quad (6)$$

The amount  $(G\hbar/c^3)^{1/2} = 1.61 \times 10^{-35} m$  is called the *Planck length*,  $l_{planck}$ , (the length scale on which quantum fluctuations of the metric of the space time are expected to be of order unity).

Thus, we can write the expression of  $\Delta F$  as follows

$$\begin{aligned}\Delta F &= -\left(\frac{2}{\pi}\right)\frac{hc}{(\Delta r)^4}l_{plank}^2 = \\ &= -\left(\frac{\pi}{480}\right)\frac{hc}{(\Delta r)^4}\left[\left(\frac{960}{\pi^2}\right)l_{plank}^2\right] = \\ &= -\left(\frac{\pi A_0}{480}\right)\frac{hc}{(\Delta r)^4}\end{aligned}\quad (7)$$

or

$$F_0 = -\left(\frac{\pi A_0}{480}\right)\frac{hc}{r^4}\quad (8)$$

which is the expression of the *Casimir force* for  $A = A_0 = \left(960/\pi^2\right)l_{plank}^2$ .

Now, multiplying Eq. (8) (the expression of  $F_0$ ) by  $n^2$  we obtain

$$F = n^2 F_0 = -\left(\frac{\pi n^2 A_0}{480}\right)\frac{hc}{r^4} = -\left(\frac{\pi A}{480}\right)\frac{hc}{r^4}\quad (9)$$

This is the general expression of the *Casimir force*.

We can then conclude that *the Casimir effect* is just a *gravitational* effect related to the *uncertainty principle*. In this context, the nature of the *Casimir force* is clearly *gravitational* as shown in the derivation of Eq. (9), which expresses, in turn, the intensity of the *gravitational force in the case of very small scale* ( $r$  very small)<sup>1</sup>.

Now consider the discovery reported recently in *Science* [1]. When the researchers have put a very weak laser beam through a dense cloud of *ultracold rubidium atoms*<sup>2</sup>, the photons bound together in pairs or triplets, suggesting an unexpected *attractive* interaction between them. Now, we will show that the nature of this interaction is *gravitational*.

According mentioned in the paper, the length of the cloud of ultracold rubidium atoms were of approximately  $130\mu m$  (along the propagation direction), while the transverse extent of the probe beam waist had about  $4.5\mu m$ .

<sup>1</sup> The Casimir force is only significative when the value of  $r$  is very small (*microcosm scale*).

<sup>2</sup> The velocities of the photons through the cloud of *ultracold rubidium atoms* are strongly reduced. This is the reason for the laser to pass through the mentioned cloud. Lene Hau et al., [3] showed that light speed through a cloud of *ultracold rubidium atoms* reduces to values much smaller than  $100m.s^{-1}$ .

Therefore, the distances  $r$  between the photons of the cloud were very small. As we have already seen, at very small scale, the *gravitational interaction* cannot be treated via usual Newton's equation of gravitation. In this case, Eq. (9) must be used. Thus, assuming  $A \approx \lambda^2 = (c/f)^2 \cong 10^{-13}m^2$ , and substituting this value into Eq. (9), we obtain:

$$F \approx 10^{-40}/r^4\quad (10)$$

Using the above equation, and considering the dimensions of the mentioned cloud ( $130\mu m \times 4.5\mu m$ ), we can calculate the intensity of the *gravitational force* between two photons of the cloud, when the distance  $r$  between them were, for example, of the order of  $1\mu m$ , i.e.,

$$F \approx 10^{-16}N\quad (11)$$

The intensity of this *gravitational force* is highly significative. Compare for example, with the *Coulombian attractive force* between an *electron* and a *proton*, separated by the same distance ( $r \approx 1\mu m$ ), which is given by

$$F_c = \frac{e^2}{4\pi\epsilon_0 r^2} \cong \frac{10^{-28}}{r^2} \approx 10^{-16}N\quad (12)$$

The *Coulombian repulsive force* between two *protons* in an atomic *nucleus*, considering that,  $r_{proton} = 1.4 \times 10^{-15}m$ , and that the distance between them is  $r = 4 \times 10^{-15}m$  [4], is given by

$$F_c = \frac{e^2}{4\pi\epsilon_0 r^2} \cong 14N\quad (13)$$

This enormous repulsive force *must be overcome* by the intense *attractive nuclear force* (*strong nuclear force*).

Now consider Eq. (9), where we put  $A = \pi r_{proton}^2 \cong 6 \times 10^{-30}m^2$  and  $r = 4 \times 10^{-15}m$ , then the result is

$$F = -\left(\frac{\pi A}{480}\right)\frac{hc}{r^4} \cong 30N\quad (14)$$

Comparing Eq. (14) with Eq. (13), we can conclude that the *attractive gravitational force* (30N) is sufficient to overcome the *repulsive Coulombian force* expressed by Eq. (13).

These results lead us to formulate the following question: What is the true nature of the "strong nuclear force"? Is it *gravitational* as shown above?

## References

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