# Gravitomoments of elementary particles

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On the analogy of the electromagnetic moments of the elementary particles, we propose novel moments associated with the gravity.

In the modern science, it is well established that every elementary particle like leptons and baryons posseses a finite mass, charge, spin, electromagnetic moments, and so on. On the other hand, the study on the possible quatities of the elementary particle associated with the gravity has been limited because of the smallness of the interaction compared with other three interactions, i.e. the strong, weak and electromagnetic interactions. Only an exceptional case is an effort to measure the gravitational moment (more specifically, this terminology should be replaced by the gravitoelectric dipole moment as we discuss below in this report) of the proton[1, 2]. This type of the experiment was initiated to investigate possible violation of the CP-invariance[3, 4, 5].

In this report, we try to evaluate possible multipole gravitational moments of the elementary particles with spins as a generalized concept of the gravitoelectric dipole moment. On the basis of a classical picture, we formulated the above moments.

A gravitoelectric dipole moment is defined in the image of the electric dipole moment by

$$\vec{d}_G = m_G \vec{\ell}, \tag{1}$$

where $m_G$ is a gravitational mass and $\vec{\ell}$ is a position vector with a doubled distance between the center of inertial mass distribution and the center of gravitational mass distribution. Eq. (1) immediately suggests that as long as the equivalence principle holds, the gravitoelectric dipole moment should not exist, since $\ell$ is zero. In other words, $\vec{d}_G$ is a good probe to check the validity of equivalence principle down to the microscopic level of elementary particles.

On the analogy of the magnetic dipole moment, we can define a gravitomagnetic dipole moment created by a moving gravitational mass. This effect was, for a long time, recognized as the frame dragging effect or the Lense-Thirring effect[6] expected for the spinning celestial bodies. According to a classical picture, a spinning elementary particle induces a gravitoelectric current on the analogy that a moving electric charge induces an electric current. This gravitoelectric current, then, creates a gravitomagnetic dipole moment, $\vec{\mu}_G$. In a similar prescription in deriving the magnetic dipole moment, $\vec{\mu}_G$ can be expressed by

$$\vec{\mu}_G = \frac{1}{2}\frac{m_G}{m} \times \vec{s}, \tag{2}$$

where m is an inertial mass, and $\vec{s}$ is a spin of elementary particle ($=\frac{1}{2}\hbar$). If one assumes that the equivalence principle holds, eq. (2) is simplified;

$$\vec{\mu}_G = \frac{1}{2}\vec{s}. \tag{3}$$

This result is quite striking. Differing from the magnetic dipole moment defined by

$$\vec{\mu}_{EM} = g \times \frac{e}{2m}\vec{s}, \tag{4}$$

where g, e, and m are a g-factor, charge and inertial mass, respectively, the gravitomagnetic dipole moment is a constant independent of a mass, and charge of the elementary particle. Since our present derivation of eq. 3 is, of course, based on a classical picture, a more complete treatment based on the theory of the general relativity is essential. Nevertheless, it is valuable to further mention that a nonzero $\vec{\mu}_G$ is expected only when the elementary particle has a definite size and definite spin. In other words, a Dirac particle, i.e., a point-like particle having a spin 1/2 such as an electron, muon, and quark should not have the gravitomagnetic dipole moments. However, it is premature to conclude the above speculation as the episode on the history of the spin demonstrated[7].

A more interesting aspect of $\vec{\mu}_G$ may be expected for the hadrons. Though according to the present estimation, all the hadrons should have the same $\vec{\mu}_G$. On the other hand, since the hadrons consist of different quarks, all the hadrons may be not always necessary to have the same value of the gravitomagnetic dipole moment.

In the next, a brief touch is given on the possible measurements of these gravito moments. The gravitoelectric dipole moment may be measured by using a polarized ultra cold neutron (UCN) in a similar method to that used in the measurement of the electric dipole moment of UCN[8], in which the energy shift due to the interaction of the electric dipole moment with an external electric field can be detected.

In addition, the group from ILL, Grenoble, recently, succeeded in observing quantum states bound in the gravitational field[9] using an unpolarized very cold neutron (VCN). If one applies a polarized UCN to the above measurement, one can measure the spin spin dependence of the gravity with improved precision.

On the other hand, the measurement of $\vec{\mu}_G$ is far more difficult than that of the gravitoelectric dipole moments because of smallness. One possibility of the measurement is proposed below. $\vec{\mu}_G$ interacts only with the gravitomagnetic field, $\mathrm{H}_G$. However, the generation of $\mathrm{H}_G$ is impossible on the laboratory scale. Fortunately, there is a report that a sizable $\mathrm{H}_G$ is expected for the spinning neutron star[10]. We believe that $\vec{\mu}_G$ will, in the near future, be measued by the aide of those celestial bodies.

## References


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