

Gravitational Field Shielding by Scalar Field and Type II Superconductors

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The gravitational field shielding by scalar field and type II superconductors are theoretically investigated. In accord with the well-developed five-dimensional fully covariant Kaluza-Klein theory with a scalar field, which unifies the Einsteinian general relativity and Maxwellian electromagnetic theory, the scalar field cannot only polarize the space as shown previously, but also flatten the space as indicated recently. The polarization of space decreases the electromagnetic field by increasing the equivalent vacuum permittivity constant, while the flattening of space decreases the gravitational field by decreasing the equivalent gravitational constant. In other words, the scalar field can be also employed to shield the gravitational field. A strong scalar field significantly shield the gravitational field by largely decreasing the equivalent gravitational constant. According to the theory of gravitational field shielding by scalar field, the weight loss experimentally detected for a sample near a rotating ceramic disk at very low temperature can be explained as the shielding of the Earth gravitational field by the Ginzburg-Landau scalar field, which is produced by the type II superconductors. The significant shielding of gravitational field by scalar field produced by superconductors may lead to a new spaceflight technology in future.

1 Introduction

Gravitation is one of the four fundamental interactions of nature. According to the Newtonian universal law of gravitation, any two objects in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. According to the Einsteinian general theory of relativity, gravitation is directly related to the curvature of spacetime. The Schwarzschild solution of the general relativity for a static spherically symmetric body predicts the perihelion precession of planets, the deflection of distant star light by the Sun, the gravitational redshift of Sun's light, and the time delay of radar echoes, which have been well tested by the measurements [1-4].

To study the shielding of the gravitational field in analogous to the shielding of the electromagnetic field, Majorana [5] in 1920 modified the Newtonian gravitational field of an object with a nonzero extinction coefficient $h \neq 0$ as

$$g = g_N \exp \left[-h \int \rho(r) dr \right], \quad (1)$$

where $g_N \equiv G_0 M / r^2$ is the Newtonian gravitational field with G_0 the gravitational constant, M the mass of the object, and r the radial distance from the object center; ρ is the mass density of the object; h is the extinction coefficient. For a spherical object with a constant mass density and radius R , Eq. (1) after integrated becomes

$$g = g_N \exp \left(-\frac{3hM}{4\pi R^2} \right). \quad (2)$$

Laboratory measurements constrained $h \lesssim 10^{-15} \text{ m}^2/\text{kg}$ [6-7]. Space measurements gave $h \lesssim 10^{-19} \text{ m}^2/\text{kg}$ [8-9]. These measurements indicated that the gravitational field shielding is negligible or undetectable in the case of weak fields.

On the other hand, Kaluza [10] in 1921 proposed a five-dimensional (5D) theory to unify the Einsteinian general relativity and Maxwellian electromagnetic theory. The geometric structure and property of the 5D spacetime were then studied by Klein [11-12]. The early Kaluza-Klein (K-K) theory of unification was further developed with a scalar field [13], which can modify both the electromagnetic and gravitational fields. Some previous studies have shown that the scalar field can reduce the electromagnetic field of a charged object and thus polarize the space around the charged object or shield the electromagnetic field from the charged object [14-15]. It is equivalent to increase the free space permittivity constant. Recently, we have shown, in accord with a 5D fully covariant K-K theory, that the scalar field can also reduce the gravitational field of a body and thus flatten the space around the body or shield the gravitational field from the body [16]. It is equivalent to decrease the gravitational constant in and around the body [17].

The scalar field that was introduced to the cosmology in various models has also been considered as a candidate of dark energy for the acceleration of the universe. As the cosmic expansion, the scalar field of the universe changes over time and became repulsive about many years ago and then overcome the gravitational force to accelerate the expansion of the universe. In addition, we have recently shown that a

massive and compact neutron star can generate a strong scalar field, which can significantly shield or reduce its gravitational field, and thus can be more massive and more compact. The mass-radius relation developed under this type of modified gravity with a scalar field can be consistent with the measurements of neutron stars [18].

In this paper, we will investigate the gravitational field shielding by scalar field and type II superconductors. We suggest that the scalar field generated by the type II superconductors has the same physics and thus addable to the scalar field generated by any other types of matter. According to the five-dimensional fully covariant K-K theory with a scalar field, the scalar field of an object can shield its gravity or decrease the equivalent gravitational constant in or around the object. Therefore, the Ginzburg-Landau scalar field [19-20] generated by type II superconductors, if it has a similar physics and thus addable to the scalar field of the Earth, can cause a sample to lose a few percent of its weight or the Earth's gravity as detected by [21]. This study will quantitatively analyze the gravitational field shielding due to the scalar field generated by type II superconductors.

2 Gravitational Shielding by Scalar Field

In the 5D fully covariant K-K theory with a scalar field that has successfully unified the 4D Einsteinian general relativity and Maxwellian electromagnetic theory, the gravitational field of a static spherically symmetric object in the Einstein frame was obtained from the 5D equation of motion of matter as [16, 22]

$$g = \frac{c^2}{2\Phi^2} \left(\frac{d\Phi}{dr} + \Phi \frac{dv}{dr} \right) e^{\nu-\lambda}, \quad (3)$$

where the metric and scalar field solutions of the 5D fully covariant K-K theory are given by [23]

$$e^\nu = \Psi^2 \Phi^{-2}, \quad (4)$$

$$e^\lambda = \left(1 - \frac{B^2}{r^2} \right)^2 \Psi^{-2}, \quad (5)$$

$$\Phi^2 = -\alpha^2 \Psi^4 + (1 + \alpha^2) \Psi^{-2}, \quad (6)$$

with

$$\Psi = \left(\frac{r-B}{r+B} \right)^{1/\sqrt{3}}, \quad (7)$$

$$B = \frac{G_0 M}{\sqrt{3}(1 + \alpha^2)c^2}, \quad (8)$$

$$\alpha = \frac{Q}{2\sqrt{G_0 M}}. \quad (9)$$

Here M and Q are the mass and electric charge of the object.

For a neutral object (i.e., $\alpha = 0$ or $Q = 0$), the gravitational field Eq. (3) obtained from the 5D fully covariant K-K theory with a scalar field can be simplified to [17]

$$g = g_N \left(1 - \frac{B^2}{r^2} \right)^{-3} \Phi^{-7} = \frac{1}{64} \left(\Phi^{\sqrt{3}} + 1 \right)^6 \Phi^{-7-3\sqrt{3}}, \quad (10)$$

where the scalar field Φ and the critical or singular radius B of the K-K solution are simplified as

$$\Phi = \Psi^{-1}, \quad B = \frac{G_0 M}{\sqrt{3}c^2}. \quad (11)$$

The singular radius B of the K-K solution is a factor of $\sqrt{3}/6$ times smaller than the Schwarzschild radius. Eq. (10) indicates that the gravitational field obtained from the 5D fully covariant K-K theory with a scalar field is influenced by the scalar field Φ . This type of influence can be understood as the gravitational field shielding by scalar field.

In the case of weak fields (i.e., $B \ll r$ or in other words, when the gravitational potential energy of a particle is much smaller than the rest energy of the particle), we can approximately simplify g as

$$g = g_N \left(1 - \frac{14G_0 M}{3c^2 r} \right) = 1 - 7\delta\Phi. \quad (12)$$

Here we have replaced $\Phi = 1 + \delta\Phi$. Comparing the field at the surface of object between Eq. (2) and Eq. (12), we obtain the extinction coefficient as

$$h = \frac{56\pi G_0 R}{9c^2} \sim 1.5 \times 10^{-26} R, \quad (13)$$

which is about $h \sim 1.5 \times 10^{-26}$ m²/kg for an object with radius of one meter and about $h \sim 10^{-19}$ m²/kg for an object with the size of Earth. It is seen that the gravitational field shielding by scalar field is undetectable in a laboratory experiment since the extinction coefficient is very small for an object with laboratory scale size. For an object with Earth's radius $R \sim 6.4 \times 10^6$ m, the extinction coefficient is $h \sim 10^{-19}$, the order of the space measurements. This analysis is valid only for the case of weak fields.

The reason for the gravitational field to be shed is the significance of the scalar field, which rapidly increases as the radial distance approaches to the singular radius, i.e., $r \rightarrow B$ (Top panel of Figure 1). The gravitational field is inversely proportional to the scalar field with a power of $7 - 3\sqrt{3} \sim 1.8$ if $\Phi \gg 1$ as shown in Eq. (10). By writing Eq. (10) as the Newtonian form of the gravitational field

$$g = \frac{GM}{r^2}, \quad (14)$$

where the G is defined as an equivalent gravitational constant

$$G = G_0 \left(1 - \frac{B^2}{r^2} \right)^{-3} \Phi^{-7} = \frac{1}{64} \left(\Phi^{\sqrt{3}} + 1 \right)^6 \Phi^{-7-3\sqrt{3}}. \quad (15)$$

This suggests that the gravitational field shielding occurs because the strong scalar field significantly varies or decreases the equivalent gravitational constant around the object.

To investigate the gravitational shielding by scalar field in the case of strong fields, we plot in the bottom panel of Figure 1 the gravitational field or constant ratio (g/g_N or G/G_0)

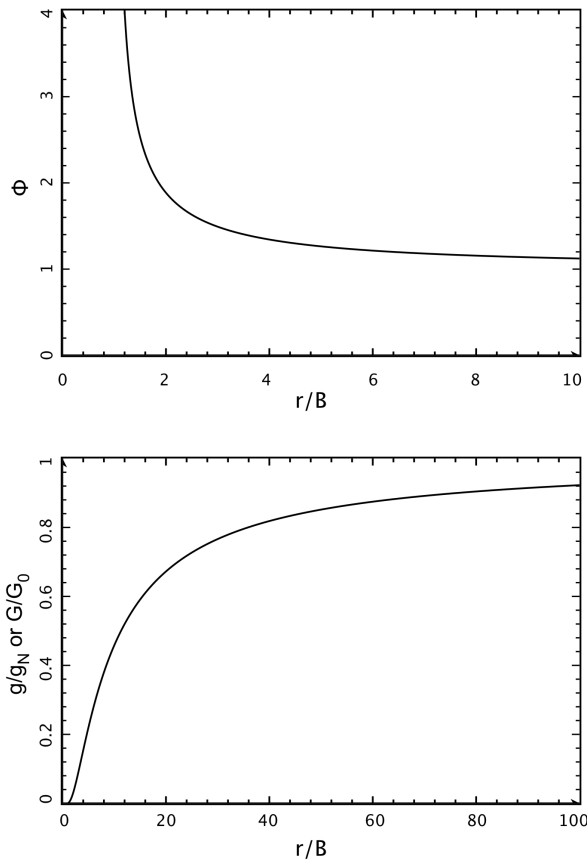


Fig. 1: Scalar field and gravitational field shielding by scalar field. Top panel: the scalar field (Φ) and bottom panel: the ratio between the K-K and Newtonian gravitational field or constant (g/g_N or G/G_0) of a neutral object vs. the normalized radial distance r/B [17].

as a function of the radius distance (r/B) [17]. It is seen that the gravitational field is significantly reduced (or shed) by the scalar field when r is comparable to B . For instances, the gravitational field is shed by $\sim 10\%$ (or the percentage of weight loss for a sample object) at $r = 100B$, by $\sim 20\%$ at $r = 35B$, by $\sim 40\%$ at $r = 15B$, by $\sim 80\%$ at $r = 5B$, and $\sim 100\%$ at $r = B$. Therefore, for a weak field, the relative difference of the field is small and thus the shielding effect is negligible. For a strong field, however, the gravitational field or constant ratio is small or the relative difference of the field is large so that the shielding effect is significant. The gravitational field of an object, when $r = B$ or its mass-to-radius ratio is about $M/r \approx 2 \times 10^{27}$ kg/m, is completely shed by the strong scalar field or by the huge amount of mass enclosed. As shown in the top panel of Figure 1, the scalar field increases as r approaches B . The scalar field is ~ 1.4 at $r = 4B$, ~ 4 at $r = 1.6B$, and tends to infinity when $r \rightarrow B$. When the scalar field is unity (i.e., $\Phi = 1$), we have $g/g_N = 1$, which refers to that the gravitational field is not shed. When the

scalar field significantly departs from the unity, for instance, at $\Phi = 1.2$ or $\delta\Phi = 0.2$, we have $g/g_N \approx 0.3$, which refers to that a 70% of gravitational field is shed by the scalar field.

3 Gravitational Shielding by Type II Superconductors

About two decades ago, Podkletnov and Nieminen [21] experimentally discovered that a bulk sintered ceramic (type II superconductor) disk of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ can have a moderate shielding effect against the gravitational field. This effect increases with the speed of disk rotation and also depends on the temperature. It was suggested that the shielding effect is the result of a certain state of energy that exists inside the crystal structure of the superconductor at low temperature. This state of energy changes the interactions between electromagnetic, nuclear, and gravitational fields inside a superconductor, and is responsible for the observational phenomena. But a shielding physics has not yet been developed.

Here, we propose a possible shielding physics to explain this phenomena. According to the Ginzburg-Landau theory, a rotating disk of type II superconductor at the phase transition with low temperature (e.g., 70K) generates a scalar field [19-20, 24-30] that varies the equivalent gravitational constant along with the Earth scalar field in and around the superconductor and thus shields the gravitational field of the Earth. According to the 5D fully covariant K-K theory and solution, the scalar field of the Earth at the surface is about the unity because $B \ll r$. Now, in the Podkletnov and Nieminen's experiment, the ceramic (or type II) superconductor can produce an extra scalar field $\delta\Phi$, which is responsible for the small weight loss of the sample.

Based on the previously-developed Landau theory of the second-order phase transition, Ginzburg and Landau [19, 30] showed that the free energy F of a superconductor per unit volume near the transition can be expressed in terms of a complex order parameter field ψ by

$$F = F_n + a|\psi|^2 + \frac{b}{2}|\psi|^4 + \frac{1}{2m}|(-i\hbar \nabla - 2e\vec{A})\psi|^2 + \frac{|\vec{B}|^2}{2\mu_0}, \quad (16)$$

where F_n is the free energy in the normal phase, a and b are phenomenological parameters, m is an effective mass, e is the charge of electron, \vec{A} is the magnetic vector potential and \vec{B} is the magnetic field. The absolute value of the complex order parameter field $|\psi|$ can be considered as a real scalar field called Ginzburg-Landau scalar field denoted here by $\Phi_{\text{GL}} \equiv |\psi|$. Then, in Eq. (16), the second and third terms are the scalar field potential energy; the first part of the fourth term is the scalar field kinetic energy; and the other parts of the fourth term give the energy that couples the scalar field and magnetic field; and the last term is the energy of magnetic field.

By minimizing F with respect to fluctuations of ψ and \vec{A} , one can derive the Ginzburg-Landau equations [30-31]

$$a\psi + b|\psi|^2\psi + \frac{1}{2m}(-i\hbar \nabla - 2e\vec{A})^2\psi = 0, \quad (17)$$

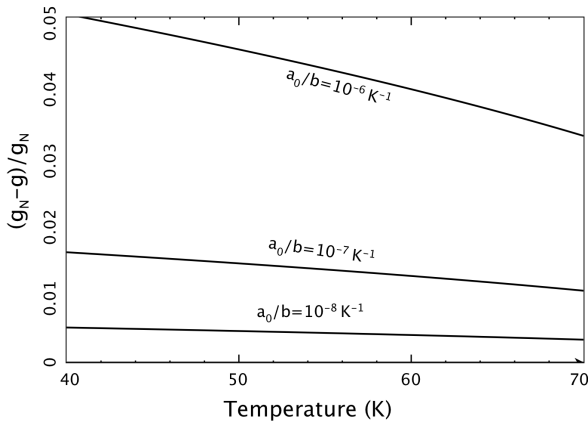


Fig. 2: Gravitational field shielding by scalar field associated with type II superconductor disk. The percentage of weight loss of the sample is plotted as a function of the temperature of the type II superconductors [17].

$$\vec{j} = \frac{2e}{m} \text{Re}[\psi^* (-i\hbar \nabla - 2e\vec{A})\psi], \quad (18)$$

where \vec{j} is the electrical current density, which is real.

For a homogeneous superconductor, in which $\vec{j} = 0$, Eq. (17) can be simplified to

$$a\psi + b|\psi|^2\psi = 0. \quad (19)$$

The solution $\psi = 0$ is trivial and corresponds to the normal state of the superconductor above the superconducting transition temperature T_c . The non-trivial solution of Eq. (19) determines the Ginzburg-Landau scalar field

$$\Phi_{\text{GL}} \equiv |\psi| = \sqrt{-\frac{a}{b}} = \sqrt{-\frac{a_0}{b}(T - T_c)}. \quad (20)$$

Here, we have assumed the temperature dependence of a to be $a = a_0(T - T_c)$ with positive ratio a_0/b . For the YBCO superconductor, $T_c \sim 93$ K. Suggesting all types of scalar fields to be similar in physics and addable, we obtain the total scalar field in or around a type II superconductor,

$$\begin{aligned} \Phi_{\text{total}} &= \Phi_{\text{Earth}} + \Phi_{\text{GL}} \\ &= 1 + \frac{2G_0 M_E}{3c^2 R_E} + \sqrt{-\frac{a_0}{b}(T - T_c)}, \end{aligned} \quad (21)$$

where M_E and R_E are Earth's mass and radius.

To quantitatively study the gravitational field shielding by the Ginzburg-Landau scalar field along with the Earth scalar field, we plot in Figure 2 the weight relative loss of the sample or the gravitational field relative change at the sample as a function of the temperature of the type II superconductor. It is seen that the weight relative loss of the sample or the gravitational field relative change increases as the temperature decreases or as the ratio a_0/b increases. At $T \sim 70$ K

and $a_0/b \sim 10^{-8} - 10^{-6}$, the weight relative loss or the gravitational field relative change is $\sim 0.5 - 3\%$, which can be the order of measurements [21].

4 Discussion and Conclusion

For a rotating disk of type II superconductor, the acceleration of inertially moving cooper pairs in the superconductor is equivalent to a gravitational field, which may couple with the Ginzburg-Landau scalar field to produce an extra shielding effect on gravity as shown in [21]. In future study, we will quantitatively analyze the rotation dependence for the gravitational field shielding by the Ginzburg-Landau scalar field of type II superconductors.

As a consequence, we have analytically studied the gravitational field shielding by scalar field and type II superconductors, in accord with the 5D fully covariant K-K theory with a scalar field and the Ginzburg-Landau theory for superconductors. The results have indicated that the gravitational field shielding by the scalar field of a body is very small at an undetectable level if the field is weak. The extinction coefficient derived from the comparison with the Majorana's gravitational field shielding theory is consistent with laboratory and space measurements. In the case of strong fields, however, the gravitational field shielding effect can be significant. This will have important applications in strong-field astrophysics and greatly impact the physics of supernova explosions, the models of neutron stars for their mass-radius relations, and the theory of black hole formations.

Detection of the gravitational field shielding is a challenge to a laboratory experiment, but possible especially when the object becomes a superconductor. A type II superconductor may produce a significant Ginzburg-Landau scalar field at the phase transition and thus may be used to shield gravity as claimed by [21]. The result obtained from this study can be consistent with the measurements. The significant shielding of gravitational field by scalar field produced by superconductors may lead to a new spaceflight technology in future. The gravitational field shielding by type II superconductors still need further experimentally confirmed.

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