

Exotic Material as Interactions Between Scalar Fields

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Many theoretical papers refer to the need to create exotic materials with average negative energies for the formation of space propulsion anomalies such as “wormholes” and “warp drives”. However, little hope is given for the existence of such material to resolve its creation for such use. From the standpoint that non-minimally coupled scalar fields to gravity appear to be the current direction mathematically. It is proposed that exotic material is really scalar field interactions. Within this paper the Ginzburg-Landau (GL) scalar fields associated with superconductor junctions is investigated as a source for negative vacuum energy fluctuations, which could be used to study the interactions among energy fluctuations, cosmological scalar (i. e., Higgs) fields, and gravity.

1 Introduction

Theoretically, exotic material can be used to establish wormholes by gravitationally pushing the walls apart [1] and for the formation of a warp bubble [2] by providing the negative energy necessary to warp spacetime. Exotic material in combination with gravitation might also produce a net acceleration force for highly advanced propellant-less space propulsion engine cycles.

Negative energy is encountered in models of elementary particles. For example, Jackson [3] invokes Poincare stress, to suppress the TeV/c^2 contribution of electromagnetic field energy to the MeV/c^2 mass of an electron. Also, the Reissner-Nordstrom metric [4], devised 50 years before the development of scalar fields, predicts effects which are negligible more than a few *femtometers* [10^{-15} m] from a charged particle.

Exotic material has the requirement of a “negative average energy density”, which violates several energy conditions and breaks Lorentz symmetries. Pospelov and Romalis [5] tell us that the breaking of Lorentz symmetry enables the CPT symmetry, which combines charge conjugation (C), parity (P), and time-reversal (T) symmetries, to be violated. In conventional field theories, the Lorentz and CPT symmetries are automatically preserved. But in quantum gravity, certain restrictive conditions such as locality may no longer hold, and symmetries may be broken. They also suggest that quintessence, a very low-energy $5 \text{ keV}/\text{cm}^3$ scalar field ψ with wavelength comparable to the size of the observable universe, is a candidate for dark energy. For in addition to its effect on the expansion of the universe, quintessence might also manifest itself through its possible interactions with matter and radiation [6, 7]. This scalar interaction could lead to a modification of a mass as a function of coordinates and violates the equivalence principle: The mass feels an

extra force in the direction of $\nabla\phi$ (ϕ is the phase of the scalar field ψ).

The question is then “Where do we look for exotic material on the scale of laboratory apparatus?” From the standpoint that non-minimally coupled scalar fields to gravity appear to be the current direction mathematically [8]. It is proposed that exotic material is really scalar field interactions.

Within this paper the Ginzburg-Landau (GL) scalar fields associated with superconductor junctions is investigated as a source for negative vacuum energy fluctuations, which could be used to study the interactions among energy fluctuations, cosmological scalar (i. e., Higgs) fields, and gravity. Such an analogy is not much a stretch as it is not hard to show that the Higgs model is simply a relativistic generalization of the GL theory of superconductivity, and the classical field in the Higgs model is analog of cooper-pair Bose condensate [9]. Here, the mechanisms for scalar field interactions or the production of exotic material from the superconductor are discussed and an analogy to energy radiated in gravitational waves is presented.

2 Background

Theoretical work [1] has shown that vacuum fluctuations near a black hole’s horizon are exotic due to curvature distortion of space-time. Vacuum fluctuations come about from the notion that when one tries to remove all electric and magnetic fields from some region of space to create a perfect vacuum, there always remain an excess of random, unpredictable electromagnetic oscillations, which under normal conditions averages to zero. However, curvature distortion of space-time as would occur near black holes causes vacuum energy fluctuations to become negative and therefore are “exotic”. In earlier wormhole theories [10, 11], exotic material was

generally thought to only occur in quantum systems [1]. It seems that the situation has changed drastically; for it has now been shown that even classical systems, such as those built from scalar fields non-minimally coupled to gravity; violate all energy conditions [8]. Gradually, these energy conditions are losing their status, which theoretically could lead even to a workable “warp drive” [12]. Further, recent mathematical models have shown that the amount of energy needed for producing wormholes (and possibly warp drives) is much less than originally thought [13], which may open the door to laboratory scale experiments.

Given that the answer to exotic material for practical propulsion applications is somewhere in between vacuum fluctuation in curved space-time and scalar fields non-minimally coupled to gravity, Ginzburg-Landau (GL) scalar fields associated with superconductor junctions could present themselves as a medium for studying the interactions among energy fluctuations, cosmological scalar fields, and gravity. As in superconductors, the GL scalar field is known [14] to extend small distances beyond the boundaries of a superconducting material. That is, in describing the operation of a Josephson junction array, two or more superconductors can be entangled over gaps of several micrometers, which is large compared to atomic distances.

The introduction of scalar fields into cosmology has been problematic. For example, the Higgs scalar field [15] of particle physics must have properties much different from the scalar field hypothesized to cause the universe to increase its expansion rate 5G years ago. However, the study of particle physics in conjunction with inflationary cosmology presents a new understanding of present day physics through the notion of symmetry breaking [9]. This suggests that the GL scalar field could possibly bridge the gap between the subatomic energy and distance scale of particle physics and the galactic scale of scalar fields in cosmology?

3 Landau-Ginzburg field in the superconductor

The Landau-Ginzburg (GL) field ψ is described as a scalar function

$$\psi = \sqrt{n} e^{j\theta}, \quad (1)$$

where \sqrt{n} infers the degree of electron interactions in the superconductor and θ is the phase factor of these interactions.

Electrons in a room temperature superconductor material or normal conductor with no applied external fields are either confined to an atom or move about the composite molecules with random phases; $\sum \phi \approx 0$ (disorder state). However, they are generally thought to be confined to the vicinity of background ions and are positionally fixed. When the superconductor material is cooled to its critical temperature at which time a phase transition occurs, the electrons suddenly agree on a common phase; $\sum \phi > 0$ (ordered state). Again they are generally thought to be confined to the vicinity of

background ions and are localized as opposed to gathering in some region creating a large space charge potential.

In a type I superconductor and as the bulk superconductor material cools down (or warms up), various size domains (depending on the cool-down, or warm up, profile) of superconductive material can form surrounded by normal conductive material. When two or more domains are in close proximity, a superconductor-normal conductor-superconductor Josephson junction is formed. In a typical bulk type I superconductor, composed of small randomly arranged crystals or grains, proximity effects would cause the electrons of a single grain to go superconductive (or normal) as a group.

In the type II YBCO superconductor this is also true with the exception that weakly coupled Josephson junctions [16] can also form between individual molecules across the copper oxide planes and across grain boundaries typically composed of an oxide layer. These are referred to as superconductor-insulator-superconductor junctions. The insulation planes degrade the time for proximity effects to cause the electrons of a single grain to go superconductive (or normal) as a group. Therefore in the type II superconductor, a superconductor domain can be as small as one molecule of superconductor material or composed of a multitude of molecules (i. e., grains).

In both the type I & II superconductor at temperatures below ~ 44 K, coherence encompasses all domains, in effect producing one single domain of phase ϕ .

When multiple domains exist, gradients between domains of differing phase ϕ are accompanied by currents that tunnel between the domains as the spaces between the domains form Josephson junctions [14]. The possible current patterns are restricted by the requirement that the GL scalar function ψ must be single-valued and infers a current flow of density \vec{J} given by

$$\vec{\nabla} \arg \psi = \vec{\nabla} \phi = \frac{m}{2\hbar e |\psi|^2} \vec{J}; \quad (2)$$

neglecting contributions from external magnetic fields.

3.1 The Landau-Ginzburg free energy potential

The Landau-Ginzburg free energy potential $V(\psi)$ refers to the energy density in the superconductor, and anywhere the scalar field is non-zero. It can even extend into a region μm outside the superconductor. The potential contribution to the free energy (neglecting contributions from external magnetic fields) is given by the energy density function:

$$V(\psi) = \alpha |\psi|^2 + \frac{1}{2} \beta |\psi|^4, \quad (3)$$

where equation (3) can be viewed as a series expansion in powers of $|\psi|^2$.

Two cases arise as depending whether α is positive or negative. If α is positive, the minimum free energy occurs at $|\psi|^2 = 0$, corresponding to the normal state. On the other

hand, if $\alpha < 0$, the minimum occurs when

$$|\psi|^2 = |\psi_\infty|^2 = \frac{1}{2} \sqrt{n_1 n_2} \approx \frac{n_{3D}}{2} \quad (4)$$

for identical domain materials (which is assumed hereon) where the notation ψ_∞ is conventionally used because ψ approaches this value infinitely deep in the interior of the superconductor [17], where it is screened from any surface fields or currents. If the two domains are similar in crystalline structure, the two domains can be viewed as a single bulk superconductor and the Landau-Ginzburg free energy potential case for $\alpha < 0$ applies. For $\alpha < 0$

$$V(\psi_\infty) = \frac{-\alpha^2}{2\beta} = \frac{1}{2} \alpha |\psi_\infty|^2, \quad (5)$$

which gives

$$\alpha = \frac{2}{|\psi_\infty|^2} V(\psi_\infty); \quad \beta = \frac{2}{|\psi_\infty|^4} V(\psi_\infty). \quad (6)$$

4 High power flow during phase transition

Given a uniform superconductor, the average energy E_J in the junction between domains is defined by

$$E_J \leq \Delta |\psi|^2 \bar{V}_g \approx \frac{1}{2} \Delta n_{3D} \bar{V}_g. \quad (7)$$

For the Type II YBCO superconductor $n_{3D} \approx 1.69 \times 10^{28} \text{ m}^{-3}$ and $\Delta = 0.014 \text{ eV}$ [17, 18]. Given that grain size diameters in a typical sinter YBCO superconductor are on the order of 1 micron, then for an average domain volume $\bar{V}_g \approx 10^{-18} \text{ m}^3$, the energy in the junction $E_J \approx 10^2 \text{ GeV}$. If the junction energy dissipates on the superconductor relaxation time τ_{sc} , the powers flow $E_J/\tau_{sc} \approx 10^{24} \text{ eV/s}$ for the YBCO relaxation time $\tau_{sc} \approx 10^{16} \text{ s}$.

Such high energy changes during a normal state transition seems a bit extreme, especially considering that not much (if any) is mentioned of this phenomena in the literature. The main reason is that most of the energy should not be seen external to the superconductor since the initial energy transfer from the state change is an internal process. However radiation is known to accompany processes involving charged particles, such as β decay.

Jackson [3] tells us that the radiation accompanying β decay is a Bremsstrahlung spectrum: It sometimes bears the name ‘‘inner bremsstrahlung’’ to distinguish it from bremsstrahlung emitted by the same beta particle in passing through matter. It appears that the spectrum extends to infinity, thereby violating conservation of energy. Qualitative agreement with conservation of energy can obtain by appealing to the uncertainty principle. That is, the acceleration time τ must be of the order of $\tau = \hbar/E$, thereby satisfying the conservation of energy requirement at least qualitatively.

In the superconductor, the uncertainty principle (at least

qualitatively) allows for the violation of energy conservation through rapid state change processes, which can produce vortices in the superconductor when proper phase alignment exists among domains [19]. In such a case, high energy radiation, such as Bremsstrahlung accompanying the rapid magnetic field formation cannot be ruled out as theories of superconductivity are not sufficiently understood. This is especially true with the type II superconductor, which exhibits flux pinning throughout the body of the superconductor and allows for flux motion during phase transition.

Further, energy levels of $E_J \approx 10^2 \text{ GeV}$ in the domain junctions could produce tunneling electrons with critical temperature for a phase transition in the Glashow-Weinberg-Salam theory of weak and electromagnetic interactions [20]. Such high energy phase transitions could then lead to effects similar to cosmology inflation, an anti-gravity force thought responsible for the acceleration of the universe [21].

5 Mechanisms for exotic material in the superconductor

In order to produce exotic material or negative vacuum energy fluctuations from superconductors in terms of curvature distortion of spacetime, asymmetric energy fluctuations must be produced. Since the Landau-Ginzburg free energy density is fixed by the number superconductor electrons, the average time rate of change or phase transition time of the superconductor electrons must be asymmetric. That is the power flow eV/s in the phase transition to the superconductor state must be higher than the power in the phase transition to the normal state or vice versa. This process of creating a time varying GL scalar field might then result in a gradient in the surrounding global vacuum scalar field (Higgs, quintessence, or etc.) in the direction of $\nabla\phi$; being measurable as a gravitation disturbance.

Asymmetric phase transitions would require electrons with group velocities that are higher than their normal relaxation times, which are already relativity short. The combination of two phenomena associated with superconductors could achieve this requirement. They are:

- (1) The dissipation of the Landau-Ginzburg free energy potential during a rapid superconductor quench referred to as spontaneous symmetry breaking phase transition [22], which implies state changes on very short time scales;
- (2) The Hartman effect [23], which implies that the effective group velocity of the electrons across a superconductor junction can become arbitrarily large.

Both spontaneous symmetry breaking and the Hartman effect illustrates Hawking’s [24] point about the elusive definition of time in a quantum mechanical process. That is, uncertainty in the theory allow time intervals to be chosen to illustrate how measurable effects might be produced outside the superconductor without contradicting experiments with

conventional solid state physics detectors. One such time interval of notice is that which occurs during a spontaneous symmetry breaking phase transitions.

5.1 Spontaneous symmetry breaking phase transition

Phase transitions between the high and low temperature phases of a superconductor involve spontaneous symmetry breaking between order (superconductor electron pair) and disorder (electron) states when the transition occurs over shorter time periods than depicted by the normal relaxation times. Kibble [25] explains that symmetry-breaking phase transitions are ubiquitous in condensed matter systems and in quantum field theories. There is also good reason to believe that they feature in the very early history of the Universe. At which time many such transitions topological defects of one kind or another are formed. Because of their inherent stability, they can have important effects on the subsequent behavior of the system. Experimental evidence validates this by the presence of a magnetic field [26, 27, 19, 28] during spontaneous symmetry breaking phase transition experiments.

In general, each superconductor domain must be taken to follow normal phase transition symmetry, which follows that the energy within these domains is conserved as anomalous energy effects have not been observed during rapid superconductor quenching of low temperature superconductive systems, which have been around for decades. However, it is conceivable that, a small fraction of the energy could be expended in disturbing nearby vacuum fields, without being noticed by crystal-switching apparatus. Since experimentally, the formation of vortices does occur during spontaneous symmetry breaking phase transitions of coupled domains in the Type II superconductor, Lorentz symmetry is violated. This allows for energy conservation violation, whereby, the assumption can be made that the energy fluctuations in the junction between superconductor domains interacts with the vacuum field on a time scale that approaches that of the Planck scale.

Evidence of this comes from Pospelov and Romalis [5], who point out that Lorentz violation could possibly be due to unknown dynamics at the Planck scale. Further, when dealing with interactions described by massless vector particles (gluons) within a relativistic local quantum field theory, Binder [42] indicates that Planck units are assigned to the background fluctuation level and provide for a common base. The gluon field plays the same role for quarks as Jackson's Poincare stress plays for electrons. Therefore, the choice for the energy fluctuation time during a spontaneous symmetry breaking phase transition of electron pairs is taken to be the Planck time T_{pl} .

However, the Planck time is too fast to be observed, which implies that human units must be artificially imposed when measuring superconductor electron fluctuations (or any

other Planck time phenomena). To explain this, it is noted that just before electron phase transition and superconductor pair bonding, each electron had an energy deficit ≈ 1 eV. From the uncertainty principle, the electron can maintain this deficit before pairing for a time t according to

$$t = \frac{\hbar}{E}, \quad (8)$$

which for the paired electron $E \approx 2$ eV giving $t \approx 3.3 \times 10^{-16}$ sec. Then by noting

$$E_p T_{pl} = E t = \hbar \quad (9)$$

a limitation on the electron power flow exist at $E = E_p$ (the Planck energy) and $t = T_{pl}$. This limitation gives the human artificial units for Planck time events according to

$$t = \frac{E_p}{E} T_{pl}. \quad (10)$$

For example, during an electron pair transition where $t \approx 3.3 \times 10^{-16}$ s, a power flow $E/T_{pl} = E_p/t \approx 10^{43}$ eV/s per superconductor electron pair is produced, which is much less than the limit defined by $E_p/T_{pl} \approx 10^{71}$ eV/s.

That is, even though the event could have occurred on the Planck time T_{pl} , it took a time t to observe/measure the energy released. According to the uncertainty principle, the observed/measured value of the energy is then

$$E = \left(\frac{T_{pl}}{t} \right) E_p. \quad (11)$$

Equation (11) then tells us that energy events that occur on the Planck time are reduced by the ratio of the Planck time to the observed/measured time.

The question is then, "Can this uncertainly in the energy be captured in such a way as to be useable on the human scale?" Evidence for a yes answer arises in superluminal electron velocities in nature, which have been associated with cosmological events, lasers and electrostatic acceleration [29, 30, 31]. In these events however, the total energy in the system is interpreted from the average group velocity, whereby energy is conserved.

5.2 The Hartman effect

In the superconductor another superluminal electron phenomena exists, the Hartman effect [23, 32, 33], which is associated with the junction tunnelling process. The Hartman effect indicates that for sufficiently large barrier widths, the effective group velocity of the electrons across a superconductor junction can become arbitrarily large, inferring a violation of energy conservation.

Muga [34] tells us that defining "tunnelling times" has produced controversial discussion. Some of the definitions proposed lead to tunnelling conditions with very short times,

which can even become negative in some cases. This may seem to contradict simple concepts of causality. The classical causality principle states that the particle cannot exit a region before entering it. Thus the traversal time must be positive. However, when trying to extend this principle to the quantum case, one encounters the difficulty that the traversal time concept does not have a straightforward and unique translation in quantum theory. In fact for some of the definitions proposed, in particular for the so called “extrapolated phase time” [35], the naive extension of the classical causality principle does not apply for an arbitrary potential, even though it does work in the absence of bound states.

Generally, the Hartman effect occurs when the time of passage of the transmitted wave packet in a tunnelling collision of a quantum particle with an opaque square barrier or junction becomes essentially independent of the barrier width [23, 36] and the velocity may exceed arbitrarily large numbers. This “fast tunnelling” has been frequently interpreted as, or related to, a “superluminal effect”, see e.g. [37, 38, 39, 40, 41].

The Hartman effect illustrates Hawking’s (1988) discussion about ambiguities in defining time in relation to quantum mechanics and cannot be ruled out during spontaneous symmetry breaking phase transition. Therefore, large power flows across the junctions between the domains or junctions are allowed.

6 Energy radiated in gravitational waves

Arbitrarily large electron group velocities (the Hartman effect) induced by spontaneous symmetry breaking phase transitions could conceivably result in a space-like (gravitational) disturbance in nearby vacuum scalar fields with possible momentum and energy transfer about these disturbances for space propulsion applications. Although, a theory that connects the GL scalar field to gravity has yet to be presented, here the general formulation for calculating gravitational radiation from quadrupolar motion [43] is used to illustrate the possible energy radiated in a gravitational wave from the instantaneous power flow through a type II superconductor.

The power radiated L_{rad} in gravitational waves is roughly approximated from the ratio of the square of the internal power flow $\Delta E/\Delta t$ by

$$L_{rad} = \left(\frac{G}{c^5}\right) \left(\frac{\Delta E}{\Delta t}\right)^2. \quad (12)$$

The time parameter Δt in equation (11) is ill-defined, since General Relativity cannot incorporate the uncertainties of quantum mechanics. For as previously pointed out, even times as short as the Planck time can be used without violating experimental observations.

Here, the time parameter is determined by noting that at the instant of the release of the GL free energy there is a

freeze out time:

$$\hat{t} = \sqrt{T_{pl} \tau_{sc}} \quad (13)$$

between the transition from the adiabatic (Planck time fluctuations T_{pl}) and impulse (relaxation time τ_{sc}) regimes [26]. This implies an inherent limitation on the power flow through the superconductor, which from equation (10) implies that

$$\frac{\Delta E}{\Delta t} = \frac{E}{T_{pl}} \rightarrow \frac{E_p}{\eta \hat{t}} \quad (14)$$

where $\Delta t = \eta \hat{t}$ and where η combines geometric (i. e., size, shape, number of domains, & etc.), I-V junction characteristics [44, 45], and any other influence on the propagation of the electrons through the superconductor.

Given that the observed/measured propagation speed of the GL free energy (i. e., electron motion) through the superconductor is limited to the speed of light c , then

$$\eta \rightarrow \frac{T_h}{c \hat{t}} \quad (15)$$

Combining equation (12) with equations (14 & 15) the instantaneous power radiated in gravitational waves is given by

$$L_{rad} \rightarrow \left(\frac{G}{c^5}\right) \left(\frac{E_p}{\eta \hat{t}}\right)^2 \approx \left(\frac{G}{c^5}\right) \left(\frac{E_p c}{T_h}\right)^2 \quad (16)$$

and the radiated energy in gravitational waves:

$$E_{rad} \rightarrow L_{rad} \hat{t} \quad (17)$$

from the freeze-out motion within the superconductor and noting that the gravitational waves is not effected by the superconductor properties (i. e., η).

Assuming a superconductor of thickness $T_h \approx 0.0254$ m, gives the maximum instantaneous power radiated in gravitational waves $L_{rad} \approx 10^{42}$ eV/s and radiated gravitational waves energy $E_{rad} \approx 10^{13}$ eV or $\approx 10^{-4}$ J; measurable on the laboratory scale.

7 Conclusions

The Ginzburg-Landau scalar field associated with the type II superconductor was discussed as a source of exotic material to produce gravitational forces for highly advanced propulsion related systems. Arbitrarily large electron group velocities (the Hartman effect) induced by spontaneous symmetry breaking phase transitions were discussed as the mechanisms for setting up a time-varying GL scalar field, which could conceivably result in gravitational disturbances in nearby vacuum scalar fields applicable to space propulsion. The short time scale behavior discussed provides a possible signature for an experimentalist to verify that new physics is occurring. Such experiments could provide insight into the laws of scalar fields, which need to be formulated for space propulsion engine cycles.

Nomenclature

- $V(\psi)$ = energy density (eV/m³)
 n = electron probability density (electrons/m³)
 ϕ = phase of the scalar field
 J = current through a superconductor junction (A/m²)
 n_{3D} = 3-D electron density (m³)
 2Δ = BCS gap energy (eV)
 \bar{V}_g = average domains volume (m³)
 T_{pl} = Planck Time = $\sqrt{\hbar G/c^5} \approx 5 \times 10^{-44}$ (s)
 \hbar = Planck's Constant $\approx 1.06 \times 10^{-34}$ (J s)
 G = gravitation constant = 6.673×10^{-11} (N m²/kg²)
 c = speed of light = 2.9979×10^8 (m/s)
 E_p = Planck Power $\hbar/T_{pl} \approx 10^{28}$ (eV)
 T_h = superconductor thickness (m)

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