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Aether as a Superfluid State of Particle–Antiparticle Pairs

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A new model for the aether is suggested according to which it is a superfluid state of fermion and antifermion pairs, describable by a macroscopic wave function. The vacuum state of this superfluid pervades the entire universe and may account for the missing matter. The visible matter in the universe appears as excitations from the underlying superfluid vacuum.

1. INTRODUCTION

The concept of a luminiferous aether as a medium sustaining electromagnetic waves was discarded after the advent of the special theory of relativity. The aether, as conceived in classical physics, does indeed lead to several contradictions; in particular, aether having a definite velocity at each space–time point will exhibit a preferred direction. This is in conflict with the relativistic requirement that all directions within the light cone are equivalent. However, several years ago Dirac[1,2] pointed out that we should take into account quantum fluctuations in the flow of the aether. His arguments involve the application of the uncertainty principle to the velocity of aether at any space–time point, implying that the velocity will not be a well-defined quantity. In fact, it will be distributed over various possible values. At best, one could represent the aether by a wave function ψ representing the perfect vacuum state for which all aether velocities are equally probable. Although this quantum description of aether meets some of the objections to its existence, the question of the viscous drag effect exerted by such an aether still remains in this model. This difficulty would disappear if the aether is a superfluid.

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2. THE NEW MODEL

In this paper, we present a new model of the aether according to which it is regarded as a "superfluid" state of fermion pairs. Although the model applies to all particle–antiparticle pairs, we shall use one species of fermion–antifermion pairs for convenience. The background vacuum of the universe is assumed to consist of such pairs—the totality defining a sea of particles and antiparticles.

Further, we consider for simplicity an "almost nonrelativistic" situation applicable to this sea. The Hamiltonian within this approximation [i.e., neglecting terms $O(1/c^2)$] will comprise the kinetic energy and a short-range interaction energy. Further, we assume that the pairs are in $\mathbf{L} = 0$ orbital states with zero value of the total spin $\mathbf{S} = \frac{1}{2}(\boldsymbol{\sigma}_+ + \boldsymbol{\sigma}_-)$, where $\boldsymbol{\sigma}_+$ and $\boldsymbol{\sigma}_-$ are the spin operators of the particles in question, for example, the positron and the electron, respectively. The Hamiltonian for a "sea" of such pairs in the momentum representation takes the form

$$H = \sum \epsilon_{\mathbf{k}} c^\dagger_{\mathbf{k},\sigma_-} c_{\mathbf{k},\sigma_-} + \sum \epsilon_{\mathbf{k}} d^\dagger_{\mathbf{k},\sigma_+} d_{\mathbf{k},\sigma_+} - \sum V_r(\mathbf{k}, \mathbf{k}')\, c^\dagger_{\mathbf{k}',\sigma_-} d^\dagger_{-\mathbf{k}',-\sigma_-} d_{-\mathbf{k},-\sigma_-} c_{\mathbf{k},\sigma_-} \tag{1}$$

where $(c^\dagger_{\mathbf{k},\sigma_-}, c^\dagger_{\mathbf{k},\sigma_-})$ and $(d_{\mathbf{k},\sigma_+}, d_{\mathbf{k},\sigma_+})$ are the particle and antiparticle (creation, annihilation) operators, respectively, for the momentum state $\mathbf{k}$ and appropriate spin orientation. Since we have chosen $\mathbf{S} = 0$, we have $\boldsymbol{\sigma}_+ = -\boldsymbol{\sigma}_-$ for the pair. This is reflected in the interaction term [third term of (1)]. The single-particle energies, which include the Hartree–Fock energies, of the fermion and the antifermion are denoted by

$$\epsilon^{(c)}_{\mathbf{k}} = \epsilon^{(d)}_{\mathbf{k}} = \epsilon_{\mathbf{k}}$$

assuming the absence of any global aligning (external) field. The effective short-range (pair) two-body interaction is represented by

$$V_r(\mathbf{k}, \mathbf{k}') \tag{2}$$

The precise nature of this interaction is assumed to be unknown (cf. Cloizeaux[3]).

The Hamiltonian given in Eq. (1) has a form similar to that of Bardeen, Cooper, and Schrieffer[4] (BCS) for superconductivity in metals. The difference is that each pair in the present case is electrically neutral. For further calculations, we shall make use of their results and assume that $V_r = V_0$, a constant, for $|\epsilon_{\mathbf{k}}| < \epsilon_c$, and zero otherwise. Thus the ground-state energy of the above fermion–antifermion vacuum will be lowered by $\Delta E = \frac{1}{2}N(0)\,\Delta^2$, where Δ is the gap parameter

$$\Delta = \epsilon_c \exp[-1/N(0)\, V_0] \tag{3}$$

and $N(0)$ is the density of states at the Fermi surface. This condensation of the above vacuum (in the zero momentum and zero spin state) will display long-range correlation as in a superfluid (or a superconductor). The aether in its ground state is identified with the above superfluid comprising a sea of such pairs. It follows that any object moving through it would be incapable of exchanging energy and momentum with the aether superfluid (up to a particular limiting momentum) and hence it will not experience any viscosity. However, if the energies involved exceed the gap parameter Δ, the situation would be different (to be taken up later). The energy of an elementary excitation $E_{\mathbf{k}}$ (of a single quasiparticle) is given by

$$E_{\mathbf{k}} = (\epsilon_{\mathbf{k}}^2 + \Delta^2)^{1/2} \tag{4}$$

For a pair it is $2E_{\mathbf{k}}$.

We postulate that the particle masses arise predominantly from interactions. Accordingly, the gap energy will account for the mass. Thus we identify (in the spirit of Nambu and Jona-Lasinio[5])

$$| \Delta | = mc^2 \tag{5}$$

where c is the velocity of light. Similarly, we identify $\epsilon_{\mathbf{k}}$, with pc, where p is the magnitude of the linear momentum of a particle. We note that, if the gap parameter Δ is much larger than $\epsilon_{\mathbf{k}} = pc$, we get the usual non-relativistic energy of the single particle. Excitation of a pair of particles will cost at least twice the gap energy, i.e., $2 | \Delta | = 2mc^2$. Thus the gap energy manifests itself in the appearance of rest mass energy of particle–antiparticle pairs over the superfluid vacuum.

The above argument is quite general and is applicable to all particle–antiparticle fermion pairs. If the particles interact very strongly, e.g., proton–antiproton or muon–antimuon, the gap will be larger, i.e., of the order of their observed rest mass energies. Thus the observed rest masses of the elementary particles may be reflections of the strength of interactions in which they take part.

It is well known that superfluid behavior occurs when the velocity of the fluid is less than the velocity of the elementary excitation. The critical velocity of the fluid above which the superfluidity conditions will not be satisfied for the aether can be estimated from

$$v_c \approx | \Delta | / \hbar k \tag{6}$$

where $\hbar k$ is the momentum of the excitation. If we choose k to be of the order of the inverse Compton wavelength of the excitation, this gives

$$v_c \approx mc^2/mc = c \tag{7}$$

which is the velocity of light. This seems to be a lower estimate; v_c may even be larger than c. Since the observed velocities of most celestial objects are well below c, the superfluidity of the aether will be retained. There is also the possibility of collective excitations having energy lower than the gap, which may be excitonlike or Goldstone modes.[6] The suggestion that the photon is a collective excitation of such fermion fields has been made earlier by several authors.[3] These are associated with broken symmetries accompanying transition to the superfluid state.

For a relativistic formulation one has to consider Higgs' type of Lagrangian.[7] It is now well realized that the Higgs Lagrangian corresponds to a relativistic generalization of the Ginzburg–Landau theory of superconductivity.[8,9] As a natural consequence, Higgs' mechanism will give massive gauge mesons.

3. COSMOLOGICAL CONSEQUENCES

There is another way of looking at this model of background superfluid aether plus the elementary excitations, the totality of which accounts for the observable universe. The Einstein field equation for this two-fluid picture, i.e., the normal matter and the superfluid (background vacuum), can be written as

$$R_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}R = -\kappa[T_{\mu\nu} + (T_{\mu\nu})_{\text{vac}}] \tag{8}$$

where $\kappa = 8\pi G/c^4$, and $T_{\mu\nu}$ and $(T_{\mu\nu})_{\text{vac}}$ are the energy-momentum tensors of the normal and superfluid matter. The latter can be reinterpreted in terms of the "cosmological" constant Λ, provided we choose

$$(T_{\mu\nu})_{\text{vac}} = (\Lambda c^4/8\pi G)\, g_{\mu\nu} \tag{9}$$

where we have used the generalized Einstein field equation with Λ, i.e., $R_{\mu\nu} - \tfrac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = -\kappa T_{\mu\nu}$, in getting Eq. (9). The above interpretation suggests a new way of looking at the de Sitter model[10] of the universe, which is now no longer empty but is filled by the superfluid aether constituting the substratum of the cosmos. Its density is given by

$$\rho \approx \Lambda c^2/8\pi G \tag{10}$$

Also, roughly identifying Λ with the inverse square root of the radius of the universe, i.e., the Hubble radius (10^{28} cm), we get, from Eq. (10),

$$\rho \approx 10^{-29}\ \text{gm/cm}^3$$

This may be compared with theoretical estimates[11] of the universal matter density of $2 \times 10^{-29}\ \text{gm/cm}^3$ and the visible matter density of

3×10^{-31} gm/cm^3. The visible matter would here correspond to the usual matter appearing as elementary excitations, and the "invisible" matter to the superfluid component. It is a well-known paradox of modern cosmology that a large amount of matter appears to be missing and is variously conjectured to be in the form of neutrinos, black holes, gravitational waves, etc.[12] The (invisible) superfluid aether proposed here would account for this missing matter.

The superfluid nature of the background aether may also explain the uniform temperature of the all-pervading blackbody radiation of 3K. Since the thermal conductivity of a superfluid is practically infinite, the uniform temperature will be quickly established except where there are energy-generating sources such as the sun. Also, in some isolated regions of the universe where the temperature of the visible matter is of the order of the pair dissociation energy, i.e., $k_B T = 2m_e c^2$, $T = 6 \times 10^9$K (with m_e the electron mass), vast number of pairs will manifest themselves from the superfluid vacuum. The annihilation energy of such pairs produced will perhaps be sufficient to account for the tremendous luminosities of these objects (e.g., quasars). This practically infinite thermal conductivity of the superfluid lends to the evolutionary model of the universe some of the features of a steady-state theory.

4. CONCLUSION

In conclusion, the aether visualized in the present paper is a superfluid of particle–antiparticle pairs. Although the main discussion has centered around one species of particle pairs for convenience, the aether is postulated to be a mixture of all particle–antiparticle pairs, each having its own characteristic energy gap. The gap manifests itself as the rest mass energy of the particle in question.

The pairs are correlated together to constitute a super macroscopic quantum state of the entire universe associated with long-range order in the momentum space which is describable by a single wave function ψ of the superfluid vacuum state.

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