Neutrino ensemble properties

Author: David R Andrews

Organization: Cambridge Ultrasonics, Horse Ware, Over, Cambridgeshire CB24 5NX, UK

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1. De Broglie wavelength calculation. Condensates. Electromagnetism. Special relativity.

Contents

Glossary of terms

BCS	Bardeen Cooper Schrieffer
BEC	Bose-Einstein condensate
LRS-Neutrinos	Low relative speed neutrinos.
NFC	Neutrino Fermionic condensate.

1 Introduction

Neutrinos have half half-integer quantum number spin, somewhat like an electron, but their most unusual property is that they have almost zero rest-mass, the precise value is still not well known (Giunti & Kim, 2007). If neutrinos have zero rest-mass then it is a particle like a photon and it can travel at the speed of light. If neutrinos have mass then they cannot travel at the speed of light. It is commonly believed that neutrinos have a small but non-zero mass.

It is the ramification of this low mass that is of particular importance in this discussion because a small rest mass results in an unusually long value of de Broglie matter-wavelength, as much as 1 m may be possible (see section 1.5). The de Broglie wavelength is determined by the speed of the particle relative to the observer as well as the rest mass of the particle. For most studies conducted so far on neutrinos, such as solar neutrinos, the relative speed has been close to the speed of light and, consequently, the de Broglie wavelength has been short, typically 10^{-12} m. Neutrinos with low relative speeds (called *LRS-neutrinos* herein) shall be the main topic of consideration here.

The exceptionally long wavelength of 1 m mentioned above for a LRS-neutrino is exceptional for any quantum mechanical particle. It should be compared with the lightest other sub-atomic particle, the electron, which at low energy and speed of 150 eV has a de Broglie wavelength of approximately 10^{-10} m. The long matter-wavelength of a neutrino should result in unusual properties of ensembles of LRS-neutrinos, particularly when their density is sufficiently high that their wave-functions overlap and become entangled. Given a de Broglie wavelength of 1 cm, then one would expect to observe entangled neutrino behaviour for LRS-neutrino densities of approximately 10^{6} neutrinos m^{-3}, which is a very low value of density. For comparison, most solids and liquids have number densities of atoms of about 3 x 10^{28} atoms m^{-3}.

1.1 Condensates

A growing number of experiments have demonstrated the existence of Bose-Einstein condensates (BECs). Simply stated, a BEC is a phase of matter of an ensemble of quantum particles, where the macroscopic physical properties of the phase are strongly affected by the entangled, quantum mechanical wave-functions of the particles. So far experiments have been performed on ensembles of relatively few but relatively heavy atomic particles. It has been necessary to cool the particles to temperatures close to absolute zero so that the de Broglie matter-wavelength is sufficiently long that the wave-functions of individual particles overlap in the confines of the apparatus used in experiments and so become entangled.

The effect of entanglement is to turn the ensemble into a phase of matter where quantum mechanical effects become observable on a macroscopic scale. The macroscopic properties of BECs are the subject of active investigation. BECs are generally not easy phases of matter to create much less to test the physical properties. However, we are more familiar with the macroscopic properties of closely related phases of matter such as super-fluids and super-conductors, phases that also rely on quantum entanglement (Annett, 2004).

One universal property of phases that have quantum entangled wave-functions is that as the vibration speed of the particles increases, with increasing temperature, there comes a speed/temperature at which the quantum entanglement ceases. Cessation can be attributed to the de Broglie wavelength becoming smaller (as the relative speeds of the particles increase) than the mean separation of the particles in the ensemble and entanglement ends. Cessation of entanglement illustrates the importance of relative speed of the particles in the ensemble. The absolute speed of the apparatus with the particles in it travelling through space is unimportant except to the observer. This appears to be a universal property of all quantum entangled condensates.

1.2 Neutrino creation

Neutrinos can be created in a variety of ways.

1. Neutron decay or β-decay: $n \rightarrow p^+ + e^- + \overline{\upsilon_e}$, in which a neutron decays into a proton, electron and an anti-electron-neutrino. This is the reaction that first highlighted the existence of neutrinos so that spin could be conserved on both sides of the equation.
2. Proton β-decay: $p \rightarrow n + e^+ + \upsilon_e$.
3. Particle – anti-particle creation: [verify].
4. Electron-positron annihilation: $e^+ + e^- \rightarrow \upsilon + \overline{\upsilon}$, in which an electron and a positron annihilate to leave a neutrino and an anti-neutrino.
5. Proton -anti-proton annihilation: $p^+ + p^- \rightarrow$ [verify].
6. Neutron – anti-neutron annihilation: $n^+ + n^- \rightarrow$ [verify].

1.3 Neutrino capture

Neutrinos can also be captured.

1. An anti-electron-neutrino and a proton combine to make a neutron and positron: $\overline{\upsilon_e} + p \rightarrow n + e^+$. This capture process was used to demonstrate the existence of neutrinos.

1.4 Neutrino density

Assuming the theory of nucleo-synthesis known as the Big Bang is correct, in which a very large number of particles and antiparticles were created simultaneously but with a small imbalance in numbers, then a very large number of neutrinos should also have been created (Perkins, 2003). Following the initial Big Bang or possibly as part of it, large numbers of particles and their anti-particles self-annihilated in particle-anti-particle pairs, leaving only the particle universe we see – with no anti-particles left behind. The process of self-annihilation also created neutrinos see section 1.2 (Giunti & Kim, 2007). There should still have been a large number of neutrinos left in the universe. The sun is creating large numbers of energetic neutrinos and so are most other active stars in the universe.

Neutrinos are stable particles like neutrons, protons and electrons; they do not decay with a half-life like radioactive nucleii or like muons or tau particles. There is some evidence that neutrinos oscillate between the different neutrino states (Giunti & Kim, 2007) namely: electron neutrino, muon neutrino and tau neutrino, but what is important is that they do not decay into other particles. It is assumed therefore that the many neutrinos created in the Big Bang are still in existence today along with all the other stable particles. This raises the questions: How many neutrinos are there in the universe? And what is the neutrino density today? Various estimates (Perkins, 2003), (Giunti & Kim, 2007) calculate there are 113 neutrinos and anti-neutrinos of each flavour per cubic centimetre (making approximately 350 $(cm)^{-3}$ in total) or 350 x 10^6 neutrinos m^{-3} everywhere in the universe. An alternative way of expressing this density is the inter-particle spacing, which is approximately 1.5 mm. Perkins and others (Perkins, 2003), (Giunti & Kim, 2007) also indicate that neutrinos that are relics of the big bang should have cooled to temperatures of about 2 K and have energies of approximately 0.001 eV.

The previous value of relic neutrino density should be compared with the threshold density 1 x 10^6 neutrinos m^{-3} calculated earlier (section 1) as a crude estimate for a neutrino-condensate to form. Upon initial consideration, it would appear there is a possibility that the entire ensemble of relic neutrinos in the universe could form a neutrino-condensate. This initial conclusion must be tempered for two reasons: firstly, not all flavours of neutrinos are expected to have cooled (Giunti & Kim, 2007) and, secondly, because neutrinos would have been created with a range of speeds and directions in the big bang then only a proportion of the neutrinos in the universe may be available to form a condensate in any particular frame of reference - the reader should note the necessity here for using the terminology of Einstein's special theory of relativity [ref]. The proportions of neutrinos available will be explored in a later section of this discussion (see section ZZZ). However, the important point to emerge from this simple consideration of a neutrino-condensate is that if it exists then it must have a close connection with the ideas in Einstein's special theory of relativity, specifically, that the existence of a neutrino-condensate and the existence of the properties of the condensate are directly connected to the relative speed of different frames of reference. Let this proposition be rephrased: every frame of reference must have either its own neutrino-condensate or one that it shares with a range of other frames moving relative to the reference frame but within some range of relative speeds.

1.5 De Broglie matter-wavelength

The following equation (Wichmann, 1967) gives the characteristic (de Broglie) wavelength, λ, of a particle.

$$\lambda = \frac{h}{p}$$

Where h is Plank's constant (6.26 x 10^{-34} Js) and p is the momentum of the particle. The equation can be expressed with explicit relativistic terms included as follows (Wichmann, 1967).

$$\lambda = \left(\frac{h}{mc}\right)\frac{\sqrt{1-\left(\frac{v}{c}\right)^2}}{\frac{v}{c}}$$

Where c is the speed of light (3.00 x 10^8 ms^{-1}) and v is the speed of the particle measured in the rest frame of the observer.

Wichmann (Wichmann, 1967) calculates the de Broglie wavelength of an electron of energy 150.4 eV to be 10^{-10} m, which is a dimension of the order of the size of an atom. Consequently, low energy electrons can be used in diffraction experiments on crystalline materials.

Annett (Annett, 2004) calculates the de Broglie wavelength of ^{4}helium atoms at a temperature of 4 K as 4 x 10^{-10} m, which apparently is greater than the typical inter-atomic distance in super-fluid ^{4}helium of 2.7 x 10^{-10} m. Annett states that because the de Broglie wavelength is longer than the inter-atomic spacing then macroscopic quantum effects, such as super-fluidity, should exist in liquid ^{4}helium.

The following table shows results of calculations for the de Broglie wavelength for neutrinos with a range of possible rest masses and a range of speeds up to 99% of the speed of light.

Calculation of de Broglie wavelength for neutrinos											
David R Andrews											
Cambridge Ultrasonics											
23/01/2006			$\lambda = \left(\frac{h}{mc}\right)\frac{\sqrt{1-\left(\frac{v}{c}\right)^2}}{\frac{v}{c}}$								
Speed of light, c=	3.00E+08 m/s										
Plank's constant=	6.26E-34 Js										
1 eV =	8.19E-14 J				Wavelength (m)						
					Neutrino speed (m/s)						
Neutrino mass (eV)	kg	3.00E-02	3.00E-01	3.00E+00	3.00E+01	3.00E+02	3.00E+04	3.00E+05	3.00E+06	3.00E+07	2.97E+08
1.00E-03	9.10E-34	2.29E+01	2.29E+00	2.29E-01	2.29E-02	2.29E-03	2.29E-05	2.29E-06	2.29E-07	2.28E-08	3.27E-10
1.00E-02	9.10E-33	2.29E+00	2.29E-01	2.29E-02	2.29E-03	2.29E-04	2.29E-06	2.29E-07	2.29E-08	2.28E-09	3.27E-11
1.00E-01	9.10E-32	2.29E-01	2.29E-02	2.29E-03	2.29E-04	2.29E-05	2.29E-07	2.29E-08	2.29E-09	2.28E-10	3.27E-12
1.00E+00	9.10E-31	2.29E-02	2.29E-03	2.29E-04	2.29E-05	2.29E-06	2.29E-08	2.29E-09	2.29E-10	2.28E-11	3.27E-13
1.00E+01	9.10E-30	2.29E-03	2.29E-04	2.29E-05	2.29E-06	2.29E-07	2.29E-09	2.29E-10	2.29E-11	2.28E-12	3.27E-14
1.00E+02	9.10E-29	2.29E-04	2.29E-05	2.29E-06	2.29E-07	2.29E-08	2.29E-10	2.29E-11	2.29E-12	2.28E-13	3.27E-15
1.00E+03	9.10E-28	2.29E-05	2.29E-06	2.29E-07	2.29E-08	2.29E-09	2.29E-11	2.29E-12	2.29E-13	2.28E-14	3.27E-16

Table 1

Calculation of the relativistic de Broglie matter wavelength for neutrinos of different masses and speeds. The green zone shows wavelengths where quantum entanglement could occur.

The green and brown sections show the range of probable neutrino rest masses [ref]. The red and brown sections show wavelengths less than 1 mm.

Perkins (Perkins, 2003) states that the relic flux of neutrinos left over from the big bang should have cooled to approximately 2 K, having energies of approximately 0.001 eV, which would lie in the top green and brown row.

Recall that the inter-neutrino spacing according to Perkins is approximately 1.5 mm – the red and brown sections show wavelengths less than 1.5 mm where a condensate may be less likely to form. However, it is worth noting that the de Broglie wavelengths for neutrinos with speeds up to 10% of the speed of light and of expected neutrino rest masses are nearly all significantly larger than typical inter-atomic spacing of regular solids and liquids.

The green section of Table 1 defines conditions where a neutrino Fermionic condensate might form. It would appear that a condensate is more likely to exist for low values of neutrino or anti-neutrino relative speeds.

2 Neutrino Fermionic condensate (NFC) properties

Neutrinos permeate space and can pass through matter considerable distances. If a vacuum pump capable of removing every molecule of gas from a perfectly sealed chamber were used on such a chamber it would remove all the molecules of gas but leave behind the neutrinos. It is probable that the space in the solar system as well as inter-stellar and inter-galactic space is filled with neutrinos (Perkins, 2003), (Giunti & Kim, 2007) and filled to a density sufficient to permit some degree of entanglement of LRS-neutrino wave-functions. It may, therefore, be possible for a neutrino-condensate to exist that spans the interior of a vacuum chamber and extends out into inter-galactic space.

Neutrinos are Leptons and Fermions (spin half). The main properties of a neutrino are: half-integer spin and almost zero mass. However, the spin of a neutrino is somewhat different to the spin of an electron. Electron spin can be aligned parallel or anti-parallel to the direction of the momentum vector ($\pm\frac{1}{2}\overline{h}$) but a neutrino spin is always anti-parallel ($-\frac{1}{2}\overline{h}$) and an anti-neutrino spin is always parallel ($+\frac{1}{2}\overline{h}$) to the momentum direction. It is common to consider the helicity of neutrinos, which arises because the spin is aligned relative to the momentum vector and therefore aligned to the direction of travel of the neutrino. A point spinning around a second point that is moving at a constant speed in a fixed direction describes a helix in space. Neutrinos do not carry charge.

At this stage it is postulated that a neutrino condensate forms a super-fluid, in a way similar perhaps to super-fluid ^{3}helium, which is a known example of a Fermionic condensate. The Boson ^{4}helium forms a regular Bose-Einstein condensate. The important point here is that the Pauli exclusion principle prevents Fermions occupying the same energy-state (in a closed system). It is postulated that neutrinos, being Fermions, form diatomic molecules of spin-up and spin-down pairs, or neutrino – anti-neutrino pairs (somewhat like super-conducting electrons ref BCS [ref]) with each molecule now effectively a Boson, with zero spin – in the same way that it is believed that helium-3 forms a condensate.

2.1 NFC structure

Of importance at this stage is to consider the inter-molecular properties of a neutrino Fermionic condensate (NFC). Does pairing of neutrinos and anti-neutrinos into a spin up-down pair create an inert, noble gas molecule so that the ensemble behaves as a fluid or is it possible for neutrinos to form a one dimensional chain of alternate spin up-down particles or a two dimensional surface of alternate spin up-down particles or a three dimensional volume (crystal) of alternate spin up-down particles, like an anti-ferromagnetic material? It seems improbable that a single crystal of neutrino Fermionic condensate could exist spanning the entire universe but it may be possible that some short range crystallization may occur, with polycrystalline structure over long ranges. In all cases of other Fermionic condensates there does exist an inter-molecular force.

2.2 NFC speed of sound

Super-fluid ^{4}He has some unusual macroscopic properties: very high speed of sound (220 ms^{-1}), zero viscosity, infinite thermal conductivity (very high speed of second sound), zero entropy and very low speed of light (high refractive index). The infinite thermal conductivity is analogous to the infinite electrical conductivity of super-conductors and makes super-fluids super-thermal-conductors. With these properties it is difficult to see how ^{4}He could come into thermal equilibrium with its surroundings.

It is suggested that a NFC has similarities to ^{4}He but made more extreme by the virtual zero mass of a neutrino. In this section we discuss the speed of sound. One can be reasonably certain that NFCs do not support mechanical pressure waves (sound) because if NFCs exist then they probably exist in space and it is known that sound does not travel in space. However, for the sake of argument we will continue down this avenue.

The speed of sound is controlled in any material by the stiffness of the material and its density (Meyers, Rober A;, 2002).

$$Speed\ of\ sound = \sqrt{\frac{Stiffness}{Density}}$$

The density of a neutrino condensate is almost certainly vanishingly small because the mass of a neutrino is almost zero and the mass is certainly very much less than the mass of all the other stable, atomic particles. The number density of neutrinos per unit volume (see section 1.4) is finite and not infinite. It is estimated here that the density is approximately 10^{-24} kgm^{-3}.The stiffness depends upon the inter-molecular forces outlined earlier and it is assumed that these are ultimately related to the spin quantum number of the neutrino, which is finite and significant. Although the effect of forming spin up-down pairs is to neutralize spin or to screen it and so reduce the stiffness, the existence of any ordering of spin over ensembles of neutrinos would require a finite inter-molecular force to exist. It is suggested that the stiffness is as yet unknown but finite in value.

Returning to the equation above, it seems possible that the speed of sound in a neutrino condensate is very high indeed, being the ratio of a finite number divided by an almost infinitesimally small number (10^{-24} kgm^{-3}). This result would be consistent with other super-fluids that have infinite thermal conductivities and zero entropy. The speed of sound 1 in super-fluid ^{4}helium is approximately 220 ms^{-1} and the density is 0.146 x 10^3 kg m^{-3} (Donnelly, 2004).

Using the equation above it is possible to calculate the stiffness (closely related to Young's modulus depending upon geometry) of super-fluid ^{4}He, with a value of 3.2 x 10^6 Pa.

In the unlikely event that the stiffness of NFC has the same value as ^{4}He then the value predicted for the speed of sound would be 1.8 x 10^{15} ms^{-1} (substituting values for ^{4}He stiffness and neutrino density into the equation above). This is a value several orders of magnitude faster than the speed of light and it appears to be implausibly high but it illustrates that we might expect the speed of sound in NFC to be high even if the stiffness of NFC is much less than ^{4}He.

What kind of wave could a NFC support, if not sound? The only significant quantum number for neutrinos is spin. If the force between neutrinos is related to spin then it should be possible to send spin-waves in a NFC.

2.3 NFC structure

Of interest is how neutrino spins are ordered in a NFC, if they are ordered at all. If the condensate in some way forms a anti-ferromagnetic crystal matrix and a polycrystalline medium over longer scales (consistent with rapid quenching to form the neutrino condensate in the cooling universe) then the condensate should support not only compression waves but also shear waves, with different wave speeds for compression and shear and different particle motions: compression waves having particle motion parallel to the direction of propagation and shear waves having particle motion perpendicular to the direction of propagation of the wave. Shear waves are transverse-motion waves that have polarization. Solid materials support both shear and compression waves but liquids support only compression waves over long range and shear over short range if the value of viscosity is significant. Super-fluids generally have low or vanishingly small values of viscosity (Annett, 2004). It is noted also that shear waves travel more slowly than compression waves, by a factor related to Poisson's ratio for the material.

3 Electromagnetism and photons

Einstein first proposed the idea of a photon to explain the photoelectric effect [ref]. A photon is a particle. Maxwell [ref], working earlier than Einstein, found an enduring description of electromagnetic phenomena in terms of fields using a set of four equations that can be combined to produce a wave equation. Maxwell's equations are consistent with Einstein's special theory of relativity [ref]. These two approaches contributed to the wave-particle duality [ref] of quantum mechanics which overcomes the contradiction of how a particle of finite size can be described by a wave field of infinite size and duration.

Essentially, a particle is a packet of waves with a bandwidth and these waves superpose to create a particle of finite size and position in space-time. Heisenberg's Uncertainty Principle arises from consideration of the range of frequencies needed to define a particle of a certain size and space-time location.

Electric and magnetic fields can exist in materials, supported by electric and magnetic displacements of the atoms in those materials. Photons can travel through materials at speeds determined by properties of the material through which they pass, essentially related to how quickly electric and magnetic displacements can occur in the material. The speed of light in a material made of atoms is always less than the speed of light in a vacuum and can vary considerably up to almost the speed of light in a vacuum. It is beyond doubt that photons are transported by a material in this case and that the speed of the photon is determined by the material. This is an important point and worth re-iterating: it is known that light and electro-magnetic waves can be transported at speeds close to the speed of light by displacements of electrons in the atoms comprising the material through which the light or electro-magnetic wave is travelling.

Electric and magnetic fields in materials can not only support waves and transport photons but the materials can also support the fields that transmit the electrostatic force, a force that does not varying in time. It is commonly believed that the electrostatic force is conveyed by photons but by their nature photons are mass-less particles travelling at the speed of light – how can they convey a static force? Photons conveying electrostatic forces would have to be photons of 0 Hz centre frequency and 0 Hz bandwidth to hold a static force indefinitely. This kind of photon is sometimes called a virtual photon. However, a virtual photon of 0 Hz centre frequency and 0 Hz bandwidth is not a packet of waves and does not appear to be consistent with the wave-particle duality. Taking into account the frequency components required for switching-on an electrostatic field and switching it off, one could construct non-zero bandwidths for the turn-on and turn-off transients in all practical cases but frequencies and bandwidths would be close to 0 Hz.

3.1 Ether – zero-point energy and particle-anti-particle creation/annihilation

It is commonly understood that in a vacuum there are no atoms to support electric and magnetic fields, consequently, there are no atoms to carry electric and magnetic displacements and no atoms to define the value of the speed of light. However, the material now commonly accepted to answer this apparent deficiency is the spontaneous creation of particle and anti-particle pairs that recombine and disappear [ref]. The energy used to create the particle pairs being zero-point energy [ref]. Physicists in Victorian times might have been happy to label particle-anti-particle creation/annihilation as *ether*. The term ether became discredited with the arrival of Einstein's special theory of relativity. We shall not dwell on the discussion of whether particle-anti-particle creation/annihilation constitutes ether except to point out that the use of such a label in this case is not completely without merit.

The existence of zero-point energy leads to a number of problems in physics, not the least being that the product of a finite energy at every infinitesimal point in space results in an infinite energy when integrated over a finite volume. The existence of zero-point energy requires infinite energy. The proposed solution to this non-physically plausible infinite energy is known as renormalization in quantum electrodynamics, an approach which still appears as somewhat unconvincing.

Currently accepted knowledge is that the spontaneous creation and annihilation of particle-anti-particle pairs creates an *ether-like* material that supports electromagnetic fields and waves and gives non-zero values for the permittivity and permeability of free-space. It is not clear how the electrostatic force could be supported by particle-anti-particle pairs that only exist fleetingly [time duration of?] but this ether must support a static force to nearby similarly fleeting neighbours. Apparently, fluctuations due to particle-anti-particle creation and annihilation have been measured in experiments on the Casimir effect [ref].

3.2 Electromagnetic fields and waves

Is it possible that the existence of neutrinos in a vacuum and in space has been ignored when seeking an explanation of how electromagnetic fields can exist there? It is proposed here that there is sufficient merit in exploring this possibility.

Electric and magnetic fields have an interesting set of properties in terms of the material that conveys them and mechanical forces in the material.

- Static electric fields – the electric vectors point along field lines that run between the exposed charges. The material supporting the electric field would experience a state of mechanical stress of either compression or tension.
- Static magnetic field – magnetic fields are caused by moving charges and so are not true static fields.
- Electric field waves – the electric field oscillates in a direction that is perpendicular to the direction of motion of the wave, it is a transverse wave. The material supporting the electric field would experience a state of mechanical stress of dynamic shear.
- Magnetic field waves – the magnetic field oscillates in a direction that is perpendicular to the direction of motion of the wave and perpendicular to the electric field. The material supporting the magnetic field would experience a state of mechanical stress of dynamic shear.

Clearly, any conventional material that can convey an electrostatic field and an electromagnetic wave must be able to support forces of static compression, static tension and dynamic shear. Compression, tension and dynamic shear forces can always be supported for a material made of atoms in a solid. For atoms in a liquid or gas the inertial force of each atom is sufficient to support the compression-force, tension-force and shear-force of a wave provided the period of oscillation is shorter than any mechanical relaxation time of the atom/molecule in the liquid/gas (the atom/molecule can be considered as a rigid point in the high frequency limit). But if the period of oscillation is longer than the relaxation-time of the atom or molecule then the material can flow in response to the mechanical force.

To illustrate this point, let us conduct a thought-experiment performed in space, in zero gravity, with two conducting plates charged so there is 1 kV oscillating potential difference between the plates. If an insulating polymer is fixed in between the plates then the plates will remain stationary relative to each other at all frequencies including 0 Hz. If the polymer is now removed and the plates are put into an insulating liquid with low viscosity then at high frequencies the plates will remain stationary but as the frequency is reduced they will start to vibrate until when the frequency is 0 Hz they will move together and touch. If the liquid is removed and the plates are put in the vacuum of space then the plates will vibrate at all frequencies although the amplitude of vibration will decrease with increasing frequency but at 0 Hz the plates will move together and touch.

This thought experiment demonstrates that whatever material is present in a vacuum it must behave electromagnetically as an insulating fluid and not as a solid, in the conventional understanding of a solid. The term solid here means a material that can withstand compression, tension and shear stresses without large mechanical strains.

3.3 NFC connection with electromagnetic fields and waves

It is known that electrons and neutrinos and anti-neutrinos can interact by elastic scattering (Giunti & Kim, 2007).

$$\upsilon_\alpha + e^- \rightarrow \nu_\alpha + e^-$$

$$\overline{\upsilon}_\alpha + e^- \rightarrow \overline{\upsilon}_\alpha + e^-$$

Where the first equation relates to neutrinos and electrons and the second equation relates to anti-neutrinos and electrons. The subscript α indicates which type of neutrino: electron-neutrino, tau-neutrino or muon-neutrino. These interactions can be represented by Feynman diagrams with either charged current (W-Boson exchange) or neutral current (Z-Boson exchange).

The equivalence of particles on the left and right-hand sides of the equations is to be expected for elastic scattering. The result of elastic scattering is a redistribution of energy between the electrons and neutrinos, it is not a change the in the type of particles.

A practical example of elastic scattering is Cherenkov radiation from water caused by high energy solar neutrinos interacting with bound electrons in water molecules. As a result of elastic scattering neutrinos lose some energy and the electrons gain the energy lost and are excited to higher energy states. The electrons then emit light as they move return to lower energy states.

There are also quasi-elastic scattering processes between muon-neutrinos and electrons that create electron-neutrinos and muons, a process called inverse muon decay.

The important point is that electrons and neutrinos can interact by elastic scattering, during which energy is redistributed between an electron and a neutrino of any type. Exchange of energy is the only tangible change – there is no conversion of particle type and the same number and type of particles exist after the interactions.

Also of relevance is the unification of the electromagnetic and weak interactions or the electroweak model (Perkins, 2003). This states that the couplings of the W and Z Bosons to fermions are the same as that of the photon. However, the larger mass of the mediating W or Z Boson requires a shorter range interaction. The important point is the equivalence of the couplings of the W and Z Bosons with the coupling to a photon.

It is now postulated that *exposed charges* in the form of electrons partially or fully exposed from any atomic or molecular binding forces and not just free electrons interact elastically with free neutrinos and NFCs. Because of the quantum entanglement of NFCs, when the neutrino nearest to the exposed or partially exposed electrons changes its energy a pulse of displacement or spin displacement travels along the NFC as a wave. When the pulse on the NFC reaches other, distant electrons or exposed charges some or all of the energy in the NFC pulse can be elastically transferred to these other electrons; when the electrons are tightly bound the coupling will be small but when the electrons are relatively free to move then they can absorb energy more readily.

It is postulated that this process of elastic scattering of electrons and neutrinos, the latter forming part of a NFC, followed by a pulse-displacement in the NFC travelling as a wave, is the mechanism for transporting photons. There must be a tension in the NFC, or an inter-neutrino force, that can be attributed to the non-zero spin quantum number of neutrinos, the Fermionic nature of neutrinos and the Pauli Exclusion Principle (Wichmann, 1967).

It is of interest that electrons, also Fermions with half-integer spin, can interact elastically with neutrinos. It is postulated that stationary free electrons and stationary exposed charge of bound electrons can also interact through their spins to impart a static or approximately static displacement to neutrinos nearby (entangled wavefunctions) in a NFC so that the state of tension in the NFC is altered and distant electrons or exposed charge can be displaced by the tension in the NFC. It is postulated that this is the mechanism for transporting the electrostatic force.

For NFCs to convey electromagnetic waves and electrostatic forces it is necessary for NFCs to support dynamic transverse fields (propagation of electromagnetic waves and photons) and static longitudinal fields (electrostatic force) – see section 3.2. It is suggested that a fluid crystal of anti-ferromagnetically arranged neutrinos and anti-neutrinos in a NFC could support both transverse displacement dynamic spin waves and longitudinal static displacements of spin.

3.4 Speed of dynamic waves on a NFC – speed of light

In section 2.2 the speed of sound of a NFC was discussed. Due to the very low density of a NFC, due both to the low rest mass of neutrinos and the low number density of neutrinos in space, it is anticipated that the speed of sound will be exceptionally high.

Sound is a mechanical pressure or stress wave. If NFCs exist then they exist in space and sound does not pass through space. In section 2.2 it was proposed that NFCs support spin waves.

It would be instructive to calculate the speed of spin waves in a NFC and to compare the value with the speed of light.

3.5 Black body radiation

The electromagnetic radiation caused by a body being hot is conducted away from the hot body at the speed of light. This is somewhat like a super-fluid that has super-thermal conductivity. If a NFC is the medium that conveys the electromagnetic radiation then the analogy becomes more meaningful because a NFC is also a condensate like a super-fluid.

Super-fluids have zero entropy because conventional super-fluids only exist close to absolute zero, 0 K, and because of the property of super-thermal conductivity which transports heat and thermal vibrations away from the super-fluid. Generally, there is a part of the super-fluid that is caused to evaporate by the heat transported across it to a free surface.

A super-fluid is not in thermal equilibrium with its surroundings.

Is a NFC in thermal equilibrium with its surroundings? What temperature are the neutrinos in the NFC? If the neutrinos are relic neutrinos then they should have cooled to a temperature close to absolute zero.

4 Special relativity and NFCs

Table 1 in section 1.5 shows that the de Broglie wavelength varies with the speed of the neutrino relative to the observer. Consider ensemble A of neutrinos moving with a sufficiently small range of relative speeds to each other and a NFC exists in ensemble A. An observer moving slowly relative to ensemble A will observe a NFC. Now consider a second ensemble B of neutrinos moving with a sufficiently small range of relative speeds to each other and a NFC exists in ensemble B. However, the same observer is travelling relatively quickly to ensemble B and will not observe a NFC. The observer will only observe a NFC if he is moving relatively slowly to the NFC.

It is postulated elsewhere in this document that the speed of light is determined by the properties of the NFC. If a NFC can only exist if it is stationary in the frame of reference of the observer, within some range, then this provides a physical mechanism of the observations that the speed of light should be constant in all frames of reference.

There are questions in this area that relate to the range of relative speeds of neutrinos in a NFC so that the NFC can exist. If the structure of a NFC is antiferromagnetic then the acceptable relative speed must be very small otherwise the structure of the NFC will be constantly disrupted. Indeed, if spin provides an inter-neutrino force then the structure must be self sustaining so that neutrinos can only vibrate about a mean position in the same way as a regular material.

Is there only one NFC or are there many NFCs, each one travelling at different average speeds?

5 Experiments to test for the existence of NFC

If NFCs are the medium that is conveying spin-waves and spin-waves can be excited by moving exposed electrons or other Fermions and the speed of spin-waves is determined by the ratio of spin-stiffness to NFC density then a number of experiments may be possible:

1. If the density of neutrinos is changed then the speed of light may change.
2. If the spin-stiffness changes then the speed of light may change too.
3. If the relative speed of neutrinos can be increased (temperature of NFC) then eventually the de Broglie wavelength will become shorter until the NFC ceases to exist and electromagnetic fields will cease to be supported.
4. Can the results of the Casimir experiment be interpreted in terms of NFCs?

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