The Neutrino: Evidence of a Negative-Energy Vacuum State

William C. Daywitt

National Institute for Standards and Technology (retired), Boulder, Colorado, USA

E-mail: wcdaywitt@earthlink.net

This note argues that the neutrino is a phonon packet that exists and propagates within the negative-energy Planck vacuum. Simple calculations connect the three neutrinos to their corresponding leptons and show: that the neutrino mass is a ficticious or effective mass; that the neutrino mass cannot be zero; that each of the three neutrinos has a unique mass that determines its velocity; and that flavor (neutrino-type) mixing does not involve mass mixing.

The total energy E of a relativistic particle of rest mass m is

$$E = (m^2c^4 + c^2p^2)^{1/2}, \tag{1}$$

where c is the speed of light, $p = m\gamma v$ is the relativistic momentum, $\gamma^2 = 1/(1-\beta^2)$, $\beta = v/c$, and v is the particle velocity. Rearranging (1) leads to

$$\frac{v}{c} = \left[1 - \left(\frac{mc^2}{E}\right)^2\right]^{1/2}, \tag{2}$$

which can be used to determine the particle mass by measuring its velocity and relativistic energy. For any measurement set (v, E), the same mass will emerge within the measurement accuracy. When this measurement procedure is applied to the neutrino [1, pp. 534–536], however, different masses emerge. Thus the neutrino is not an elementary particle in the usual sense of the term "elementary particle". It is not surprising, then, that the "mystery of neutrino mass" is currently the most important subject of study in neutrino physics [1, p. 180].

The present note argues that the neutrino is a massless phonon packet traveling within the negative-energy Planck vacuum (PV), the primary task being to determine the structure of that packet. Taking the decay of the neutron into a proton and an electron as an example, the heuristic calculations proceed as follows: the sudden appearance of the electron as a decay product sets up a periodic disturbance in the PV from which the packet emerges; it is then assumed that the packet is the same as a phonon packet traveling a linear lattice whose lattice points are separated by a distance equal to the electron's Compton wavelength. Treating the neutrino as a phonon packet tracks the solid state theory remarkably well, but the presentation here is sketchy because of the formal complexity of the latter theory with its "undergrowth of suffixes" as Ziman would put it [2, p. 17]. The more precise details are left to a subsequent paper.

The PV [3] is an omnipresent degenerate gas of negative-energy Planck particles (PP) characterized by the triad (e_*, m_*, r_*), where e_*, m_*, and r_* $(\lambda_*/2\pi)$ are the PP charge, mass, and Compton radius respectively. The vacuum is held together by van-der-Waals forces. The charge e_* is the bare (true) electronic charge common to all charged elementary particles and is related to the observed electronic charge e through the fine structure constant $\alpha = e^2/e_*^2$ which is a manifestation of the PV polarizability. The PP mass and Compton radius are equal to the Planck mass and length respectively. The particle-PV interaction is the source of the gravitational $(G = e_*^2/m_*^2)$ and Planck $(\hbar = e_*^2/c)$ constants, and the Compton relations $(r_* m_* c^2 = r_c mc^2 = e_*^2)$ relating the PV and its PPs to the observed elementary particles, where the charged elementary particles are characterized by the triad (e_*, m, r_c), m and r_c being the mass and Compton radius $(\lambda_c/2\pi)$ of the particle (particle spin is not yet included in the theory). A feedback mechanism in the particle-PV interaction leads to the Lorentz transformation. The zero-point random motion of the PP charges e_* about their equilibrium positions within the PV, and the PV dynamics, are the source of the quantum vacuum [4].

The mean power flux of phonons traveling a linear lattice chain in an elastic medium is [2, p. 15]

$$U = \langle \mathcal{U} \rangle = \left\langle \sum_k \hbar\omega_k v_k a_k^* a_k \right\rangle = \sum_k \hbar\omega_k v_k N_k\,, \tag{3}$$

where $0 \leqslant k \leqslant \pi/r_a$, $\hbar\omega_k$ is the phonon energy for the k-th mode, v_k is the phonon group velocity, a_k^* and a_k are the phonon creation and annihilation operators, and $N_k = \langle a_k^* a_k \rangle$ is the number of phonons per unit length in the kth mode. Restricting k to non-negative values (non-positive values would work just as well) implies that only traveling waves (rather than standing waves) are of interest in the calculations.

The dispersion relation connecting the phonon frequency ω_k and wavenumber k is [2, p. 12]

$$\omega_k = \left(\frac{4g_a}{m}\right)^{\frac{1}{2}} \left|\sin\left(\frac{\phi_{n,k}}{2}\right)\right| = \left(\frac{4g_a}{m}\right)^{\frac{1}{2}} \sin\left(\frac{kr_a}{2}\right), \tag{4}$$

where g_a is the "spring constant". The angle $\phi_{n,k} = 2n\pi + kr_a$, where $n\,(= 0, 1, 2, \ldots)$ are the positive branches or Brillouin zones of interest and $k_a\,(= 2\pi/\lambda_a = 1/r_a)$ is the k-axis scaling factor. The absence of absolute-value bars in the final expression follows from the fact that $0 \leqslant kr_a \leqslant \pi$. The group velocity

$$v_k = \frac{d\omega_k}{dk} = \left(\frac{r_a^2 g_a}{m}\right)^{1/2} \cos\left(\frac{kr_a}{2}\right) \tag{5}$$

is the velocity of the k-mode phonons. The phonon number N_k is then the number of k-phonons per unit r_a.

For a single phonon packet (a neutrino) traveling the chain, i.e. for a single value of n and k, (3) leads to

$$U_k = \hbar\omega_k \cdot v_k \cdot N_k = E_k \cdot v_k \tag{6}$$

where $\hbar\omega_k$ is the phonon energy of the packet and $E_k \equiv \hbar\omega_k N_k$ is the total energy carried by the packet. The index k corresponds to the type of neutrino (ν_e, ν_μ, or ν_τ) participating in the decay or capture processes.

The PV is an elastic medium and, because a free particle distorts the PV, the sudden appearance or disappearance of a free particle will initiate a corresponding phonon disturbance in that vacuum. In the rest frame of the particle the static distortion force is [3]

$$F(r) = \frac{e_*^2}{r^2} - \frac{mc^2}{r}\,, \tag{7}$$

where m is the particle mass and the first and second forces are the polarization and curvature force respectively. (In the laboratory frame these opposing forces lead to the particle's de Broglie radius [4, Append. A].) The two forces on the right side of (7) are equal at the Compton radius ($r_c = e_*^2/mc^2$) of the particle, the positive polarization force dominating inside this radius ($r < r_c$) and the negative curvature force outside ($r > r_c$). These opposing forces result in a harmonic-oscillator-type disturbance within the PV, the effective "spring constant" of which is easy to derive from (7):

$$\Delta F(x) = \frac{e_*^2}{(r_c+x)^2} - \frac{mc^2}{r_c+x} = \\ = \frac{e_*^2}{r_c^2}\left[-\frac{x}{r_c} + 2\left(\frac{x}{r_c}\right)^2 - \cdots\right] \approx -\frac{e_*^2}{r_c^3}\,x = -g_c x\,, \tag{8}$$

where x is the excursion of the disturbance about its equilibrium position at $x=0$, and where the particle Compton relation $e_*^2/r_c^2 = mc^2/r_c$ is used in deriving the second expression. For small excursions ($x/r_c \ll 1$) the force reduces to the final expression where $g_c \equiv e_*^2/r_c^3$ is the desired "spring constant".

Using $r_a = r_c$ and $g_a = g_c$ and the Compton radius (it is $r_c = e_*^2/mc^2$) of the free particle (the lepton) in (4) and (5) leads to

$$\hbar\omega_k = \frac{e_*^2}{r_c}\,\frac{\sin(kr_c/2)}{1/2} \approx e_*^2 k \tag{9}$$

and

$$\frac{v_k}{c} = \cos\left(\frac{kr_c}{2}\right) \approx 1 - \frac{1}{2}\left(\frac{kr_c}{2}\right)^2 = 1 - \frac{1}{2}\left(\frac{e_*^2 k/2}{mc^2}\right)^2 \tag{10}$$

to second order in $kr_c/2$. The "spring constant" (g_c) and scaling factor ($k_c = 1/r_c$) tie the m-phonons to the m-lepton that created them, where the prefix "m" stands for the lepton mass in (10). Inserting (9) and (10) into (6) yields

$$U_k = \frac{e_*^2}{r_c}\,\frac{\sin(kr_c/2)}{1/2} \cdot c\cos(kr_c/2) \cdot N_k \tag{11}$$

$$\approx e_*^2 k \cdot c\left[1 - \frac{1}{2}\left(\frac{e_*^2 k/2}{mc^2}\right)^2\right] \cdot N_k \tag{12}$$

for the mean power flux of the lepton-induced neutrino. The magnitude of N_k varies with the needs of the decay or capture process to conserve momentum and energy (and spin, although spin is not included in the present discussion). That is, the PV absorbs the unbalanced momentum and energy of the process.

Using $r_c = e_*^2/mc^2$, (11) and (12) can be put in the more convenient form

$$U_k = mc^2\,\frac{\sin(m_k c^2/2mc^2)}{1/2} \cdot c\cos(m_k c^2/2mc^2) \cdot N_k \tag{13}$$

$$\approx m_k c^2 \cdot c\left[1 - \frac{1}{2}\left(\frac{m_k c^2}{2mc^2}\right)^2\right] \cdot N_k \tag{14}$$

where $m_k \equiv e_*^2 k/c^2$ is a ficticious or effective mass. It is clear from (14) that m_k cannot vanish for then the packet flux U_k would also vanish. The bracket shows that the packet propagates at somewhat less than the speed of light.

It is instructive at this point to compare the particle and phonon-packet models of the neutrino. In the particle model described by (1) and (2), the energy and velocity of the neutrino are

$$E'_\nu = cp'_\nu = m'_\nu c^2 \cdot \beta\gamma \tag{15}$$

and

$$\frac{v'_\nu}{c} = 1 - \frac{1}{2}\left(\frac{m'_\nu c^2}{E'_\nu}\right)^2 \tag{16}$$

for $E'_\nu \gg m'_\nu c^2$. As discussed in the first paragraph, the particle mass m'_ν is a variable mass and, in order to make the equations fit the experimental data, mass and flavor mixing (see below) must be brought *ad hoc* into the particle model, destroying the particle description of the neutrino in the process. From (14) for the packet model

$$E_k = m_k c^2 \cdot N_k \tag{17}$$

and

$$\frac{v_k}{c} = 1 - \frac{1}{2}\left(\frac{m_k c^2}{2mc^2}\right)^2 \tag{18}$$

for small $m_k c^2$. Equation (17) shows that the neutrino energy E_k is the product of the phonon energy $m_k c^2$ and the number of phonons N_k in the packet. Equation (18) shows that the neutrino velocity is determined solely by the neutrino mass m_k and its corresponding lepton mass m.

The three types (or flavors) of neutrinos are the electron (ν_e), muon (ν_μ), and tau (ν_τ) neutrinos and, in the particle model, each flavor is assumed to have one or a combination of three masses (m_1, m_2, m_3) [1, p. 452]. The corresponding three-neutrino mixing (or flavor oscillation) is a phenomenon in which a neutrino created with a particular flavor is later measured to have a different flavor due to a mismatch between the flavor and mass eigenstates of the three neutrinos. In the packet model each neutrino has its own mass as seen in (17) and (18), leading to the more straightforward flavor-oscillation process described below.

The harmonic (quadratic) approximation [2, p. 12] to the Hamiltonian for a linear lattice chain leads to the calculations in equations (3) through (14). For a three-dimensional lattice, the addition of the anharmonic cubic term [2, pp. 130–136] to the quadratic Hamiltonian, along with the effects of the selection rules, lead to a three-phonon process

$$(\mathbf{k},\mathbf{p})+(\mathbf{k}',\mathbf{p}') \Longleftrightarrow (\mathbf{k}'',\mathbf{p}'') \tag{19}$$

that can be tied to the three-neutrino mixing phenomenon, where $\mathbf{k}$ and p, etc., are the wavenumber vector and polarization of the three phonons. That is, the only allowed transitions are those in which two phonons combine to give a third, or vise versa. In addition, conservation of energy requires that

$$\hbar\omega_{\mathbf{k},\mathbf{p}}+\hbar\omega_{\mathbf{k}',\mathbf{p}'}=\hbar\omega_{\mathbf{k}'',\mathbf{p}''} \tag{20}$$

and the conservation of wave vector for a *continuous* medium gives

$$\mathbf{k}+\mathbf{k}'=\mathbf{k}'', \tag{21}$$

where, although the PV is discontinuous at the Planck level ($l\sim r_*$), it is effectively continuous at lengths $l\sim r_c \gg r_*$ where the observed particle Compton radius r_c is concerned. When the phonons are traveling the same straight line, the $\mathbf{k}$s in (19)–(21) can be replaced by their magnitudes. To illustrate the "physical" meaning of (19), consider the equation going from left to right, where the $\mathbf{k}$ and $\mathbf{k}'$ phonons combine to produce the phonon $\mathbf{k}''$: as $\mathbf{k}$ propagates, it distorts the medium in such a fashion as to create an effective "diffraction grating" off of which $\mathbf{k}'$ reflects, destroying the $\mathbf{k}$ and $\mathbf{k}'$ phonons while creating the $\mathbf{k}''$ phonon [2, p. 133].

Equations (19)–(21) are the foundation of the phonon-packet description of flavor mixing which involves three packets (one for each type of neutrino) of the form found in (14). For example, employing (19) from right to left, the neutrino described in (3) through (14) can change into two different neutrinos according to a given probability law [2, eqn.(3.1.6)]. Ignoring polarization and assuming the phonons travel the same straight line, (20) and (21) reduce to

$$m_k c^2 + m'_k c^2 = m''_k c^2 \tag{22}$$

and

$$k+k'=k'', \tag{23}$$

which are the same equation as $m_k c^2 = e_*^2 k$, etc.. Thus the effective masses of the neutrinos drop out of the mixing process; i.e. there is no mass mixing in the packet description of flavor mixing.

In summary, the ease with which the phonon-packet model of the neutrino, based on the negative-energy PV, describes and explains the experimental data makes a compelling case for that model and for a negative-energy vacuum state. With the inclusion of flavor oscillations and variable neutrino masses, on the other hand, the free-particle model appears to be an exercise more in curve fitting than physical modeling.

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