Vacuum Structure and Potential

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Abstract

Based on overall experimental observations, especially the pair processes, I developed a model structure of the vacuum along with a basic-particle formation scheme begun in 2000 (with collaborator P-I Johansson). The model consists in that the vacuum is, briefly, filled of neutral but polarizable vacuuons, consisting each of a p-vaculeon and n- vaculeon of charges $+e$ and $-e$ of zero rest masses but with spin motions, assumed interacting each other with a Coulomb force. The model has been introduced in full in a book (Nova Sci, 2005) and referred to in a number of journal/E-print papers. I outline in this easier accessible paper the detailed derivation of the model and a corresponding quantitative determination of the vacuuon size.

1   Introduction

Vacuum is the continuum in the absence of all material particles like the molecules and atoms, and the matters or substances made up of these. That this vacuum continuum is itself substantial is uniformly pointed to by a range of phenomena, especially the pair processes which take place at the interface between (ordinary) matter and vacuum[1, 2, 3]. I shall here mainly discuss the indication by the pair processes, illustrated for the electron-positron annihilation, and derive based on this a model vacuum structure. This will point to a vacuuonic vacuum structure whose inner property has not been appreciated prior to the author's recent work (with P-I J). The model structure of the vacuum, and a particle formation scheme along with it, have, in terms of first-principles classical-mechanics solutions, facilitated predictions [4a-k] of a range of properties of basic particles and the vacuum that are directly comparable with observations.

2   The observational substantial vacuum

When an electron e^- meets a positron e^+, pair annihilation can occur, with a highest probability if both being at rest, in a reaction process:

$$e^- + e^+ \rightarrow \gamma + \gamma \tag{1}$$

The observed final products are the two gamma rays, γ's on the right-hand side, emitted in opposite directions. These carry the energies converted from and *only* from the *masses* of the electron and positron, $M_{e^-} + M_{e^+} \geq 2 \times 0.511$ MeV. The energy equation for this is:

$$M_{e^-}c^2 + M_{e^+}c^2 = h\mathcal{V}_\gamma + h\mathcal{V}_\gamma \tag{2}$$

with c the velocity of light, h Planck constant, and $\mathcal{V}_\gamma$ the frequency of the emitted gamma rays. (3) is today (incompletely) regarded as a total energy equation for the pair process.

In addition to the masses, the electron e^- and positron e^+ on the left-hand side of (1) we stress are described by their another elementary properties, the charges $-e$ and $+e$, that maintain an interaction energy between the two according to the Coulomb's law.

To explicitly reflect both the two elementary and independent parameters, the mass and the charge of each particle that are each associated with an energy of a specified form and amount, we put these as independent variables, for the entities $e^-(M_{e^-}, -e)$, $e^+(M_{e^+}, +e)$, appearing on the left-hand side of (1). (Their spins are by observation unchanged in the reaction and are thus not explicated here.) On an equal footing, in order to conserve the energy we need to include on the right-hand side of (1) two new entities, v_p and v_n, that are requisite as the carriers of the Coulomb interaction energies between e and $-e$, so that (1) modifies to the complete form

$$e^-(M_{e^-}, -e) + e^+(M_{e^+}, e) \rightarrow \gamma(h\mathcal{V}_\gamma) + \gamma(h\mathcal{V}_\gamma) + v_n(-e) + v_p(e) \tag{3}$$

We below prove that the $v_n(-e)$ and $v_p(e)$ must exist on the right-hand side of (3) in order to conserve energy. Suppose an electron and positron annihilate at a separation distance a_v in the vacuum and, for simplicity when at rest; assume at the scale of a_v their charges continue to interact according to Coulomb's law. (Any specific form of interaction will affect its quantitative scale only but not the general energy conservation equations below.) Just before the annihilation, the two particles carry therefore a zero total kinetic energy $\mathcal{E}_v(a_v) = 0$, and a Coulomb interaction potential energy

$$V(a_v) = -\frac{e^2}{4\pi\epsilon_0 a_v} \tag{4}$$

Or, they together carry a total mechanical energy

$$\mathcal{E}_{+;-}(a_v) = V(a_v) + \mathcal{E}_v(r_0) = -\frac{e^2}{4\pi\epsilon_0 a_v} + 0. \tag{5}$$

After the annihlation, $\mathcal{E}_{+;-}(a_v)$ which cannot be destroyed, must therefore necessarily present in a certain (new or the same) form $\mathcal{E}'_{+;-}(a_v)$ which is assumed to be carried by certain entities denoted earlier by v_p and v_n. Suppose v_p and v_n, are so chosen that they carry all of the mechanical energy and are subject to no external force

(the latter will plausibly hold if the products are as a whole electrically neutral and situated in unperturbed vacuum). Then, it follows from the requirement of energy conservation that the total energy after annihilation must be

$$\mathcal{E}'_{+;-}(a_{\mathrm{v}}) \equiv \mathcal{E}_{+;-}(a_{\mathrm{v}}), \tag{6}$$

with $\mathcal{E}_{+;-}(a_{\mathrm{v}})$ given by (5) and being finite, and in fact being enormously large for a_{v} extraordinarily small. Hence, that the annihilation products v_p and v_n carry an energy equal to the mechanical energy $\mathcal{E}_{+;-}(a_{\mathrm{v}})$ of the electron-positron, is proven.

As to the form of $\mathcal{E}'_{+;-}(a_{\mathrm{v}})$; formally $\mathcal{E}'_{+;-} = V' + \mathcal{E}'_v$. Since no observational indications suggest otherwise, it would be natural to assume in the first place that after the annilation, the two charges $-e$ and $+e$ are unchanged in charge quantities but only transformed to new dynamical states in the forms of the new entities v_n and v_p, that are separated a_{v} apart, and that they continue to interact by $V'(a_{\mathrm{v}})$ according to Coulomb's law. Then, $V'(a_{\mathrm{v}}) = V(a_{\mathrm{v}}) = -\frac{e^2}{4\pi\epsilon_0 a_{\mathrm{v}}}$. Since a_{v} is after annihilation unchanged here, the (center-of-mass) kinetic energy must be $\mathcal{E}'_v(a_{\mathrm{v}}) = \mathcal{E}_v(a_{\mathrm{v}}) = 0$. ($\mathrm{v}_n$ and v_p ought to have rotations that preserve the spins kinetic energies of the electron and position; see [4] for an explicit treatment.)

3   The vacuum structure: Proposition

Two such entities as v_n and v_p as probed with today's instruments are together merely an electrically neutral point in the vacuum. That is, such a point is no different from any other points and may apparently be assigned to everywhere in the vacuum. Such a point ought therefore necessarily to be assigned to everywhere in a vacuum which gives off pair productions on absorbing a high energy light qunta and which propagates light wave everywhere the same way. We therefore induce that, the vacuum must be filled of such entities, v_n and v_p paired together, by Coulomb energy $V_{\mathrm{v}} \equiv V(a_{\mathrm{v}})$ at a distance a_{v}, so as to be externally electrically neutral. We call each such entity a **vacuuon**.

An electrically neutral vacuuon may be formed of two concentric opposite charged spheres, or alternatively a jelly-like mixture of two intermingling opposite charged fluids. The latter, the jelly-like structure, must however be rejected, in order to account for the positron experiments. These experiments inform that single positrons do not exist as free particles [1, 2, 3], they once created will appear to instantly vanish into the vacuum. In other terms, the vacuum seems to be a negatively charged sea, as originally proposed by Paul Dirac in 1930[3], which traps any single positive charge in it, unless the charge has a high enough (oscillatory) kinetic energy (amounting to a proton mass) to escape.

Based on the above considerations taking the simplest structure for two concentric spheres, I propose a model for the vacuum structure to be:

1. The vacuum is uniformly filled of building entities termed **vacuuon**s that are electrically neutral and essentially completely at rest in the absence of external disturbances, and have each a zero rest mass (Figure 1a).
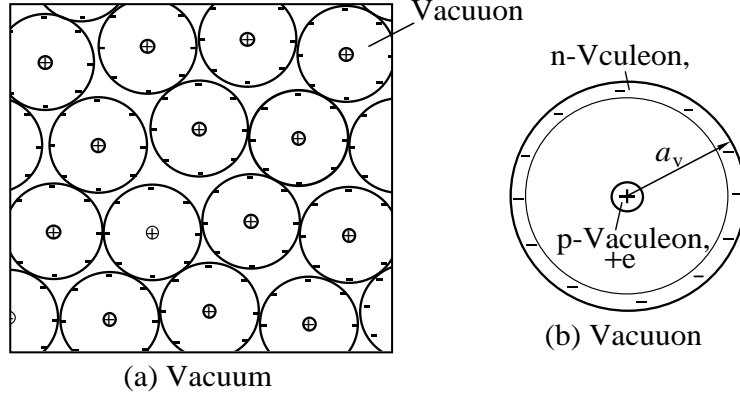
Figure 1: Schematic diagrams of the structures of (a) the vacuum, being uniformly filled of electrically neutral vacuuons, and (b) a vacuuon, being composed of a p-vaculeon at the center (being point-like), of a charge +e, and an n-vaculeon of a charge -e on a concentric spherical shell of a radius a_v as envelope. The finite thickness of the n-vaculeon envelope and the finite size of the p-vaculeon as drawn are only for illustrating the charges locations; their actual sizes are non observables for the presently available information.

2. A vacuuon is composed of a **p-vaculeon** having an electric charge $+e$ and an **n-vaculeon** having an electric charge $-e$, where $e = 1.602 \cdot 10^{-19}$ C being the elementary charge. The p- and n-vaculeons have each a zero rest mass. 3. In the vacuuon in its ground-state, the n-vaculeon forms an envelope, a spherical shell of radius a_v, about the point-like p-vaculeon at the center (Figure 1b).

4. The n- and p- vaculeons have each a rotational motion, or spin (a more suitable term in their freed states), about their own coincidental axes, and hence have a angular momentum, L_s. L_s equals $\mp\frac{1}{2}\hbar$ as for the electron and proton spins, $2\pi\hbar$ being Planck constant.

5. The vacuuon, and the n- and p- vaculeons are assumed to obey the basic laws of classical mechanics under the equivalent conditions (in particular in a vacuum background) under which the basic laws are established.

The nature of the vacuum as induced above is similarly, though indirectly, pointed to by the antiproton production (O. Chamberlain, et. al., 1955, 1957; J. Eades, 1999; E. Segre, 1958), and antineutron production (B. Cork, et al., 1960). The neutral but polarizable vacuuon construction is also indicated by the observed Lamb shift, and the capability of the vacuum to propagate electromagnetic waves like a sound wave in a stretched string, among others. The vacuuonic vacuum structure also enables one to comprehend among other the following three prominent experimental phenomena: (i). The fact that the annihilation of an "existing" electron

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with a (yet "non-existing") positron takes place most probably within a material substance. We now see that, since the positron is trapped in a negative potential well as mentioned above, to lift it to the (vacuum) level at which annihilation occurs, there requires firstly the presence of some external energy supply; this supply may be provided by the potential field of a proton or of a matrix of protons as naturally provided by a material substance. (ii). The fact that there exist in nature two and only two species long-lived free basic material particles, the proton and the electron. The fact that the proton is much heavier by a specified amount than the electron. (iii). From the two only stable simple (termed also basic) material particles, the proton and the electron with a positive and an negative charge respectively, an atom is formed always with the former at the core and the latter at the outskirt.

The vacuum structure proposed here resembles characteristically Dirac's vacuum, with the sea of negatively charged n-vaculeon envelopes loosely corresponding to Dirac's sea of negative charges.

4   Vacuum potential

Applying Coulomb's law to the charge $+e$ on the point-like p-vaculeon and the charge element dq on the enveloping n-vaculeon, integrating over the entire surface on the n-vaculeon spherical shell, we obtain the total force the p- vaculeon acting on the n- vaculeon: $F_{pn} = \int_0^q \frac{edq}{4\pi\epsilon_0 a_v^2} = \frac{e}{4\pi\epsilon_0 a_v^2}(\frac{-e}{4\pi})\int_0^{4\pi} d\sigma$. Or,

$$F_{pn} = -\frac{e^2}{4\pi\epsilon_0 a_v^2} \tag{7}$$

At a variant separation distance r, (7) writes as $F_{pn}(r) = -\frac{e^2}{4\pi\epsilon_0 r^2}$. The interaction potential between the p- and n- vaculeons, or the intervaculeon potential, follows to be

$$V_{np}(r) = -\int_r^\infty F_{pn}dr = \int_\infty^r \frac{e^2}{4\pi\epsilon_0 r^2}dr = -\frac{e^2}{4\pi\epsilon_0 r} \tag{a}$$

The function $V_{np}(r)$ here corresponds to the $V'(r)$ in Sec. 2. Figure 2 shows a plot of $V_{np}(r)$. At the equilibrium separation distance $r = a_v$, we have a **ground-state vacuuon**, and the corresponding potential:

$$V_v \equiv V_{np}(a_v) = -\frac{e^2}{4\pi\epsilon_0 a_v} \tag{8}$$

The reference level of $V_{np}(r)$, $V_{np}(r) = 0$, is in the above taken at $r \to \infty$. The zero intervaculeon potential level $V_{np}(\infty)$ may be taken to coincide with the energy level of **ground-state vacuum**—the vacuum in the absence of any external disturbance and being thus composed of unperturbed neutral vacuuons. Unperturbed neutral vacuuons do not interact with each other and thus have a zero interaction potential. See discussion in [4a] regarding vacuum potential in the presence of an external vaculeon charge.
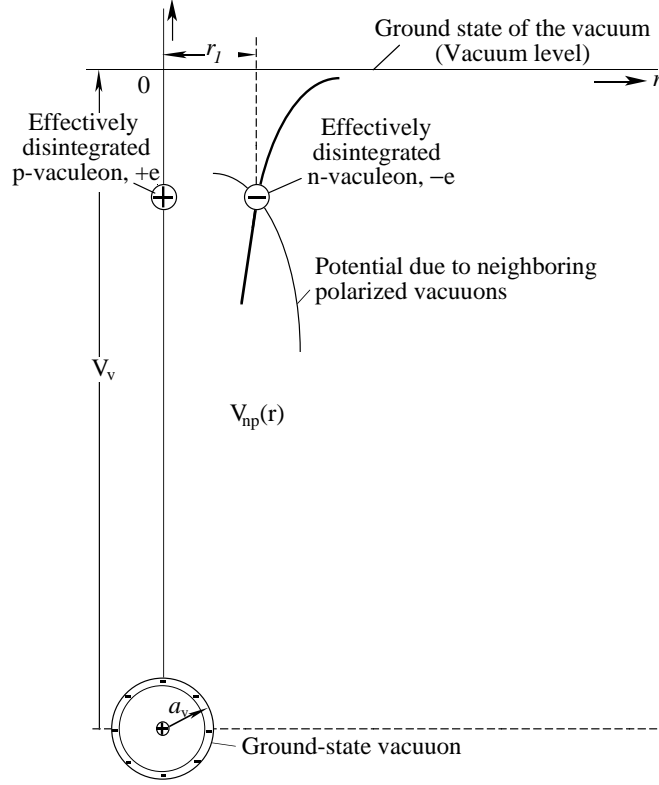
Figure 2: Electrostatic potential $V_{np}(r)$, thick solid curve, between a bound p-vaculeon and n-vaculeon as a function of separation distance r, effectively within r_1; at the equilibrium separation distance a_v these make up a ground-state vacuuon, with $V_{np}(a_v) = V_v$. The infinite separation distance corresponds to the vacuum level (vacuum ground state), $V_{np}(\infty) = 0$. As ordinarily situated among other vacuuons close-packed (these making up the vacuum), the two bound vaculeons in the reference vacuuon will be effectively disintegrated already at a finite distance $< r_1$. Beyond r_1 the vaculeon are each primarily subject to the potential field from the surrounding vacuuons as polarized by the vaculeons' own charges.

a_v and V_v have been quantitatively determined with reasonable confidence in [4a]. This involves some lengthy procedure, I thus give an outline of the solutions only below. Based on classical-mechanics solution for the potential energy of an external p-vaculeon in the vacuum, combined with the minimum kinetic energy requirement for a free p-vaculeon in the vacuum, which is equivalent to a proton mass (M_p), a_v is given by the solution:

$$a_v = \frac{-M_p c^2 + \sqrt{(M_p c^2)^2 + 4(2\rho_l c^2)\frac{Z_X' e^2}{4\pi \in_0}}}{2(2\rho_l c^2)} \qquad (9)$$

Where Z_X' is a parameter related to the explicit vacuuonic configuration and is estimated (for a dense-packed structure) to be ~ 1.7; ρ_l is the linear mass density of the vacuum. ρ_l can be fixed separately from the solution for gravitational constant (G) [4e,b], to be

$$\rho_l = \frac{\chi_{0^*} e^4}{4\pi \in_0^2 \hbar^2 G} = 1.05(36) \times 10^{-17} \ \ \text{kg/m} \qquad (10)$$

Where χ_{0^*} is the electric susceptibility of the vacuum and has been more recently determined by an exact solution for between an electron and proton to be (internal work)

$$\chi_{0^*} = \frac{\in_0 G M_e M_p}{3e^2} = 1.16(9) \times 10^{-41}. \qquad (11)$$

Using the above Z_X' and ρ_l values in (9), a_v is computed to be:

$$a_v \approx 2.70(5) \times 10^{-18} \ \ \text{m} \qquad (12)$$

With this a_v value in (8), the intervaculeon potential energy of a ground-state vacuuon is estimated to be

$$V_v \approx -8.52(8) \times 10^{-11} \ \ \text{J}$$

Or, it equals -0.532 GeV. Using the a_v value, the the maximum frequency of elastic waves (corresponding to the electromagnetic waves) that can be propagated in the vacuum can be readily estimated to be $\sim 8 \cdot 10^{24}$ 1/s. This is close to the experimentally observed upper limit of electromagnetic wave frequency.

Acknowledgements

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