Reply to "Comment on 'Source of vacuum electromagnetic zero-point energy'"

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A missing redshift factor in my paper [Phys. Rev. A **40**, 4857 (1989)] brought to my attention by E. Santos is corrected. The correction results in a better match between theory and observation, thereby strengthening the original argument that the zero-point energy fields are dynamically generated by the quantum-fluctuation motion of charged particles distributed over cosmological space.

I wish to express my appreciation to Professor E. Santos for bringing to my attention a missing redshift factor in my paper concerning the source of the vacuum electromagnetic zero-point energy (ZPE) [1]. Specifically, an additional redshift multiplier $(1+z)^2$ is required in the substitution of Eq. (20) into Eq. (24) in Ref. [1]. As is shown here, proper inclusion of this additional factor serves to further strengthen the argument presented there, namely, that the ZPE fields are dynamically generated by the quantum-fluctuation motion of charged particles distributed over cosmological space.

That the additional redshift factor is required can, within the context of Ref. [1], be seen most easily by reference to the discussion preceding Eq. (24) concerning the general invariance under redshift of the ratio $\rho(\omega)/\omega^3$, applicable to any spectral energy distribution $\rho(\omega)$ [2]. In the nomenclature of Ref. [1], during scattering of the ZPE distribution by individual electrons, the density $\rho_i(\omega_r)$ at a receiver now located a distance r_r from an emitter is derived from that at the emitter, $\rho_i(\omega_e)$, as

$$\rho_i(\omega_r)=\left[\frac{\omega_r}{\omega_e}\right]^3\rho_i(\omega_e)=\left[\frac{\omega_r}{\omega_e}\right]^3\left[\frac{3\hbar\Gamma^2\omega_e^3}{4\pi^2cr_e^2}\right]=\left[\frac{3\hbar\Gamma^2\omega_r^3}{4\pi^2cr_r^2}\right](1+z)^2 . \tag{1}$$

As seen, the redshift factor $(1+z)^2$, missing in Ref. [1], is derived from the relationship $r_r/r_e=(1+z)$, corresponding to the expansion of space between the times of emission and reception (Eq. (22), Ref. [1]). Thus, although the overall integrated ZPE distribution $\rho(\omega)=\hbar\omega^3/2\pi^2c^3$ is redshift invariant (redshift factor free), this invariance is not shared by the individual radiation contributions hypothesized to comprise this distribution.

Mathematically, the additional redshift factor in the integration of Eq. (24) results in a simple numerical multiplier

$$(1/R_{\text{comm}})\int_0^{z_m}(1+z)^2\frac{dr}{dz}dz$$

of the parameter γ in the expression derived for the generation of the ZPE distribution by regenerative electron scattering, (Eq. (25)ff, Ref. [1]),

$$\rho(\omega)=\gamma\left[\frac{\hbar\omega^3}{2\pi^2c^3}\right] . \tag{2}$$

In the redshift multiplier, R_{comm} is the cosmological radius of communication in a given metric (defined by $z\to\infty$), and z_m corresponds to the maximally redshifted radiation significantly contributing to the local ZPE energy density. For the Einstein–de Sitter inflationary model explored in the remainder of Ref. [1], the corrected value for γ (in the nomenclature of Ref. [1]) is given by

$$\gamma=6\pi\Gamma^2c^2\eta R_{\text{comm}}\left[\frac{(1+z_m)^{3/2}-1}{3}\right] , \tag{3}$$

where the expression in large parentheses is the resulting numerical correction factor. Equation (3) is identical to the expression derived by Santos as his Eq. (4).

From a physical standpoint, the redshift-factor correction discussed here can be seen to reinforce the thesis of Ref. [1] concerning an underlying, cosmologically based ZPE generation mechanism based on self-regenerative electron ZPE scattering. First, the rough order-of-magnitude agreement with observation reported in Ref. [1] fell about an order of magnitude short of the $\gamma\equiv1$ requirement for the hypothesized dynamic-generation process. With the redshift-correction factor in place, however, the summed contributions of significant unscattered ZPE radiation back to an initial epoch t_i within the first percent or so of the age of the universe ($z_m>10$) permit an exact match to observation. For example, if the age of an Einstein–de Sitter universe is taken to be $\sim15\times10^9$ yr, the $\gamma\equiv1$ requirement can be met with $z_m\sim13$ (thereby setting the value for the optical depth for unscattered ZPE radiation).

Secondly, as shown in Ref. [1], $\gamma\equiv1$ yields directly the "cosmological coincidence" $N_1=N_2$ ($\sim10^{39}$), where N_1 is the ratio of electromagnetic to gravitational force between an electron and proton, and N_2 is the ratio of the Hubble distance $L_H=c/H$ to the diameter of the classical electron. Discussed most often within the context of Dirac's large-numbers hypothesis (LNH) [3], attempts to account for such a cosmological coincidence generally share the weakness of Dirac's LNH in that a time-varying Hubble constant must be offset by a time-varying G to maintain constancy of the other parameters appearing in N_1 and N_2. With the addition of the correction factor discussed here, however, the time-varying Hubble constant $H(t)$ in the $N_1=N_2$ relationship is replaced by $H(t_i)/3$ (a change by a factor ~ 17), where $H(t_i)$ is the (constant) value of the Hubble constant at the earlier initial epoch (corresponding to the present redshift factor z_m) back to from which, statistically speaking, ZPE radiation can arrive unscattered. [To see this, note that, for $z_m \gg 1$, the correction factor in Eq. (3) above is proportional to

$$(1+z_m)^{3/2}=t/t_i=H(t_i)/H(t)$$

[for the Einstein–de Sitter geometry.] Thus, the effect of the redshift correction factor is, to first order, to place the cosmological coincidence relationship $N_1 \sim N_2$ on a time-invariant basis, thereby overcoming the standard objections to an underlying, cosmologically based mechanism for such a relationship.

In summary, the basic argument presented in Ref. [1] is that the vacuum electromagnetic ZPE fields are generated by the (quantum-fluctuation) motion of the charged particles that constitute matter, distributed over cosmological space. The redshift-factor correction discussed here is found to strengthen the original argument by permitting a better match between theory and observation, and by removing a weakness in the cosmological numerical-coincidence result implicit therein [4].

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[1] H. E. Puthoff, Phys. Rev. A **40**, 4857 (1989). I also wish to acknowledge Professor Paul Wesson for useful correspondence on this same issue.

[2] C. W. Misner, K. S. Thorne, and J. A. Wheeler, *Gravitation* (Freeman, San Francisco, 1973), p. 588.

[3] E. R. Harrison, Phys. Today **25**, 30 (1972).

[4] Additional errata for Ref. [1]: The symbol l in the third line preceding Eq. (3) should read e; the symbol "c^3" in the denominator of the expression for d_0 in the sixth line preceding the discussion section should read "c^2;" with the redshift-factor correction introduced here, the prediction of Eq. (31) is no longer valid.