Comment on "Sonoluminescence as Quantum Vacuum Radiation"

In a recent Letter, Eberlein [1,2] has claimed to expain sonoluminescence as a phenomenon of quantum vacuum radiation (QVR); i.e., the light emitted by repetitive sound-driven implosion of gas bubbles in fluids, usually air bubbles in water [3,4], as a quantum relativistic effect. In this Comment we want to stress that, for any realistic experimental values of the parameters involved, the light energy emitted by the bubbles due to QVR is 25 orders of magnitude smaller than that observed experimentally [3]. Only when the parameters used are completely unrealistic, the speed of the bubble surface is of the order of or higher than the speed of light, and the turnaround or relaxation time is about 10^{-21} s can QVR explain the observed data.

To proceed with the argument, we use formula (10) of Ref. [1]. The energy (W) radiated in a cycle of the expansion and contraction of the bubble is

$$W = \frac{(n^2 - 1)^2}{n^2} \frac{\hbar}{480\pi c^3} \int_0^T dt \, \frac{\partial^5 R^2(t)}{\partial t^5} R(t)\beta(t) \, , \quad (1)$$

where $R(t)$, $\beta(t)$ are the bubble radius and speed, expressed in units of speed of light c, and n and $\hbar$ are the refraction index and the Planck constant, respectively. This formula is valid for the so-called short-wave limit [1,2] which is quite enough to estimate the irradiated energy in real experimental conditions [3,4]. Taking for $R(t)$ formula (4.9) of Ref. [2],

$$R^2(t) = R_0^2 - (R_0^2 - R_{\min}^2) \frac{1}{(t/\gamma)^2 + 1} \, , \quad (2)$$

where R_0 is the initial (before the collapse) and $R_{\min}$ is the minimum radius of the bubble, one obtains for the energy

$$W = 1.16 \, \frac{3(n^2 - 1)^2}{512 n^2} \frac{\hbar}{c^4 \gamma^5} (R_0^2 - R_{\min}^2)^2 . \quad (3)$$

One sees that the energy is the characteristic photon energy, $\hbar\gamma^{-1}$, multiplied by the ratio of the mean bubble speed to the speed of light to the fourth power, a quantum relativistic effect of the fourth order. For typical values of the experimental parameters in qualitative agreement with the Rayleigh-Plesset equation [3,4]: $\gamma \sim 10^{-9}$–10^{-10} s and $R_0 \sim 10$ μm ($R_{\min} \sim 0.5$ μm and can be neglected), we find that $W = 10^{-40}$ J while the experimental value of Ref. [3] is 10^{-14}–10^{-15} J. That means that we miss the data by 25 orders of magnitude. Only when γ is taken to be 0.1 fs [1] to explain the emission spectrum of light [3] one has agreement with the data, but that implies speeds of 10–100 times the speed of light.

In Ref. [2] Eberlein says that formula (4.9) (which is Eq. (2) of the Comment) is oversimplified with unrealistic properties, but that the superluminal velocity of this model is without consequences because it is the fourth order derivative of the speed that matters, and this can be very large even if the speed is very small. Eberlein says that one can opt for more complicated model functions where the maximum velocity is controlled, for example,

$$R(t) = R_{\min} + \beta_0 t \tanh \frac{t}{\gamma'} \, , \quad (4)$$

with

$$W = 1.16 \, \frac{(n^2 - 1)^2}{n^2} \frac{\hbar}{c^2 \gamma^3} \beta_0^2 R_{\min}^2 \frac{1}{45\pi} \left(1 + \frac{\pi^2}{21}\right) . \quad (5)$$

From formula (4) one sees that the speed of the bubble surface $\sim\beta_0$, and if, as before, $\gamma' = 0.1$ fs we find $\beta_0 \approx 30$ (30 times the speed of light). Alternatively, taking β_0 as the speed of sound (the maximum speed of the bubble surface) and fitting the value of γ' to the observed emitted intensity, one finds that γ' (the time to accelerate the surface of the bubble of micron size) is 10^{-21} s. This is 10^{-3} of the time that light takes to cross an atom.

It is clear that the situation cannot be improved by proposing another function $R(t)$. Any changes in any derivative of $R(t)$ occur during the times which are no shorter than 10^{-13} s (the time it takes for sound to cross interatomic distances), and it is quite different from the above time. In any case, $R(t)$ is given by the hydrodynamic equations [4] and it has the consequences discussed above.

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