Does Transmission of Light through a Window Involve Physics at the Planck Scale?

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1 Problem

While it would be generally considered that transmission of light through a glass window does not involve physics at the Planck length scale (sec. 26 of [1]),

$$L_P = \sqrt{\hbar G/c^3} \approx 1.6 \times 10^{-35} \text{ m}, \tag{1}$$

a recent suggestion by Bekenstein [2, 3] is that it does.[1]

The comment is that when a single photon of momentum $\mathbf{p}$ and energy $E = pc$ enters a transparent block of mass M and index of refraction n, which block is initially at rest, the momentum of the photon[2] is reduced to $\mathbf{p}/n_{\text{group}} \approx \mathbf{p}/n$, and the momentum of the block is temporarily increased to $\mathbf{P} \approx \mathbf{p}(1-1/n)$ for the time interval $\Delta t = n_{\text{group}}L/c \approx nL/c$, where L is the length of the block, c is the speed of light in vacuum, and $n_{\text{group}} = c/v_g = c\, dk/d\omega = d(\omega n)/d\omega = n + \omega\, dn/d\omega \approx n$ for glass. During this time interval the center of mass of the block[3] moves along the direction of the photon by a distance $\Delta x = v\Delta t = P\Delta t/M = (1 - 1/n)pnL/Mc = (n-1)EL/Mc^2$. For example, if $n \approx 1.5$, $E \approx 2$ eV $\approx 3.2 \times 10^{-19}$ J, $L = 0.01$ m and $M = 0.1$ kg, then $\Delta x \approx 1.6 \times 10^{-36}$ m $\approx 0.1L_P$. *This indicates that the Planck scale is in some way relevant to transmission of light through a window.*

The argument is then that if space is grainy on the Planck scale (as suggested by Wheeler [6]), such a tiny displacement would be impossible, and the single photon would not be transmitted, but would be reflected. Hence, if the transmission coefficient of the window is smaller for a single photon than for a pulse, this could be evidence that space is grainy on the Planck scale.

Can this be so?

2 Solution

The presence of $\hbar$ in the definition (1) of the Planck length reminds us that the argument has a quantum character.[4] An issue is that in the quantum view, the quantity Δx does not

[1] A related suggestion is made in [4].

[2] This statement corresponds to supposing the relevant momentum of the photon inside a medium is the so-called Abraham momentum. See footnote 3 of [5] for comments by the author on this topic.

[3] Is it doubtful that the block acts like a rigid body under the impact of the photon, whose wavepacket length could be a few wavelengths, much less than L. Hence, the discussion should not be about, say, the front or the back face of the block, which oscillates as a result of the passage of the photon.

[4] The Appendix of [2] notes that since $\Delta x = P\Delta t/M \propto P$, Δx and P commute, and both can have precise values, IF measured (and IF operators based on the assumption of a spacetime continuum are relevant to the grainy spacetime).

have a value unless it is measured. As remarked by Peres [7]: *Unperformed experiments have no results*. That is, unless the experiment includes a measurement of the displacement Δx, accurate to the Planck scale, then the center of mass of the block does not actually have the tiny displacement that might be forbidden by the graininess of space.

A measurement of the displacement of the center of mass of the block on the Planck scale is not feasible at present, so a measurement only of the transmission coefficient of the block for single photons cannot be expected to reveal physics at the Planck scale.

One can also be skeptical of the claims in [2, 3, 4] on "philosophical" grounds that if space(time) is grainy, then one cannot expect concepts, such as velocity, momentum and center-of-mass position, which are based on the assumption of continuous spacetime, to be valid. For example, if two (tiny) equal masses existed at adjacent "grains" in space, their center-of-mass position does not exist in "real" space, but only in a "Platonic" idealization of a spacetime continuum. It does not seem reasonable to argue, in the spirit of [2, 3], that, say, the first of the two particles cannot move by two "grains" from its original position because the center of mass of the final state would not lie on a "grain" (Zeno's paradox for "spacetime foam"). The abstract concept of the center of mass of a system, which does not correspond to a "material point", need not lie on a "grain".

If spacetime is grainy, a continuum analysis cannot be used to predict experimental results accurately, and a conflict between the continuum analysis and experimental possibility in grainy spacetime cannot be used to deduce limits on the experimental possibilities. Rather, such conflicts only point out the limits of the continuum analysis.

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References

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