entropy

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Correction

Correction: Kay, B.S. Entropy and Quantum Gravity. *Entropy* 2015, *17*, 8174–8186

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The following corrections should be made to the published paper [1]:

First, the paragraph beginning with "One might argue that ... " and ending with "... increase monotonically with time." on page 8175 should be replaced by the following two corrected paragraphs:

"One might argue that none of this matters and entropy is not a fundamental quantity; the only truly fundamental and natural value for the W in Boltzmann's formula is 1 (all distinct microstates are ultimately distinguishable) and the only natural value for the entropy, S, of any state of any closed system is therefore zero. Likewise, a full description of a quantum closed system would be with a *pure* density operator, for which the von Neumann entropy is again zero.

And yet, there seem to be reasons [2,3] to believe that the universe really does have a non-zero entropy—and that this is quite independent from any subjective judgments that we may make about what we can and cannot distinguish (see Endnote [4]–which refers to Reference [5]). Indeed its value has been estimated (see e.g., [6]). Furthermore, thanks to Hawking [7], we know that a black hole has an entropy equal to a quarter of the area of its event horizon—and there certainly seems to be nothing subjective about a quarter of an area! Moreover, presumably the entropy of the universe really is increasing and the entropy of a model closed system consisting of a star in empty space which collapses to a black hole, and subsequently Hawking-evaporates, will (when we include the contribution to the entropy from the radiated particles) increase monotonically with time."

Second, the two paragraphs beginning with "Our proposal resembles ... " and ending with "... (See also Endnote [4].)" on page 8176 should be replaced by the following two corrected paragraphs:

"Our proposal resembles the environment-induced decoherence paradigm [20, 21] but with a crucial difference: In the environment paradigm, one separates one's total closed system into a "subsystem of interest" and an "environment" and regards the subsystem-environment entanglement entropy as the physical entropy of the (*open*) subsystem. But, in our proposal, the matter-gravity entanglement entropy is identified with the entropy of the total closed system—and will, in general, be non-zero even though the state of the total closed system is, at all times, a pure state!

Our proposal can easily be extended to include both closed and open systems by realizing the matter Hilbert space as a tensor product of a matter-system and a matter-environment Hilbert space: In some given closed matter-gravity system, in some given total pure state, we then define the entropy of some given open subsystem of the matter to be the von Neumann entropy of its reduced density operator—obtained by taking the partial trace of the total density operator over the appropriate matter-environment Hilbert space as well as over the gravity Hilbert space (*i.e.*, by taking the partial trace over the tensor product of the latter two Hilbert spaces). See Endnote (xii) of [10] for details. Now as one considers increasing the size of what we consider to be the matter system, and concomitantly reducing the size of what we consider to be the matter environment—schematically indicated by sliding the vertical dotted line to the right in Figure 1a, one expects the entropy of the matter system to tend, in the limit as one slides it fully to the right, to the non-zero value for the entropy of the total closed system—as in the schematic graph in Figure 2a. This is to be contrasted with what would happen on the standard environment paradigm (on the assumption of a total pure state) schematically illustrated by sliding the dividing line between system and environment to the right in Figure 1b. The entropy may increase at first, but eventually it must decrease towards the value zero for the total closed system, as in the schematic graph in Figure 2b. (See also Endnote [4].)"

The opportunity of this correction is also taken to correct the following two small errors:

Page 8178, 3rd paragraph, 3rd sentence: the last eight words should be removed, so the sentence should be:

"In particular, for our box model, one expects it would predict an increase in entropy, even if our box were a truly closed system, with no matter environment – albeit this increase might be very small."

Page 8185: End Note number 28. Line 4 should be altered to read

"Gibbons-Hawking Euclidean quantum gravity partition function [29], (in Planck units) $Z(\beta) = e^{-\beta^2/16\pi}$, for pure ..."

Conflicts of Interest: The author declares no conflict of interest.

Reference

1. Kay, B.S. Entropy and Quantum Gravity. *Entropy* **2015**, *17*, 8174–8186.