We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900
Open access books available

185,000
International authors and editors

200M
Downloads

Our authors are among the

154
Countries delivered to

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter 9

The Planck Power – A Numerical Coincidence or a Fundamental Number in Cosmology?

Jack Denur

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/61642

Abstract

The Planck system of units has been recognized as the most fundamental such system in physics ever since Dr. Max Planck first derived it in 1899. The Planck system of units in general, and especially the Planck power in particular, suggest a simple and interesting cosmological model. Perhaps this model may at least to some degree represent the real Universe; even if it does not, it seems interesting conceptually. The Planck power equals the Planck energy divided by the Planck time, or equivalently the Planck mass times c^2 divided by the Planck time. We show that the nongravitational mass-energy of our local region (L-region) of the Universe is, at least approximately, to within a numerical factor on the order of 2, equal to the Planck power times the elapsed cosmic time since the Big Bang. This result is shown to be consistent, to within a numerical factor on the order of 2, with results obtained via alternative derivations. [We justify employing primarily L-regions within an observer's cosmological event horizon, rather than O-regions (observable regions) within an observer's cosmological particle horizon.] Perhaps this might imply that as nongravitational mass-energy leaves the cosmological event horizon of our L-region via the Hubble flow, it is replaced at the rate of the Planck power and at the expense of negative gravitational energy. Thus the total mass-energy of our L-region, and likewise of all L-regions, is conserved at the value zero. Some questions concerning the Second Law of Thermodynamics and possible thwarting of the heat death of the Universe predicted thereby, whether via Planck-power input or via some other agency, are discussed. We then give a brief review of the Multiverse, and of some alternative viewpoints.

Keywords: Planck system of units, L-regions (local regions), O-regions (observable regions), comoving frame, Second Law of Thermodynamics, heat death, Planck power versus heat death, low-entropy boundary conditions versus heat death, kinetic versus thermodynamic control, kinetic control versus heat death, minimal Boltzmann brains, extraordinary observers.

INTECH
open science | open minds

© 2015 The Author(s). Licensee InTech. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

1. Introduction

In Sect. 2 we define and distinguish between local regions (L-regions) within an observer's cosmological *event* horizon and observable regions (O-regions) within an observer's cosmological *particle* horizon, of the Universe, and justify primarily employing L-regions. In Sect. 3 we discuss the importance of the Planck system of units, which has been recognized as the most fundamental such system in physics ever since Dr. Max Planck first derived it in 1899. We then consider a possibly important role of the Planck system of units, especially of the Planck power, in cosmology. Perhaps the ensuing cosmological model may at least to some degree represent the real Universe; even if it does not, it seems interesting conceptually. The Planck power equals the Planck energy divided by the Planck time, or equivalently the Planck mass times c^2 divided by the Planck time. In Sect. 3 we show that the nongravitational mass-energy of our local region (L-region) of the Universe is, at least approximately, to within a numerical factor on the order of 2, equal to the Planck power times the elapsed cosmic time since the Big Bang. This result is shown to be consistent, to within a numerical factor on the order of 2, with results obtained via alternative derivations. We consider the possible inference that as nongravitational mass-energy leaves the cosmological event horizon of our L-region via the Hubble flow, it is replaced at the rate of the Planck power and at the expense of negative gravitational energy. The problem of consistency with astronomical and astrophysical observations is discussed in Sect. 4. In Sects. 3 and 4 we consider only nonoscillating cosmologies (except for brief parenthetical mentions of oscillating ones in the second-to-last paragraph of Sect. 4). In Sects. 5–8 we consider both nonoscillating and oscillating cosmologies. Some questions concerning the Second Law of Thermodynamics and possible thwarting of the heat death predicted thereby are discussed with respect to the Planck power in Sect. 4, with respect to cosmology in general and minimal Boltzmann brains in particular in Sect. 5, with respect inflation to in Sect. 6, and with respect to kinetic versus thermodynamic control in Sects. 4 and 7. (We discuss possible thwarting of the heat death with respect to kinetic versus thermodynamic control mainly as regards the Planck power in particular in Sect. 4 but more generally in Sect. 7.) A brief review concerning the Multiverse, and some alternative viewpoints, are given in Sect. 8.

2. L-regions and O-regions

In this chapter we will consider primarily *local* regions or L-regions of the Universe rather than *observable* regions or O-regions [1] thereof, although we will also consider O-regions as necessary [1].[1] We now define and distinguish between L-regions and O-regions, and justify primarily employing L-regions, as opposed to O-regions only occasionally, as necessary [1]. Let R be the radial ruler distance or proper distance [2] to the boundary of our L-region, that is to our cosmological *event* horizon [3], where the Hubble flow is at c, the speed of light in vacuum; beyond this horizon it exceeds c. Thus if the Hubble constant $H(\tau)$ does not vary with cosmic time [4,5] τ and is always equal to its present value H_0, then light emitted at the *present* cosmic time [4,5] τ_0 by sources beyond our cosmological event horizon [2,3] and hence beyond our L-region can never reach us. Likewise, light emitted at the *present* cosmic time [4,5] τ_0 by us can never reach them. Also, if the Hubble constant $H(\tau)$ does not vary with cosmic time [4,5] τ and is always equal to its present value H_0, then our cosmological event horizon [2,3] is always at fixed ruler distance $R_0 = c/H_0$ away and hence our L-region

[1] (Re: Entry [1], Ref. [1]) In Ref. [1] observable regions of the Universe are referred to as O-regions for short. We have followed this notation with respect to both O-regions and local regions (L-regions) in this chapter, with L-regions being of primary interest to us.

http://dx.doi.org/10.5772/61642

of the Universe is always of fixed size. [We denote the value of a given quantity Q *today* (at the *present* cosmic time τ_0) by Q_0 and its value at *general* cosmic time τ by $Q(\tau)$.]

Light emitted at *past* cosmic times $\tau < \tau_0$ (but not too far in the past) by sources now beyond (but not too far beyond) our cosmological event horizon [$R_0 = c/H_0$ always if $H(\tau) = H_0$ always] and hence beyond our L-region but still within our O-region [1–3] can reach us, because when this light was emitted these sources were still within our L-region. Likewise, light emitted in the *past* $\tau < \tau_0$ (but not too far in the past) by us can reach them. The boundary of our O-region of the Universe is our cosmological *particle* horizon [1–3]. The boundary of our O-region (our cosmological particle horizon) is further away than the boundary of our L-region (our cosmological particle horizon) [1–3]. If $H(\tau) = H_0$ always, not only is the boundary of our O-region currently at ruler distance $\mathfrak{R}_0 > R_0 = c/H_0$ but $\mathfrak{R}(\tau)$ gets further away with increasing cosmic time τ [4,5], while the boundary of our L-region $R(\tau)$ always remains fixed at $R_0 = c/H_0$. The fixed size of our (or any) L-region given constant $H(\tau) = H_0$ simplifies our discussions. More importantly, all parts of our (or any) L-region are *always* in casual contact, while outer parts of our (or any) O-region beyond the limit of the corresponding L-region *were* but no longer *are* in causal contact. Hence we will primarily employ L-regions rather than O-regions.

Hubble flow exceeding c may seem to violate Special Relativity. But General Relativity — not Special Relativity — is applicable in cosmology [6]. Special Relativity is applicable only within local inertial frames, and any given observer is not — indeed cannot be — in the same local inertial frame as this observer's cosmological event horizon [1–6] (and even less so as this observer's cosmological particle horizon [1–6]). Thus Hubble flow exceeding c does not violate General Relativity [6]. It should also be noted that the Hubble flow is motion with space rather than through space — every object in the Hubble flow is at rest in the comoving frame [7]. An object's motion, if any, relative to the comoving frame [7] is its *peculiar* motion.[2]

At the 27th Texas Symposium on Relativistic Astrophysics [8], values of the Hubble constant today H_0 from the upper 60s to the low 70s $(\text{km}/\text{s})/\text{Mpc}$ were given [8], so $H_0 \approx 70\,(\text{km}/\text{s})/\text{Mpc}$ splits the difference [8]. These values were essentially unchanged from those obtained shortly preceding this Symposium [9,10]. The *Planck* 2015 results [11] state a value of $H_0 = 68\,(\text{km}/\text{s})/\text{Mpc}$ [11], but this *Planck* 2015 work [11] also cites other recent results that range from the low 60s $(\text{km}/\text{s})/\text{Mpc}$ to the low 70s $(\text{km}/\text{s})/\text{Mpc}$. Thus the value $H_0 = 68\,(\text{km}/\text{s})/\text{Mpc}$ [11] not only is the most reliable and most recent one as of this writing, but it also splits the difference of the range of other recent results cited in this *Planck* 2015 work [11]. Hence we take the Hubble constant today to be $H_0 \approx 68\,(\text{km}/\text{s})/\text{Mpc} \approx 2.2 \times 10^{-18}\,(\text{km}/\text{s})/\text{km} = 2.2 \times 10^{-18}\,\text{s}^{-1}$ [11].[3]

[2] (Re: Entry [7], Ref. [2]) An observer in the comoving frame (ideally in intergalactic space as far removed as possible from local gravitational fields such as those of galaxies, stars, etc.) sees the 2.7 K cosmic background radiation as isotropic (apart from fluctuations of fractional magnitude $\mathcal{F} \approx 10^{-5}$, which can be "smoothed out" via, say, computer processing to yield a uniform background). But even Earth is a fairly good approximation to the comoving frame: Earth's peculiar motion $\approx 380\,\text{km}/\text{s} \ll c$ (see p. 352 of Ref. [2]) with respect to the cosmic background radiation is fairly slow, and local gravitational fields are fairly weak ($v_{\text{escape}} \ll c$).

[3] (Re: Entries [8]–[11], Refs. [2], [8], [10], and [11]) As per Entries [8]–[11], results for the Hubble constant have improved with time, asymptotically converging onto those provided by Ref. [11]. The results for the Hubble constant as per Ref. [8] are in essential agreement with Entry [9]. The history of values of the Hubble constant also is briefly discussed in Entry [9] and Ref. [10]. Reference [10] surveys the history of values of the Hubble constant determined via work done through 2012. Reference [10] was for sale at the 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas, December 8–13, 2013.

3. The Planck power in cosmology

The Planck system of units has been recognized as the most fundamental such system in physics ever since Dr. Max Planck first derived it in 1899 [12–15]. It is based on Planck's reduced constant $\hbar \equiv h/2\pi$ (or Planck's original constant h), the speed of light in vacuum c, and the universal gravitational constant G, with Boltzmann's constant k usually also included. These four fundamental physical constants are seen by *everything*, corresponding to the Planck system of units encompassing *universal* domain. By contrast, for example, the fundamental electric charge is seen only by electrically-charged particles.[4]

The Planck system of units in general, and especially the Planck power in particular, suggest a simple and interesting cosmological model. Perhaps this model may at least to some degree represent the real Universe; even if it does not, it seems interesting conceptually.

Multiply the Planck mass $m_{\text{Planck}} = (\hbar c/G)^{1/2}$ by c^2 to obtain the Planck energy $E_{\text{Planck}} = \left(\hbar c^5/G\right)^{1/2}$ [12–15]. Divide the Planck energy by the Planck time $t_{\text{Planck}} = \left(\hbar G/c^5\right)^{1/2}$ to obtain the Planck power $P_{\text{Planck}} = c^5/G \doteq 3.64 \times 10^{52}\,\text{W} \iff P_{\text{Planck}}/c^2 = c^3/G \doteq 4.05 \times 10^{35}\,\text{kg / s}$ [12–15]. [The dot-equal sign ($\doteq$) means "very nearly equal to."] Note that — unlike the Planck length, mass, energy, time, and temperature $T_{\text{Planck}} = E_{\text{Planck}}/k = \left(\hbar c^5/G\right)^{1/2}/k$, indeed unlike most if not all other Planck units (at least most if not all other useful ones except the Planck speed $l_{\text{Planck}}/t_{\text{Planck}} = c$) — the Planck power (whether or not divided by c^2) does *not* contain $\hbar$, but only G and c. Thus — unlike the Planck length l_{Planck}, Planck mass, Planck energy, Planck time, and Planck temperature, indeed unlike most if not all other Planck units (at least most if not all other useful ones except the Planck speed $l_{\text{Planck}}/t_{\text{Planck}} = c$) — is the Planck power a *classical* quantity *in*dependent of quantum effects, if not absolutely then at least via opposing quantum effects canceling out, as $\hbar$ cancels out in the division $P_{\text{Planck}} = E_{\text{Planck}}/t_{\text{Planck}}$? With respect to the Planck speed $l_{\text{Planck}}/t_{\text{Planck}} = c$ note that c is the fundamental speed in the classical (nonquantum) theories of Special and General Relativity.

Now multiply P_{Planck}/c^2 by the age of the Universe, the elapsed cosmic time [4,5] since the Big Bang, $\tau_0 \approx 4.5 \times 10^{17}\,\text{s} \approx 1.4 \times 10^{10}\,\text{y}$ [11]. This yields an estimate of

$$M_0 \approx \frac{P_{\text{Planck}}\,\tau_0}{c^2} \approx 1.8 \times 10^{53}\,\text{kg} \tag{1}$$

for the mass of our L-region (not considering the negative gravitational energy). But $M_0 \approx 1.8 \times 10^{53}\,\text{kg}$ is of order-of-magnitude agreement with an estimate of M_0 assuming that the mass-energy density of of our L-region of the Universe [1,3] equals the critical density ρ_{crit} [16], as seems to be the case if not exactly then at least to within a very close approximation. The density critical density ρ_{crit} corresponds to the borderline between ever-expanding and oscillating Universes given vanishing cosmological constant, i.e., $\Lambda = 0$,

[4] (Re: Entries [12] and [15], Refs. [12] and [15]) A concise listing of Planck units and other useful data, entitled "Some Useful Numbers in Conventional and Geometrized Units," is provided in the back endcover of Ref. [12]. In this back endcover of Ref. [12] the Planck length is referred to as the Planck distance (elsewhere in Ref. [12] it is referred to as the Planck length) and the Planck power is referred to as the emission factor. Reference [12] cites Ref. [13] as the most important work in the derivation of the Planck system of units. Reference [15], like Ref. [12], cites Ref. [13]. Additionally, in Sect. 31.1, Ref. [15] gives a brief historical survey of works deriving the Planck system of units. Reference [15] extends the Planck system of units to also include Boltzmann's constant k.

http://dx.doi.org/10.5772/61642

and to spacetime being flat, and hence space Euclidean, on the largest scales, i.e., to the spatial curvature index being 0 rather than $+1$ or -1, given *any* value of Λ [16–20].[5] The critical density is

$$\rho_{\mathrm{crit}} = \frac{3H_0^2}{8\pi G} \approx 8.65 \times 10^{-27} \frac{\mathrm{kg}}{\mathrm{m}^3}. \tag{2}$$

Applying the most recent and best result for H_0, namely $H_0 \approx 68\,(\mathrm{km}\,/\,\mathrm{s})\,/\,\mathrm{Mpc} \approx 2.2 \times 10^{-18}\,(\mathrm{km}\,/\,\mathrm{s})\,/\,\mathrm{km} = 2.2 \times 10^{-18}\,\mathrm{s}^{-1}$ [11], yields as an estimate of M_0

$$M_0 \approx \frac{4\pi}{3}\rho_{\mathrm{crit}}R_0^3 = \frac{4\pi}{3}\frac{3H_0^2}{8\pi G}\left(\frac{c}{H_0}\right)^3 = \frac{c^3}{2GH_0} \approx 9.2 \times 10^{52}\,\mathrm{kg}\,. \tag{3}$$

In Eq. (3) we assume that the volume of our L-region is given by the Euclidean value $4\pi R_0^3/3$. But since astronomical observations indicate that spacetime is flat, and hence space is Euclidean, on the largest scales, i.e., that the spatial curvature index is 0 rather than $+1$ or -1, this assumption seems justified [11,16–20]. Is the order-of-magnitude agreement between Eqs. (1) and (3) merely a numerical coincidence? Or does it suggest that the Planck power plays a fundamental role in cosmology — entailing a link between the smallest (Planck-length and Planck-time) and largest (cosmological) scales?

While there is order–of magnitude agreement between Eqs. (1) and (3), there is a discrepancy between them by a factor of ≈ 2. That is, Planck-power input as per Eq. (1) seems to imply $\rho \approx 2\rho_{\mathrm{crit}}$. Since in this era of precision cosmology all quantities in Eqs. (1)–(3) are known far more accurately than to within a factor of 2, it seems that this factor of ≈ 2 can*not* simply be dismissed. But we admit that we have no explanation for this factor of ≈ 2. Furthermore, we will see that Eqs. (5)–(7) seem to imply a discrepancy with Eq. (1) by a factor of $\approx 3/2$ in the opposite direction, i.e., that Planck-power input as per Eq. (1) seems to imply $\rho \approx 2\rho_{\mathrm{crit}}/3$. Such discrepancies by numerical factors on the order of 2 may prove our Planck-power hypothesis to be wrong. At the very least they prove that even if it is right *in general* it is only an *introductory* hypothesis whose *details* still need to be understood. Then again, perhaps because there *is* consistency to within a small numerical factors of $O \sim 2$, our Planck-power hypothesis may be correct *in general* as an *introductory* hypothesis, even though, even if correct *in general*, its *details* still need to be understood.

Do our considerations so far in this Sect. 3 suggest that, even though the Universe certainly began with the Big Bang, there has been since the Big Bang mass-energy input, at least on the average, at the Planck power, into our L-region of the Universe? We list several alternative proposals for such input (this list probably is not exhaustive): (a) steady-state-theory mass-energy input *ex nihilo* [21–23], (b) mass-energy input *ex nihilo* via other means [24,25], (c) mass-energy input at the expense of negative gravitational energy [26–32] rather than *ex nihilo*, or (d) mass-energy input at the expense of nongravitational negative energy, for example, at the expense of the negative-energy C field in some versions of the steady-state theory [33–35]. If at the expense of negative gravitational energy as per proposal (c), then *forever* the total (mass plus gravitational) energy of our L-region, and likewise of any L-region, of the Universe, and hence of the Universe as a whole, is conserved at the value

[5] (Re: Entry [20], Ref. [14]) The critical density and density parameter are employed on various occasions throughout Chap. 29 on cosmology in Ref. [14].

zero [26–32]. (There are "certain 'positivity' theorems ... which tell us that the total energy of a system, including the 'negative gravitational potential energy contributions' ..., cannot be negative [32]." But positivity theorems do seem to allow the total energy of a system, including the negative gravitational energy, to be strictly zero. Also, perhaps positivity theorems need necessarily apply only for isolated sources in asymptotically-flat spacetime.) In this chapter we will mainly presume proposal (c) from the immediately preceding list, for the following reasons: (i) Unlike proposals (a) and (b), proposal (c) entails no violation of the First Law of Thermodynamics (conservation of mass-energy). (ii) Negative gravitational energy is *known* to exist, unlike the negative-energy C field of proposal (d), which was perhaps introduced at least partially *ad hoc* to render the steady-state theory consistent with the First Law of Thermodynamics (conservation of mass-energy). Moreover, unlike gravity, the C field not only has never been observed, but also entails difficulties of its own [34,35]. (iii) We will show that proposal (c) need not be inconsistent with the observed features of the Universe.

The Universe clearly shows evolutionary rather than steady-state [21–23,33–35] behavior since the Big Bang. But it could stabilize to a steady state in the future. It could already now be thus stabilizing or even thus stabilized in the very recent past with as yet no or at most very limited observational evidence that might be suggestive of such stabilization. Thus even if there is steady-state-type creation of mass-energy since the Big Bang at the rate of the Planck power (we presume, in light of the immediately preceding paragraph, most likely at the expense of the Universe's negative gravitational energy), perhaps this might be compatible with the observed evolutionary behavior of the Universe since the Big Bang. (This point and related ones will be discussed in more detail in Sect. 4.)

Although General Relativity is required for an accurate consideration of the Universe's gravity, the following Newtonian approximation may be valid as an order-of-magnitude estimate [26–32]. Such an estimate is suggestive in favor of Planck-power input at the expense of negative gravitational energy [26–32], which does not require a violation of the First Law of Thermodynamics (conservation of mass-energy) [26–32], as opposed to Planck-power input *ex nihilo* [21–25], which would require such a violation, or via C-field input, the C field never having been observed and also entailing its own difficulties [34,35]. In accordance with the last paragraph of Sect. 2, we take the Hubble constant today to be $H_0 \approx 68\,(\mathrm{km/s})/\mathrm{Mpc} \approx 2.2 \times 10^{-18}\,(\mathrm{km/s})/\mathrm{km} = 2.2 \times 10^{-18}\,\mathrm{s}^{-1}$ [8–11]. Thus neglecting any variation of $H(\tau)$ with τ, $\tau_0 = 1/H_0 \approx 4.5 \times 10^{17}\,\mathrm{s}$ consistently with the previously given value, and the ruler radius of our L-region of the Universe is $R_0 = c\tau_0 = c/H_0 \approx 1.4 \times 10^{23}\,\mathrm{km} = 1.4 \times 10^{26}\,\mathrm{m}$. The positive mass-energy of our L-region of the Universe within our cosmological event horizon is M_0c^2 and the negative Newtonian gravitational energy of our L-region is $\approx -GM_0^2/R_0$. Hence in the Newtonian approximation setting the total energy equal to zero yields [26–32]

$$\begin{aligned} E_{\mathrm{total}} &= E_{\mathrm{mass}} + E_{\mathrm{gavitational}} = 0 \\ &\Longrightarrow\ M_0c^2 - \frac{GM_0^2}{R_0} = 0 \\ &\Longrightarrow\ \frac{M_0}{R_0} = \frac{c^2}{G}. \end{aligned} \tag{4}$$

http://dx.doi.org/10.5772/61642

Applying our previously derived values of M_0 and R_0 yields $M_0/R_0 \approx 1.8 \times 10^{53}\,\text{kg}\,/1.36 \times 10^{26}\,\text{m} \approx 1.32 \times 10^{27}\,\text{kg}\,/\,\text{m}$. We have $c^2/G \doteq 1.35 \times 10^{27}\,\text{kg}\,/\,\text{m}$. Thus Eq. (4) is fulfilled as closely as we can expect, especially given that our Newtonian approximation should be expected to provide only order-of-magnitude estimates, and also perhaps because (even after an initial fast inflationary stage) $H(\tau)$ may not be strictly constant.

There is yet another order-of-magnitude result that is consistent with our Planck-power hypothesis. Applying Eq. (1), rate of Planck-power mass input into our L-region is

$$\left(\frac{dM}{d\tau}\right)_{\text{in}} \approx \frac{M_0}{\tau_0} \approx \frac{P_{\text{Planck}}}{c^2} = \frac{\frac{c^5}{G}}{c^2} = \frac{c^3}{G}. \tag{5}$$

Letting ρ be the average density of our L-region, the rate of Hubble-flow mass-export from our L-region is

$$\left(\frac{dM}{d\tau}\right)_{\text{out}} = 4\pi R_0^2 \rho c = 4\pi \left(\frac{c}{H_0}\right)^2 \rho c = \frac{4\pi\rho c^3}{H_0^2}. \tag{6}$$

In Eq. (6) we assume that the surface area bounding our L-region is given by the Euclidean value $4\pi R_0^2$. But since astronomical observations indicate that spacetime is flat, and hence space is Euclidean, on the largest scales, i.e., that the spatial curvature index is 0 rather than $+1$ or -1, this assumption seems justified [11,16–20]. For steady-state to obtain we must have

$$\begin{aligned}
&\left(\frac{dM}{d\tau}\right)_{\text{net}} = \left(\frac{dM}{d\tau}\right)_{\text{in}} - \left(\frac{dM}{d\tau}\right)_{\text{out}} = 0 \\
&\implies \frac{c^3}{G} - 4\pi R_0^2 \rho c = \frac{c^3}{G} - \frac{4\pi\rho c^3}{H_0^2} = 0 \\
&\implies \frac{1}{G} - \frac{4\pi\rho}{H_0^2} = 0 \\
&\implies \rho = \frac{c^2}{4\pi G R_0^2} = \frac{H_0^2}{4\pi G} \approx 5.8 \times 10^{-27}\,\frac{\text{kg}}{\text{m}^3}.
\end{aligned} \tag{7}$$

The numerical value for ρ obtained in the last line of Eq. (7) is in order-of-magnitude agreement with ρ_{crit} as per Eq. (2), as well as in order-of-magnitude agreement with observations.

Recalling the second paragraph following that containing Eqs. (1)–(3), note that Eqs. (5)–(7) seem to imply a discrepancy with Eq. (1) by a factor of $\approx 3/2$ in the opposite direction from the discrepancy with Eq. (1) by a factor of ≈ 2 implied by Eq. (3). Planck-power input as per Eq. (1) seems to imply $\rho \approx 2\rho_{\text{crit}}$, while Eqs. (5)–(7) seem to imply $\rho \approx 2\rho_{\text{crit}}/3$. Since in this era of precision cosmology all quantities in Eqs. (1)–(3) and (5)–(7) are known far more accurately than to within a factor of 2, such discrepancies by numerical factors of $O \sim 2$ may prove our Planck-power hypothesis to be wrong. At the very least they prove that even if it is

right *in general* it is only an *introductory* hypothesis whose *details* still need to be understood. Then again, perhaps because there *is* consistency to within small numerical factors of $O \sim 2$, our Planck-power hypothesis may be correct *in general* as an *introductory* hypothesis, even though, even if correct *in general*, its *details* still need to be understood.

While, even accepting discrepancies by a factor of $O \sim 2$, the fulfillment of Eqs. (1)–(7) does not constitute proof of Planck-power input, it at least seems suggestive. Could Planck-power input, if it exists, be a classical process *in*dependent of quantum effects, if not absolutely then at least via opposing quantum effects canceling out, as $\hbar$ cancels out in the division $P_{\text{Planck}} = E_{\text{Planck}}/t_{\text{Planck}}$? Note that perhaps similar canceling out obtains with respect to the Planck speed $l_{\text{Planck}}/t_{\text{Planck}} = c$: c is the fundamental speed in the classical (nonquantum) theories of Special and General Relativity.

According to most current cosmological models, there probably have been one-time initial mass-energy inputs, for example associated with phase transitions ending fast-inflationary stages during the very early history of the Universe [36–40]. We should note that while the majority opinion is certainly in favor of inflation [36–50], there is some dissent [36–50]. (The difficulty in squaring inflation with the Second Law of Thermodynamics, and a possible resolution of this difficulty, will be discussed in Sect. 6.) Observational evidence that in early 2014 initially seemed convincing for inflation in general [41,42], albeit possibly ruling out a few specific types of inflation [41,42,47], has been questioned [43–50], but not disproved [43–50].[6] Moreover, even if an inflationary model is correct, recent observational findings disfavor simple models of inflation, such as quadratic and natural inflation [47]. Even if such one-time initial mass-energy inputs [36–40] occurred, could sustained mass-energy input then continue indefinitely such that the Planck power is at least a *floor* below which the *average* rate of mass-energy input into our L-region of the Universe cannot fall? It at least *appears* not to have fallen below this floor [16]. By the cosmological principle [51], if this is true of our L-region of the Universe then it must be true of *any* L-region thereof.

Thus our Planck-power hypothesis at least *appears* to entail a link between the smallest (Planck mass and Planck time) and largest (cosmological) scales, rather than being merely a numerical coincidence.

4. Planck power and kinetic control versus heat death: Big-Bang-initiated evolution merging into steady state?

In the simplest ever-expanding cosmologies, the Universe begins with a Big Bang and expands forever, with flat geometry on the largest scales, and with the Hubble constant $H(\tau)$ not varying with cosmic time [4,5] τ and always equal to its present value H_0. As the Universe expands the Hubble flow carries mass-energy past the cosmological event horizon of our L-region of the Universe. But this "loss" is replaced by new positive mass-energy continually created within our L-region of the Universe *forever* at the rate of the Planck power and at the expense of our L-region's negative gravitational energy. This compensates

[6] (Re: Entry [48], Ref. [48]) Reference [48] shows that previous measurements of the acceleration of the Universe's expansion may require reconsideration, owing to discrepancies between visible-light and UV observations of type 1a supernovae.

http://dx.doi.org/10.5772/61642

for "losses" streaming past the cosmological event horizon of our L-region of the Universe via the Hubble flow — and does so consistently with the First Law of Thermodynamics (conservation of mass-energy) [26–32]. Because by the cosmological principle [51] our L-region is nothing special, the same is true of *any* L-region [3] of the Universe. Thus *forever* the total (mass plus gravitational) energy of our L-region, and likewise of any L-region, of the Universe, and hence of the Universe as a whole, is conserved at the value zero [26–32].

There is needed a mechanism whereby a sufficiently large fraction f of the Planck-power mass-energy input within the cosmological event horizon of our L-region, and of any L-region, of the Universe is produced in the form of hydrogen [52–57] (as in the original steady-state theory [21–23,33–35]), so that there will be fuel for stars [52–57]. Then there will *always* be stars [52–57], planets, and life — not only at the periphery but *even at the center* [58] of our island Universe [1] and likewise of every other island Universe [1] in the Multiverse [52–58]. Then the heat death predicted by the Second Law of Thermodynamics [59–63] will be thwarted not only at the periphery but *even at the center* [58] of our island Universe and likewise of every other island Universe in the Multiverse.[7] The required sufficiently large fraction f is actually quite small. An order-of-magnitude estimate of the total number of stars within the cosmological event horizon [3] of our L-region of the Universe is $\sim 10^{22}$ [64]. By the cosmological principle [51] our L-region of the Universe is nothing special, so there is no reason to suspect a substantially different total number of stars in other L-regions. The Sun's luminosity is $L_{\text{Sun}} = 3.828 \times 10^{26}\,\text{W} \approx 10^{-26} P_{\text{Planck}}$ [56,57]. Thus if the average star were as luminous as the Sun then the total luminosity of $\sim 10^{22}$ stars would be $L_{\text{total}} \sim 10^{-26} P_{\text{Planck}} \times 10^{22} \sim 10^{-4} P_{\text{Planck}}$, implying that we require $f \sim L_{\text{total}}/P_{\text{Planck}} \sim 10^{-4}$ [56,57,64]. But the average star is considerably less luminous than the Sun [56,57], so the best order-of-magnitude estimate is perhaps $L_{\text{total}} \sim 10^{-5} P_{\text{Planck}}$, implying that we require only $f \sim 10^{-5}$ [56,57,64]. (Properties of the Sun, including its luminosity, are given in both conventional and geometrized units in the inside back cover of Ref. [12], and in conventional units in Appendix A in the inside front cover of Ref. [14] and in Table 8.1 on p. 219 of Ref. [10].) This small value $f \sim 10^{-5}$ is sufficient to sustain star formation *forever* not only at the periphery but *even at the center* [58] of our island Universe [1] and likewise of every other island Universe [1] in the Multiverse [52–58]. The remainder of the Planck-power input would be in forms other than hydrogen (perhaps traces of heavier elements, elementary particles of normal and/or dark matter, dark energy, etc.?).

But perhaps the *simplest* mode of Planck-power input is *initially* in the form of the *simplest* possible type of dark energy, corresponding to *positive constant* Λ — a *positive* cosmological *constant*. *Constancy* of Λ is required for *constancy* of Planck-power input initially in the form of Λ. *Positivity* of Λ seems to be required for *positivity* of Planck-power input being initially in the form of Λ, because negative Λ corresponds to contraction of space and hence to diminution of Λ-mass-energy. Thus the *simplest* possible type of dark energy, corresponding to *positive constant* Λ — a *positive* cosmological *constant* — is perhaps the type of dark energy that is most easily reconcilable with Planck-power input, in particular with

[7] (Re: Entry [63], Ref. [63]) Reference [63] considers various aspects of the Second Law of Thermodynamics and its relation to the arrow of time and to cosmology. Reference [63] was for sale at the 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas, December 8–13, 2013.

constancy of Planck-power input. Moreover, *constant* Λ — a cosmological *constant* — is the *only, unique,* choice for Λ that can be put on the left-hand (geometry) side of Einstein's field equations without altering their symmetric and divergence-free form [65–67], "belonging to the field equations much as an additive constant belongs to an indefinite integral [65–67].[8] Nevertheless the current trend is to put Λ on the right-hand (mass-energy-stress) side of Einstein's field equations, which allows more freedom [66]. But if Λ is put on the right-hand side "the rationale for its uniqueness then disappears: it no longer needs to be a divergence-free 'geometric' tensor, built solely from the $g_{\mu\nu}$ ... the geometric view of Λ ... is undoubtedly the simplest [66]". Thus we might speculate about a link between constancy of Λ as a (positive) cosmological constant [65–67] and constancy of (positive) Planck-power input: Perhaps Planck-power input occurs *initially* as (positive) cosmological-constant Λ, with $f \sim 10^{-5}$ thereof, then hopefully, somehow, via an as-yet-unknown mechanism, being transformed into hydrogen. It is important to note that — unlike equilibrium blackbody radiation — (positive) cosmological-constant-Λ dark energy seems to be at less than, indeed at far less than, maximum entropy. Thus there seems to be more than enough entropic "room" for $f \sim 10^{-5}$ of positive-cosmological-constant-Λ dark energy to decay into hydrogen, without requiring decay all the way to iron. Positive-cosmological-constant-Λ Planck-power input thus seems to offer the benefits but not the liabilities of the steady-state theory [21–23,33–35] [violation of mass-energy conservation without the C field (which has never been observed and which also entails other difficulties [34,35]) — recall the second paragraph following that containing Eqs. (1)–(3)]. Positive cosmological-constant Λ also implies, or at least is consistent with, *constant* $H(\tau) = H_0$ at all cosmic times τ, and hence a fixed size of our L-region, with its boundary (event horizon [2,3]) $R(\tau)$ always fixed at $R_0 = c/H_0$. Thus to sum up this paragraph, the *simplest* model *overall* seems to entail (a) positive-cosmological-constant Λ, (b) Planck-power input *initially* as positive-cosmological-constant Λ at the expense of negative gravitational energy, with (c) $f \sim 10^{-5}$ of Planck-power input, then hopefully, somehow, via an as-yet-unknown mechanism, being transformed into hydrogen. We note that the most reliable and most recent astronomical and astrophysical observations and measurements as of this writing are consistent with *positive* cosmological-*constant*-Λ dark energy [68,69], indeed possibly or even probably *more* consistent with *positive* cosmological-*constant*-Λ dark energy than with any other alternative [68,69]. But, of course, this issue is far from being definitely decided [68,69]. Even though our main point in this chapter most naturally based on positive constant Λ, in Sects. 5–7 some other possibilities for Λ will be qualitatively considered.

We cannot help but notice that temperature fluctuations in the cosmic background radiation have a typical fractional magnitude of $\mathcal{F} \approx 10^{-5}$ [70,71]. The *observed and measured* value $\mathcal{F} \approx 10^{-5}$ [70,71] is obviously far more certain than the *speculated* value $f \sim 10^{-5}$; hence the distinction between the $\approx$ symbol as opposed to the $\sim$ symbol. Although it is unlikely that there is any connection between $\mathcal{F} \approx 10^{-5}$ [70,71] and $f \sim 10^{-5}$, it doesn't seem to hurt if we at least mention this numerical concurrence — just in case there might be a connection.

But the following question arises: Even if there is Planck-power input, why is not *all* of it in a thermodynamically-most-probable maximum-entropy form such as (iron + equilibrium

[8] (Re: Entry [67], Ref. [67]) Reference [67] is cited in the passage from Ref. [2] that we cite in Entry [65].

http://dx.doi.org/10.5772/61642

blackbody radiation) and *none* of it as hydrogen — why is not $f = 0$ [52–57]? If this were the case then the heat death predicted by the Second Law of Thermodynamics [59–63] would *not* be thwarted *even with* Planck-power input. While we are not sure of an answer to this question, we can venture what *prima facie* at least seems to be a reasonable guess: (a) Planck-power input (if it exists) generates equal nonzero quantities of both positive mass-energy and negative gravitational energy starting from (zero positive energy + zero negative energy = zero total energy), and the entropy of (zero positive energy + zero negative energy = zero total energy) is *perforce* zero: There is only one way for there to be nothing ($\Omega = 1$), and hence by Boltzmann's relation between entropy and probability $S = k \ln \Omega = k \ln 1 = 0$. (b) Planck-power input is a steady-state but nonequilibrium process that does not allow enough time for complete thermalization of the input from the initial value of zero entropy of (zero positive energy + zero negative energy = zero total energy) to the maximum possible positive entropy of (nonzero positive energy + nonzero negative energy = zero total energy) in a form such as (iron + equilibrium blackbody radiation). That is, Planck-power input is *kinetically rather than thermodynamically controlled* [72–77].[9]

Thus even though, *thermodynamically*, Planck-power input should be in a maximum-entropy form such as (iron + equilibrium blackbody radiation), *kinetically* the reaction

$$\begin{aligned} &\text{zero positive energy} \;+\; \text{zero negative energy} \;=\; \text{zero total energy} \\ &\longrightarrow \text{nonzero positive energy} \;+\; \text{nonzero negative energy} \;=\; \text{zero total energy}. \end{aligned} \tag{8}$$

occurs too quickly to allow thermodynamic equilibrium = maximum entropy to be attained. Yet even Planck-power input initially as positive-cosmological-constant Λ, with a fraction $f \sim 10^{-5}$ of Planck-power input hopefully, somehow, via an as-yet-unknown mechanism, being transformed into hydrogen, entails *some* entropy increase. The entropy increase ΔS that it *does* entail is sufficient to render the probability of its reversal as per Boltzmann's relation between entropy and probability, expressed in the form $\text{Prob}\,(\Delta S) = \exp\,(-\Delta S/k)$, equal to zero for all practical purposes. Thus we are justified in placing only a forward arrow (no reverse arrow) at the beginning of the second line of Eq. (8). Thus Planck-power input entails enough entropy increase to stabilize it and prevent its reversal. But it occurs quickly enough to allow *kinetic control* [72–77] to prevent it from entailing *maximal* entropy increase.

To recapitulate out considerations thus far in Sect. 4: Perhaps the simplest possible Planck-power input is *initially* as positive-cosmological-constant Λ. *Positivity* of Λ is required for *positivity* of Planck-power input, and *constancy* of Λ is required for *constancy* of Planck-power input. *Constancy* of Λ is requisite for Λ to be most simply encompassed within Einstein's field equations [65–67], besides correlating with constancy of Planck-power input. Positive-cosmological-*constant* Λ also implies, or at least is consistent with, *constant*

[9] (Re: Entries [72–77], Refs. [72–77]) Kinetic versus thermodynamic control is specifically discussed on pp. 41–42 of Ref. [72], p. 43 of Ref. [73], p. 35 of Ref. [74], pp. 311–312 of Ref. [76], and p. 438 of Ref. [77]. Kinetic versus thermodynamic control are contrasted in Sects. 2.18 and 19.11 of Ref. [75]. Helpful auxiliary material is provided in Sects. 2.15–2.17, 2.19–2.21, and 19.16 of Ref. [75]. Reference [73] does not render Ref. [72] obsolete, because Ref. [72] discusses aspects not discussed in Ref. [73], and vice versa. Likewise, Reference [77] does not render Ref. [76] obsolete, because Ref. [76] discusses aspects not discussed in Ref. [77], and vice versa.

$H(\tau) = H_0$ at all cosmic times τ, and hence a fixed size of our L-region, with its boundary (event horizon [2,3]) $R(\tau)$ always fixed at $R_0 = c/H_0$. But we wish for a fraction $f \sim 10^{-5}$ of Planck-power input hopefully, somehow, via an as-yet-unknown mechanism, being transformed into *hydrogen*. *Hydrogen*, so that stars can have fuel. But why hydrogen? Why not a thermodynamically dead form such as (iron + equilibrium blackbody radiation)? Because kinetically, it would be much more difficult for positive-cosmological-constant Λ to be transformed into a complex atom such as iron than into the simplest one — hydrogen. Thus while *thermodynamic* control would favor iron, if *kinetic* control wins then hydrogen is favored [72–77]. Note that kinetic control is vital not only in initial creation of hydrogen, but also in then preserving hydrogen long enough for it to be of use. It is owing to *kinetic* control that the Sun and all other main-sequence stars fuse hydrogen only to helium, not to iron, and are restrained to doing so slowly enough to give them usefully-long lifetimes. Main-sequence fusion of hydrogen to iron is thermodynamically favored, but kinetically its rate of occurrence is for all practical purposes zero. Thus kinetic control wins, limiting main-sequence fusion to helium and at a slow enough rate to give stars usefully-long lifetimes [72–77]. Indeed it is owing to *kinetic* control that not only hydrogen, but also all other elements except iron, do not instantaneously decay to iron. Kinetic control may also argue against positive-cosmological-constant Λ being *completely* transformed into equilibrium blackbody radiation (without iron). A single hydrogen atom can be created at rest with respect to the comoving frame [7]. By contrast, to conserve momentum, at least two photons must be created simultaneously, which may impose a bottleneck that diminishes the rate of such a process kinetically. Hence $f \sim 10^{-5}$ of the Planck-power input in the positive-but-much-less-than-maximal-entropy form of hydrogen may at least *prima facie* seem plausible. Again it doesn't seem to hurt to at least mention the numerical concurrence between $\mathcal{F} \approx 10^{-5}$ [70,71] and $f \sim 10^{-5}$, even if any connection is unlikely.

Note that a zero value for the initial entropy as per the paragraph containing Eq. (8) would also obtain if Planck-power input were *ex nihilo* [21–25] or at the expense of a negative-energy C field (despite its never having been observed and its other difficulties [34,35]) or other negative-energy field rather than at the expense of negative gravitational potential energy: the entropy of (zero positive energy + zero negative energy = zero total energy) would still *perforce* be zero. Thus our considerations of this Sect. 4, including that of dominance of kinetic over thermodynamic control [72–77], would still be applicable.

Our L-region and O-region clearly manifest evolutionary behavior, for example increasing metallicity [52–55] and a decreasing rate of star formation [52–55]. But our Planck-power hypothesis seems to suggest that its evolutionary behavior could gradually merge towards steady-state behavior. Early in the history of our L-region and O-region, star formation occurred at a much faster rate than now, and stars were on the average much more massive and hence *very* much faster-burning [main-sequence hydrogen-burning rate $\sim$ (mass of star)^3]. Thus hydrogen was consumed faster than a conversion of $f \sim 10^{-5}$ of Planck-power input could replace it: Stars were burning capital in addition to (Planck-power) income — indeed more capital than income. But with decreasing rate of star formation and decreasing average stellar mass, perhaps a steady-state balance between hydrogen consumption and its replacement via $f \sim 10^{-5}$ of Planck-power input could be approached, with stars living solely on (Planck-power) income. Merging of evolutionary towards steady-state behavior could already be beginning or could have even begun in the very recent past with as yet no or at most very limited observational evidence that might be suggestive of it. If such

http://dx.doi.org/10.5772/61642

merging exists then both metallicity and star formation rate could stabilize in the future. Perhaps they even could already now be stabilizing or have even already begun stabilizing in the very recent past with as yet no or at most very limited observational evidence that might be suggestive of such stabilization in particular, or of such merging in general. This stabilization, if it exists, would require only a small fraction $f \sim 10^{-5}$ of Planck-power as hydrogen to maintain the current status quo in our L-region and O-region. This would allow star formation to continue forever not merely at the peripheries of island Universes, but *even in their central regions* [58]. We note that there is observational evidence that might at least be suggestive of "unexplained" hydrogen [78], which perhaps might qualify as such very limited suggestive observational evidence of merging towards steady-state behavior [78].

It should perhaps be re-emphasized that even Planck-power input as hydrogen entails *some* entropy increase and therefore is thermodynamically irreversible, consistently with the Second Law of Thermodynamics, while still thwarting the heat death. The heat death is thus thwarted via *dilution* of entropy as an island Universe [1] expands indefinitely, which is consistent with the Second Law [59–63] — not via *destruction* of entropy, which is not: Planck-power input as hydrogen represents input at *positive but far less than maximum* entropy. Thus Planck-power input (if it exists) defeats the heat death predicted by the Second Law of Thermodynamics [59–63] even though it does not defeat the Second Law itself.

Thus with only $f \sim 10^{-5}$ of the Planck-power input as hydrogen, the heat death predicted by the Second Law of Thermodynamics [59–63] of our L-region of our island Universe [1], and likewise of any L-region of any island Universe [1], is thwarted *forever*. The heat death is thwarted *forever* not only at the periphery but *even at the center* [58] of our and every other island Universe [1]. The heat death is thwarted consistently with, not in violation of, the Second Law of Thermodynamics [59–63]. Hubble flow export of entropy (along with mass-energy) out of our L-region of our island Universe [1], and likewise out of any L-region of any island Universe [1], as its expansion creates more volume *forever*, is compensated *forever* by creation of thermodynamically fresh but still positive-entropy mass-energy — most importantly, hopefully, the fraction $f \sim 10^{-5}$ thereof as hydrogen — via Planck-power input.

Steady-state balance between Planck-power input and Hubble-flow expansion of space can allow both the entropy density and the nongravitational mass-energy density in our L-region of our island Universe [1], and likewise in any L-region of any island Universe [1], to remain constant, even as the total entropy and nongravitational mass-energy of the entire island Universe increase indefinitely. As mass-energy creation at the rate of the Planck power and at the expense of negative gravitational energy is matched by mass-energy dilution via an island Universe's expanding space, so is entropy production matched by entropy dilution. Thus the negative-energy gravitational field of an island Universe is an inexhaustible fuel (positive mass-energy and negative-entropy = negentropy = less-than-maximum-entropy) source. Gravity is a bank that provides an infinite line of credit and never requires repayment [79]. Planck-power input draws on this infinite line of credit [79], which never runs out — indeed which can*not* ever run out. [Of course, if (positive) nongravitational mass-energy density remains constant, then so must (negative) gravitational energy density, if the balance of zero total energy is to be maintained. Thus Planck-power input if it exists is really equally of positive nongravitational mass-energy and negative gravitational energy simultaneously.]

Additional questions bearing on the Second Law of Thermodynamics will be discussed in Sects. 5–7. In this chapter, whether concerning Planck-power input or otherwise, we

limit ourselves to considerations of thwarting the heat death within the restrictions of the Second Law. Nonetheless we note that the universal validity of the Second Law of Thermodynamics has been seriously questioned [80–84], albeit with the understanding that even if not universally valid at the very least it has a very wide range of validity [80–84].

There are two difficulties that should at least be briefly mentioned and, even if only briefly and only incompletely, also addressed. (i) In order for negative gravitational energy to balance positive mass-energy of a hydrogen atom (or of any other entity), a hydrogen atom (or other entity) newly created via Planck-power input would have to interact gravitationally *infinitely fast or instantaneously* [85,86] — and hence universally simultaneously [85,86] — with our *entire* L-region of the Universe within our cosmological event horizon [3]. But if a *signal* of mass-energy and/or information is not *transmitted*, no violation of relativity is required [85,86]. Perhaps this may be possible if, as suggested in the third paragraph of this Sect. 4, Planck-power input occurs *initially* as positive-cosmological-constant Λ [65–67], with $f \sim 10^{-5}$ thereof, then hopefully, somehow, via an as-yet-unknown mechanism, being transformed into hydrogen. Perhaps the gravitational interaction of positive-cosmological-constant Λ [65–67], and thence of hydrogen atoms (and/or other entities) newly created therefrom via Planck-power input can be instantaneously "*rubber-stamped*" onto our entire L-region at once, rather than being *transmitted* as a "*signal*" from one place to another within our L-region. (ii) *Even if* an interaction, or any other process such as "rubber-stamping," can be infinitely fast or instantaneous — and hence universally simultaneous — it can be so in only *one* reference frame [86]. A superluminal phenomenon, even be it only the motion of a geometric point that possesses no mass-energy and carries no information (for example the intersection point of scissors blades) [86], can be infinitely fast and hence instantaneous — universally simultaneous — in only one reference frame [86] (as a subluminal phenomenon can be infinitely slow — at rest — in only one reference frame [86]).[10] But there is a natural choice for this frame: The comoving frame [7], in which the cosmic background radiation and Hubble flow are isotropic [7], even if not an absolute rest frame, is at least a preferred rest frame [87], indeed *the* preferred rest frame [87], of our L-region of the Universe. If any one reference frame can claim to be preferred, it is the comoving frame [7,87]. Since by the cosmological principle [51] there is nothing special about our L-region of the Universe, the same likewise obtains in any other L-region thereof. The existence of this universal preferred frame [7,87] implies the existence of a preferred, perhaps even absolute, cosmic time τ [4,5,87]. A clock in the comoving frame measures cosmic time τ [4,5,87] — the *longest* possible elapsed time from the Big Bang until now (and also the *longest* possible elapsed time from the Big Bang to the Big Crunch in an oscillating cosmology [16,88–94]) — clocks in all other frames measure *shorter* elapsed times [4,5,88–94].[11] A clock in the comoving frame also measures the *longest*

[10] (Re: Entry [86], Ref. [2]) Special Relativity permits arbitrarily fast superluminal phenomena that transmit no mass-energy or information, as well as mutual velocities up to $2c$: see pp. 56 and 70 of Ref. [2]. Section 2.10 of Ref. [2] states that the speed U of transmission of information must not exceed c if violation of causality is to be prevented in Special Relativity. But Eqs. (2.21) and (2.22) in Sect. 2.10 of Ref. [2] at least suggest the possibility that Special Relativity may be consistent with a somewhat less conservative limit, namely $U \leq c^2/v$, where v is the relative velocity between the transmitter and receiver. Of course to guarantee causality Nature must then have a method to checkmate any attempt by the transmitter and/or receiver to "cheat" by increasing v while a signal is en route.

[11] (Re: Entry [88], Ref. [2]) The following is a near-quote from p. 402 of Ref. [2]: "Though unlikely to represent the actual Universe (according to present data) the oscillating-Universe model is interesting in itself."

http://dx.doi.org/10.5772/61642

possible elapsed time $\Delta\tau$ corresponding to a given decrease in the temperature of the cosmic background radiation (or to a given increase in this temperature during the contracting phase in an oscillating cosmology). This *longest* possible elapsed time *is* cosmic time [4,5,87]. A clock moving at velocity v *relative to the comoving frame* [7,87] measures times *shorter* by a ratio of $\left(1 - v^2/c^2\right)^{1/2}$ [7,87]. Thus the existence of this universal preferred frame and hence of cosmic time [4,5] weakens [87] the concept of relativity of simultaneity [85] as obtains within "the featureless vacuum of Special Relativity" [4,5,85–87]: Events, *even if spatially separated*, can be considered *absolutely* simultaneous if they occur *when* — with "when" having an *absolute* meaning — the cosmic background radiation as observed in the comoving frame has the same temperature, this temperature currently decreasing monotonically with increasing cosmic time τ since the Big Bang [4,5,87].[12] (Simultaneity of *non*-spatially-separated events is absolute even in Special Relativity [85].) Also, the contribution to the total nongravitational mass of our L-region of the Universe of a body of rest-mass [95] m is equal to m only if it is at rest in the comoving frame; if it moves at velocity v relative to the comoving frame [7,87] then its contribution is $m\left(1 - v^2/c^2\right)^{-1/2}$ [7,87]. For a zero-rest-mass particle the contribution is $m = E/c^2$ where E is its energy as measured in the comoving frame (for example $m = E/c^2 = h\nu/c^2$ for a photon of frequency ν as measured in the comoving frame). Thus the total nongravitational mass-energy M_0 of our L-region as per Eq. (1) is that measured *with respect to the comoving frame*.

It should be noted that these two difficulties (i) and (ii) discussed in the immediately preceding paragraph [85,86] also plague Universes created via the Everett interpretation of quantum mechanics [96–98], provided that creation of Everett Universes [96–98] is required to obey mass-energy conservation (no creation of mass-energy *ex nihilo* [21–25]). The creation of Everett Universes [96–98] with no higher entropy (or entropy density if they are infinite) than that of their precursor Universe could perhaps obtain for reasons similar to Planck-power input into our L-region being at positive but less-than-maximum entropy as per our considerations in this Sect. 4 — perhaps most importantly kinetic control winning over thermodynamic control [72–77].

5. The Planck power: One-time and two-time low-entropy boundary conditions, and minimal Boltzmann brains

As discussed in Sects. 3 and 4 (recall especially the third paragraph of Sect. 4), the simplest model of Planck-power input entails a fixed positive cosmological constant Λ. Also, from the viewpoint of General Relativity [65–67], a fixed cosmological constant Λ is the simplest choice for Λ [65–67]. Yet we should also consider other possibilities [66].

False-vacuum high-energy-density-scalar-field regions — the inflaton field — of the Multiverse separating island Universes [1] inflate much faster than they decay to non-inflating true-vacuum regions. Hence while inflation had a beginning once begun it is eternal [99]. Within island Universes high-cosmological-"constant" regions play essentially the same role that inflationary regions play between island Universes: they double in size much faster than their half-life against decay, so each island Universe expands forever,

[12] (Re: Entry [87]) The phrase "the featureless vacuum of Special Relativity" is a quote from a very thoughtful and insightful letter from Dr. Wolfgang Rindler, most probably in the 1990s, in reply to a question that I raised concerning relativity of simultaneity.

albeit more slowly than inflationary regions separating island Universes [1,100]. Yet the cosmological "constant" is not high everywhere in an island Universe [1]; in L-regions and O-regions such as ours regions it is sedate. As decay of the inflaton field gives birth to island Universes, within each island Universe decay of high-cosmological-constant-field regions gives birth to new sedate L-regions and O-regions such as ours. In these sedate L-regions and O-regions, the cosmological "constant" may eventually decay to negative values, resulting in a Big Crunch — and perhaps oscillatory behavior, even as entire island Universes expand forever and the spaces between them expand forever even faster. For simplicity, as noted in the first paragraph of this Sect. 5, thus far in this chapter (except for brief parenthetical remarks in the second-to-last paragraph of Sect. 4) we considered our L-region and O-region to be ever-expanding [more often than not assuming constant $H(\tau) = H_0$ for consistency with a fixed positive cosmological constant Λ and for maximum simplicity]. We now offer a few brief speculations concerning the role of the Planck power if the Universe, or at least our L-region and O-region, is oscillating with two-time low-entropy boundary conditions at the Big Bang and at the Big Crunch [16,88–94,101–105]. It is important to note that there exist oscillating cosmological models, including those with thermodynamic rejuvenation, both in conjunction with and apart from the concept of an inflationary Multiverse [16,88–94,101–105]. Some of these models [16,88,89,101–104] were developed well before inflationary cosmology, when our *observable* Universe or O-region was construed to be the *entire* Universe or at least a major fraction thereof. Within inflationary cosmology, it has been theorized based on quantum considerations that the probability that an oscillating L-region and O-region will have a given lifetime τ_{osc} from Big Bang to Big Crunch decreases towards zero with increasing τ_{osc} such that $\tau_{\text{osc}} = \infty$ — a nonoscillating L-region and O-region — is impossible [88,90], even as entire island Universes expand forever and the spaces between them expand forever even faster. Based on this theoretical analysis [88–90] the dark energy *must* eventually switch sign and become attractive instead of repulsive [88–90]: Hence according to this theoretical analysis [88–90] not only the current acceleration of our L-region's and O-region's expansion but even the expansion itself *must* be a passing fad — our L-region and O-region *must* be oscillatory [88–90].[13] Shortly we will discuss Dr. Roger Penrose's central point [61,62] concerning entropy in the context of both ever-expanding and oscillatory behavior.

If Planck-power input is positive when our L-region expands, could it be negative if and when it contracts? Could this reduce or at least help to reduce the (nongravitational) mass-energy, and hence also entropy, during contraction, possibly to zero, by the time of the Big Crunch? If so, could a singularity at the Big Crunch thereby be evaded, thus ensuring a new thermodynamically fresh Big Bang to begin a new cycle? Moreover, since the Planck power (whether or not divided by c^2) does *not* contain $\hbar$, but only G and c, would or at

[13] (Re: Entries [89]–[94], Refs. [1], [12], and [90]–[93]) The analysis showing that our L-region and O-region must be oscillatory is discussed qualitatively in the passages from Ref. [1] cited in Entry [89], with more technical discussions provided in Ref. [90]. At the 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas, December 8–13, 2013, I asked Dr. Michael Turner about the theory discussed in Entry [89] and Ref. [90], according to which the Universe, or at least our L-region and O-region, *must* be oscillatory, also mentioning Entry [89] and Ref. [90]. Dr. Turner is familiar with the passages from Ref. [1] cited in Entry [89] and with Ref. [90], but nevertheless seemed to favor an ever-expanding Universe. An alternative model of an oscillating Universe is discussed in the work in Ref. [63] cited in Entry [92]. In the alternative model of an oscillating Universe investigated in this work, even a Big Rip is shown to be consistent with and indeed part of an oscillating Universe's life cycle. The work in Ref. [63] cited in Entry [93] considers related issues. Also, we should mention that an oscillatory Universe is closer to Einstein's conception of cosmology than a nonoscillatory one. A closed oscillating Universe with $\Lambda = 0$, similar to that considered by Dr. Albert Einstein in the early 1930s, is discussed in the material from Ref. [12] cited in Entry [94].

http://dx.doi.org/10.5772/61642

least might this evading of a Big Crunch singularity be a *classical* process *in*dependent of quantum effects, if not absolutely then at least via opposing quantum effects canceling out, as $\hbar$ cancels out in the division $P_{\text{Planck}} = E_{\text{Planck}}/t_{\text{Planck}}$ [12–15]? Note again that perhaps similar canceling out obtains with respect to the Planck speed $l_{\text{Planck}}/t_{\text{Planck}} = c$: c is the fundamental speed in the classical (nonquantum) theories of Special and General Relativity.

But *negative* Planck-power input requires entropy *reduction*. Hence it seems to require *two-time* low-entropy boundary conditions [101–105] at the Big Bang *and* at the Big Crunch — although two-time, or one-time, low-entropy boundary conditions can also obtain in a "traditional" oscillating Universe without any (positive or negative) Planck-power input [16,88,89,101–105] and without any (repulsive or attractive) dark energy or cosmological constant [16,88,89,101–105]. (In "traditional" oscillating cosmologies, one-time low-entropy boundary conditions imply increasing entropy from cycle to cycle, with each succeeding cycle being longer and reaching a larger maximum size [106,107]. In nonoscillating, ever-expanding, cosmologies, only one-time low-entropy boundary conditions can occur.) Two-time low-entropy boundary conditions require that not only the Big Bang but also the Big Crunch must be special [61,62,101–105]. But even *one-time* low-entropy boundary conditions at the Big Bang that are required for our L-region and O-region to exist as it is currently observed are equally special [61,62]. We will not address the question of whether or not the decrease in entropy during the contracting phase of an oscillating universal cycle imposed by two-time low-entropy boundary conditions [101–105] should be construed as contravening the Second Law of Thermodynamics. It could perhaps be argued that, *within* the restrictions of the Second Law, given two-time low-entropy boundary conditions [101–105] there is no *net* decrease in entropy for an entire cycle, or that two-time low-entropy boundary conditions [101–105] impose such a tight constraint on an oscillating Universe's journey through phase space that there is *no change* in entropy from the initial and final low value during a cycle. In accordance with the third-to-last paragraph of Sect. 4, in ideas developed in this chapter per se (as opposed to brief descriptions of ideas developed in cited references) we limit ourselves to considerations of thwarting the heat death within the restrictions of the Second Law of Thermodynamics. Nonetheless we again note that the universal validity of the Second Law has been seriously questioned [80–84], albeit with the understanding that even if not universally valid at the very least it has a very wide range of validity [80–84].

The reduction of the (nongravitational) mass-energy of a contracting Universe to zero or at least close to zero at the Big-Crunch/Big-Bang = Big Bounce event might thus be a way, although not necessarily the only way [101–105], to ensure zero entropy — the entropy of nothing is *perforce* zero [recall the paragraph containing Eq. (8) in Sect. 4] — or at least low entropy at the Big Bounce. It should be noted that a zero- or at least low-entropy state at the Big Bounce is *imposed* in models with *two-time* low-entropy boundary conditions [101–105]. Thus the cosmic time [4,5] interval from the Big Bang to the Big Crunch can be incomparably shorter than and is totally unrelated to the Poincaré recurrence time [108].[14]

[14] (Re: Entry [108], Ref. [5]) Contrary to what is stated on p. 192 of Ref. [5], in ever-expanding cosmological models Poincaré fluctuations on the scale of galactic — or smaller, indeed, even minimal-Boltzmann-brain — dimensions in spite of the dissipation due to expansion would *not* be expected, because the energy of starlight and ultimately *all* energy would be irrevocably lost from each and every galaxy into infinitely-expanding space and (without compensating input via a Planck-power or other mechanism, which is not considered on p. 192 of Ref. [5]) never replaced.

But whether low-entropy or equivalently high-negentropy boundary conditions are one-time, or two-time in oscillating cosmologies [61,62,101–105], Dr. Roger Penrose's central point [61,62] concerning entropy survives unscathed. This point had been brought out previously [108–110], but Dr. Roger Penrose's more modern analysis [61,62] takes into consideration inflation, which was not generally recognized prior to the late 1970s [108–110]. (See Sect. 6 concerning the connection with inflation.) This point begins with but does not end with recognizing that the L-region and O-region of our Universe are not merely special. They are *much more* special than they have to be — their negentropy is *much* greater than is required for conscious observers to exist. *By far* the *minimum* negentropy consistent with conscious observation would be that required for the *minimal* existence of a *single minimally*-conscious observer — *one and only one minimal Boltzmann brain* [111–118] with no body or sense organs, and with zero information including zero sensory input even if fictitious [112] and zero memory even if fictitious [113], save only the *minimal* information that one exists and is conscious and even this *minimal* information only for most *minimal* fleeting split-second of conscious existence consistent with recognition that one exists and is conscious, in an otherwise *maximum*-entropy and therefore dead L-region and O-region of our Universe — no other observers, no Sun or other stars, no Earth or other planets, no Darwinian evolution, no nothing (at any rate no nothing worthwhile). Input of *any* sensory information even if fictitious [112], and/or *any* memory even if fictitious [113], is incompatible with the *minimalness* of a Boltzmann brain required by Boltzmann's exponential relation between negentropy $\sigma \equiv S_{\max} - S$ and its associated probability $\text{Prob}(\sigma) = \exp(-\sigma/k)$. [Note: *Negentropy* $\sigma \equiv S_{\max} - S$ should not be confused with the *entropy change* ΔS associated with a given reaction or process introduced in the paragraph containing Eq. (8), even though Boltzmann's relation has the same exponential form for both.] Even fictitious sensory input [112] or fictitious memory [113], as in a dream or in a simulated Universe, requires larger σ than none at all and hence is exponentially forbidden. Thus Boltzmann's exponential relation $\text{Prob}(\sigma) = \exp(-\sigma/k)$ allows not *any* Boltzmann brain but only a *minimal* Boltzmann brain — and only *one* of them. Based *solely* on Boltzmann's exponential relation $\text{Prob}(\sigma) = \exp(-\sigma/k)$ a lone *minimal* Boltzmann brain is not merely by far but *exponentially by far* the most probable type of observer to be and *exponentially by far* the most probable type of L-region and O-region of our Universe — or of any Universe in the Multiverse — to find oneself in: One should then expect not even fictitious sensory input [112], not even fictitious memory [113], but only the most fleeting split-second of conscious existence consistent with recognition that one exists and is conscious.

But a basis *solely* on Boltzmann's relation $\text{Prob}(\sigma) = \exp(-\sigma/k)$ is incorrect, or at the very least incomplete. Boltzmann's relation $\text{Prob}(\sigma) = \exp(-\sigma/k)$ is valid *only* assuming thermodynamic equilibrium — that the ensemble of L-regions and O-regions corresponds to that at thermodynamic equilibrium. Probably the most powerful argument against this being the case is the *vast* disparity between our L-region and O-region that we *actually* observe and what one *would* observe as per the immediately preceding paragraph based *solely* on Boltzmann's relation $\text{Prob}(\sigma) = \exp(-\sigma/k)$. This disparity, the minimal-Boltzmann-brain disparity, by a factor of $O \sim 10^{10^{123}}$ [61,62], utterly dwarfs the disparity by a factor in the range of $O \sim 10^{120}$ [119] to $O \sim 10^{123}$ [120] between the observed and predicted values of the cosmological constant [119,120] — indeed it may utterly dwarf *all other disparities combined* [121]. These other disparities [121] relate mainly to the fundamental and effective laws of physics and physical constants requisite for the existence even of a minimal Boltzmann brain. Yet, even apart from viewpoints [122] that not all of them [121] may be significant, they are utterly dwarfed by the minimal-Boltzmann-brain disparity that

http://dx.doi.org/10.5772/61642

obtains *even given* these requisite fundamental and effective laws of physics and physical constants.[15] In contrast to minimal Boltzmann brains, we are sometimes dubbed "ordinary observers" [115–117] — but based *solely* on Boltzmann's relation $\text{Prob}\,(\sigma) = \exp(-\sigma/k)$ dubbing us even as *extra*ordinary observers would be a vast understatement. Indeed the same reasoning can be extended to *extra*ordinary observers. For, based *solely* on Boltzmann's relation $\text{Prob}\,(\sigma) = \exp(-\sigma/k)$, *exponentially by far* the most probable *extra*ordinary observer (say, a human with a typical life span) is a *minimal extra*ordinary observer, and only *one* of these per L-region or O-region. While σ required for a lone *minimal extra*ordinary observer greatly exceeds that required for a lone minimal Boltzmann brain, it is *still* utterly dwarfed by the actual σ of our L-region and O-region: The disparity of $\text{Prob}\,(\sigma) = \exp(-\sigma/k)$ between that corresponding to a lone *minimal extra*ordinary observer and that corresponding to our observed L-region and O-region is *still* by a factor of $O \sim 10^{10^{123}}$ [61,62]. We are privileged to be not merely *minimal extra*ordinary observers but *super-extra*ordinary observers — more correctly *hyper-extra*ordinary observers — with an entire Universe to explore and enjoy [61,62].

There are many arguments against Boltzmann-brain hypotheses [111–118]. Indeed, if there exist (a) *imposed* one-time low-entropy boundary conditions, (b) *imposed* two-time low-entropy boundary conditions [16,88–94,101–105] in an oscillating L-region and O-region, or (c) Planck-power (or other [21–25,33–35]) *imposed* low-entropy mass-energy input such as hydrogen in a nonoscillating one [78], then such *imposition* would *preclude* thermodynamic equilibrium. Indeed, given (b) or (c), thermodynamic equilibrium would not only be precluded but be precluded *forever*. Given (b) or (c), there would be no need to assume a decaying or finite-lived Universe [117] to help explain consistency with our observations. But even given (a) the heat death $\sigma = 0$ need *not* be the most probable *current* state of the L-region or O-region of our Universe and hence a *minimal* Boltzmann brain [111–118] need *not* be the most probable *current* observer therein, because at the *current* cosmic time decay to maximum entropy has not yet occurred. Since by the cosmological principle [51] our L-region and O-region are nothing special, this must likewise be true with respect to any L-region or O-region in our island Universe — and likewise with respect to those in any other island Universe in the Multiverse. Moreover, it has even been argued that low-entropy boundary conditions are *not* required to avoid minimal Boltzmann brains being exponentially by far the most probable type of observer, or even the most probable type of observer at all [116]. Also, it has been argued that special, i.e., low-entropy, conditions are not required at Big Bangs or Big Bounces [123,124]. [Clustering of matter at $t = 0$, which might typically be expected to increase entropy in the presence of gravity [125,126], does not do so because in this model [123,124] it is prevented owing to positive kinetic energy equaling negative gravitational energy in magnitude, so that the total energy (which in a Newtonian model excludes mass-energy) equals zero. But on pp. 3–4 of Ref. [124], friction, which generates entropy, is invoked during the time evolution of the system. Frictional damping, by degrading part of the macroscopic kinetic energy of any given pair of objects into microscopic kinetic energy (heat), facilitates their settling into a bound Keplerian-orbit state. But because friction thus generates entropy, this may correspond to a hidden, overlooked, pre-friction low-entropy assumption concerning the initial $t = 0$ state of this model [123,124] in either of its two directions of time [123,124]. But a Kepler pair can be formed without friction, for example via a three-body collision wherein a third body removes enough macroscopic

[15] (Re: Entry [122], Ref. [112]) Reference [112] provides discussions of a spectrum of numerous viewpoints concerning Multiverses and related topics, Dr. Steven Weinberg's viewpoint among this spectrum of viewpoints.

kinetic energy from the other two — without degrading any into heat — that they can settle into a bound Keplerian-orbit state.]

Low-entropy Planck-power (or other [21–25,33–35]) input such as hydrogen in nonoscillating cosmologies, or two-time low-entropy boundary conditions in oscillating ones [61,62,101–105], would enable our Universe — and likewise any Universe in the Multiverse — to *forever* thwart the heat death predicted by the Second Law of Thermodynamics. It should be noted that there also are other ways that the heat death can be thwarted: see, for example, Ref. [127]. Hopefully, one way or another, the heat death *is* thwarted in the *real* Universe, whether within an inflationary Multiverse [89–94,105] or otherwise [88,89,101–105,127].

Perhaps we should also note that the fraction $f \sim 10^{-5}$ of Planck-power input as hydrogen mentioned in Sect. 4 would maintain our L-region and O-region *much farther* from thermodynamic equilibrium than is required for existence of one and only one minimal Boltzmann brain. Thus *if* Planck-power input exists *then* $f \sim 10^{-5}$ rather than $f = 0$ can*not* be explained owing to our L-region being lucky: Boltzmann's exponential relation $\mathrm{Prob}\,(\sigma) = \exp(-\sigma/k)$ on the one hand, and σ being a monotonically increasing function of f on the other, rules out any values of σ and f larger than the absolute minima that allow the existence of one and only one minimal Boltzmann brain obtaining by dumb luck. Thus *if* Planck-power input exists *then* perhaps there is an underlying principle or law of physics *requiring* $f \sim 10^{-5}$ not only in our L-region but in accordance with the cosmological principle [51] in every L-region of our, and also every other, island Universe [1] in the Multiverse [52–58].

6. Dr. Roger Penrose's concerns: Both sides of the inflation issue

We still must consider Dr. Roger Penrose's difficulty with inflation per se, the evidence for inflation not yet being totally beyond doubt [36–50]. Dr. Penrose has shown that, as per Boltzmann's exponential relation between negentropy and probability $\mathrm{Prob}\,(\sigma) = \exp(-\sigma/k)$, the probability Prob 1, per "attempt," of creation of a Universe *as far from thermodynamic equilibrium as ours* without inflation, while extremely small, is nevertheless enormously larger than the probability Prob 2 with inflation. That is $\mathrm{Prob}\,2 \lll \mathrm{Prob}\,1 \lll 1$. At the 27th Texas Symposium on Relativistic Astrophysics [8], I asked Dr. Penrose the following question (I have streamlined the wording for this chapter): No matter how much smaller Prob 2 is than Prob 1 (so long as Prob 2, however miniscule even compared to the already miniscule Prob 1, is finitely greater than zero), inflation has to initiate *only once* — after initiating *once* it will then overwhelm all noninflationary regions. Dr. Penrose provided a concise and insightful reply [128], and also suggested that I re-read the relevant sections of his book, "The Road to Reality [15,61,62]" I did so. Dr. Penrose's key argument seems to be centered on squaring inflation with the Second Law of Thermodynamics. Dr. Penrose's central point, already briefly discussed in Sect. 5, begins with but does not end with recognizing that our L-region and O-region are *much* more thermodynamically atypical — with *much* lower entropy — than is required for us to exist even as *hyper-extra*ordinary observers, as opposed to only one of us as a minimal extraordinary observer, let alone only one of us as a minimal Boltzmann brain. Our L-region and O-region are thermodynamically extremely atypical not merely with respect to all possible L-regions and O-regions. They

http://dx.doi.org/10.5772/61642

are thermodynamically extremely atypical even with respect to the extremely tiny subset of already thermodynamically extremely atypical L-regions and O-regions that allow us to exist as *hyper-extra*ordinary observers, as opposed to only one of us as a minimal extraordinary observer, let alone only one of us as a minimal Boltzmann brain. But now the link to inflation per se: As thermodynamically untypical as our L-region and O-region are today, they become as per Boltzmann's relation $\mathrm{Prob}\,(\sigma) = \exp(-\sigma/k)$ *exponentially ever more* thermodynamically untypical as one considers them backwards in time [61,62]. Thus the disparity *today* by a factor of $O \sim 10^{10^{123}}$ between the minimal-Boltzmann-brain or even minimal-extraordinary-observer hypothesis and observation becomes *exponentially* ever more severe as one considers our L-region and O-region backwards in time [61,62]. Thus the connection with inflation: Since inflation smooths out temperature differences and other nonuniformities, the very existence of temperature differences and other nonuniformities prior to inflation implies lower entropy than without such nonuniformities and hence renders the thermodynamic problem of origins worse not better [61,62]. In fact *exponentially* worse as per Boltzmann's *exponential* diminution $\mathrm{Prob}\,(\sigma) = \exp(-\sigma/k)$ of probability with increasing negentropy σ [61,62]. As thermodynamically atypical and hence *exponentially* improbable as our Big Bang was, it must have been thermodynamically *more* atypical and hence *exponentially more* improbable if it was inflation-mediated than if it was not. This is the basic reason for Dr. Penrose's extremely strong inequality $\mathrm{Prob}\,2 \lll \mathrm{Prob}\,1$. (We should, however, cite the remark that prior to inflation there may have been little mass-energy to thermalize [129].) Nevertheless my question still persists: In infinite time, or even in a sufficiently long finite time, even the most improbable event (so long as its probability, however miniscule, is finitely greater than zero) not merely can occur but *must* occur. It has been noted "that whatever physics permitted one Big Bang to occur might well permit many repetitions [130]." But suppose that Universe creations can occur via both noninflationary and inflationary physics. Even if because $\mathrm{Prob}\,2 \lll \mathrm{Prob}\,1$ there first occurred an enormous but finite number N_1 of noninflationary Big Bangs yielding Universes *as far from thermodynamic equilibrium as ours*, so long as $\mathrm{Prob}\,2$, however miniscule even compared to the already miniscule $\mathrm{Prob}\,1$, is finitely greater than zero, after a sufficiently enormous but finite number N_1 of such noninflationary Universe creations inflation *must* initiate. And it need initiate *only once* to kick-start the inflationary Multiverse. Thereafter the inflationary Multiverse rapidly attains overwhelming dominance over the noninflationary one — with the number N_2 of inflation-mediated Big Bangs yielding Universes *as far from thermodynamic equilibrium as ours* henceforth overwhelming the number N_1 of noninflationary ones by an ever-increasing margin. To reiterate, no matter how much smaller $\mathrm{Prob}\,2$ is than $\mathrm{Prob}\,1$ (so long as $\mathrm{Prob}\,2$, however miniscule even compared to the already miniscule $\mathrm{Prob}\,1$, is finitely greater than zero), in infinite time, or even in a sufficiently long finite time, inflation *must* eventually initiate *once*, kick-starting the inflationary Multiverse, which henceforth becomes ever-increasingly overwhelmingly dominant over the noninflationary one. But even if inflation is eternal, it did have a beginning [99], and hence so did the inflationary Multiverse [99].

While in this Sect. 6 the focus is on thermodynamic issues concerning inflation, we note that Dr. Penrose also considers nonthermodynamic issues, specifically the smoothness and flatness problems [131].

7. Kinetic control versus both heat death and Boltzmann brains?

A tentative solution to the thermodynamic problem of origins, namely dominance of kinetic over thermodynamic control [72–77] has already been proposed, as a reasonable guess, for the special case of Planck-power input discussed in association with Eq. (8) in Sect. 4 and Everett-Universe creation in the last paragraph of Sect. 4. We would now like to consider this issue somewhat more generally.

A generalized form of this *prima facie* perhaps reasonable guess might include: (a) Creation in general, by whatever method, both initial via Big Bang with or without inflation, etc. [26–31], via Everett [96–98], and sustained via Planck-power (or other [33–35]) input of equal nonzero quantities of both positive mass-energy and negative gravitational (or other negative [33–35]) energy starting from (zero positive energy + zero negative energy = zero total energy) entails an initial entropy of zero — the entropy of (zero positive energy + zero negative energy = zero total energy) is *perforce* zero: recall the paragraph containing Eq. (8) in Sect. 4. (b) Creation in general, by whatever method, both initial via Big Bang with or without inflation, etc. [26–31], via Everett [96–98], and sustained via Planck-power (or other [33–35]) input of equal nonzero quantities of both positive mass-energy and negative gravitational (or other negative [33–35]) energy starting from (zero positive energy + zero negative energy = zero total energy) is a nonequilibrium process. These processes do not allow enough time for complete thermalization of the input from the initial value of zero entropy of (zero positive energy + zero negative energy = zero total energy) to the maximum possible positive entropy of (nonzero positive energy + nonzero negative energy = zero total energy). Thus even though, *thermodynamically*, *exponentially* the most probable creation, initial or sustained, by any method, would yield a maximum-entropy Universe with *exponentially* the most probable observer a *minimal* Boltzmann brain, *kinetically* the reaction

$$\begin{aligned} &\text{zero positive energy} + \text{zero negative energy} = \text{zero total energy} \\ &\longrightarrow \text{nonzero positive energy} + \text{nonzero negative energy} = \text{zero total energy} \end{aligned} \tag{8 (restated)}$$

occurs too quickly to allow thermodynamic equilibrium = maximum entropy to be attained. Thus creation, initial or sustained, by whatever method, yields (nonzero positive energy + nonzero negative energy = zero total energy) at positive but far lass than maximum entropy, consistently with the Second Law of Thermodynamics but not with the heat death. Thus the basis of our proposed tentative solution to the thermodynamic problem of both initial and sustained-input origins: the reaction (rx) of Eq. (8) is *kinetically* rather than *thermodynamically* controlled [72–77]. This kinetic control does not defeat thermodynamics (specifically the Second Law of Thermodynamics) but it does defeat the heat death. Thus if the reaction of Eq. (8) is kinetically rather than thermodynamically controlled then the heat death is thwarted, but within the restrictions of the Second Law of Thermodynamics. This kinetic as opposed to thermodynamic control could similarly obtain at the initial creation in accordance with Eq. (8) of an oscillating Universe with two-time low-entropy boundary conditions at the

http://dx.doi.org/10.5772/61642

Big Bang and at the Big Crunch [16,61,62,88–94,101–105], and in the case of creation *ex nihilo* (in contravention of the First Law of Thermodynamics) [21–25].

But as we discussed in the third paragraph of Sect. 4, perhaps the *simplest* model of Planck-power input is *initially* in the form of the *simplest* possible type of dark energy, corresponding to *positive constant* Λ — a *positive* cosmological *constant* [65–67]. The *simplest* possible type of dark energy, corresponding to *positive constant* Λ — a *positive* cosmological *constant* [65–67] — is perhaps the type of dark energy that is most easily reconcilable with Planck-power input, in particular with *positive constant* Planck-power input. As we have mentioned, it is also simplest with respect to General Relativity [65–67], and it also implies, or at least is consistent with, *constant* $H(\tau) = H_0$ at all cosmic times τ, and hence a fixed size of our L-region, with its boundary (event horizon [2,3]) $R(\tau)$ always fixed at $R_0 = c/H_0$.

Let ΔS_{rx} be the increase in entropy associated with the reaction (rx) of Eq. (8), with respect to our L-region. If $0 \ll \Delta S_{\mathrm{rx}} \ll S_{\max} \sim 10^{123}k$, then, on the one hand, the strong inequality $0 \ll \Delta S_{\mathrm{rx}}$ ensures an equilibrium constant $K_{\mathrm{eq}} = \exp(\Delta S_{\mathrm{rx}}/k)$ sufficiently large that the reverse reaction is forbidden for all practical purposes, thus stabilizing creation [72–77]. Thus the strong inequality $0 \ll \Delta S_{\mathrm{rx}}$ justifies the placement of only a forward arrow (no reverse arrow) at the beginning of the second line of Eq. (8) [72–77]. On the other hand, the strong inequality $\Delta S_{\mathrm{rx}} \ll S_{\max} \sim 10^{123}k$ ensures against the doom and gloom that one would dread based *solely* on Boltzmann's relations $\mathrm{Prob}(\Delta S) = \exp(-\Delta S/k)$ and $\mathrm{Prob}(\sigma) = \exp(-\sigma/k)$. Note for example that even if $\Delta S_{\mathrm{rx}} = 10^{120}k$ and hence for the reaction (rx) of Eq. (8) $K_{\mathrm{eq}} = e^{10^{120}}$, the entropy of our L-region is still only $O \sim 10^{-3}$ of that corresponding to thermodynamic equilibrium and hence still $\sigma \sim \left(10^{123}k - 10^{120}k\right)$, which is for all practical purposes still $\sigma \sim 10^{123}k$. [References [73–77] express the equilibrium constant as $K_{\mathrm{eq}} = \exp(-\Delta G_{\mathrm{rx}}/kT)$, where ΔG_{rx} is the Gibbs free energy change per molecular reaction in the special case of a system maintained at constant temperature T and constant ambient pressure. (To be precise, the ambient pressure must be maintained strictly constant during a reaction, but the temperature of the reactive system can vary in intermediate states so long as at the very least the initial and final states are at the same temperature, for this definition of ΔG_{rx} to be valid [132–135].[16]) In this special case, $|\Delta G_{\mathrm{rx}}|$ is the maximum work obtainable per molecular reaction if $\Delta G_{\mathrm{rx}} < 0$ and the minimum work required to enable it if $\Delta G_{\mathrm{rx}} > 0$. But in this special case $\Delta G_{\mathrm{rx}} = -T\Delta S_{\mathrm{rx}}$ where ΔS_{rx} is the *total* entropy change of the (system + surroundings) per molecular reaction. Hence $K_{\mathrm{eq}} = \exp(-\Delta G_{\mathrm{rx}}/kT)$ is the corresponding special case of $K_{\mathrm{eq}} = \exp(\Delta S_{\mathrm{rx}}/k)$. In this chapter ΔS and ΔS_{rx} are always taken to be *total* entropy changes of the entire Universe or at least of our L-region thereof.]

[16] (Re: Entry [132], Ref. [132]) One point: On p. 479 of Ref. [132], it is stated that in an adiabatic process all of the energy lost by a system can be converted to work, but that in a nonadiabatic process less than all of the energy lost by a system can be converted to work. But if the entropy of a system undergoing a nonadiabatic process *increases*, then *more* than all of the energy lost by this system can be converted to work, because energy extracted from the surroundings can then also contribute to the work output. In some such cases positive work output can be obtained at the expense of the surroundings even if the change in a system's energy is *zero*, indeed even if a system *gains* energy. Examples: (a) Isothermal expansion of an ideal gas is a thermodynamically spontaneous process, yielding work even though the energy change of the ideal gas is *zero*. (b) Evaporation of water into an unsaturated atmosphere (relative humidity less than 100%) is a thermodynamically spontaneous process, yielding work even though it costs heat, i.e., yielding work even though liquid water *gains* energy in becoming water vapor: see Refs. [133–135] concerning this point.

Thus the doom and gloom that one would dread based *solely* on Boltzmann's relation $\text{Prob}(\sigma) = \exp(-\sigma/k)$ does *not* obtain, and furthermore will *never* obtain if there exists *imposed* two-time low-entropy boundary conditions in an oscillating cosmology [16,61,62,88–94,101–105], or Planck-power (or other [21–25,33–35]) *imposed* sustained low-entropy mass-energy input such as hydrogen in a nonoscillating one [78]. Thus creation — initial via Big Bang with or without inflation, etc. [26–31], via Everett [96–98], and sustained via Planck-power (or other [21–25,33–35]) input — being kinetically rather than thermodynamically controlled [72–77] seems to be at least a reasonable tentative explanation of why we are privileged to be not merely *minimal extra*ordinary observers but *super-extra*ordinary observers — more correctly *hyper-extra*ordinary observers — with an entire Universe to explore and enjoy [61,62]. By the cosmological principle [51] we may hope that this is true everywhere in the Multiverse.

As a brief aside, we note that many chemical reactions are similarly kinetically rather than thermodynamically controlled [72–77], in like manner as Eq. (8). While only chemical reactions are discussed in Refs. [72–77], the same principle likewise applies with respect to *all* kinetically rather than thermodynamically controlled processes, for example kinetically rather than thermodynamically controlled physical and nuclear reactions. As we discussed in Sect. 4 if nuclear reactions were thermodynamically rather than kinetically controlled then there would be nothing but (iron + equilibrium blackbody radiation) — an iron-dead Universe.

8. A brief review concerning the Multiverse, and some alternative viewpoints

Four Levels of the Multiverse have been recognized [136–141]: Level I, the infinite number of L-regions and O-regions within an island Universe, with identical fundamental and effective laws of physics but with generally different histories (given the infinite number of L-regions and O-regions per island Universe, identical histories must occur in sufficiently widely separated ones); Level II, an infinite number of island Universes with identical fundamental but different effective laws of physics; Level III, Dr. Hugh Everett's many worlds [96–98]; and Level IV, wherein — within limits [136–142] — different fundamental laws of physics are allowed [136–142].[17]

Dr. Max Tegmark [138,139] writes that Level III is at least in some sense may be equivalent to Levels I+II: Level I incorporates different quantum branches within one single given Hubble volume of an infinity of such volumes contained in an island Universe. Level II incorporates different quantum branches within an entire island Universe. Level III incorporates different Level I and Level II Universes within one single given quantum branch. But it seems that Levels I+II, or at the very least Level I, must exist *first*, because Levels I+II, or at the very least Level I, seems *prerequisite* for the existence of entities capable of executing Dr. Hugh Everett's program [96–98].

[17] (Re: Entry [137], Ref. [112]) Reference [112] provides discussions of a spectrum of numerous viewpoints concerning Multiverses and related topics, Dr. Max Tegmark's viewpoint among this spectrum of viewpoints.

http://dx.doi.org/10.5772/61642

We should note that *if* conscious observers, also referred to as self-aware substructures (SASs) [143–145], are not merely self-aware but also have free will, *then* they have at least *some* degree of *choice* concerning creation of Level III Universes: They then have at least *some* freedom to *choose* whether or not to make a given observation or measurement, which observations and measurements to make, and when to make them. Even if the Everett interpretation [96–98] of quantum mechanics is incorrect [146] and Level III Universes exist only in potentiality until one and only one of them is actualized [146], say via wave-function collapse [147], then an SAS with free will still has this degree of *choice*. Even if the probabilities of the possible outcomes of any given observation or measurement cannot be altered, the set of possible outcomes on offer to Nature depends on which observations and measurements are chosen by an SAS with free will, and when they are on offer depends on when an SAS with free will chooses to observe or measure. Thus irrespective of the character of Level III Universes, *if* free will exists *then* there is this *qualitative* difference between unchosen observations and measurements made by Nature herself, say via decoherence [148,149], and chosen ones made by an SAS with free will. Furthermore, a choice made by an SAS with free will seems to be an initial condition on the future history of the Universe, or on the future history of the Level III Multiverse of quantum branches given the Everett scenario [96–98]. The question then arises of compatibility with the Mathematical Universe Hypothesis (MUH), according to which initial conditions can*not* exist [150,151]. But both the very notion of *choice* [152] and exhortations to "Let's make a difference!" [153] seem incompatible with denial of free will. Moreover, "decoherence" is perhaps too strong a term; "delocalization of coherence" seems more correct. Since quantum-mechanical information in general cannot be destroyed, quantum-mechanical coherence in particular is never really destroyed, merely delocalized. As with any delocalization process there is an accompanying increase in entropy. But within a system of finite volume this increase in entropy is limited to a finite maximum value, implying recoherence, or more correctly relocalization of coherence, after a Poincaré recurrence time [108,154,155]. Of course, typical Poincaré recurrence times [108,150,151] of all but very small systems are inconceivably long, but in a very small system at least partial recoherence, or more correctly relocalization of coherence, may occur in a reasonable time. We should mention that even before the term "decoherence" had been coined, some aspects of decoherence, or more correctly delocalization of coherence, had been partially anticipated [156,157]. For general reviews concerning the quantum-mechanical measurement problem see, for example, Refs. [149] and [156–159].[18]

Perhaps the concepts considered in this chapter may be at least to some degree applicable to the maximal proposed version of the Multiverse, the Level IV Multiverse [136–145], wherein all well-defined mathematical structures [140–145] — but *not* all arbitrary figments or fantasies of one's imagination [140–142] — would be realized as physically-existing Universes [140–145]. But as Dr. Alex Vilenkin points out, not all mathematical structures, indeed not even all *allowable* mathematical structures given the restrictions stated by

[18] In Chap. 23 of Ref. [156], Dr. David Bohm expresses the viewpoint that classical mechanics should be considered in its own right and as prerequisite for quantum mechanics, rather than as a limiting case of quantum mechanics. This is opposed to the more generally accepted viewpoint that classical mechanics should be considered as a limiting case of quantum mechanics. Moreover, even Dr. David Bohm expresses the latter viewpoint in his own recognition of the Universe as ultimately quantum-mechanical, in Chap. 8 (especially Sects. 8.22–8.23) and Chap. 22 (especially Sects. 22.2–22.3) of Ref. [156]. But, in any case, this is apart from Dr. David Bohm's partial anticipation of certain aspects of decoherence, or more correctly delocalization of coherence, in Sect. 6.12 and Chap. 22 (especially Sects. 22.11–22.12) of Ref. [156].

Dr. Max Tegmark [140–142], are equal: some are more beautiful and hence more equal than others [160]. Alex Vilenkin writes: "Beautiful mathematics combines simplicity with depth [160]." (But also that "simplicity" and "depth" are almost as difficult to define as "beauty [160].") But Dr. Alex Vilenkin also writes: "Mathematical beauty may be useful as a guide, but it is hard to imagine that it would suffice to select a unique theory out of the infinite number of possibilities [161]." These points are also considered by Dr. Roger Penrose [162]. Yet even so mathematical beauty should have at least *some* selective power. A case in point: Newton's laws have both simplicity and depth, and hence are beautiful. But Einstein's laws have *both greater simplicity and greater depth*, and hence are *more* beautiful. The laws of motion have the same form in all reference frames in General Relativity but not in Newton's theory (for example, Newton's theory requires extra terms for centrifugal and Coriolis forces in rotating reference frames), thus General Relativity has greater simplicity; additionally, Newton's theory is a *limiting case* of Einstein's but not vice versa, thus General Relativity also has greater depth. Hence might a Universe wherein Newton's laws are the *fundamental* laws, not merely a limiting case of relativity and quantum mechanics, be denied physical existence in a Level IV Multiverse — because even though it is a beautiful mathematical structure, it is not the *maximally*-beautiful one that *maximally* entails both simplicity and depth? While (even neglecting quantum mechanics) we can*not* be sure if General Relativity *is* the maximally-beautiful mathematical structure, we *can* be sure that Newtonian theory, while beautiful, is *not* maximally beautiful. Moreover, while the Multiverse is eternal, it nonetheless, at least below Level IV [136], did have a beginning [99]. The laws of quantum mechanics — *our* laws of quantum mechanics — governed the initial tunneling event that created not merely our Universe but the Multiverse, at least through Level II [99,136]. Thus these laws, on whatever tablets they are written, must have existed before, and must exist independently of, the Multiverse at least through Level II [99,136] — not merely of our island Universe [99]. Concerning Level III, it seems that Levels I+II, or at the very least Level I, must exist *first*, because Levels I+II, or at the very least Level I, seems *prerequisite* for the existence of entities capable of executing Dr. Hugh Everett's program [96–98]. But might the prerequisites for a beginning and for the pre-existence of *our* laws of quantum mechanics be general, operative even at Level IV [136]? But if so then might Level IV — but not Levels I, II, and III — be more restricted than has been suggested [136]? For then might *our* laws of quantum mechanics be part of the *one* maximally-beautiful mathematical structure that *maximally* entails both simplicity and depth — *our* fundamental (not merely effective) laws of physics [136] — after all? Then perhaps this *one* maximally beautiful mathematical structure, this *maximal* possible entailment of both simplicity and depth, is the only one realized via physically-existing Universes. But if this is the case then the question arises: Why does this *one* maximally beautiful mathematical structure permit life [163] (at the very least, carbon-based life as we know it on Earth)?

We must admit that in this chapter we have not even scratched the surface, as per this paragraph and the two immediately following ones. There are many alternative viewpoints concerning the Multiverse and related issues. We should at least mention a few of them that we have not mentioned until now. According to at least one of these viewpoints, inflation is eternal into the past as well as into the future, and hence has no beginning as well as no end [164–166]. But perhaps this is compatible with inflation having a beginning if regions of inflation in the forward and backward time directions are disjoint and incapable of any interaction with each other [167]. Then perhaps observers in both types of regions would consider their home region to be evolving forward, not backward, in time. According to

http://dx.doi.org/10.5772/61642

other viewpoints, inflation not only has a beginning but also has an end — eternal inflation is impossible [168,169]. According to one of these viewpoints, the end of inflation is imposed by the increasingly fractal nature of spacetime [168,169]. We also note that Dr. Roger Penrose considered another difficulty associated with possible fractal nature of spacetime: inflation does not solve the smoothness and flatness problems if the structure of spacetime is fractal, let alone worse than fractal [170]. According to another of these viewpoints, the end of inflation is imposed by the Big Snap, according to which expansion of space will eventually dilute the number of degrees of freedom per any unit volume, and specifically per Hubble volume, to less than one, although the Universe will probably be in trouble well before the number of degrees of freedom per Hubble volume is reduced to one [171,172]. But perhaps new degrees of freedom can be created to compensate [171,172]. Perhaps Planck-power input, if it exists, can, because it replenishes mass-energy, also replenish degrees of freedom — thereby precluding the Big Snap. In Dr. Max Tegmark's rubber-band analogy, this corresponds to new molecules of rubber being created (at the expense of negative gravitational energy of a "rubber-band Universe") the rubber band stretches, thereby keeping the density of rubber constant [171,172]. But, with or without a Big Snap [171,172], if inflation does have an end for any reason whatsoever, then my question to Dr. Roger Penrose in Sect. 6 is answered negatively: then the vast majority of Big Bangs will be noninflationary.

There are also many proposed solutions to the entropy problem (why there is so very much more than one minimal Boltzmann brain in our L-region and O-region), some of which we have already discussed and/or cited in Sects. 5–8, other than Planck-power input. But there are still other proposed solutions to the entropy problem. One other proposed solution that we have not yet cited entails quantum fluctuations ensuring that every baby Universe starts out with an unstable large cosmological-constant, which corresponds to low total entropy because it is thermodynamically favorable for the consequent high-energy false vacuum to decay spontaneously [173,174]. Yet another proposed solution that we have not yet cited entails observer-assisted low entropy [172].

There are also many alternative viewpoints concerning fine-tuning and life in the Universe. It has been noted that since physical parameters such as constants of nature, strengths of forces, masses of elementary particles, etc., all have real-number, or perhaps rational-number, values. The range of real numbers, or even of rational numbers, is infinite. (The countable infinity of rational numbers is smaller than the uncountable infinity of real numbers, but even a countable infinity is still infinite.) Hence, if the probability of occurrence of a given real-number, or even rational-number, value of a given parameter is uniform, or at least non-convergent, then there is only an infinitessimal probability of this value being within any finite range [175,176]. But if thee are an infinite number of L-regions and O-regions, this infinity may be as large or even larger. We should also note that while some scientists are favorable towards the idea of fine tuning [177], others are skeptical to the point of not requiring a Multiverse to explain it away, but stating that it is an invalid concept even if our O-region constituted the entire Universe [178–180]. Even this skeptical viewpoint admits that only a very small range of parameter space is consistent with carbon-based life as we know it on Earth [180], but assumes that a much larger range of parameter space is consistent with life in general [180]. But life, at least chemically-based life, probably must be based on carbon, because no other element even comes close to matching carbon's ability to form highly complex, information-rich molecules. Even carbon's closest competitor, silicon, falls woefully short. Also, nucleosynthesis in stars forms carbon more easily than silicon [181], so

carbon is more abundant in the Universe [181]. We conclude by citing a paper that, while favoring a purely materialistic viewpoint, discusses would be required to seriously question it [182], and a book that explores many topics and viewpoints [183]. Reference [183] considers not only many, probably most, of the topics and viewpoints also considered in references that we have previously cited, but also many additional topics and viewpoints.

Acknowledgments

I am especially grateful to Dr. Wolfgang Rindler, Dr. Donald H. Kobe, Dr. Bruce N. Miller, and Dr. Roger Penrose for very helpful, thoughtful, and insightful discussions, communications, and advice concerning relativity, cosmology, and thermodynamics. I am also grateful to Dr. Roger Penrose for valuable insights and clarifications concerning the relation between thermodynamics on the one hand, and inflation and cosmology on the other, and to Dr. Michael Turner for valuable insights and clarifications concerning oscillating versus nonoscillating universes, both at the 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas on December 8–13, 2013 (website: nsm.utdallas.edu/texas2013/). I am also grateful to Dr. Wolfgang Rindler, Dr. Bruce N. Miller, and Dr. Roger Penrose for helpful general discussions concerning physics and astrophysics, both at the 27th Texas Symposium on Relativistic Astrophysics and otherwise, and to Dr. Donald H. Kobe for such discussions on various occasions. I also thank Dr. Marlan O. Scully and Dr. Donald H. Kobe for helpful insights concerning decoherence (perhaps, more correctly, delocalization of coherence). I am thankful to Dr. Paolo Grigolini for very helpful and thoughtful considerations concerning both earlier and the most recent versions of manuscripts of this chapter in Special Problems courses, and for many very helpful insights concerning thermodynamics, especially the Second Law. I am also thankful to Dr. Daniel P. Sheehan for many very helpful insights concerning possible limitations of the Second Law. Also, I thank Dr. S. Mort Zimmerman for engaging in general scientific discussions over many years, both Dan Zimmerman and Dr. Kurt W. Hess for brief yet helpful discussions concerning this chapter and for engaging in general scientific discussions at times, and Robert H. Shelton for very helpful advice concerning diction. I also thank Dr. Iva Simcic, Publishing Process Manager at InTech, for much very helpful advice in preparing this chapter and for much extra time to prepare it, and Technical Support at MacKichan Software for their very helpful advice concerning Scientific WorkPlace 5.5.

Author details

Jack Denur

Address all correspondence to: jackdenur@my.unt.edu

Electric & Gas Technology, Inc., Rowlett, Texas, USA

References

[1] Vilenkin A. Many Worlds in One: The Search for Other Universes. New York: Hall and Wang; 2007. DOI: 10.1063/1.2743129. See Chaps. 10 and 11, pp. 203–205, and the associated Notes including references cited therein.

[2] Rindler W. Relativity: Special, General, and Cosmological. 2nd ed. New York: Oxford University Press; 2006, pp. 367, 374, and 384.

[3] Reference [2], Sects. 16.1G and 17.1–17.4 (especially Sect. 17.3), also Exercise 16.3 on p. 369.

[4] Reference [2], Sects. 16.2–16.4 (especially pp. 359–360 and 367).

[5] Davies PCW. The Physics of Time Asymmetry. 2nd ed. Berkeley: University of California Press; 1977, Sect. 1.4.

[6] Reference [2], pp. 376–377.

[7] Reference [2], Exercise 7.22 on pp. 160–161, Sects. 16.1E–16.1G, p. 362, p. 366, Sect. 17.2, and Exercise 17.4 on p. 388.

[8] 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas, December 8–13, 2013. [Internet]. 2013. Available from: nsm.utdallas.edu/texas2013/ [Accessed: 2016-05-03]

[10] Lang KR. Essential Astrophysics. Berlin: Springer-Verlag; 2013, Sect. 14.3 and references cited therein.

[11] Planck Collaboration. *Planck* 2015 results. XIII. Cosmological parameters. arXiv:1502.01589v2 [astro-ph.CO] 6 Feb 2015: 67 pages. [Internet]. 2016. Also in Astronomy and Astrophysics. Available from: www.cosmos.esa.int/web/planck/publications [Accessed: 2016-05-03].

[12] Misner CW, Thorne KS, Wheeler JA. Gravitation. New York: W. H. Freeman; 1973, pp. 10–13 and 1180, and Sects. 43.4, 44.3, and 44.6 (especially pp. 1215–1217).

[13] Planck M. Über irreversible Strahlangdvorgänge. Sitzungsber. Deut. Akad. Wiss Berlin Kl. Math–Phys. Tech. 1899; 440–480.

[14] Bradley W. Carroll BW, Ostlie DA. An Introduction to Modern Astrophysics. 2nd ed. San Francisco: Pearson Addison Wesley; 2007, pp. 1233–1235.

[15] Penrose R. The Road to Reality: A Complete Guide to the Laws of the Universe. New York: Alfred A. Knopf; 2005, Sects. 27.3, 27.10, and 31.1. See also references cited in Sect. 31.1.

[16] Reference [2], Sects. 16.1G–16.1K.

[17] Reference [2], Sects. 16.4, 18.3, and 18.4.

[18] Reference [10], Sects. 14.6 and 15.6.2.

[19] Reference [11], Sect. 6.2.4.

[20] Reference [14], Chap. 29.

[21] Reference [1], pp. 27–28, 37, and 170–171.

[22] Reference [2], pp. 359, 368–369, 387–388, and 411.

[23] Reference [14], pp. 1163–1167.

[24] Harrison ER. Mining Energy in an Expanding Universe. Astrophys. Jour. 1995; 446: 63–66. DOI: 10.1086/175767

[25] Sheehan DP, Kriss VG: Energy Emission by Quantum Systems in an Expanding FRW Metric. arXiv:astro-ph/0411299v1. 11 Nov 2004. 12 pages. [Internet]. 2004. Available from: xxx.lanl.gov/abs/astro-ph/0411299v1 or arxiv.org/abs/astro-ph/0411299v1 [Accessed: 2016-05-03]

[26] Tryon EP. Is the Universe a Vacuum Fluctuation? Nature 1973; **246**: 396–397. DOI: 10.1038/246396a0

[27] Reference [1], pp. 11–12 and 183–186.

[28] Filippenko A, Pasachoff JM. A Universe From Nothing. 2 pages. [Internet]. 2006. Available from: https://www.astrosociety.org/publications/a-universe-from-nothing/ [Accessed: 2016-05-03]

[29] Potter F, Jargodzki C. Mad About Modern Physics. Hoboken, N. J.: John Wiley & Sons; 2005, Question 224, "The Total Energy," on p. 115, and Answer 224, "The Total Energy," along with cited references, on pp. 275–276.

[30] Berman MS. On the Zero-Energy Universe. Int. J. Theor. Phys. 2009; **48**: 3278–3286. DOI: 10.1007/s10773-009-0125-8

[31] Berman MS, Trevisan LA. On Creation of Universe Out of Nothing. Int. J. Modern Phys. B. 2010; **19**: 1309–1313. DOI: 10.1142/S021827181007342

[32] Reference [15], Sects. 19.7–19.8 (especially Sect. 19.8 and most especially pp. 468–469). See also references cited therein; also Notes for Sects. 19.7–19.8 on pp. 469–470. Of these references, see especially the references cited in Note 19.17 on p. 470.

[33] Reference [5], Sect. 7.2 and references cited therein.

[34] Reference [5], the last sentence on p. 187 and the reference cited therein.

[35] Davies PCW. Is the Universe Transparent or Opaque? J. Phys. A: Math. Gen. 1972; **5**: 1722–1737. DOI: 10.1088/0305-4470/5/12/012. See especially Sect. 8.

[36] Reference [1], pp. 48–52 and 67–69; also Notes for Chaps. 5 and 6 on pp. 211–212, especially Notes 2 and 3 for Chap. 5 on p. 211.

[37] Reference [2], pp. 379–380 and Sects. 18.5–18.6.

[38] Reference [14], Sect. 30.1.

[39] Reference [15], Chap. 28, including Notes for Chap. 28 on pp. 778–781.

[40] Reference [10], pp. 523–524.

[41] Crockett C. Primordial gravitational waves found: Researchers see traces of cosmic expansion just after Big Bang. Science News. April 5, 2014; **185 (7)**.

[42] Krauss LM. Beacon from the Big Bang. Sci. Amer. October, 2014; **311 (4)**: 58–67.

[43] Flauger R, Hill JC, Spergel DN. Toward an understanding of foreground emission in the BICEP2 region. Journal of Cosmology and Astroparticle Physics. 2014; **08**: 039. DOI: 10.1088/1475-7516/2014/08/039

[44] Crockett C. Gravitational wave discovery gives way to dust. Science News. October 18, 2014; **186 (8)**: 7.

[45] Crockett C. Dust obscures possible gravitational wave discovery. Science News. December 27, 2014; **186 (13)**: 16.

[46] Grant A. Gravitational wave claim bites dust. Science News. February 21, 2015; **187 (4)**: 13.

[47] Grant A. The past according to Planck: Cosmologists got a lot right. Science News. March 21, 2015; **187 (6)**: 7.

[48] Milne PA, Foley RJ, Brown PJ, Narayan G. The Changing Fractions of Type 1A Supernova NUV-Optical Subclasses with Redshift. Astrophys. Jour. 2015; **803:20**: 15 pages. DOI: 10.1088/0004-637X/803/120

[49] Reference [15], Sects. 28.4–28.7. See also references cited therein; also Notes for Sects. 28.4–28.7 on pp. 779–781; also pp. 1037–1038.

[50] Witze A. Inflation on trial. Science News. July 28, 2012; **182 (2)**: 20–21.

[51] Reference [2], Sects. 1.11 and 16.1–16.2.

[52] Reference [14], Sect. 13.3 and pp. 886–887, 957–958, 986–987, 1011–1013, 1018–1020, and 1028.

[53] Reference [14], pp. 1011–1013, 1018–1020, and 1028.

[54] Reference [10], Sect. 15.4.2 on pp. 542–545 and references cited therein.

[55] Reference [1], Chap. 10. Also see Notes for Chap. 10. on p. 213 and the reference cited in Note 1.

[56] Reference [14], Chaps. 7–16.

[57] Reference [10], Chaps. 2 and 8–13.

[58] Reference [1], Chap. 10, especially pp. 93–94. Also see Notes for Chap. 10. on p. 213 and the reference cited in Note 1.

[59] Reference [1], pp. 25–28 and 171–175, also Note 4 for Chap. 3 on p. 210.

[60] Reference [5]. See especially Chaps. 1, 2, 4, and 7.

[61] Reference [15], Sects. 19.7–19.8, Chaps. 27 and 28, and references cited therein; also Notes for Sects. 19.7–19.8 and Chaps. 27 and 28 on pp. 469–470, 732–734, and 778–781, respectively; also pp. 1037–1038. See especially Sects. 27.13 and 28.1–28.5, and the associated Notes.

[62] Reference [2], p. 380.

[63] Mersini-Houghton L, Vaas R, Editors. The Arrows of Time: A Debate in Cosmology. Berlin: Springer-Verlag; 2012.

[64] See, for example, Ref. [2], Sect. 16.1D.

[65] Reference [2], Sects. 10.5, 14.2–14.3 and 18.2E. See also the reference cited in Sects. 14.2–14.3.

[66] Reference [2], Sect. 18.2E.

[67] Lovelock D. The Four-dimensionality of Space and the Einstein Tensor. Jour. Math. Phys. 1972; **13**: 874–876. DOI: 10.1063/1.1666069

[68] Reference [11], Sect. 6.3.

[69] Planck Collaboration. *Planck* 2015 results. XIV. Dark energy and modified gravity. arXiv:1502.01590v1 [astro-ph.CO] 5 Feb 2015: 64 pages. [Internet]. 2016. Also in Astronomy and Astrophysics. Available from: www.cosmos.esa.int/ web/ planck/ publications [Accessed: 2016-05-03].

[70] Reference [10], Sect. 15.2. See especially Subsects. 15.2.3–15.2.4, and most especially Table 15.1.

[71] Planck Collaboration. *Planck* 2015 results. I. Overview of products and scientific results. arXiv:1502.01582v2 [astro-ph.CO] 10 Aug 2015: 40 pages. [Internet]. 2016. Also in Astronomy and Astrophysics. Available from: www.cosmos.esa.int/ web/ planck/ publications [Accessed: 2016-05-03].

[72] Noller CR. Chemistry of Organic Compounds, 2nd ed. Philadelphia: W. B. Saunders; 1957, pp. 41–42 and 165–170.

[73] Noller CR. Chemistry of Organic Compounds, 3rd ed. Philadelphia: W. B. Saunders; 1965, Chap. 3.

[74] Noller CR. Textbook of Organic Chemistry, 3rd ed. Philadelphia: W. B. Saunders; 1966, Chap. 3.

[75] Morrison RT, Boyd RN. Organic Chemistry, 6th ed. Englewood Cliffs, N. J.: W. B. Prentice Hall; 1992.

[76] Mahan BM. University Chemistry, Reading, Mass.: Addison Wesley; 1965, Chaps. 8–9.

[77] Mahan BM, Myers RJ. University Chemistry, 4th ed. Menlo Park, Calif.: Bejamin/Cummings; 1980, Chaps. 8–9.

[78] Redd NT. Rivers of Hydrogen Gas May Fuel Spiral Galaxies [Internet]. 2014. Available from: http://www.space.com/24780-spiral-galaxies-hydrogen-gas-river.html (February 21, 2014, 05:25 PM ET) [Accessed 2016-05-03]

[79] Dan Zimmerman, private communications, 2014. When I mentioned this analogy to Dan Zimmerman, he encouraged me to include it in this chapter.

[80] Sheehan, DP, editor. Quantum Limits to the Second Law, AIP Conference Proceedings Volume 643. Melville, N. Y.: American Institute of Physics; 2002.

[81] Nikulov AV, Sheehan DP, editors. Special Issue: Quantum Limits to the Second Law of Thermodynamics. Entropy. March 2004: Vol. 6, Issue 1.

[82] Čápek V, Sheehan DP. Challenges to the Second Law of Thermodynamics: Theory and Experiment. Dordrecht, The Netherlands: Springer; 2005.

[83] Sheehan, DP, editor. Special Issue: The Second Law of Thermodynamics: Foundations and Status. Found. Phys. December 2007: Vol. 37, Issue 12.

[84] Sheehan, DP, editor. Second Law of Thermodynamics: Status and Challenges, AIP Conference Proceedings Volume 1411. Melville, N. Y.: American Institute of Physics; 2011.

[85] See, for example, Ref. [2], Sects. 2.4–2.10 and 3.5, especially Sects. 2.4–2.6 and pp. 56–57. Relativity of simultaneity is most directly discussed in Sects. 2.4–2.6.

[86] Reference [2], Sects. 2.10 and 3.6.

[87] Dr. Wolfgang Rindler, private communications, 1980s–2010s, including at the 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas, December 8–13, 2013. [Internet]. 2013. Available from: nsm.utdallas.edu/texas2013/ [Accessed 2016-05-03]

[88] Reference [2], pp. 398 and 402–403.

[89] Reference [1]. See pp. 120–121 and Note 4 for Chap. 16 on p. 219 for pre-inflationary ideas concerning oscillating cosmologies, and Chap. 18 (especially pp. 197–198), Note 3 for Chap. 18 on p. 221, pp. 203–205, and Note 9 for Chap. 19 on p. 222 for oscillating cosmologies considered in light of inflation.

[90] Vilenkin A, Garriga J. Testable anthropic predictions for dark energy. Phys. Rev. D 2003; **67**: 043503–1-11.

[91] Dr. Michael Turner. private communications, at the 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas, December 8–13, 2013. [Internet]. 2013. Available from: nsm.utdallas.edu/texas2013/ [Accessed 2016-05-03]

[92] An alternative model of an oscillating Universe is discussed in Freese K, Brown MG, Kinney WH. The Phantom Bounce: A New Proposal for an Oscillating Cosmology. In Ref. [63], pp. 149–156.

[93] Zeh HD. Open Questions Regarding the Arrow of Time. In Ref. [63], pp. 205–217.

[94] Reference [12], Sect. 27.10 (especially Box 27.4 on p. 738).

[95] Reference [2], Sects. 6.2–6.3.

[96] Reference [1], pp. 114–116 and 187–188.

[97] Tegmark M. Our Mathematical Universe. New York: Vintage Books; 2015, p. 179, Chap. 8, pp. 284–286 and 314–315.

[98] Tegmark M. The Mathematical Universe. Found Phys. 2008; 38: 101–150. DOI: 10.1007/s10701-007-9186-9. See Sect. 5.2.

[99] Reference [1], Chaps. 5–8 (especially Chaps. 6 and 8), Chaps. 16 and 17, and pp. 203–205. Also see Notes for Chaps. 5, 6, 8, 16, and 17 and for pp. 203–205 including references cited therein on pp. 211–212 and 219–222. See especially Chaps. 16 and 17, and most especially pp. 180–181 and 204–205.

[100] Reference [1], Chaps. 12 and 13, and Notes for Chaps. 12 and 13 including references cited therein on pp. 214–216.

[101] Reference [5], Chap. 7, especially Sect. 7.4, and most especially the first complete paragraph on p. 193 and the references cited therein, especially Refs. [102–104] of this chapter immediately following.

[102] Cocke J. Statistical Time Symmetry and Two-Time Boundary Conditions in Physics and Cosmology. Phys. Rev. 1967; **160**: 1165–1170. DOI: 10.1103/PhysRev.160.1165

[103] Schmidt H. Model of an oscillating cosmos which rejuvenates during contraction. J. Math. Phys. 1966; **7**: 494–509. DOI: 10.1063/1.1704949

[104] Davies PCW. Closed Time as an Explanation of the Black Body Background Radiation. Nature Physical Science. 1972; **240**: 3–5. DOI: 10.1103/physci240003a0

[105] Hartle J, Hertog T. Arrows of Time in the Bouncing Universes of the no-boundary quantum state. Phys. Rev. D. 2012; **85**: 13 pages. DOI: 10.1038/PhysRevD.85.103524

[106] Reference [5], Sect. 7.3.

[107] Tolman RC. Relativity, Thermodynamics, and Cosmology. Oxford, England: Oxford University Press; 1934. Unaltered and unabridged republication: New York: Dover; 1987, Chaps. IX–X, especially Sects. 130–131, and 169–175 (most especially Sects. 131 and 175).

[108] The Poincaré recurrence time is discussed in Ref. [5], Chap. 3, Sect. 5.2, pp. 131, 144, 164, 173–175, and 192–193, and Sect. 7.4. See also references cited therein.

[109] Reference [5], p. 103.

[110] Reference [2], p. 380 and Sects. 18.5–18.6.

[111] Reference [63]. Boltzmann-brain hypotheses and closely related topics are reviewed on pp. 3, 12–22, 29, 98–102, 193–195, and 205–211. See also relevant references cited therein.

[112] Carr B, Editor. Universe or Multiverse? Cambridge, U. K.: Cambridge University Press; 2007, p. 67.

[113] Reference [97], pp. 305–308 and 313–314.

[114] Reference [98], Sect. 4.2.4.

[115] Bousso R. Vacuum Structure and the Arrow of Time. Phys. Rev. D. 2012; **86**: 16 pages. DOI: 10.1103.PhysRevD.86.123509

[116] Garriga J, Vilenkin A. Watchers of the Multiverse. Journal of Cosmology and Astroparticle Physics. 2013; **05**: 037. DOI: 10.1088/1475-7516/2013/05/037

[117] Page DN. Is the Universe Decaying at an Astronomical Rate? Phys. Lett. B. 2008; **669**: 197–200. DOI: 10.1016/j.physletb.2008.039

[118] Susskind L. Fractal-Flows and Time's Arrow. arXiv:1203.6440v2 [hep-th] 7 Apr 2012. 25 pages. [Internet]. 2012. Available from: xxx.lanl.gov/abs/1203.6440v2 or arxiv.org/abs/1203.6440v2 [Accessed: 2016-05-03]

[119] Reference [1], Chap. 12, and pp. 135–136 and 164.

[120] Reference [97], pp. 140–141, 353–354, and 362–363.

[121] Reference [97], pp. 132–150 and 311–312.

[122] Reference [112]. See especially Chaps. 1, 2, 3, 5, 22, 23, and 25; most especially Chap. 2: Weinberg, S. Living in the Multiverse.

[123] Grant A. Time's Arrow: Maybe Gravity Shapes the Universe Into Two Opposing Futures. Science News. July 25, 2015; **188 (2)**: 15–18.

[124] Barbour J, Koslowski T, Flavio M. Identification of a Gravitational Arrow of Time. Phys. Rev. Lett. 2014; **113**: 118101 (5 pages).

[125] Reference [5], Sect. 4.6.

[126] Vaas R. Time After Time — The Big Bang Cosmology and the Arrows of Time. In Ref. [63], pp. 5–42. See especially pp. 8–9, including Figure 1 on p. 9.

[127] Reference [1], pp. 171–172 and Note 5 for Chap. 16 on p. 219; also, Refs. [24], [25], and [59–63] of this chapter.

[128] Dr. Roger Penrose. private communications, at the 27th Texas Symposium on Relativistic Astrophysics, held at the Fairmont Hotel in Dallas, Texas, December 8–13, 2013. [Internet]. 2013. Available from: nsm.utdallas.edu/texas2013/ [Accessed 2016-05-03]

[129] Reference [2], the last paragraph on p. 413.

[130] Reference [2], p. 416.

[131] Reference [15], pp. 747 and 756–757.

[132] Berry RS, Rice SA, Ross J. Physical Chemistry. 2nd ed. New York: Oxford University Press; 2000, pp. 476–479.

[133] Bachhuber C. Energy from the evaporation of water. Am. J. Phys. 1983; **51**: 259–264.

[134] Güémez J, Valiente B, Fiolhais C, Fiolhais M. Experiments with the drinking bird, Am J. Phys. 2003; **71**: 1257–1264.

[135] Temming M. Water, Water Everywhere. Sci. Am. 2015; **313 (3)**: 26.

[136] Reference [97], pp. 134–140, Chap. 12, and pp. 358–370. Concise summaries of Multiverses are provided in Table 6.1 on p. 139, Figure 12.2 on p. 322, and Figure 13.1 on p. 358.

[137] Tegmark M. The Multiverse Hierarchy (Chap. 7). In Ref. [112]. Carr B, Editor. Universe or Multiverse? Cambridge, U. K.: Cambridge University Press; 2007.

[138] Reference [97], pp. 220–226.

[139] Tegmark M. Sect. 7.4. In Ref. [112].

[140] Reference [97]. See especially Chaps. 6, 8, and 10–12, also pp. 358–370 (most especially Chaps. 10 and 12).

[141] Tegmark M. The Multiverse Hierarchy (Chap. 7). In Ref. [112]. See especially Sects. 7.4.4–7.6.

[142] Reference [98], Sect. 5.4.

[143] Reference [97], Chaps. 8 and 11, especially pp. 291–299.

[144] Tegmark M. pp. 116–120. In Ref. [112].

[145] Reference [98], Sects. 2.3, 4.2.4, and 5.3.

[146] Lindley D. Where Does the Weirdness Go?: Why Quantum Mechanics is Strange, But Not as Strange as You Think. New York: Basic Books; 1996, pp. 107–111 and the 2nd Note on p. 233.

[147] Reference [97], pp. 175–183 and Chap. 8.

[148] Reference [97], Chap. 8.

[149] Reference [146], Act III, also Notes for Act III on pp. 234–240.

[150] Reference [97], pp. 272–276 and 339–340.

[151] Reference [98], Sect. 4.2.

[152] Reference [97], pp. 392–393.

[153] Reference [97], p. 398.

[154] Reference [5], pp. 173–175.

[155] Reference [146], pp. 177–203, especially pp. 199–203; also the last 3 Notes on p. 237 (the 3rd of these Notes continuing on p. 238), and the 2 Notes on p. 240.

[156] Bohm D. Quantum Theory. Englewood Cliffs, N. J.: Prentice-Hall; 1951. Unaltered and unabridged republication: New York: Dover; 1989, Sect. 6.12 and Chap. 22 (especially Sects. 22.11–22.12).

[157] Reference [5], Sect. 6.3.

[158] Reference [15], Chaps. 29 and 30.

[159] Reference [97], Chaps. 7 and 8, especially Chap. 8.

[160] Reference [1], pp. 202–203 and Notes 6–9 for Chap. 19 on p. 222. See also the reference cited in Note 6.

[161] Reference [1], pp. 201–202 and Notes 2–6 for Chap. 19 on p. 222. See also references cited in Notes 3, 4, and 6.

[162] Reference [15], Sect. 34.9.

[163] Reference [2], Sect. 18.6.

[164] Aguirre A, Gratton S. Steady-state eternal inflation. Phys. Rev. D. 2002; **65**: 083507, 6 pages. DOI: 10.1103/PhysRevD.65.083507

[165] Aguirre A, Gratton S. Inflation without a beginning: A null boundary proposal. Phys. Rev. D. 2003; **67**: 083515, 16 pages. DOI: 10.1103/PhysRevD.67.083515

[166] Aguirre A. Eternal Inflation, past and future. arXiv:0712.0571v1 [hep-th] 4 Dec 2007: 38 pages. [Internet]. 2007. Available from: xxx.lanl.gov/abs/0712.0571v1 or arxiv.org/abs/0712.0571v1 [Accessed: 2016-05-03]

[167] Vilenkin A. Arrows of time and the beginning of the universe. Phys. Rev. D. 2013; **88**: 043516, 10 pages. DOI: 10.1103/PhysRevD.88.043516

[168] Mersini-Houghton L, Perry MJ. The end of eternal inflation. Class. Quantum Grav. 2014; **31**: 165005, 11 pages. DOI: 10.1088/0264-9381/31/16/165005

[169] Mersini-Houghton L, Perry MJ. Localization on the landscape and eternal inflation. Class. Quantum Grav. 2014; **31**: 215008, 17 pages. DOI: 10.1088/0264-9381/31/21/215008

[170] Reference [15], Sects. 28.4–28.5. See especially pp. 746–747 and 756–757.

[171] Reference [97], pp. 366–370.

[172] Tegmark M. How unitary cosmology generalizes thermodynamics and solves the inflationary entropy problem. Phys. Rev. D. 2012; **85**: 123517, 19 pages. DOI: 10.1103/PhysRevD.85.123517

[173] Carroll SM, Chen J. Spontaneous Inflation and the Origin of the Arrow of Time. arXiv:0410270v1 [hep-th] 27 Oct 2004: 36 pages. [Internet]. 2004. Available from: xxx.lanl.gov/abs/0712.0571v1 or arxiv.org/abs/0712.0571v1 [Accessed: 2016-05-03]

[174] Carroll SM. From Eternity to Here: The Quest for the Ultimate Theory of Time (Kindle Edition, Version 6). New York: Penguin; 2010. See especially Chaps. 15–16 and most especially Locations 6576–6846; also, Notes 291–295 at Locations 8218–8233.

[175] Davies P. Universes galore: where will it all end? (Chap. 28). In Ref. [112]. Carr B, Editor. Universe or Multiverse? Cambridge, U. K.: Cambridge University Press; 2007. See especially Sect. 28.3.2.

[176] Reference [98], Sect. 4.3.

[177] Barnes LA. The Fine-Tuning of the Universe for Intelligent Life. Publications of the Astronomical Society of Australia. 2012; **29**: 529–564. DOI: 10.1071/AS12015

[178] Stenger VJ. The Fallacy of Fine-Tuning: Why the Universe Is Not Designed for Us (Kindle Edition). Amherst, N. Y.: Prometheus Books; 2011.

[179] Stenger VJ. God and the Multiverse. Amherst, N. Y.: Prometheus Books; 2014. See especially Chap. 16.

[180] Stenger VJ. Defending The Fallacy of Fine-Tuning. arXiv:1202.4359v1 [physics.pop-ph] 28 Jan 2012: 12 pages. [Internet]. 2012. Available from: xxx.lanl.gov/abs/1202.4359v1 or arxiv.org/abs/1202.4359v1 [Accessed: 2016-05-03]

[181] See the Wikipedia article entitled "Abundance of the chemical elements." [Internet]. 2016. Available from: www.wikipedia.org [Accessed: 2016-05-03]

[182] Edis T, Boudry M. Beyond Physics? On the Prospects of Finding a Meaningful Oracle. Found. Sci. 2014; **19**: 403–422. DOI: 10.1007/s10699-014-9349-z

[183] Vidal C. The Beginning and the End: The Meaning of Life in a Cosmological Perspective. [Internet]. 2013. Available from: arXiv:1301.1648v2 [physics.gen-ph]. DOI: 10.1007/978-3-319-05062-1. [Accessed: 2016-05-03]

IntechOpen

IntechOpen