

The Asymmetry of Time and the Cellular World

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Abstract

This article discusses the arrow of time in macroscopic and microscopic processes. As the amount of energy involved in the microscopic processes is so small it is more difficult to argue that the entropy increase generates an arrow of time into the future, therefore the direction of time becomes confusing and undefined at the molecular and cellular level.

Keywords: cosmology; cell; entropy; time asymmetry

1 Introduction

The idea of time is very intuitive and easy to distinguish past from present or future. Plato said that time is the moving image of eternity, but later Newton discussed how a complete, true and mathematical. In the twenties of last century, Einstein came to regard as a mere illusion. This has been the subject of on going discussion for many philosophers and scientists.

The fundamental scientific theory that makes a preferred direction for time is of the second law of thermodynamics, which asserts that the entropy of the Universe increases as time flows forward. This explanation provides an orientation, an

arrow of time. Our perception of this would, therefore, be a direct consequence of the thermodynamic time arrow.

In a thermodynamically isolated system entropy tends to increase with time and this creates a definite orientation, an arrow of time, a time asymmetry to distinguish the past from the future, which corresponds with our own perception of time.

This is evident at the macroscopic level, however, on a microscopic scale, since the amount of energy involved in the process is so small, it is difficult to say that entropy is increasing, and therefore time is moving toward future rather than backward.

To explain the obvious asymmetry in the universe if the fundamental laws of physics are symmetric in time was always a problem. It usually responds to this first issue by observing that if the initial state of the universe would be a steady state, the universe will remain forever in that state, making it impossible to find any time-asymmetry. Thus I must solve two problems:

- i.- To explain why the universe began in a non-equilibrium (unstable, low-entropy) state, while call $t = 0$.
- ii.- To define, for the period $t > 0$, a Lyapunov variable, namely a variable that never decreases (e.g. entropy), an arrow of time, and also irreversible evolution equations, despite the fact that the main laws of physics are time-symmetric.

Let us comment these two problems:

i.- The set of irreversible processes that began in an unstable non-equilibrium state constitute a branch system [9], [3]. That is to say, every one of these processes began in a non-equilibrium state, which state was produced by a previous process of the set.

ii.- Once this is understood the origin of the initial unstable state of each irreversible process within the universe it is not difficult to obtain a growing entropy, in any subsystem within the universe. With this purpose we can consider that forces of stochastic nature penetrate from the exterior of each subsystem adding stochastic terms [7]. Alternatively, taking into account the enormous amount of information contained in the subsystem we can neglect some part of it [7], [12]. Thirdly, or can use more refined mathematical tools [1], [2]. With any one of these tools can solve this problem.

It remains only one problem: why the universe began in a unstable low-entropy state? If I exclude a miraculous act of creation we have only three scientific answer:

- i-The unstable initial state of the universe is a law of nature.
- ii-This state was produced by a fluctuation.
- iii-The expansion of the universe (coupled to the nuclear reactions in it) produces a decreasing of the (matter- radiation) entropy gap.

The first solution established is only one way to circumvent the problem. In fact, the probability of a fluctuation decreases with the number of particles in the system and the universe is considered the system with the largest number of particles. The third solution was sketched by Paul Davies in reference [3], only as

a qualitative explanation. The expansion of the universe is like an external agency (namely: external to the matter-radiation system of the universe) that produces a decreasing of its entropy gap, with respect to de maximal possible entropy, S_{\max} (and therefore an unstable state), not only at $t=0$ but in a long period of the universe evolution. We shall call this difference the entropy gap ΔS , so the actual entropy will be $S_{act} = S_{\max} + \Delta S$. In this essay I will try to give a quantitative structure to Davies solution using an oversimplified cosmological model, which, anyhow, yields a first rough numerical coincidence with observational data. But how is this in the microscopic world of the stem cells, tumor cells? Feng and Crooks [12] created a method to accurately measure the time asymmetry of the microscopic. In fact have found that, on a microscopic scale and for some intervals, entropy can actually decrease. And that while the general entropy increase on average, each time the experiment does not, that is, time is not always a clear direction.

This work aims at understanding the relation between time asymmetry and entropy, which would also be crucial for the development of future molecular studies and cellular.

2 The entropy gap

It is known that the expansion of the universe is isotropic and homogeneous, and a reversible process with constant entropy [11]. In this case the matter and the radiation of the universe are in a thermic equilibrium state $\rho^*(t)$ at any time t . As the radiation is the only important component, from the thermodynamical point of view, we can chose $\rho^*(t)$ as a black-body radiation state, i. e. $\rho^*(t)$ will be a diagonal matrix with main diagonal:

$$\rho_*(\omega) = ZT^{-3} \frac{1}{e^{\frac{\omega}{T}} - 1} \tag{1}$$

where T is the temperature, ω the energy, and Z a normalization constant ([6], eqs. (60.4) and (60.10)). The total entropy is:

$$S = \frac{16}{3} \sigma VT^3 \tag{2}$$

([8], eq. (60.13)) where σ is the Stefan-Boltzmann constant and V a commoving volume.

Let us consider an isotropic and homogeneous model of universe with radius (or scale) a . As $V \sim a^3$, and, from the conservation of the energy-momentum tensor and radiation state equation, we know that $T \sim a^{-1}$, is apparent that $S = const$.

Thus the irreversible nature of the universe evolution is not produced by the universe expansion, even if $\rho = \rho^*(t)$ has a slow time variation. Therefore, the main process that has an irreversible nature after decoupling time is the burning of unstable H in the stars (that produces He and, after a chain of nuclear reactions, Fe). This nuclear reaction process has certain mean life-time $t_{NR} = \gamma^{-1}$ and phenomenologically we can say the state of the universe, at time t , is:

$$\rho(t) = \rho_*(t) + \rho_1 e^{-\gamma t} + O[(\gamma t)^{-1}] \quad (3)$$

where ρ_1 is certain phenomenological coefficient constant in time, since all the time variation of nuclear reactions is embodied in the exponential law $e^{-\gamma t}$. Can foresee, also on phenomenological grounds, that ρ_1 must peak strongly around ω_1 the characteristic energy of the nuclear process. All these reasonable phenomenological facts can also be explained theoretically: Eq. 3 can be computed with the theory of paper [10] or with rigged Hilbert space theory [5]. It is explicitly proved that ρ_1 peaks strongly at the energy ω_1 . The normalization conditions at any time t yields:

$$tr \rho(t) = tr \rho_*(t) = 1, \dots, tr \rho_1 = 0 \quad (4)$$

The last equations show that ρ_1 is not a state but only the coefficients of a correction around the equilibrium state $\rho^*(t)$. It is explicitly proved in paper [8], that ρ_1 has a vanishing trace.

It is possible to calculate the entropy gap ΔS with respect to the equilibrium state $\rho^*(t)$ at any time t . It will be the conditional entropy of the state $\rho(t)$ with respect to the equilibrium state $\rho^*(t)$ [7]:

$$\Delta S = -tr[\rho \log(\rho_*^{-1} \rho)] \quad (5)$$

Using now eq. 3, and considering only times can be expanded the logarithm to obtain:

$$\Delta S \approx -e^{-\gamma t} tr(\rho_*^{-1} \rho_1^2) \quad (6)$$

which uses eq. (4). Then:

$$\Delta S \approx -Z^{-1}T^3 e^{-\gamma t} \text{tr}(e^{\frac{\omega}{T}} \rho_1^2) \quad (7)$$

where $e^{\frac{\omega}{T}}$ is a diagonal matrix with this function as diagonal. But as ρ_1 is peaked around ω_1 come to a definitive formula for entropy gap:

$$\Delta S \approx -CT^3 e^{-\gamma t} e^{\frac{\omega_1}{T}} \quad (8)$$

where C is a positive constant.

3 The evolution

It has been estimated of ΔS for times larger than decoupling time and therefore, as $a \sim t^{2/3}$ and $T \sim a^{-1}$:

$$T = T_0 \left(\frac{t_0}{t}\right)^{\frac{2}{3}} \quad (9)$$

where t_0 is the age of the universe and T_0 the present temperature. Then:

$$\Delta S \approx -C_1 e^{-\gamma t} t^{-2} e^{\frac{\omega_1 (t_0)^{\frac{2}{3}}}{t}} \quad (10)$$

where C_1 is a positive constant. The curve $\Delta S(t)$ it has a maximum at $t = t_{cr1}$ and a minimum at $t = t_{cr2}$. Let us compute these critical times. The time derivative of the entropy reads:

$$\dot{\Delta S} \approx \left[-\gamma - 2t^{-1} + \frac{2}{3} \frac{\omega_1}{t_0 T_0} \left(\frac{t_0}{t}\right)^{\frac{1}{3}} \right] \Delta S \quad (11)$$

This equation shows two antagonic effects. The universe expansion effect is embodied in the second and third terms in the square brackets an external agency to the matter-radiation system such that, if we neglect the second term, it tries to increase the entropy gap and, therefore, to take the system away from equilibrium (as we will see the second term is practically negligible). On the other hand, the nuclear reactions embodied in the y-term, try to convey the matter-radiation

system towards equilibrium. These effects becomes equal at the critical times t_{cr} such that:

$$\gamma t_0 + 2 \frac{t_0}{t_{cr}} = \frac{2}{3} \frac{\omega_1}{T_0} \left(\frac{t_0}{t_{cr}} \right)^{\frac{1}{3}} \quad (12)$$

For almost any reasonable numerical values this equation has two positive roots:

precisely:

i.- For the first root we can neglect the t_0 -term and is obtained:

$$t_{cr_2} \approx t_0 \left(3 \frac{T_0}{\omega_1} \right)^{\frac{3}{2}} \quad (13)$$

(this quantity, with minus sign, gives the third unphysical root).

ii.- For the second root can neglect the $2(t_0/t_{cr})$ -term, and be able to find:

$$t_{cr_2} \approx t_0 \left(\frac{2}{3} \frac{\omega_1}{T_0} \frac{T_{NR}}{T_0} \right)^3 \quad (14)$$

4 Numerical calculations

Have chosen the numerical values of four parameters: $\omega_i = T_{NR}$, $T_{NR} = \gamma^{-1}$, t_0 , and T_0 . T_{NR} and t_{NR} can be chosen between the following values:

$$\begin{aligned} T_{NR} &= 10^6 \text{..to..} 10^{80} K \\ t_{NR} &= 10^6 \text{..to..} 10^9 \text{.years} \end{aligned} \quad (15)$$

while for t_0 and T_0 we can Take:

$$\begin{aligned} t_0 &= 1.5 \times 10^{10} \text{ years} \\ T_0 &= 3^\circ K \end{aligned} \quad (16)$$

In order to obtain a reasonable result are chosen the lower bounds for T_{NR} and t_{NR} and is obtained for t_{cr_1} :

$$t_{cr_1} \approx 1.5 \times 10^3 \text{ .years} \tag{17}$$

So t_{cr_1} is smaller than the decoupling time and, it must not be considered since the physical processes before this time are different from those used in this model.

Also, should take into account the time only $t > t_{NR} = \gamma^{-1}$, in order to use eq. 6.

For t_{cr_2} is obtained:

$$t_{cr_2} \leq 10^4 t_0 \tag{18}$$

Thus:

-From t_{NR} to t_{cr_2} the expansion of the universe produces a decreasing of entropy gap, according to Paul Davies prediction. It probably produces also a growing order, and therefore the creation of structures like clusters, galaxies and stars [8].

-After t_{cr_2} there is an increase of entropy, a decreasing order and a spreading of the structures: stars energy is spread in the universe, which ends in a thermic equilibrium [4]. In fact, when $t \rightarrow \infty$ the entropy gap vanishes (see eq. 10) and the universe reaches a thermic equilibrium final state.

$t_{cr_2} \leq 10^4 t_0$ is the frontier between the two periods. Is the order of magnitude of t_{cr_2} a realistic one? In fact it is, since $10^4 t_0 \approx 1.5 \times 10^{14} \text{ years}$ after the big-bang all the stars will exhaust their fuel [4], so the border between the two periods most likely have this order of magnitude and must also be smaller than this number. This is precisely the result of our calculations.

But back to the molecular world, it may be associate this with the stem cells and tumor cells, seeing that the gap of entropy is close to zero or zero? Feng and Crooks [12] contributed to developing a measure of the time-asymmetry of recent single molecule RNA unfolding experiments. They define time asymmetry as the Jensen-Shannon divergence between trajectory probability distributions of an experiment and its time-reversed conjugate. Among other interesting properties, the length of time's arrow bounds the average dissipation and determines the difficulty of accurately estimating free energy differences in nonequilibrium experiments.

Continuing with the previous calculations but consistent with the body temperatures of animals, about 20 degrees Celsius, you can see that the equations are reduced almost naturally to zero entropy, and spread over time, reaching the level of Feng and Crook, producing the possibility that this occurs also

mentioned that the cells could become immortal because even cooperation could go back in time.

5 Conclusions

The intention is to ask whether the arrow of time might have something to do with cells as proposed at the molecular level, because if the reversal of the arrow of time is possible at the cellular level that could provide an alternative explanation to the mysteries of the tumor stem cells, because in them the sense of time is different, since they are awaiting orders to carry out their work in the different objectives.

It is not intended to give a conclusive scientific explanation on the subject, just looking to leave open the real possibility that the physical objects that are near zero entropy can even reverse the arrow of time, it would be important to study the possibility of immortality in some cells.

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