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Reflections on Second Law of Thermodynamics

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Several aspects of the Second Law of Thermodynamics are discussed.

1. Introduction

The Second Law of Thermodynamics is a theme for eternal reflections; it seems to be a most mysterious law of the Nature. I consider below several important points connected with entropy interpretation.

At the beginning of the 19-th century when the caloric theory was dominating one and the energy conservation law was not till discovered, the genial French engineer Sadi Carnot proposed the brilliant idea to compare a heat engine with a hydraulic one. The mechanical work of a heat engine is proportional to the *temperature difference* on its input is similar to the mechanical work of a hydraulic engine is proportional to the *height difference* on its input. One can deduce from that the famous relation for ideal heat engine efficiency: $\eta = (1 - T_2/T_1)$, where T_2 is the cooler temperature, T_1 is the heater temperature.

Departing from the ideas of Carnot and other researchers, Clausius introduced the entropy notion and stated the First and Second Laws of Thermodynamics:

1. The energy of the Universe remains a constant.
2. The entropy of the Universe tends to a maximum.

The First Law extends the mechanical energy features on the heat energy only. Meanwhile, the Second Laws seemed to be very mysterious as far as Boltzmann statistical meaning based on the matter corpuscular hypothesis appeared[1].

One usually thinks that a relaxation process (when the system entropy maximum is obtained) determines a so-called Arrow of Time. However, I believe that a previous stage has to take into account when initial disequilibrium is created by some way.

2. Is it possible to convert a heat into mechanical work without a loss?

After Carnot results the answer is clear due to the above expression of the efficiency, i.e., the Second Law[2]. However, I would like to discuss here the macroscopic difference between mechanical motion energy and the heat one. In fact, I mean the regular motion and chaotic walk that does not give any contribution to a mass transport. If we consider the molecules as simple balls, then two approaches are possible in order to convert a heat into mechanical work.

In the first case only average chaotic energy per one molecule is changed by an *external* way. In other words, when one extracts a heat from an engine, the average chaotic motion velocity is simply decreased. Of course, if the cooler temperature is more

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[1] In fact, the Boltzmann approach is not ideal, see **[Hitun, 1996]**.

[2] Note, the Second Law of Thermodynamics is implicitly based on the assumption that the heat is always transported from a warm body to a cool one. One often associates such the assumption with a diffusion process where a heat-transfer agent flow from the warm body is larger than inverse flow from the cool source. However, this assumption is correct only for a body having a *positive* heat capacity for which the temperature *decreases* while it returns a heat.

than absolute zero, then in fact a part of the source energy can only be extracted, as Carnot said.

However, one can try to act from *inside* of a system (for example, the "Maxwell demon" sorts the molecules having different velocities). If we operate with the large *macroscopic* balls (not with real molecules) then such the scheme can really work during some finite time period (since result will be obtained with some given precision). But for a gas containing the *real* molecules any measuring devices are build from the similar molecules or another elementary particles and consume (as it was shown) the same (or more) energy as is extracted from the heat-transfer agent.

3. Evolving thermodynamics systems

The investigation of thermodynamic processes was initiated by the using of the heat engines where a conversion of the heat into mechanical work (or vice verse) is executed. A thermodynamic process represents any change in a thermodynamic system that is connected with one (or more) its state parameter. Of course, such the systems exchange by an energy with another systems and thus are *open* in the thermodynamic sense. For this kind of systems it is reasonable to consider two types of flows of the heat and entropy: input and output ones. Remember, the heat dQ and entropy dS increments are connected between them by the relation dS= dQ/T, where T is the system temperature. Since we consider the open systems (see Fig. 1), then the difference between input and output entropy flows may be as negative as well as positive and zero.

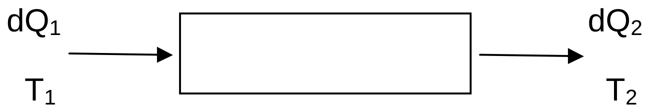

Figure 1. A thermodynamic system

The systems having constant or increasing entropy are well studied in the thermodynamics. Due to that we will not consider them. Instead of that we will consider the systems where the *negative* entropy accumulates. I would like two examples of such the systems.

Let us consider the system "Sun-Earth-Cosmos" as the first remarkable example. The Sun surface temperature that plays the role of "the heater" is near 6000 K (T_1), while effective temperature of the Cosmos ("the cooler") where the Earth reradiates the solar heat is less than 3 K (T_2). Note, this process is executed during billions years and the Earth's temperatures does not increase. In such open system the entropy of the Earth continuously *decreases* (because $dQ_1 = dQ_2$ and $T_2 < T_1$)[3].

What means the Earth entropy decreasing? It is clear, the essential regular differentiation of physical, chemical and biological structures happens, i.e., it leads to a progressive evolution of the Earth biosphere. I believe, the same processes having different rates happen on the other planets.

The second example may be yet more (and exclusively) important. Some time ago the excellent American physicist John Archibald Weeler (see **[Smolin, 1994]**) suggested that our Universe and other universes are black holes that irreversibly expand in Time. I independently (of course, later) came to the same idea (see **[Shulman, 2004, 2007]**). The striking but inevitable conclusion follows from such the

[3] Here the ratio (T_1/T_2) specifies the numeric entropy flow relation.

idea: the energy of our Universe does not remain constant; contrary, it irreversibly increases due to its absorption from outside.

On the other hand, some decades ago the astrophysicists revealed that galaxy cores contain supermassive black holes that total entropy is 20 orders more than another constituents of the Universe (see **[Egan and Lineweaver, 2009]**). The calculation shows that their surface temperature is practically equal to the absolute zero, so it is wittingly less than average temperature of the Universe. Hence, such the cores are ideal and extremely power heat absorbers.

Thus, if our Universe is a black hole in an *external world* and has the *internal* black holes, then it can be considered as a thermodynamic system that is "blown" by an energy regular flow, where the cooler temperature is much less than the heater one. So, such the system entropy is permanently *decreasing,* and we have to reject its "heat death" as observed data confirm.

4. Gravitating systems entropy

In the review **[Ivanov]** the entropy additivity problem is discussed[4]. The author of the review notes that such the feature is typical for the systems in which forces between its constituents are essential at the short distances. However, for a large astrophysical object where far gravitational forces dominate (for example, a cool interstar dust cloud), it is not so. Each particle senses all the system, not a separate neighbor. And if we will virtually divide the cloud on two parts then these ones will interact by all their volumes, not along the bound between them. Thus, in the large self-gravitating system the thermodynamic additivity is violated very much; such the system cannot be divided on several independent subsystems. Entropy of such the system is not an extensive quantity. These systems cannot be described using typical Boltzmann's thermodynamics.

Meanwhile, J. Bekenstein proposed the famous formula to calculate the black hole (BH) entropy:

$$S_{BH} = c^3A/4G\hbar,$$

where S_{BH} is the BH entropy, c is the velocity of light, A is the BH event horizon surface area, G is the gravity constant, ħ is the Planck constant.

Note, for an *external* observer BH is exactly similar to *2D* membrane (i.e., it has the same mechanical, electromagnetic and thermodynamic properties), but is specified by a topology different from this one of its environment. And now the entropy additivity is restored, but it is the *surface* additivity (we operate with a 2D-object), not the volume one.

In the cited review **[Ivanov] i**t is noted that the entropy calculation may be simplified using a new freedom degree set. For example, it is impossible to calculate a crystal entropy through the individual atoms behavior statistics; however, one easy solves this problem if he uses the atom collective oscillations (phonons) where there exists the high crystal symmetry. In the case of black hole the entropy additivity is really obtained using the similar approach: Bekenstein replaced the volume entropy by the surface one since black hole just represents 2D object for an external observer.

An attractive idea appears: can we find out an analogous approach for a "usual" gravity source (not black hole)? In the famous paper **[Verlinde, 2010]** its author suggested that gravity is secondary concept and origins from entropy. I show below, that the situation is opposite: well defined entropy corresponds inevitably to any massive (gravitating) body.

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[4]The review is devoted to a new approach to entropy calculation that was proposed by Brazilian scientist Constantino Tsallis (1988).

In fact, let a body having a mass create a *central symmetric* gravity field with a potential $\Phi(r) \sim 1/r$. As it is well known the field at the distance r from such the source is determined only by the part of mass that is concentrated *inside of* this sphere radius only. Like BH event horizon we can then formulate that *a field at a distance r is determined by equivalent surface gravity* $\sigma(r) \sim 1/r^2$*. Note, the same equivalent value of σ can correspond to a great configurations number of real mass distribution inside of the sphere*. The key fact is the central symmetry conservation. The new freedom degrees are spherical layers that one may virtually replace one by another.

In other words, an observer connected with a test particle has always a real uncertainty of the mass distribution, because the interaction between the central source and the particle simply is not physically able to provide more information about it. At a given mass value the uncertainty is depending on the distance between the test particle and the source center. As the gravitational field intensity can be expressed through the equal surface gravity, the entropy corresponding to the sphere surface is equal to the (dimensionless) sphere area.

One can formulate this in terms of thermodynamics. As it is known, a small increment of energy/work ((dW) may be written as the product of generalized force and increment of generalized coordinate. For example, it may be the product of a usual force (e.g., gravity) and displacement ($dW=F \cdot dx$), or the product of a (gas) pressure and a volume increment ($dW=p \cdot dV$). But it may also be the product of a temperature (the energy per the surface unit) and a surface increment ($dW=T \cdot dA$), so, the surface area can play role of entropy.

Let us consider (like Bekenstein) a situation when a test particle falls onto a gravitational field source. At a several time moment the particle will transverse a virtual sphere having some radius that surrounds the source (not black hole in our case). For another test particle outside of this sphere the source mass seems to be increasing due to the first test particle mass accounting. So, the amount of the mass distributions inside the sphere increases too. I.e., the first test particle brings its entropy into the sphere like a situation when a black hole absorbs a particle.

For the Swhwarzschild black hole the entropy is proportional to the event horizon area. The Verlinde's holographic horizon entropy is also proportional to its area, however, this leads to the fundamental problem which was noted by Verlinde himself: if the proportionality factor was the same, then the BH's entropy had to be *extremely much less* than a usual body's entropy, because its gravitational radius is much less! To eliminate this problem I propose to multiply this proportionality factor by the additional ratio (ρ/ρ_{cr}), where ρ is the actual body density, ρ_{cr} is the "critical" density of the collapsed body with the same mass. Thus, the proposed formula for arbitrary body (including a BH) entropy S is:

$$S = S_{BH} \cdot (\rho/\rho_{cr})$$

One can see the values of the factor (ρ/ρ_{cr}) for the different astrophysical objects n the Table 1. As it is clear, such the ratio effectively increases the body entropy while it approaches to the collapse state. In addition, it naturally takes into account the direct correlation between the entropy and the mass under imaginary sphere area A.

Note that the area A is proportional to the square of the sphere radius, while the density ρ is inversely proportional (at a given mass) to the radius cube. Hence, finally the entropy is inversely proportional to the radius, i. e., *it rises while the radius decreases*. We are coming to the remarkable result: the mutual attraction process of massive bodies *increases their total entropy*, i.e., corresponds to the natural time evolution due to the second law of thermodynamics.

Table 1

Ratio (ρ/ρ_{cr}) for different astrophysical objects

Object	Mass M (kg)	Radius R (m)	Gravitational radius R_G (m)	$(\rho/\rho_{cr}) = (R_G/R)^3$
Earth	$6\cdot10^{24}$	$6\cdot10^{6}$	10^{-2}	$\sim 10^{-26}$
Sun	$2\cdot10^{30}$	$7\cdot10^{8}$	$3\cdot10^{3}$	$\sim 10^{-16}$
Milky Way	$3\cdot10^{42}$	$\sim 10^{19}$	$\sim10^{15}$	$\sim 10^{-12}$
Universe	$\sim 10^{53}$	$\sim 10^{26}$	$\sim 10^{26}$	~ 1

One can come to the same result while considers the "energetic" aspect: a test particle attracts to a gravitational source and so minimizes the gravitational potentials difference between its current location and the source surface. When the test particle rotates with a constant velocity around the source, then it minimizes the algebraic sum of the gravitational energy and the kinematic one, due to that the rotation occurs at a stationary orbit.

The known "Bekenstein bound" (the universal entropy bound) allowed so far to estimate the massive body entropy using the entropy of BH having the same size. However this estimate is extremely high one. Our result replaces such the estimation by the exact relation.

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