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Is There a Relationship between Energy, Amount of Information and Temperature?

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Aims: To use the generally accepted formulas linking energy, temperature and information, and not requiring any additional restrictions, to introduce a *practical* numerical value of the energy of any specific object based on the amount of information and thermodynamic temperature.
Place and Duration of Study: Beer-Sheba, between January 2019 and July 2019.
Methodology: By combining the Landauer limit and Bekenstein's proof that the amount of information of any physical system must be finite, if the object space and its energy are finite, the values of energy-matter and energy, based on the amount of information, were calculated for various elements of nature. In addition, a formula is presented for the energy of the universe containing these two components.
Results: The energy content of an object depends not only on its mass and speed. The value of the additional independent component, due to the amount of information contained in the object, is caused by its size and the ambient temperature. This component has never been considered in the scientific literature. This means that energy is inextricably linked with both the space and the thermodynamic component of Nature.

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Conclusion: Using the generally accepted formulas linking energy, temperature and information and not requiring any additional restrictions, we have shown that it is possible to represent the energy of the universe on the basis of information theory.

Keywords: Amount of information; Bekenstein bound; dark matter; energy; $E=\gamma \bullet m \bullet c^2$; Landauer limit; university.

1. INTRODUCTION

Einstein's insights help physicists pose questions about the nature of space, time, temperature and information itself. First of all, we return to the three basic concepts that are of interest for further discussion.

1. Einstein proposed (he did not actually prove it, at least according to his own special relativity) the formula

$$E_{\mathrm{m}} = \mathrm{m} \cdot c^2 \quad (1)$$

where E_{m} is the total energy of the matter object under study. It exists in many forms and can be transferred from one system to another. The basic unit of measurement of energy is the joule (m^2 kg s^{-2}). Einstein discovered a source of energy where no one had experienced before. The source is hidden in the substance; m is the particle mass and measured in kg, and c is the speed of light in vacuum, c = 299,792,458 m s^{-1} [1]. Equation (1) expresses the equivalence of energy and mass, connected by a simple relation. Einstein supposed that *the areas of application of this formula cover both micro and macro space*. However, until now, scientists have not succeeded in developing a unified field theory covering both the macro and micro worlds in physics.

2. In turn, the concept of temperature is a statistically formed thermodynamic value determined by the level of the internal energy of the body, consisting of a large number of particles. Applied to a very small object, the concept of temperature does not make sense. So, temperature is not a fundamental force, but a phenomenon resulting from the motion of particles.

At the same time, the combination of thermodynamics and Einstein's theory is a very active discussion. However, even if the assumption of temperature invariance holds for a non-inertial observer outside the system, this does not mean that the temperature is invariant if the observed system accelerates and/or the system is exposed to a strong gravitational field [2].

Perhaps scientists achieve the greatest success when they combine two or more seemingly incompatible concepts or theories. Shortly after Einstein published the special theory of relativity, the question naturally arose about the applicability of the concept of temperature to a moving reference system and the influence of relativity on its thermodynamic properties. Numerous theories about the effect of motion on temperature have been proposed after his publication, but none of them has been confirmed or disproved by experiment.

3. The role of information in understanding the fundamental relationship between entropy and energy has been confirmed by numerous works presented in theoretical physics in recent decades. The concept of the amount of information was successfully used to explain the emerging complexity of the universe in one of the fundamental studies in this area [3]. Bekenstein proved that the amount of information Y_{b} of any physical system must be finite if the space of an object and its energy are finite, and it is enough to describe the physical system down to the quantum level:

$$Y_{\mathrm{b}} \leq (2 \cdot \pi \cdot R \cdot E^*)/(\hbar \cdot c \cdot \ln 2), \quad (2)$$

where Y_{b} is an amount of information expressed in the number of bits contained in the quantum states of the chosen object sphere. The ln2 factor (approximately 0.693149) comes from defining the information as the natural logarithm of the number of quantum states, R is the radius of an object sphere that can enclose the given system, E^* is the total mass–energy, including rest masses, $\hbar$ is the reduced Planck constant, $\hbar$ = $1.054572 \cdot 10^{-34}$ m^2 kg s^{-1} [4]. It was clearly shown that evaluation takes place in wide classes of equilibrium systems [5].

Brillouin [6] suggested viewing information and physical entropy on an equal basis. This idea (exchange of energy and information) found its realization in further developments made by

Landauer [7]. He proved that a logically irreversible process reduces the degree of freedom of the system, and therefore entropy, and hence it must dissipate energy in the environment, therefore erasing information in memory entails an increase in entropy in the environment [8]. This statement was confirmed experimentally [9,10].

The number of scientists in the field of physics, astronomy and quantum mechanics has grown over the past three decades, perhaps not according to Moore's law, but at a very fast pace. All of them must confirm their scientific status. In this regard, there are many articles explaining some of the tantalizing hints published in any article. However, the results of research, for the most part, are far from the possibilities of their practical verification.

The possible unification of Einstein's theory, the concept of temperature and the amount of information is certainly important for modern physics and may have significant implications for science. The purpose of this work is to use the generally accepted formulas linking energy, temperature and information, and not requiring any additional restrictions, to introduce a *practical* numerical value of the energy of any specific object based on the amount of information Υ and thermodynamic temperature θ.

2. A SHORT REVIEW OF PUBLICATIONS

Here, without pretending to be complete, we describe some of the studies that in one way or another combine the three declared quantities. The compressed list of presented studies does not reflect the author's unwillingness to carefully analyze numerous articles on this topic. This is due to two reasons. On the one hand, there are many articles in which there are no criteria to check whether a scientist is right or not, in combination with the statement about the scientific nature of his ideas. On the other hand, from the point of view of the author, who is a staunch practitioner, there is a shortage of publications containing effective practical results with accurate numerical calculations and conclusions relating to the topic of this study.

Motivated by Bekenstein's argument [3] that the entropy of a black hole is proportional to the area of its horizon, in [11] Susskind advanced a postulate on the applicability of this idea to any point in space, calling it a holographic principle. This principle was based on the thermodynamics of a black hole, which suggests that the maximum entropy in any region scales with the square of the radius, and not in a cube, as one would expect. The name is associated with the analogy with holograms, when a two-dimensional film contains all the information necessary to recreate a three-dimensional image. In other words, an image of an object of higher dimension can be obtained from holograms having a lower dimension.

In [12–14] an original solution was suggested for calculating the dark energy of the cosmos. According to El Naschie, an exact ratio of the energy and mass of quantum gravity were found, predicting the missing hypothetical dark energy. Using 10 different theories to test his assumptions, the author substantiated the presented calculations, which he claimed are consistent with *the Wilkinson Microwave Anisotropy Probe* and measurements of supernovae. For these purposes, the author applied concepts and tools of fractal geometry, instead of "differential equations and Lagrangian dictionaries." One of the main achieved results declares that Einstein's equation must be modified in a scaled form

$$E_{\mathrm{m}} = \gamma \cdot m \cdot c^2 \quad (3)$$

$$\gamma = 1/21.65934694 \quad (4)$$

These results were confirmed in [15].

In a developed and published original article [16], relating to this topic, Verlinde, using the minimum number of assumptions, put forward the thesis that the central concept necessary to explain gravity is the amount of information related to the substance and its location, and is measured in terms of entropy. Changes in entropy with the movement of a substance lead to an entropic force that takes the form of gravity. The main assumption was that the information associated with a part of the space is subject to the holographic principle [11,17]. It was presented that Newton's laws can be derived by using only the concepts of energy, entropy and temperature, and the energy equivalent to matter is distributed evenly over the degrees of freedom and leads to the concept of temperature. It was shown that the product of temperature and the change in entropy as a result of the displacement of matter is equal to the work done by the gravitational force. Thus, the law of Newton appears surprisingly simple. In contrast to many scientific studies, the achievement of this article is that Verlinde presented a theory in which gravity is no longer a fundamental force, but rather an effect of entropy.

In [18], Chivukula carefully analyzed the advantages and disadvantages of Verlinde's idea. Having taken Verlinde's point of view on the nature of gravity, the author raised several questions that need to be answered, including: is entropy connected with extensive information? Can string theory match entropic gravity? and so on. After a careful analysis of Verlinde's assumptions, the author argued that there is still no accurate evidence that gravity is really an entropic force and in which directions progress should develop. This is unclear because Verlinde's proposal did not immediately solve the problems that physicists had previously had.

In [19], Alfonso-Faus showed that a bit of information is equivalent to a minimum energy quantum. It was defined in terms of the size of the universe R. Therefore, the temperature T follows the well-known cosmological relation $T \propto 1/R$. The author also suggested that there is a large reservoir with a constant energy density as a Bose condensate cosmic background. This background of pure information consists of a large number of quanta in a state of minimum energy.

This explains the expansion of the universe as Maxwell's demon transforming information into energy. In addition, a formula was obtained for calculating a quantum of gravitational potential energy (the lowest quantum energy level) that can exist, 10^{-52} m^2 kg s^{-2}, depending only on Planck's constant, the speed of light and the Hubble parameter, and which corresponds to data published in [20].

Summing up, it should be noted that all sorts of theories and mathematical tools, however useful they are, do not necessarily dictate exactly how we should perceive the fundamental nature of reality. There is no theory that would not contradict any experiment. Therefore, there is a dilemma about the validity of a particular theory. What is more important: its subsequent confirmation or prediction of a new effect? On the one hand, the theorist can choose a rationale so that the theory will explain any known experimental facts. On the other hand, before conducting the tests, the experimenter already knows the theoretical result. Therefore, it is obviously very difficult to stop the search for observation errors if this result fails. At the same time, the author believes that our theories can be verified only through observations.

The mentioned works fall into the category of those that refute long-accepted theories that have become part of the standard physical worldview. Only subsequent new concepts and experiments will allow finding out who is right.

3. RESULTS AND DISCUSSION

The Landauer principle arises: any logically irreversible manipulation of information, such as erasing bits, must be accompanied by a corresponding increase in the entropy of the information processing device or its environment [7]. Consequently, there is the minimum possible amount of energy E_L needed to erase one bit of information, the so-called "Landauer limit":

$$E_L = k \cdot \theta \cdot \ln 2, \tag{5}$$

where θ is the temperature in Kelvins of the environment, k is the Boltzmann constant, k = $1.380649 \cdot 10^{-23}$ m^2 kg/(s^{-2} K^{-1}) [4]

Taking into account (5), the informational limit Y_b (2) may be reformulated as

$$Y_E \leq Y_b \cdot E_L = (2 \cdot \pi \cdot R \cdot E^* \cdot k \cdot \theta)/(\hbar \cdot c), \tag{6}$$

where Y_E is energy contained in a sphere with radius R in terms of ordinary energy (m^2 kg s^{-2}), E* is the total mass–energy of the observed sphere.

Using mass–energy equivalence (1), one can get the following

$$Y_E \leq (2 \cdot \pi \cdot R \cdot m^* \cdot k \cdot \theta \cdot c)/\hbar = 2.4661 \cdot 10^{20} \cdot R \cdot m^* \cdot \theta, \tag{7}$$

where R is the radius of the sphere that can cover this system, m* is the mass arising in that part of the space which is surrounded by the sphere, $\hbar$ is the reduced Planck constant, $\hbar$ = $1.054572 \cdot 10^{-34}$ m^2 kg s^{-1}.

The physical content of Y_E is that its value is determined by the amount of information contained in the object under study. Table 1, in accordance with Equations (1) and (7), presents the approximate values of E_m and Y_E of some elements of Nature with different R, m and θ. These values can be checked in a very short time using a simple and accurate calculation.

Table 1. The energy caused by matter and amount of information

Variable	Dimension	Proton	Water molecule	Red blood cell	Carat	Human head	Earth	Sun
R	m	$8.41\cdot10^{-16}$	$2.8\cdot10^{-10}$	$7.00\cdot10^{-6}$	$3.0\cdot10^{-3}$	$6.7\cdot10^{-2}$	$6.37\cdot10^{6}$	$6.96\cdot10^{8}$
θ	K	1	273	309	300	309	287	5,778
m	kg	$1.67\cdot10^{-27}$	$3.00\cdot10^{-26}$	$2.90\cdot10^{-14}$	$2.00\cdot10^{-4}$	5.00	$6.0\cdot10^{24}$	$2.0\cdot10^{30}$
E_m	kg m^2 s^{-2}	75.6	$2.52\cdot10^{7}$	$6.29\cdot10^{11}$	$2.70\cdot10^{14}$	$6.0\cdot10^{15}$	$5.7\cdot10^{23}$	$6.3\cdot10^{25}$
γ_E	kg m^2 s^{-2}	$3.46\cdot10^{-22}$	$5.66\cdot10^{-13}$	$1.55\cdot10^{4}$	$4.44\cdot10^{16}$	$2.55\cdot10^{22}$	$2.7\cdot10^{54}$	$2.0\cdot10^{63}$

It is obvious that for micro-objects the energy caused by matter prevails over energy due to information. However, for macro-objects, the situation is completely the opposite. It should be noted that the presented results were obtained using three quantities recognized as constant and independent of time: k, $\hbar$ and c.

Of particular interest is the calculation of the ratio between the energy corresponding to ordinary matter in the universe, and the energy due to the amount of information embedded in a spherical universe with a radius of R_u. Because the boundary of the visible cosmic horizon is unknown, R_u is the approximate distance to the most distant objects that can be seen from Earth. From the everyday point of view, what we do not see does not mean that there is nothing beyond the horizon.

Scientific calculations show that the age of the universe, T_u, is about $4.308595 \cdot 10^{17}$ s [21]. Then, the imaginary spherical shell of the universe has a radius:

$$R_u = T_u \cdot c = 1.291684 \cdot 10^{26} \text{ m}. \quad (8)$$

Taking into account (1), the estimated energy E_{mu} corresponding to the ordinary matter of the observable universe equals

$$E_{mu} = (4/3) \cdot \rho \cdot \pi \cdot (R_u)^3 \cdot c^2 = 8 \cdot 10^{69} \text{ kg m}^2 \text{ s}^{-2}, \quad (9)$$

where ρ is the mass density of the universe, $\rho = 9.9 \cdot 10^{-27}$ kg m^{-3} [22], π = 3.141593.

In turn, based on measurements of cosmic microwave background (CMB) radiation, the average temperature of the universe today is approximately [23]:

$$\theta = 2.73 \text{ K}. \quad (10)$$

According to (7), (8) and (10), the estimated information-based energy of the observable universe Y_{Eu} equals

$$Y_{Eu} \le 2.4661 \cdot 10^{20} \cdot R_u \cdot (4/3) \cdot \rho \cdot \pi \cdot (R_u)^3 \cdot \theta \approx \quad (11)$$
$$\approx 7.8 \cdot 10^{98} \text{ (kg m}^2 \text{ s}^{-2})$$

Comparing Equations (9) and (11), everyone can be convinced that information-based energy prevails over the energy of matter in the modern universe. Thus, information, the amount of which physicists usually identify with entropy, may be more general when used to explain the emerging complexity of the universe. If this statement is true, then the question arises, how can we modify equation (1)? Considering (1) and (11), and taking into account that energy is an additive quantity, we can write the following equation

$$E_t = E_m + Y_E = E_m (1 + (2 \cdot \pi \cdot R \cdot k \cdot \theta)/(\hbar \cdot c)) = \quad (12)$$
$$= m \cdot c^2 \cdot (1 + 2{,}744 \cdot R \cdot \theta) = \beta \cdot m \cdot c^2,$$

$$\beta = (1 + 2{,}744 \cdot R \cdot \theta), \quad (13)$$

where E_t is the total energy of the object under study at ambient temperature θ, including energy associated with the mass of the object, and energy due to information that is enclosed in a sphere of diameter R, β is the coefficient of proportionality.

It must be mentioned that equation (12) was derived under the following assumptions: 1. energy is an additive quantity; 2. $E_m = E^*$; 3. $m = m^*$; 4. k, $\hbar$ and c are time-constant quantities; 5. the mass of the object m corresponds to its radius R; 6. gravitational constant is not represented in Equation (12); 7. Equations (1) and (4) are valid at the moment. In addition, equation (12) is derived without using the complex mathematical apparatus of quantum electrodynamics and the fractal geometry. Its reasoning is simple and obvious. If all these assumptions are correct, then the following conclusions are true.

Does the energy content of an object depend only on its mass and speed? Judging by equation (12), the answer should be negative. The unconditional component is the energy associated with the mass of the body, moving with a certain speed. However, the value of the additional independent component in (13), due to the amount of information contained in the object, is calculated taking into account its size (R) and the ambient temperature θ. This component has never been considered in the scientific literature. At the same time, starting with Umov [24] and up to the present time [25], attempts are being made to change equation (1), including the proportionality coefficient β, which varies in different limits.

From Equation (12) it follows that energy is inextricably intertwined with both the space (R) and the thermodynamic component of Nature (θ). Such an assertion is a complex concept to wrap our minds around. But it starts to make sense if we think about the true meaning of the expression "amount of information." Any moving object is not an ideal point in mathematical space, but a real body with nonzero dimensions, and contains a nonzero amount of information. Moreover, regardless of the speed of the object, small or close to the speed of light, it constantly has a structure inherent only in this object and determines the amount of information contained in it. The first component in equation (12) dominates at small distances but is very weak at large scales. In other words, the second energy component in Equation (13) begins to manifest itself at a level of 10^{-3} m and dominates at cosmological scales. That is why this component must be taken into account when explaining large-scale gravitational phenomena.

If the energy of an object depends not only on its mass and speed but also on the geometric dimensions and temperature of the medium in which it moves, then the existing principles of interaction between two or more bodies should be revised. Inexplicable, but true. Then, the famous mental experiment of Einstein about a person falling from a building, or Galileo's experiments with balls require new thinking. At the same time, so far there is an obstacle for understanding these experiments due to the accuracy of the gravitational constant: its relative standard uncertainty is $4.7 \cdot 10^{-5}$, according to the CODATA method [1]. This is a relatively large uncertainty compared with the uncertainty of other fundamental constants [26]. In addition, the results obtained are still not very consistent with each other. This gives reason to suspect hidden systematic uncertainties in some experiments [27]. A possible reasonable explanation for the inconsistency of the gravitational constant measurements is that some unknown physics still exists [28].

4. CONCLUSIONS

Equation (12), obtained on the basis of the theory of information and the Landauer principle, clearly visualizes the relationship of the energy of a physical object not only with its own mass, but also with its geometric size and the temperature of the environment surrounding it.

The presence of equation (12) with all the above considerations raises a simple question: is there a way to describe physical reality without considering black matter and energy, but only using the concept of information? Of course, no one gives up on $E = m \cdot c^2$ and the general theory of relativity in the near future because giving up on it means for many physicists giving up on the grandiose theoretical and experimental results achieved over the past 100 years. At the same time, some scientists feel the need to make some additions to this theory because of the recognition of the amount of information as a necessary element for a more accurate description of the surrounding nature.

Given the considerable mathematical complexity of the problem, the presented results, from a theoretical point of view, look unexpectedly simple. These results have a huge advantage in that dark matter is not required for calculations. Thus, the principle of Occam's razor is fulfilled, according to which, with all factors being equal, solving the problem is the simplest.

The difference compared to the existing theories of dark energy and matter is that the proposed approach does this with the widespread and used information theory and the amount of information as the most basic building block of reality. Einstein connected two concepts (energy and mass) together with the simplest and most well-known formula, which must be corrected if we want to understand Nature on a more fundamental level. The results of this article suggest that energy, thanks to information, plays a decisive role on a cosmological scale. This should have important implications for many areas in which energy and temperature play an important role, in particular in explaining the missing visible energy in the universe.

Using generally accepted formulas that relate energy, temperature and information and do not require any additional restrictions, we have shown that it is possible to represent the energy of the universe on the basis of information theory. This, in turn, allows us to explain large-scale gravitational phenomena, such as the movement of galaxies: the outer regions of galaxies rotate as fast as around their galactic centers. In this case, "cementitious mortar" is information (bits). This hypothesis was first put forward by Eric Verlinde [16].

ETHICAL ISSUES

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4. The manuscript contains nothing obscene, indecent, objectionable or libelous.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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