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# DEFINITION OF TIME: FROM THE SECOND TO CONSTRUCTAL LAW

UMBERTO LUCIA[a*], GIULIA GRISOLIA[b]

[a] Dipartimento Energia "Galileo Ferraris" Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy, umberto.lucia@polito.it

[b] Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy, giulia.grisolia@polito.it

*Correspondence: umberto.lucia@polito.it; Tel. +39 011 090 4558

One of the open problems in Physics is the analytical definition of time. This paper addresses a possible answer to this topic by proposing an analytical definition of time obtained by the Second Law of Thermodynamics and the Constructal Law approach.

**Keywords:** Constructal law; Quantum thermodynamics; Definition of time**.**

## 1. **INTRODUCTION**

The definition of time represents one of the open problems in physics. In Galilei's approach to motion, time represents an absolute and fundamental quantity [1], while Isaac Newton considers time as only a mathematical entity [2], without any real or physical essence; simultaneity and durations of phenomena are absolute [3]. On the contrary, Albert Einstein derived the concept of time from the postulate of invariance of the speed of light [4], with the consequence that duration becomes a quantity dependent on the observer (local quantity [5]). Moreover, Einstein introduced the concept of the isoentropic Universe [6], but understanding entropy in the context of the Universe is crucial for comprehending its evolution. Indeed, as the Universe expands, its energy and matter distributions undergo transformations that lead to changes in entropy. In all these approaches, time is used and defined in an operative way based on the concept of duration. Still, its analytical definition was not explicitly introduced until 2009, when an analytical mechanical approach was suggested [7], which, however, does not consider the energy conservation of all its components, particularly irreversibility.

In this paper, following Barbour's idea of an analytical approach, we propose a definition of time, not referring to Lagrangian mechanics as Barbour did, but starting from the Second Law of thermodynamics and evaluating each term by using the Constructal Law.

## 2. **MATERIALS AND METHODS**

We consider the Second Law of Thermodynamics:

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$$\frac{dS}{dt} = \frac{\dot{Q}}{T} + \dot{S}_g, \dots, \tag{1}$$

where $S$ is the entropy [J K$^{-1}$], $Q$ is the heat power [W], $T$ is the temperature [K], $\dot{S}_g = dS_g/dt$ is the entropy generation rate [W K$^{-1}$], and $t$ is the time [s]. Considering our Universe in a stationary expansion [5] $dS/dt = 0$, so it follows:

Now, we consider a Hydrogen-like atom in interaction with an electromagnetic wave. The electromagnetic wave is a flow of photons. They income into the atoms and outcomes from them. At the atomic level, the photons can be absorbed by the atomic or molecule electrons, and an electronic energy transition occurs between energy levels of two atomic stationary states. Then, the photons can be also emitted by the excited electrons, when they jump down into the energy level of the original stationary state. Apparently, there are no changes in the atom energy, but only in the electronic transition. But, on the contrary, there exists a change in the kinetic energy of the centre of mass of the atom, but its amount is negligible in relation to the energy change in electronic transition, and its time of occurrence ($10^{-13}$ s) is greater than the time of electronic transition ($10^{-15}$ s). However, its contribution to the energy balance becomes relevant when we consider a great number of interactions as it happens in macroscopic systems, as shown by Condon [8]. In our analysis of a Hydrogen-like atom, of atomic number Z, in interaction with an external electromagnetic wave (a photon), we consider the apparent atomic radius, $s_1r_n = 4\pi\varepsilon_0\hbar^2n^2/m_eZe^2$ where $\varepsilon_0$ is the electric permittivity, $\hbar$ is the reduced Plack constant, $m_e$ is the mass of the electron, $e$ is the elementary charge, $n$ = 1, 2, 3, ..., is the principal quantum number, always integer, and the energy of the atomic level, $E_n = m_eZ^2e^4/32\pi^2\varepsilon_0^2\hbar^2n^2$. The atomic electron absorbs the incoming photon when its frequency, $\nu$, is the resonant frequency, required by the transition between the initial $E_i$ and final $E_f$ energy levels, corresponding to the quantized energy $\nu = \left(E_f - E_i\right)/h$, where $h$ is the Planck's constant. The emission of this photon results in the reverse process. In this approach, the atom has a *finite size*, and the interaction occurs in a *finite time*. Constructal Law evaluated the energy footprint of this process in Ref. [9–12]:

$$E_{ftp} = \Delta(h\nu) = -\frac{m_e}{M}h\nu. \tag{3}$$

The electromagnetic inflow power is well known from Electromagnetism:

$$\dot{Q} = \frac{A}{2}\varepsilon_0 cE_{el}^2 + \frac{A}{2\mu_0}cB_m^2, \dots \tag{4}$$

where $E_{el}$ is the electric field and $B_m$ is the magnetic field, $c$ is the velocity of light. Consequently, time results the mean value of the following relation:

$$\tau = \frac{T}{\frac{A}{2}\varepsilon_0 cE_{el}^2 + \frac{A}{2\mu_0}cB_m^2}\frac{m_e}{M}h\nu, \dots, \tag{5}$$

with respect to all the local possible interactions.

## 3. **RESULTS**

We have introduced an analytical definition of time which emerges from the Second Law of Thermodynamics. Time results in the footprint of irreversibility from all the possible electromagnetic interactions, as Einstein conjectured. The footprint of atomic irreversibility has been evaluated by using a Constructal Law approach, considering the atom as a finite-size system.

## 4. **DISCUSSION AND CONCLUSIONS**

The result obtained satisfies all the requests from physics; indeed, time is a local quantity, it can be measured in any laboratory, and results strictly related to the evolution of the Universe, in agreement with the General Theory of Relativity [13–18]. Last, the analytical results allow us to obtain duration, $\tau = t - t_0$, and by setting $t_0 = 0$, we can obtain the definition of time.

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