

The cut of time

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Abstract

After a short review on the use of time in various branches of physics, I suggest to change the interpretation of time, from a duration to a cut. A reassessment of terminology is also required to avoid meaning traps. I also address the problem of estimating the energy needed by a physical object to shift in time without any other interaction or motion, that is, only to exist.

Keywords: physics of time – classical physics – quantum mechanics – relativity – quantum gravity.

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“What is time?” – the error is already contained in the question, as if the question were: of what, of what material, is time made? As one might say – of what is this fine dress made? (Ludwig Wittgenstein [18])

1 Introduction

Time is intrinsically different from space, but it has been often spatialized or, more often, neglected. The difference should be apparent at the very moment one wants to measure it. If one measures the size of an object, he takes a ruler, puts it on one side of the object, and reads the numbers on it. This is not possible to measure time. There is no ruler between now and

then, yesterday and today. One can only make the hypothesis that time flows with constant and uniform speed, so to use cyclic motion as ruler for time. A pendulum, a mechanical clock, the heart rate, repeating one word or one number (e.g. 1001, 1002, 1003,...), an atomic clock... In addition, the cyclic motion also requires the assumption that the starting and ending points of the cycle are the same, but this would require the time reversibility, which in turn is not possible.

The constant and uniform time hypothesis was never verified. On the opposite, the development of devices based on relativity (e.g. Global Positioning Systems, GPS) clearly showed that the rhythm of time is not constant. As known from almost all textbooks on this topic (e.g. [3]), according to special relativity, satellite clocks are slower than those on ground by $\sim 3.7 \mu\text{s}$, because the former have an orbital speed of $\sim 4 \text{ km/s}$. Also general relativity implies a different rhythm: as satellites are distant $\sim 20000 \text{ km}$ from the Earth, the weaker gravitational field makes clocks to run faster of $\sim 22.5 \mu\text{s}$. The net correction to be applied to GPS devices is $+3.7 - 22.5 = 18.8 \mu\text{s}$ (per orbit). As one microsecond is equal to about three hundreds metres on the ground, such an illusory small drift in the rhythm translates into an error on the ground of $\sim 5.6 \text{ km}$.

The constant and uniform time hypothesis was born with classical physics, where dealing with macroscopic objects implied negligible perturbations, making it possible to neglect time or to consider it as a space dimension. Later, relativity and quantum mechanics made it impossible to neglect time. However, it remained the spatialization, the reference to the duration, particularly in relativity, where time is often considered as the fourth dimension. Aim of the present essay is to emphasise the role of time in physics and to propose a different interpretation. After a short review on how time is taken, or not taken, into account in some branches of physics (more examples and details can be found in [9]), I will show that thinking at time as a cut could open interesting questions and remove some paradoxes. It is worth noting that I am just proposing to recover the original meaning of time. The Italian word *tempo* derives from Latin *tempus*, which in turn come from Greek *tem-nô*: to divide. The English word *time* has a different etymology, coming from nordic languages, but is anyway linked to the proto-indo-european root *da-*, which means again to divide¹. Therefore, time as a cut is just a recovering

¹All the etymological information used in this essay have been taken from <http://www.etimo.it/> for Italian words and from <https://www.etymonline.com/> for English words.

of the original meaning of time.

2 Classical physics

It is often written and said that basic physics laws are not affected by the direction of time². As it is possible to move in space toward left or right, up or down, it should be possible to move in time forward and backward (reversibility). Laws of physics do not change if one substitutes t with $-t$. This means that time is spatialised, nothing else than one more spatial dimension. However, as already noted by Wittgenstein [18], one could walk along one direction and, then, walk backward exactly on his own footsteps, but this does not mean to go backward in time. Therefore, the simple substitution of t with $-t$ is not equivalent to a spatial inversion ($x \rightarrow -x$).

A classical example is the linear harmonic oscillator, whose general solution is $x(t) = A \sin \omega t + B \cos \omega t$. This is a periodic oscillation independent on time sign: it is the same if one substitutes t with $-t$. This equation is also the basis for the isochronous pendulum. However, this is just an ideal case. If one adds friction, this extra term means that the general solution must be convolved with an exponential $e^{-\rho t}$ (ρ being a friction term): the result is a damped oscillation and a clear direction of time. If one wants to keep constant the motion, then it is necessary to add energy to the device (old mechanical clocks needed to be charged each day). If one wants to invert time, then it is also necessary to reverse the energy dissipation due to the friction. Damped oscillations should become amplified. Obviously, this cannot happen, as it would imply the generation of energy from nothing.

The same concept can be applied to many particles (thermodynamics): whatever is the starting distribution of particles, after a while it becomes a Maxwell-Boltzmann distribution and the entropy increases (in absence of external energy input). In the ideal case, the time direction due to the increase of entropy is a purely probabilistic matter and, as a matter of principle, it might be reversed, although the expected time for a spontaneous inversion, named after Poincaré, is quite large. For an Avogadro number of particles, the Poincaré time has been estimated to be $10^{10^{23}}$ s [12]. However, again, it is worth reminding that the above condition is valid in an ideal case (for example, the container of the gas must have rigid walls, particles must be

²See, for example, Sean Carroll in a recent interview by K. Becker at <https://fqxi.org/community/articles/display/236>.

hard spheres,...). The addition of reality elements, i.e. energy dissipation, enforces the direction of time.

To summarise, in classical physics, time reversibility is only an ideal case. As one considers energy dissipation, then it is evident a one-way direction time.

3 Quantum physics

In classical physics, the state of a particle is defined when its position $x(t)$ and momentum $p(t)$ are known at a certain time. These quantities should be measured at the same time, but, obviously, this is not possible. Again, we are facing an ideal case. It is taken for granted that the measurements made in two consecutive close times, either $x(t)$ and $p(t + \delta t)$, or $x(t + \delta t)$ and $p(t)$, could be considered as done at the same time, because the perturbations on the measured quantities are negligible. Time can be neglected. Therefore, $x(t) \sim x(t + \delta t)$ and $p(t) \sim p(t + \delta t)$, so that it is possible to define the state of a particle via the conjugated variables $x(t), p(t)$.

As known, this is no more possible in quantum mechanics, because of the principle of indeterminacy. Perturbations are no more negligible, which mean that $x(t) \neq x(t + \delta t)$ and $p(t) \neq p(t + \delta t)$. Quantum mechanics forces us to take time into account. There is a *before* and an *after* the measurement. This also means that measurements cannot be repeated, as it could seem in classical physics on first approximation. One can prepare an ensemble of particles all in the same way, make many measurements and calculate statistics. However, there will always be an intrinsic dispersion due to the randomness of the interactions. This cannot be reduced, as it can be done in classical physics by repeating the measurement many times.

Before the measurement, one does not know where a particle is, but it is possible to estimate the probability. After the measurement, one knows where the particle *was*, as the measurement changed the impulse. The hinge of measurement is not the observer or its interaction, but the irreversibility [2, 4]. The well-known metaphor of the *collapse of the wave function* is useful to emphasise the key role of the time operating a cut, dividing before and after the measurement. A beautiful example of the time cut is given by the theory of β -decay by Enrico Fermi [8]. Before, there is one neutron. After, there are one proton, one electron, and one neutrino. It is worth noting that the neutron does not *contain* the proton, the electron and the neutrino.

These three particles are generated when the neutron vanishes.

Another important example is the entanglement. There is one particle A with spin 0 that decay into two particles, B and C, with opposite spins ($+1/2, -1/2$). Thinking in terms of non locality means: the two particles B and C are united in A before the decay, then separated and correlated. Thinking in terms of time cut: the particle A, at the time t , generates two particles, B and C, which are linked by a physical law (conservation of angular momentum, at least until the next interaction), not by a mysterious and instantaneous non locality. Time cuts, divides one particle into two other particles. These particles B and C did not exist before the decay. They were generated when A vanished. No property at a certain time t is determined or affected by events that could happen after t . If one eats an apple today, this does not affect his body and his life before that meal.

4 Relativistic physics

As known, in classical physics, space and time are separated. The latter is something external, and independent on space. One point in space is a geometric point and it can move as the time flows. In relativistic physics, space and time are merged into spacetime. One point is an event. The measurement is defined as a procedure performed simultaneously with a clock. Again, the key issue is simultaneity. Relativity forces us to take time into account on another side with respect to quantum physics, the side of the large scale.

As the speed of light in vacuum is constant ($c \sim 3 \times 10^5$ km/s), and given the time employed by the human brain to process information from senses ($\sim 0.2 - 0.5$ s), each event happening within $(6 - 15) \times 10^4$ km from us, is considered as instantaneous. A delay can be already perceived in communications with astronauts on the Moon (average distance $\sim 3.8 \times 10^5$ km equivalent to ~ 1.3 light seconds). The Sun light needs of ~ 8 minutes to reach the Earth, and the closest star (Proxima Centauri) is ~ 4.23 light years distant from us. These examples suggest that time might be considered as the fourth dimension, equivalent to one space dimension. This is just what happen in a spacetime without matter: past, present, and future exist all together (*block universe*). As there is a panorama for space, there is also a *temporama* for time. Simultaneity has no more meaning: what is in the past for one, could be in the future of another. Time is then an illusion.

However, this is again an ideal case, because matter exists and curves spacetime. This generates local asymmetries, because accelerated observers are no more equal each other, as it was for inertial frames. A rock falls toward the Earth, while the opposite never happens, unless one provides energy to the rock. Moreover, the matter alters the rhythm of time: the closer the clock, the slower the pace.

The case studied by Kurt Gödel deserves particular attention. He developed a solution for the Einstein's equations in the case of a non-expanding, but rotating, universe, where closed timelike curves were present [10]. After the publication, some cosmologists told him that the universe is expanding, so that Gödel updated his solutions, with the result that closed timelike curves disappeared [11]. Gödel was interested in a timeless Parmenidean world and, therefore, as involuntarily proved the opposite, he did not continue his studies. Anyway, his studies confirmed that time cannot be reduced to a spatial dimension: the expansion of the universe generated a preferential cosmic time, which in turn prevent the formation of closed timelike curves, making time something intrinsically different from space dimensions.

5 Quantum Gravity

There are many theories about quantum gravity. I think that the most promising approach is to start from a $3 + 1$ spacetime, organised as three dimensional hypersurfaces with constant time [1, 14, 5, 6]. This fits well the cosmological spacetime, but can work well also on smaller scales, for example in the study of black holes [17]. The lapse function sets up the relationship between the proper time and the coordinated time, which is the time distance between two hypersurfaces along their normal (Fig. 1). This parameter should be interpreted in a different way, as the cut of time, dividing what happened from what can happen.

It is also necessary another revision of terms. What can happen is generally indicated as the future. This word derives from the Latin word *futurus*, which is the future perfect of an archaic form – *fuo* – of the verb to be. Therefore, it means something that will be. This is a problem, as the verb to be is not the proper verb to indicate something that has still to be generated. Inevitably, it carries meaning of existence. The word future has the meaning of something already existing, but not yet reached by the now³. It would be

³It has also the significant drawback of superstition and fate.

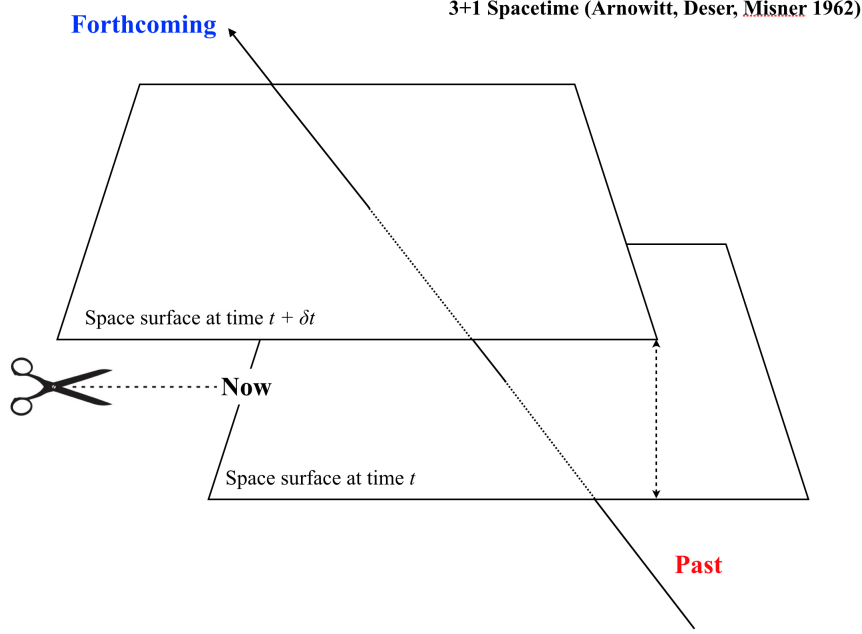


Figure 1: 3 + 1 spacetime and the cut of time.

the proper word for a spacetime without matter (see the previous section), for a temporama. But, if one thinks that what can happen is still to be generated, then it is necessary to use another word. In Italian, there is the proper word, *avvenire*, but it has no correspondence in English. It can be translated with world to come or with forthcoming, although the latter has a meaning of something to happen very close in time. In the following, I will use forthcoming to translate *avvenire*. What happened has less problems of translations: past is still a useful term.

Back to the 3 + 1 spacetime, the cosmological time sets up again the simultaneity, although in a different way. A hypersurface corresponds to the space of a cosmological now, which is valid for each point on the surface. On the Earth, one cannot know in real time what is happening on Proxima Centauri *now*, because of the constant and limited speed of light. Nevertheless, this does not mean that nothing is happening. The simultaneity becomes an abstract, but useful, idea, like the rigid body or the material point in classical physics.

6 Time as cut

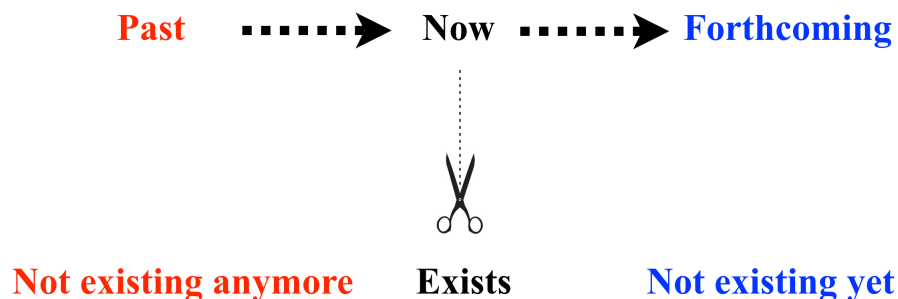
The language of classical physics, including the measurements, neglected the time. This was necessary, as many other abstractions, to find universal laws and to build the bases of a reliable science. However, today it is necessary to remind what was neglected. It is not true that laws of physics are time invariant. It is rather obvious that if one removes time or its effects (dissipation of energy), then equations are time invariant! But it is also an ideal case, not the reality. As soon as dissipation is included, then equations are no more time invariant.

Time, neglected in classical physics, emerged overwhelmingly in quantum mechanics and relativity, although in different ways, and it exploded when trying to elaborate a theory of quantum gravity. In quantum mechanics, time is essential to cut before and after a measurement. One can call it collapse of the wave function or invent another name, but what is important is that time cannot be neglected anymore. Bohr's complementarity states that the cut of time is essential to keep consistency between mutually exclusive behaviours (wave/particle). Relativity has shown that the rhythm of time is no more constant, but it depends on the energy-impulse. The cosmological expansion sets up a preferential time, making it something different from spatial dimensions. Therefore, the best approach to a theory of quantum gravity is a $3 + 1$ spacetime, where the cut function divides constant-time hypersurfaces.

Being a cut, there is no more a minimum time, it is useless to ask what is its size. It is like to ask what is the minimum size of a line one could draw: it depends on the pencil. This does not hamper the concept of interval, but one should not think to the duration. It is not an interval of integers, rather to an interval of real numbers, which is open on infinity. Like real numbers, there is an order, but there is no minimum quantity, no quantum, between one number and its follower. One could still invoke the Planck scale, but it could be a transition from a spacetime language to a time-only one, as suggested by [15].

The order of time is neither spatial, nor relational: there is no here, no there, like in space, because the past and the forthcoming do not exist as the now. The past has been: one can have memory of it with measurements or with objects, but it does not exist anymore. In astronomy and astrophysics is common to think that photons from cosmic objects come from the past, so one is doing some kind of archaeology. That is true, but one has to think

The cut of the time



- **The order of time is neither spatial nor relational: there is no here and there, as in space.**
- **Energy is needed to translate in time. Without energy, there is no time, there is no existence (even the void has energy!).**
- **Forthcoming must be generated (expansion of the universe).**
- **One could make inferences on the basis of physical laws, calculate expectations, but never predictions.**

Figure 2: The cut of time.

really as an archaeologist: pyramids were built in the past, but the buildings one can touch today are not exactly the same building of a few thousands of years ago. Time changed the matter. Recently, even the Grand Kilo has been abandoned, because it has lost about $50 \mu g$ in more than one century, and the unit of mass has been substituted by a measurement via the Planck constant⁴. For a macroscopic object, it is easy to recognise the decay (loss of energy) due to the time cut on long time scale, but it is necessary to avoid the usual simplifications of classical physics and stop neglecting time. For particles is a bit more difficult, but there could be an opportunity (see the next Section).

The forthcoming does not exist yet and *must be generated*. This is a key point, a key difference with respect to the block universe or the multiverse. Therefore, the now, the cut of time, is a transition surface open to the infinite

⁴<https://phys.org/news/2019-05-adieu-le-grand-kilogram-redefined.html>.

possibilities offered by the laws of physics. Now what is possible according to physical laws becomes into existence while doing. It is worth noting that, although the forthcoming is driven by the laws of physics, it is intrinsically unpredictable, as known from quantum physics and dissipative processes. One can draw inferences by using physical laws, calculate probabilities and expected outcomes, but there is no way for predictions, as the forthcoming does not exist yet and must be generated. Prediction is just superstition⁵. A short summary of the idea of time as a cut is displayed in Fig. 2.

The interpretation proposed in this essay is in partial agreement with Ellis' evolving block universe (e.g. [5, 6, 7]). The key differences are two: first, Ellis thinks that the past continues to exist, so that there is a block universe continuously growing, made by the past and the now, which in turn is the border surface; second, time is still viewed as duration, not as a cut.

7 The existence energy

As known from quantum mechanics and relativity, the motion in space is related to the impulse, while that in time is related to the energy. I would like to focus on the time shift only. Any physical object needs some energy to exist, just to shift in time without any other type of motion or interaction. It is reasonable to think that pure time shift requires energy to be done and that will be somehow lost⁶ as time goes by. Existence is just time shift and must not be confused with life. A human being needs a certain amount of calories per day just to live (basal metabolic rate), which is much greater than the energy needed by the particles constituting his body to exist (and that will continue to exist after his death). Lifeless objects also have various types of energy not related to their plain existence. For example, atoms in the lattice of a solid body vibrate because of thermal energy, and also require energy to be bounded each others in the lattice, as well as electrons are bounded to atoms. All these particles, regardless their interactions, require a much smaller quantity of energy to simply exist. It is not thermal or chemical or any other type of known energy. I do not know what type of energy could be, and I do not want to go too far with speculations, but there must be some

⁵To predict derives from Latin *prae-dicere*, to say in advance, to announce with certainty that something in the future will happen. Therefore, it is not the proper word to use in physics, unless you are an incurable determinist.

⁶For the moment, I do not care about where this energy goes.

energy to allow a physical body to shift in time without any other motion or interaction. Pure existence. The space too needs some energy to exist, and it could be the void energy.

This existence energy must be a very small amount, because the matter is stable on long time scales and it was never necessary to include it when applying the principle of energy conservation or any other calculation. I would like to try estimating at least an upper limit. I consider the basic constituents of matter, protons and electrons, without any other type of energy due to interactions. This existence energy should be stored in the rest mass, minus the energies of the products of natural decay. The order-of-magnitude calculations for the two cases are as follows:

1. *Proton*: the main branch of the expected decay $p \rightarrow e^+ \pi^0 \pi^0$ has a lower limit for the lifetime $\tau > 1.47 \times 10^{32}$ years [16]. The difference in energy (mass) between the proton and its decay products (positron and pions) is $\Delta E \sim 1.1 \times 10^{-10}$ J. Part of this energy could be redistributed in kinetic energy of particles generated after the vanishing of the proton. Therefore, this ΔE can be considered an upper limit of the energy available for the existence. The upper limit of the power needed to shift in time is then $\Delta E/\tau \lesssim 2.4 \times 10^{-50}$ J/s.
2. *Electron*: the expected decay is $e^- \rightarrow \gamma \nu_e$, where the photon energy is ~ 256 keV, and the lower limit of lifetime is $\tau > 6.6 \times 10^{28}$ years [16]. The difference in energy is $\Delta E \sim 4.1 \times 10^{-14}$ J, which in turn implies an upper limit in the existence power of $\Delta E/\tau \lesssim 2.0 \times 10^{-50}$ J/s, consistent with the proton value.

The consistency of the two calculations could be a chance coincidence, but it is intriguing. Such a small quantity is still beyond the capability of the present day experimental technology. Nevertheless, the search for the tiniest measurable amount of energy, the quest for the existence energy, could open an interesting research direction, at least for those interested in understanding the physics of time.

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References

- [1] Arnowitt, R., Deser, S., & Misner, C. W.: “The dynamics of general relativity”, in: *Gravitation: an introduction to current research*, edited by L. Witten (Wiley, New York, 1962), p. 227.
- [2] Bohr, N.: *The philosophical writings of Niels Bohr*, 4 volumes (Ox Bow Press, Woodbridge, 1987-1988).
- [3] Cheng, T.-P.: *Relativity, Gravitation and Cosmology – A basic introduction*, (Oxford University Press, Oxford, 2005).
- [4] Daneri, A., et al.: “Quantum theory of measurement and ergodicity conditions”, *Nuclear Physics*, **33** (1962) 297.
- [5] Ellis, G. F. R.: “The arrow of time and the nature of spacetime”, *Studies in History and Philosophy of Modern Physics*, **44**, (2013), 242.
- [6] Ellis, G. F. R.: “The evolving block universe and the meshing together of times”, *Annals of New York Academy of Sciences*, **1326**, (2014), 26.
- [7] Ellis, G. F. R., & Goswami, R.: “Spacetime and the passage of time”, in: *Springer Handbook of Spacetime*, edited by A. Ashtekar & V. Petkov (Springer, Heidelberg, 2014).
- [8] Fermi, E.: “Tentativo di una Teoria Dei Raggi β ”, *Il Nuovo Cimento*, **11** (1934) 1.
- [9] Foschini, L.: *Fisica del tempo* (Bonomo, Bologna, 2018).
- [10] Gödel, K.: “An example of a new type of cosmological solutions of Einstein’s field equations of gravitation”, *Review of Modern Physics*, **21** (1949) 447.
- [11] Gödel, K.: “Rotating universes in general relativity theory”, *Proceedings of the International Congress of Mathematicians*, Cambridge (MA, USA), August 30 - September 6, 1950, vol. 1, p. 175.
- [12] Huang, K.: *Statistical mechanics* (J. Wiley & Sons, New York, 1963).
- [13] Hutchison, K.: “Is classical mechanics really time-reversible and deterministic?”, *British Journal of Philosophy of Science* **44** (1993) 307.

- [14] Kuchař, K.: “Canonical quantization of cylindrical gravitational waves”, *Physical Review D*, **4** (1971) 955.
- [15] Markopoulou, F.: “Space does not exist, so time can”, (2009), [arXiv:0909.1861](#).
- [16] Tanabashi, M., et al. (Particle Data Group), “Review of Particle Physics”, *Physical Review D*, **98** (2018) 030001.
- [17] Thorne, K. S., Price, R. H., & MacDonald, D. A.: *Black holes: the membrane paradigm* (Yale University Press, New Haven, 1986).
- [18] Wittgenstein, L.: *The Big Typescript TS 213*, German-English Scholars’ Edition, Edited and translated by C. Grant Luckhardt and M. A. E. Aue, Blackwell Publishing (Malden, MA, USA, 2005).