It's about time

Jonathan Hobley*

OndaLabs R&D Consultancy, Deca Homes, Clark Free-Port, Mabalacat, Angeles, the Philippines 20102

ABSTRACT

Time is an enigmatic dimension. People assign somewhat mystical properties to time, especially the prospect of time travel. Nearly everyone has considered the possibility of a time machine at some point in their life, and this isn't just because of the author Jules Verne. When you consider wanting a time machine, do you want to travel forwards or backwards in time? Since we are always apparently moving forwards in time, I would assume that the obsession is going backwards. The reason for this is that all people make mistakes and have regrets, and they would like to do some things differently in hindsight. But these are all humanistic desires, and it is this humanistic desire that incites people to give a mystical and magical property to time. It is probable that most people would wish to correct a past mistake at some point in their lives. The truth is that people can atone for their mistakes, but they can never absolutely undo them as if they never happened. The desire and ability to reverse time is currently only scientific on a psychological level. In fact, in the absence of some as-yet undiscovered physics the arrow of time is decided by Bolzmann's entropy, therefore if a person can appreciate the meaning of entropy then they will fundamentally understand the arrow of time. Hence, chemistry students are in a good position when it comes to understanding time.

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* jonathan.hobley@gmail.com

A brief introduction to time

Some people say that the Sumerians "invented" time around 5000 years ago (Bertman, 2003). At the same time, in England, Stonehenge was being built by pre-Celtic tribes. Stonehenge has features that that align with the Sun during the winter and summer solstices, so it demonstrates that these tribes had an appreciation of time and developed an astronomical clock (Cunliffe, 1997). The Sumerian concept of time was possibly more sophisticated based upon available records. However, it was still based upon astronomical observations. The Sumerians gave us our basic units of time, namely 60 minutes in an hour, 24 hours in a day, 360 days in a year (more correctly 365 days as later established). The reason for these divisions was that the Sumerian mathematical system operated in base 60 and 60 multiplied by 6 is equal to 360. The choice of 60 seconds in a minute and 60 minutes in an hour is convenient in base 60. 12 multiplied by 5 is equal to 60. The ancient Egyptians used shadow clocks to determine 10 daylight hours. They also added two twilight hours when it may not have been possible to use a shadow clock, but it was still possible to see. So, there were twelve hours when people could see. The 12 hours of nighttime were determined by observation of star constellations on the ecliptic, which is the circle in the celestial sphere which the Sun appears to move on during the passage of one year. This is where the 12 signs of the zodiac are found.

The Sumerians also divided a circle into 360^{o}, so they probably understood that the Earth was going around the Sun in a near circular orbit and that the Earth was round like the Sun and the Moon (actually spherical). Hence the divisions that describe a section of a circle are the same as the divisions of time.

The astronomical clock at Stonehenge is also built in a circle, so although the culture that built it left no written records, they were probably operating with a common set of understanding of the cyclic nature of seasons, night and day and astronomical motions. Similar stone circles of similar age can be found all over England, Scotland, Ireland and Scandinavia. Clearly, there was a need to understand seasons for religious and practical reasons. It is probably no coincidence that pastoral societies were developing at the same time so that knowing when to plant crops would have been helpful.

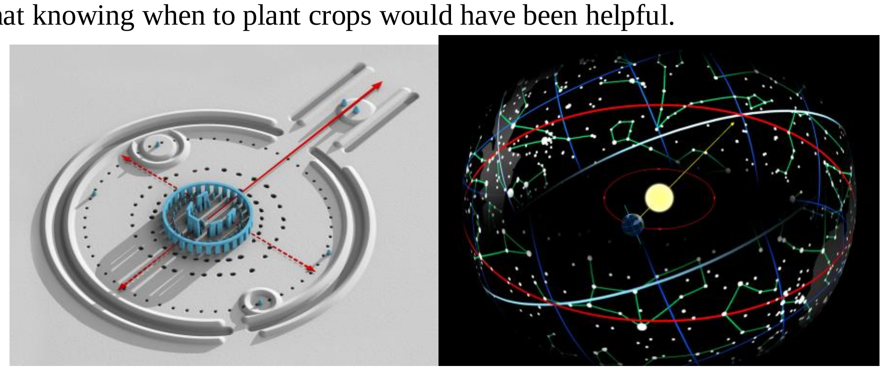

Figure 1. Left. A reconstruction of Stonehenge. Right. The Earth, Sun, Celestial Sphere and the ecliptic. (Public Domain)

For thousands of years celestial bodies have been used for navigation. It is easy to tell your latitude using stars *etc.* because their height in the sky is determined by latitude. Longitude presented a new problem, because the Earth's rotation affects the positions of the stars that are required to determine the location east to west. This problem was solved by John Harrison early in the 18^{th} Century (Sobel, 1996). He created the first workable ships clock, which had an accuracy that could keep time for the long periods that were typical during voyages of exploration at the time. Knowing the time, referenced to the Greenwich Meridian (longitude of zero) it was then possible for the navigator to derive their current longitude by correcting for the Earth's rotation using astronomical almanacs. This enabled voyages of discovery to be undertaken which led to the colonization of the Earth by seafaring western countries. Despite the controversy behind colonization it has to be recognized that an accurate knowledge of time significantly altered the history of the world.

More recently science uses atomic clocks as an accurate measurement of time. This involves analysis of the frequency of transitions between hyperfine energy levels of atoms (McCarthy and Speidelmann, 2009). Hyperfine structure is the small splitting of the energy levels of an atom due to the interaction between the state of the nucleus and the electron cloud. More precisely the hyperfine splitting is partly caused by the interaction of the nuclear magnetic dipole moment and the magnetic field caused by the electron cloud. The interaction of the nuclear electric quadrupole moment and the electric field gradients in the atom also contribute to the splitting. Since 1968 the SI definition of time has been based on the transition frequency between two energy levels in the ground state of the cesium 133 atom (^{133}Cs). 1 second is equal to the time it takes for 9192631770 transitions to occur.

The design of the atomic clock is based on a tunable microwave cavity or maser. The masing (equivalent to microwave lasing) medium is ^{133}Cs gas, at close to absolute zero temperature, that is in one hyperfine state that is excited within the microwave cavity. The number of atoms excited to the other hyperfine state is detected and the cavity is tuned to maximize the number of excited states. From this the frequency of the transition is measurable. The National Physics Laboratory in the UK has an atomic clock that would lose or gain less than 1s over a timescale of 138 million years. The accuracy of all other SI units such as amps, volts *etc.*, which have definitions that dimensionally contain seconds, are enhanced by an accurate measurement of the second.

1. The arrow of time and Boltzmann's entropy

In many processes the direction in which the process goes is determined by energy. In a sand-clock the sand falls from the upper to the lower chamber due to the decrease in potential energy as the sand enters the lower chamber. In order to reverse this, the user has to input some energy by turning the sand clock upside down again so that the sand is once again in the upper chamber. Actually this process needs to be done twice in order to get the sand back into the same up chamber as it was in at the start. However by turning the clock twice we did not turn back time. This is because the position of each particle of the sand in the upper chamber is completely different to the individual sand grain positions in the initial state. Furthermore, friction as each sand grain rubs against the others as it falls will alter the surface of each sand grain on the molecular level a tiny bit. This could never be compensated for by simply turning the sand clock twice. Consider this in terms of Gibbs free energy of the system.

$$\Delta G = \Delta H - T\Delta S \tag{1}$$

ΔG is the overall energy change of the process and it must become more negative for the entire process to be spontaneous. ΔH is the enthalpy change of the process and is linked to the reduction in potential energy of the system. As the sand falls down it becomes more negative. When the user turns the clock energy is added that can overcome the entropy reduction and make the sand gain potential energy, which again reduces as the sand then falls. ΔS is the entropy of the system. It is a measure of the increase in disorder during the process. Probably the entropy of the process is rather unchanged as the sand falls and as the sand clock is turned, because it is always similarly random. However if the act of turning the glass was going to "turn back time" even on a local scale inside the sand clock then every atom worn off every grain of sand would need to return to the exact same position in the lattice upon turning the glass and every grain of sand would need to return to its original position oriented in exactly the same way. This is entropy. Moving forwards we can let the sands randomly fall into any of the possible positions that are available because going forwards is a random process. If we specified that only the original set of grain orientations is acceptable then that would increase the energy of the process because we are specifying the process to be non-random. This is an argument against pre-ordained futures.

Consider what entropy is based upon a simple model of socks. If you have socks of different colors and you put them into your sock drawer without first combining them into matching pairs then when you wake up late for class and go to the sock drawer to get a pair of your socks (lets make it harder by saying you must do it without looking) then the chance that you will retrieve a matching pair before the class is over is very small. However, if you took the time to match them then you would get a matching pair the first try every time. The reason for this is that the entropy of the unpaired socks is higher than the matched socks. However, in order to make the entropy decrease by matching up the socks we had to do a bit more work and that cost some energy. The point being that decreasing entropy in equation 1 takes quite a lot of energy in even a moderately complicated system.

People often say that time can go backwards in the quantum world. It is true that quantum processes can be very reversible, just like a videotape is reversible. But when we reverse a videotape we don't rewind the entire universe. We are just rewinding the cassette! Furthermore, just like the sand clock there would be slight differences in the state of the rewound tape compared to the initial state. In the quantum world an atom can quite easily slip between two states with near perfect reversibility due to the quantization of states, especially for a simple atom like hydrogen. However it would probably have changed its location a bit during the transition, because translational motion is not quantized, so it has not really gone backwards in time. Additionally going backwards in time should require the entire Universe to go back in time and a nearly reversible transition in an atom would certainly not influence the entire universe.

The reversibility of a process with respect to time does not mean that time goes backwards. An orbiting planet can move clockwise over time or it can move in the opposite anti-clockwise direction over time. Gravity and orbits can just work either way with equal ability. But just because one planet moves one way and the other another way does not mean people on one planet get older with time whilst people on the other planet get younger with time.

The "arrow of time" is clearly determined by the second law of thermodynamics. There is nothing mysterious. It's just that the entropy of the universe always increases, *i.e.* disorder increases. Going forwards in time by one unit of Planck time, $\sim 10^{-44}$ of a second, the Universe can move into any one of a enormous number of possible future permutations. The more permutations available the lower the energy required to proceed into any one of them. To go backwards by $\sim 10^{-44}$s to a point in which every atom and subatomic particle was in exactly the same state is to forbid the possibility of choosing any of the huge number of other available possibilities. The process of managing to forbid any of the other permutations would take an energy input approaching infinite. Hence, we cannot really travel back in time. This is simple thermodynamics. Equally a pre-ordained future is also going to involve huge amounts of energy that is simply not available.

Some people claim that time is merely an illusion. The time clock of everything in our universe began with the Big Bang. The evidence I will state for this is the CMBR (cosmic microwave background) radiation. The CMBR gives us our closest picture of the distribution of energy in the universe just after the Big Bang. The radiation was not always microwave, once it was much shorter wavelength but as the universe expanded over time so did the space in which the light was traveling. Hence that light now has microwave frequency and wavelength. Hence, it is apparent that time is not an illusion and that things are changing over time since the Big Bang. We have to trust our everyday experiences and accept this. A person cannot become younger; a tomato left long enough will go rotten & you cannot make it become un-rotten, you cannot un-boil an egg; entropy increases.

From the chemistry point of view, chemical reactions can go forwards and backwards but we should not consider them as reversing in time. In fact the critical driving force is the need to establish a stable thermal equilibrium, which is governed by the following equation,

$$\Delta G = RT\ln K_e \tag{2}$$

Where R is the gas constant and K_e is the equilibrium constant.

Reversible equilibrium is established from whichever direction is least stable. The method of flash photolysis in photochemistry often takes advantage of the possibility to shift a previously stable equilibrium to a higher energy state or to produce an excited state by adding photon energy in a light pulse from a flash-lamp or a laser. Rapidly, sometimes in femtoseconds the more energetic state returns to the ground state by dissipating its energy. However entropy will not allow every molecule to go into the same place and be in the same orientation as in the pre-pulsed original state. Similarly irreversible exothermic explosions can not suddenly reverse to form an in-tact bomb.

Without invoking some currently undiscovered physics it does seem that the arrow of time is fixed to going forwards by the huge energy of going perfectly backwards in time due to entropy. However, some unusual things do happen with time. Time dilation is one such phenomenon. However, time dilation is arguably only unusual because it does not noticeably occur under any conditions that we are used to in our everyday lives on Earth. There are two types of time dilation. One is derived from differences in velocity between two observers and the other is derived from differences in gravitational field (Einstein, 1905).

Velocity time dilation occurs because the speed of light is constant irrespective of the relative motion of two observers. If two observers separated by a distance L are stationary relative to each other and light travels from one observer to the other and is then reflected back then, using the formula Distance divided by Speed is equal to time, the time it takes for the round trip (Δt) is equal to 2L/C:

$$\Delta t = 2L/C \tag{3}$$

However, if one observer is moving relative to the other, the length of the path of the light will be different D. D is longer L and the difference in length depends upon the relative speed of the observers and Pythagorean mathematics.

$\Delta t' = 2D/C$ (4)

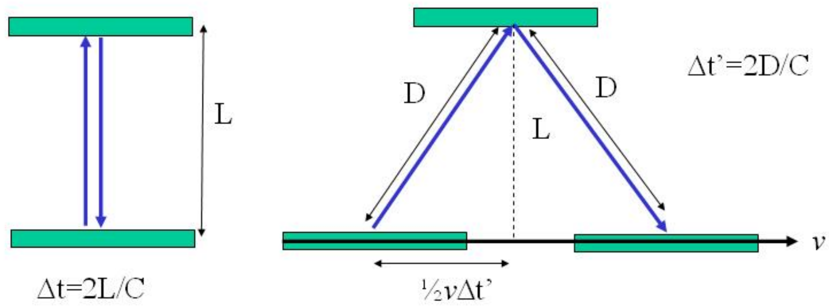

Figure 2. Schematic of the concept of time dilation for stationary observers and observers moving relative to each other.

From equations 4 and 5 we can derive:

$$D = \sqrt{\left(\frac{1}{2}v\Delta t'\right)^2 + L^2}$$

and by elimination we can get

$$\Delta t' = \frac{\Delta t}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (5)$$

If each observer carried a clock then each would see the others clock ticking more slowly than their own.

Gravitational time dilation also occurs (not derived here) and results that the observers' clock is ticking faster in a reduced gravitational field compared to an observer in a stronger gravitational field. Hence, time would be slower on Jupiter compared to Earth.

From the equations for velocity dilation due to the v^2/C^2 relationship the dilation is miniscule at the speeds at which we normally travel. However for photons and light particles traveling at very close to light speed $\Delta t = \Delta t'/0$, the time for light speed objects has not got any consequence. Hence, for a photon there is no longer any time.

$$L = L_0\sqrt{1 - v^2/c^2} \quad (6)$$

Equally from the Fitzgerald Lorenz contraction (Lorentz, 1892) for a photon, space is no longer consequential. And this could go some way towards explaining how a single photon can pass through both slits in the Young's double slit experiment. As a rippling wave traveling through the Universe at light speed the photon does not experience the Universe in the "usual" way that we do on the Earth. If v^2/C^2 became greater than 1, then both the time dilation and the Fitzgerald Lorentz equations would involve the square root of -1, which is an imaginary number. This would give us some problems which is why it is said that light speed cannot be superseded and why ideas such as travelling faster than light in order to travel through time are equally problematic. After all we live in a real world, so that with our current understanding, although time dilations occur and time can be stopped. The direction of time travel is always in a forward direction. Couple that with entropy and we will probably always struggle to make a time machine to turn back time to the good old days.

Conflict-of-Interest Statement

There are no conflicts of interest in this work

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