The Thermodynamics of Time Travel

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Abstract The concept of time travel captures the imagination of scientists and nonscientists alike. Though theoretical mathematical treatment of the issue in the realm of physics has offered potential means, albeit, wormholes requiring some rather strange conditions such as negative energy, what does thermodynamics suggest for the potential of time travel? Examination of the thermodynamic state functions of enthalpy and entropy from the Gibbs free energy relationship suggest that the final enthalpy after travel will be greater than the initial enthalpy before travel. The final entropy after travel will be greater than the initial entropy before travel. Transfer of mass from one multiverse to another would seem to violate various mass energy conservation laws, as well as strictures on the Second Law of Thermodynamics for the originating and a target multiverse.

Keywords Thermodynamics, Time Travel, Entropy, Second Law, Enthalpy, Temperatures

is central to the formulation of physical theories, and as a result, time travel and any paradoxes must be considered with considerable caution [12].

The question of the feasibility of time travel has been a subject of exclusive consideration by the discipline of physics. Might not classical thermodynamics shed light on the issue of time travel and also answer the question: wouldn't time travel potentially violate a few existing, established Laws of Nature as we currently know and understand them? This work suggests that there arises differences in the thermodynamic state functions of enthalpy and entropy from the originating and destination multiverse. The enthalpy after time travel is increased over that before time travel. The entropy after time travel is greater than that before time travel. There is an implied difference between the before and after time travel temperatures. This difference is a function of a wormhole throat temperature.

1. Introduction

Time travel is an intriguing prospect that has spawned both written stories and movies. Serious scientific consideration of time travel emerged from concepts within the Special and General Theories of Relativity. The possibility or impossibility of time travel seems to depend upon the innovative supplemental considerations introduced. Such concepts as wormholes [1-5], closed time-like curves [6, 7] and the resort to quantum mechanics [8] all add to the flavor of this tantalizing prospect.

The concept of time travel has also raised the concerns about "illogical" consequences of time travel, namely the so-called grandfather paradoxes [4, 9, 10]. One theory proposes that time travel paradoxes are avoided by what is called the Chronology Protection Conjecture, wherein the chronology of history (events that have evolved and happened) can not be altered. This is due to the assertion that the laws of physics prevent the occurrence of closed time-like curves [7]. Another theory proposes a finite universe with no beginning or end, disallows time travel, and is without singularities and increasing entropy requires no causal explanation [11]. Another view asserts that causality

2. The Meaning of Time Travel

If one travels (say in outer space) with a velocity of upwards of 99% of the speed of light, time will considerably slow for him, while for those back on Earth, time will continue "as normal". Thus for such a traveler, only years may elapse, while for those on Earth, perhaps hundreds or thousands of years may have elapsed. If such a traveler then returned to Earth he would see an Earth in its "future" existence. However, under such a concept of "time travel", such a traveler can not return to the Earth's past spacetime from which he departed. Such a "time travel" seemingly would have no practical value or advantage to the traveler or those left behind. In such a case of "time travel", any discovery by the traveler of some "future" cataclysm in store for Earth would have already happened and no warning could be "returned" to the Earth's past spacetime period for any possible preemptive action. Such "time travel" is stretching the meaning of time travel. It is somewhat analogous to saying that if one "distance traveled" from say Los Angeles to New York, you could not return to your departure location. One seemingly advantageous point to any travel is the desire to be able to return to the departure point, whether one may actually wish to or not.

For time travel to have any value of advantage in practical

service, one should be able to return to the past spacetime period from which one traveled. To do so means that we transport matter in its various states from a point A in space-time (d^3, t) to a point B in a different space-time (d'^3, t') where d and d' are linear dimensions of 3D space and t and t' are times such that $t \neq t'$ (ideally t' could be $< t$ or t' could be $> t$), and d^3 is not necessarily the same coordinate space as d'^3 . Furthermore, the measurement of time t and t' must be self-consistent for the Universe as a whole, meaning that they are not arbitrary time measure conventions. More on this below. Control and specification of space and time becomes a penultimate concern since one does not want to accidentally pick a time and space to which to travel (backward or forward) in time and “land” in an erupting volcano, be transported to the depths of the Mariana trench, or for that matter end up transported to some point on or below the surface of some star in some far-flung reaches of the Universe. The consequences of such poor locations and time specifications are clearly bad news for such a traveler.

3. Thermodynamics of Time Travel

From an observational standpoint, it would seem operationally apparent that time travel is not a spontaneous process as we have no record of any such occurrence. Conceptually, any spontaneity for time travel would seem to be operative in a bidirectional sense, meaning that a person or thing could travel to some other spacetime period, but also that said person could travel back to his starting spacetime period. Of course, this is more a matter of not just the physics of time travel being worked out, but also the engineering for the hardware required to engage in time travel. As an observational fact, time travel clearly does not, and has not happened. (Some may be willing to argue that the controversial if not enigmatic sightings of “alien space craft and or beings” may be a case of time travel by a very advanced and intelligent life form. Maybe, but I will ignore this in light of the lack of any credible and substantiating, “hard” scientific or engineering evidence.) But specifically where is (are) the stricture(s) for time travel among the thermodynamic variables? The three thermodynamic quantities of enthalpy, entropy and free energy are of concern in examining the efficacy of time travel. Clearly, if time travel is thermodynamically nonspontaneous, then the free energy of time travel, ΔG , is greater than zero, and the stricture(s) must reside in either the enthalpy and/or the entropy, or both. At some point, an equilibrium must be attained.

ENTHALPY and TRANSPORT TEMPERATURES

Consider the process of time travel of a cup through say a wormhole between two space-time eras as a two-step process:

ΔH_i

Cup (before) -----> Near Singularity (en route)

S₁, initial; T_i, origin S₂, maximum, T_{wh}

ΔH_f

Near Singularity (en route) -----> Cup (after)

 $S_2, \text{ maximum, } T_{wh}$

S_3 final; T_f destination

Let's assume that before and after, a state of equilibrium exists. If a system is at equilibrium, then its free energy, the ΔG , is zero:

$$\Delta G = \Delta H - T\Delta S = 0 \quad (1)$$

We can determine the relationship between ΔH_f and ΔH_i . The overall process initially (i) before time travel to final (f) after time travel states are:

$$0 = \Delta H_i - T_i \Delta S_i \quad (2)$$

$$0 = \Delta H_f - T_f \Delta S_f \quad (3)$$

then.

$$\Delta H_i - T_i \Delta S_i = \Delta H_f - T_f \Delta S_f \quad (4)$$

We can solve for T_f :

$$T_f = -(\Delta H_i - T_i \Delta S_i - \Delta H_f) / \Delta S_f \quad (5)$$

Since upon time transport, the system must be reassembled from the near, if not actual singularity state it passed through in its travel through a wormhole, the entropy of ordering upon arriving at its destination time must be negative, so $\Delta S_f < 0$. (From the equations of general relativity, a singularity represents a location and state of infinite density of matter, infinitely curved space, and time ends.) The terms within the closed brackets of (5) must collectively be greater than zero as the temperature in Kelvin can not be negative.

With these constraints in mind it follows:

$$\Delta H_i - T_i \Delta S_i - \Delta H_f > 0 \quad (6)$$

and

$$T_i < (\Delta H_i - \Delta H_f) / \Delta S_i \quad (7)$$

since our time traveler, our cup, is initially ordered, $\Delta S_i < 0$, thus

$$(\Delta H_i - \Delta H_f) < 0 \quad (8)$$

and

$$\Delta H_f > \Delta H_i \quad (9)$$

The final enthalpy of the object system, our cup, is greater (more positive) after time transport than before it started.

Enthalpy change can be regarded as a function of temperature. That is, enthalpy follows the relationship:

$$\Delta H = \int_{T_i}^{T_f} C_p dT \quad (10)$$

where C_p is the heat capacity at constant pressure and is itself a function of temperature. Upon integration the enthalpy change will have a form such as:

$$\Delta H = A(T_f - T_i) + \frac{1}{2}B(T_f^2 - T_i^2) + \frac{1}{3}C(T_f^3 - T_i^3) + \dots \quad (11)$$

The coefficients A , B , C , etc are experimentally determined for each substance. Certainly for some of the common simple binary nonmetal compounds and elemental gases, some of these coefficients are negative as well as negative powers of ten (B is $\times 10^{-3}$ and C is $\times 10^{-7}$) [13]. If the

heat capacity of our time traveler, the cup, is moderately independent of temperature for low temperatures, then integration of (10) yields:

$$\Delta H = C_p(T_f - T_i) \quad (12)$$

Using C_p as the heat capacity of our time traveler for simplicity's sake, what is the relationship between the values of T_f and T_i ? If the cup or time traveler passes through a wormhole, then it passes through an intermediate wormhole temperature T_{wh} . Then,

$$\Delta H_i = \int_{T_i}^{T_{wh}} C_p dT = C_p(T_{wh} - T_i) \quad (13)$$

and

$$\Delta H_f = \int_{T_{wh}}^{T_f} C_p dT = C_p(T_f - T_{wh}) \quad (14)$$

and adding the two paths,

$$\Delta H = \Delta H_i + \Delta H_f = C_p(T_{wh} - T_i) + C_p(T_f - T_{wh}) \quad (15)$$

If $T_f = T_i$, then $\Delta H = 0$ and nothing meaningful has happened. If $T_f < T_i$, then (12) is less than zero and the transport is exothermic. If $T_f > T_i$, then (12) is greater than zero and the transport is endothermic. So, which is greater, T_f or T_i ?

At equilibrium, $\Delta G = 0$, and

$$\Delta H_i = T_i \Delta S_i \text{ and } \Delta H_f = T_f \Delta S_f \quad (16)$$

but $\Delta H_f > \Delta H_i$ and thus, $\Delta H_f / \Delta H_i > 1$, and the signs of the enthalpies are the same ($\pm$), therefore,

$$T_f \Delta S_f > T_i \Delta S_i \quad (17)$$

and

$$T_f / T_i > \Delta S_i / \Delta S_f > 1 \quad (18)$$

and the signs of ΔS_i and ΔS_f must be the same. Since $\Delta S_f < 0$, $\Delta S_i < 0$, and

$$\Delta S_i < \Delta S_f \quad (19)$$

From (9), (13), and (14):

$$C_p(T_{wh} - T_i) < C_p(T_f - T_{wh}) \quad (20)$$

and

$$T_f > 2 T_{wh} - T_i \quad (21)$$

and by (9), if ΔH_f is more positive than ΔH_i , and $T_f > T_i$, on arrival at the destination or on return to the departure time frame, our time traveler or cup will be much warmer than when it departed. How much warmer? Impossible to say. What is the temperature of a wormhole throat? We can say that the initial departure temperature, T_i , departing from Earth is likely in the neighborhood of 298 K (25°C). And since the arrival temperature, T_f , must not be zero or certainly not negative, the wormhole temperature, T_{wh} must be greater than $\frac{1}{2} T_i$.

ENTROPY & TIME TRAVEL BETWEEN MULTIVERSES

The Second Law of Thermodynamics among other statements ascribed to it, classically states the entropy of the

Universe is always increasing:

$$dS_{sys} + dS_{surr} = dS_{Univ} > 0 \quad (22)$$

where dS_{sys} is the entropy change of the system under consideration, dS_{surr} is the entropy change of the surrounding universe (everything not part of the system), and dS_{Univ} is the entropy change of the universe as a whole. Our universe is an isolated system with no "environment" with which to interact [14]. As our universe is also not at equilibrium and is an irreversible system itself, $dS_{Univ} > 0$. Treating the entropy of a time traveler (tt) as a system for transport in time, then the remainder of our universe is the surrounding universe (surrUniv).

$$dS_{Univ} = dS(t)_{tt} + dS_{surrUniv} > 0 \quad (23)$$

where $dS(t)_{tt}$ is the entropy change of the time traveler to be transported in time in our universe. What happens if the time traveler system is removed from the "current" universe at time t and sent to some other time era, say maybe another parallel universe (a multiverse)?

Suppose we have a case of multiverses, two separate, isolated but alike "universes". The transport is from multiverse A at time t to multiverse B at a time t' where t and t' may or may not be the same self-consistent times. According to (23), at a time t , the entropy of each multiverse A and B is greater than zero, call them some value S_A and S_B , respectively.

If the time traveler t-selected system is removed from the "current" universe (multiverse A) and time transported to some other time era universe (multiverse B), perhaps say via a wormhole between multiverses A and B, multiverse A's entropy is then less than S_A by the value of $dS(t)_{tt}$ at time instant t :

$$dS_{Univ A} = dS(t)_{tt} + dS_{surrUniv A} \geq S_A \quad (24)$$

and,

$$dS_{Univ A} - dS(t)_{tt} = dS_{surrUniv A} \geq S_A - dS(t)_{tt} < S_A \quad (25)$$

where S_A is the whole multiverse A's entropy at a time instant just before transport at time t . Thus, the universe's entropy has *decreased*.

Multiverse B now has the time traveler system at its time t' at a time in its entropic history evolution was not there originally. Even if this is not problematic for multiverse B (presumably a multiverse's entropy can increase), it in theory can alter the entropic history evolution of multiverse B. What has happened in multiverse B does not happen in multiverse A where the time traveler originated, and thus all entropic historical evolutions remain in effect up to certainly the time t that the time traveler left multiverse A to travel to multiverse B in time. But now the two multiverses are not the theoretically postulated coexistent, alike tracking multiverses.

Given that the entropy of the universe (or a multiverse) with a value of S is large compared to the entropy of a component system at time t , the entropy of the universe (multiverse) remains much greater than zero. But (24) states that the entropy of the universe (multiverse) also decreased

(by the value of $\Delta S(t)_{it}$) which it cannot do by the Second Law of Thermodynamics. But another issue arises in this time travel matter in addition to the question of violating the Second Law of Thermodynamics. That issue is violation of the Law of Conservation of Mass and Energy.

MASS-ENERGY ISSUES

After transport, and dissolution of the wormhole, multiverse A also experienced a simultaneous decrease in its mass/energy state by the loss of the mass of the time traveler system to multiverse B, which gained that mass/energy. This represents a violation of conservation of mass and energy for each. Multiverse A lost a quantity of mass (the time traveler), and the energy of multiverse A did not increase by its equivalent. For multiverse B, its mass increased by that quantity of mass, but its energy did not correspondingly decrease by the mass's value (mc^2). Furthermore, if there is an exchange of mass and/or energy between multiverses A and B, then neither is isolated.

By the world's most famous equation, Einstein's $E = mc^2$, we know that matter and energy are interconvertible. We can take a quantity of matter, and convert it to energy. The Big Bang actually did the reverse, it converted energy to matter as the universe cooled in its expansion (matter can be regarded as condensed energy). When it is sought to displace a quantity of matter from the current spacetime era, d^3t , to some other spacetime era, d^3t' , we in effect remove that quantity of matter.

The ENTROPY

In a simplest case consideration of the entropy where the heat capacity of the time traveler or cup is independent of temperature (say for low temperatures),

$$\Delta S_i = \int_{T_i}^{T_{wh}} (C_p / T) dT = C_p \ln(T_{wh} / T_i) \quad (26)$$

and

$$\Delta S_f = \int_{T_{wh}}^{T_f} (C_p / T) dT = C_p \ln(T_f / T_{wh}) \quad (27)$$

The total sum for the path from departure to arrival is:

$$\Delta S = \Delta S_i + \Delta S_f = C_p (\ln(T_{wh}/T_i) + \ln(T_f/T_{wh})) \quad (28)$$

$$\Delta S = C_p \ln(T_f/T_i) \quad (29)$$

Again. If $T_f = T_i$, then the entropy change is zero which it presumably can not be. If $T_f < T_i$, then the entropy change is less than zero. If $T_f > T_i$, then the entropy change is greater than zero, and $T_f > T_i$ represents a condition overall consistent with the Second Law of Thermodynamics.

S_3 (above) must be less than S_2 , since S_3 represents ordering of information from the worm hole value S_2 . S_3 would have to be greater than S_1 , since according to the Second Law of Thermodynamics, entropy must increase for the universe. But if S_2 is the entropy on time travel through the throat and the near singularity state of a wormhole, then S_2 is part of the maximum of the Universe's entropy and any ordering from that represents a decrease in the Universe's

entropy—a violation of the Second Law of Thermodynamics.

4. Thermodynamics and Considerations of (IR) Reversibility

One aspect of time travel's value is that if one could travel in time, one wishes to come back to one's own originating spacetime. This would imply a necessary reversibility to the process of time travel. The reversibility of time travel is then an issue of some import, certainly for the organism's own interests, if not from a purely thermodynamic sense.

For reversibility to apply, the process of time travel would have to be infinitely slow. Thus, just to begin the travel much less to get to our destination, would require unimaginable amounts of elapsed time. It is logical to conclude that even in such a reversible case, we would never get back home to our departure origin.

If the process of time travel is fast, and thus, irreversible, what advantage is there in going if one can not come back home because of its irreversibility? The Second Law of Thermodynamics is the hurdle if not the roadblock.

The Second Law also can be stated to mean that not all the energy derived from a process can be realized for use. In other words, as with other real processes such as walking, driving a car, etc., there are frictional losses of the energy required to perform the process. So, there are "frictional" energy losses which can not be conserved for use and are part of the entropy realized. Thus a portion of the energy utilized to travel across spacetime is lost in the "machinery" used to travel. To reversibly travel, we must not lose even a tenth of an erg of the total energy. Is this not also impossible?

5. Universal Reference Frames—Space and Time

The second problem with time travel is designating the space-time coordinates from which you wish to launch and to which you wish to go. What is the coordinate system of the universe? Perhaps, logically, the best and simplest origin for a coordinate system is to use the origin ($d_0^3, t_0 = 0,0,0$) of the Universe, which logically would be the location of the Big Bang. Where is it? How does the Universe gage distance? The measure of time may also be a factor.

How does the Universe mark time? What is time to the Universe? We use years, days, hours, minutes and seconds on Earth, but these are sidereal time conventions of anthropogenic definition and provincial choice. The Universe does not know sidereal time references from *Alice in Wonderland* time convention. After all, the solar system is currently a third of the age of the Universe. The Universe predates our time convention's basis.

Clifford Will asserts that the most fundamental unit of time is associated with atomic processes [15]. He cites the use of a basic time unit in physics derived from the "time required for light to travel a characteristic distance sometimes called the classical electron radius." This unit of

time is 10^{-23} seconds (again in our time defined convention). How long after the Big Bang was it before fundamental particles such as electrons came into existence? And isn't the speed of light limit applicable only to matter, not space itself?

If time travel should prove workable, then we need to know how time is kept and how distance is quantified by the Universe and from that its "universal units." We need to know what constitutes the geometric or spherical origin of the Universe as the reference for measurement of distance. And we need to determine the unit of length "fundamental" to the Universe. Meters are a human contrivance. Entropy of the Universe may be the key to the time piece. Entropy certainly is independent of our provincial time conventions. But its current units are also anthropogenically derived and designated.

6. Conclusions

Setting aside any questions about facilities required at the origin and destination points used in time travel, the mathematics of theoretical physics tells us that under various theoretical considerations, time travel may be possible. Given the real "world" principles of thermodynamics, reversibility versus irreversibility, isolated, adiabatic systems and not, entropic considerations required to take place in the course of time travel are problematic if the Second Law of Thermodynamics is to reign valid, true and supreme in its own right. There are fundamental conflicts between the theoretical principles on the one hand, and other established, real principles of physics on the other hand as it pertains to the question of time travel. The previous treatment suggests that for a system at equilibrium before and after time travel, the final enthalpy is greater than the initial enthalpy. Also, the final entropy is greater than the initial. There is a temperature difference between the before and after time travel.

The physical movement of mass and energy from one multiverse to another, with one of the multiverses being the current universe, requires violation of conservation of mass and energy principles. This also entails reducing entropy in the origin universe, while increasing it in the destination universe, though such an increase in the receiving multiverse may not be a violation.

Additionally designating the criteria of space and time for travel from and to, seems currently ambiguous. Our conventions for designating time or distance are very provincial in origin. They would appear meaningless as the means for designating time and distance in defining the space-time dimensions for unambiguous space-time

quantification applied to 'spaces and times' in this Universe, which time and space predate human based systems by some 9.2 billion of our years measure. As an example, designating the longitude and latitude of a point on Earth at 10,000 B.C. would be meaningless. What do those values mean to a wormhole, or to the Universe?

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