Chapter 2
Time in Physics and Time in Awareness

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2.1 Introduction

Time is a part of our immediate awareness. We come across it as duration without necessarily attributing a measure to it; as sequencing with the notion of "before" and "after" between pairs of "events"; as a cyclic variable related to some natural process like the diurnal cycle—morning, noon, evening, midnight or like the pulse or heartbeat or the ticking of the clock. The time labelling astronomical events looks the same whether things are going forward or backward while time labelling the germination, growth, maturity, decline and perishing of a plant or animal does look different and strange backwards.

This megalomorphian zoology of time is reflected both in our language and in our science. We talk of "this time tomorrow" or "whenever I am afraid I become confused" in which we embed a cyclic process in a well ordered time. We will return to cyclic time later.

2.2 Durational Time in Mechanics; Linear and Cyclic Time

In mechanics processes are described in time and the laws of motion pertain to rates of change with respect to time. While time *ab initio* is defined in a bizarre fashion by Newton as "flowing uniformly" it is definition without content since flowing requires something else with respect to which this flow is measured! Further how does one

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recognize the flow of time? It is like asking "Where does this road go?" meaning thereby where do people, vehicles and objects traversing the road go—the road does not go anywhere!

A practical measure of time is obtained by observing the change in configuration of a physical system that is believed to be "moving" uniformly. It becomes acceptable since many such physical systems exist and the time as measured by each of these coincide more or less. It could be the pulsations of a quartz crystal or of radio frequency electromagnetic wave. For longer measures of time we could use the change of seasons, the ebb and flow of tides, sunrise and sunset. We could use as a rough and ready reckoning our heartbeats or the hunger or sleep cycle. For precision measurements we could use a precise system like quartz crystal or an isolated atom—to the extent that these are uniform we could expect that time as measured by them would all give a measure of "true time".

The first law of motion asserts that an isolated body has a constant rate of change of position, an uniform motion. So, to the extent that we have isolated bodies and to the extent that we can keep it in the view, the measurement of time is reduced to a measurement of distance. The time so measured is a linear time or, rather, only a segment of it since the uniformly moving body was not in our vicinity either for a very early time or for very late time. By extending our method of length measurement to greater distances we could measure a longer segment of time: longer but still finite.

If the motion is not uniform but still the departure from uniformity is known we can correct for the variation and determine the "uniformly flowing" time. Use a sundial shadow to measure time on a sunny day is a familiar example. A cheap clock gains time in cold weather and loses time in hot weather; if we know the temperature and thermal expansion of the pendulum suspender we could determine the correct time.

In contrast to linear time most clocks are cyclic. The first example is the motion of planets around the sun, where the line joining the planet to the sun describes equal areas in equal times (that is, constant areal velocity). So if we measure the area described (for a purely circular orbit this is proportional to the angular displacement) we can measure the time elapsed.

For times longer than a complete revolution we need to count the number of complete revolutions together with the angular displacement. The same is true if we are using the oscillations of a pendulum (or the days spent in confinement). Now the counters that we have are usually cyclic, though the complete cycle is a long time. Most wrist chronometers indicate time in seconds (or fractions thereof), minutes, hours, days and months. We could build a calender that goes over a century or a millennium. But eventually, like the odometer of a Volvo, the counter will recycle! We can extend the period as much as we want by having more digits on the counter; but any finite system configuration reading time must be cyclic. Linear time going from minus infinity to plus infinity is an abstraction. When quantum theory is invoked, this cyclicity can be proved based on the positivity of the energy of any isolated system.

2.3 Metric Time and Its Relation to Symmetry Principles

The use of linear and of angular motion for measuring time by comparison of configurations (linear position and angular orientation respectively) is not accidental but due to certain symmetry requirement on physical laws for an "isolated" system. The quantity of linear motion ("momentum") and of angular motion ("angular momentum") of an isolated body should be unchanged with respect to time if the physical laws governing the system are to be unchanged by change in spatial location or by change in angular orientation. These are part of relativity laws of Newton-Galileo Mechanics. They are based on our ideas of homogeneity and isotropy of our space.

To give a measure of time ("metrizing" time) we need to invoke yet another physical quantity that is also invariant stemming from another symmetry, that is the irrelevance of the epoch in which we study a physical system. For a known "particle" (an isolated body whose structure can be disregarded for describing the motion) given its mass and its energy we can determine the momentum which is also mass times velocity (in non-relativistic theory). Similarly for angular motion, given the "moment of inertia" of the rotating system and its energy we could determine the angular velocity. In terms of knowing the angular velocity and the angular displacement we can measure the time elapsed.

It is interesting to recognize that the determination of time elapsed can be even more intimately related to the principle of relativity if we have also the requirement that laws of physics should be unchanged when one goes from one inertial frame to another inertial frame; including the one which moves uniformly with respect to another.

The quantity that is associated with this invariance (and in a technical sense, generating this transformation) is a quantity called the mechanical moment. This quantity increases linearly with respect to time, the coefficient of increase being the momentum. Thus time elapsed is the ratio of the change in the mechanical moment divided by the momentum. This general form of metrization is valid even when Einstein's relativity has to be used. We can work out a similar relation between the ratio of the generator of changes in angular velocity and the angular momentum. The times so defined are the same for all (isolated) systems.

There is thus an intimate relation between elapsed time measured by the comparison of configurations and the basic principles governing the laws of motion. Since configurations (spatial location or angular orientation) involves comparison between something fixed and something moving, there must be parts, that is structure in a physical system used as a measuring instrument of time in addition to the instrument for measuring position or orientation. The time measured in all these cases is "duration" which is metrized as described above. Nothing has "happened": the motion could be reversed without our finding anything different from the forward motion. Forwards and backwards do not have anything intrinsically different though by conventions we could make some distinction as for example a clock that goes anti clockwise. [Is a clock that goes anticlockwise a clock or an anticlock?] This mechanical time has no "sense".

2.4 Irreversibility and Historical Time

Our usual experience (in the waking state!) is with a “sense” of time. In fact much more than metric time, our time is a directed time in which a temporal order is imposed on our experiences. We have memory of the past but not of the future; and we distinguish the distant past from our recent past. Our internal measure of time is not very reliable but our temporarily sequencing is generally very good. When we look outside for evidence of this sequencing we find many processes with such time sense. Trees grow, rivers and wind erode land, ice melts and hot coffee cools. Light bulbs and candles shed light, broadcasting antennas and stars radiate, our bodies age.

There is a curious connection with a class of physical processes involving heat. We know that mechanical energy can be converted into heat: after a cold shower on a cool day we rub ourselves vigorously with a towel! But if we use heat to do mechanised work as in a steam engine we can convert only a part of the heat. Of all such “heat engines” the most efficient are reversible engines and even they are only partially efficient. The irreversible processes seem to declare that time is some intrinsic change, a degradation of energy. This is the second law of thermodynamics. The irreversible changes increase a quantity called entropy. Thermal equilibrium states have the maximum entropy under these conditions. All natural evolutions seem either to increase entropy (irreversible processes) or keep it unchanged (reversible processes). Natural evolution is towards thermal equilibrium, towards increasing entropy.

Irreversible processes have a sense of time and run backwards they look bizarre and whether it would be a splash in pond converging towards a point from which a stone is ejected or a dead body becoming alive and growing younger by the day. Candles don’t grow absorbing candlelight converging on it (though sometimes we feel rejuvenated). Time as history relates to irreversible processes and the “second law of thermodynamics”.

There is now a fundamental problem of relating historical directed time to durational (mechanical) undirected time. Undoubtedly irreversible process not only take place but are the very mechanism of metabolism and nourishment for organisms and lead to pattern formation and structure in physical systems. But if mechanics is at the basis of all physical laws how can we obtain the observable irreversibility based on a reversible mechanics? This is an old problem of physics. There has been repeated attempts at solution, the latest being based on the “mixing” or “chaotic” behavior of complex dynamical systems.

In an irreversible system as a rule transient structures arise, which are called “dissipative structures” by Prigogine. Familiar examples are singing telegraph wires (aeolian tones) arising out of eddy viscosity as wind blows past a highly stretched wire, the dancing brilliance of gas jet (or candle) that is about to get extinguished or the wild oscillations of a bridge about to collapse. But the most familiar one is the generation of metastable states and a definite lifetime: like the excited states of an atom or a radioactive nucleus. In the domain of high energy physics most particles are unstable. The regularity of decay law tells us that this law itself could be used as a clock—the fraction of the surviving particles depends experimentally on the time elapsed. Historical time and durational time can be compared.

2.5 The Birth of Time

Does time have a beginning? In Newtonain physics time has no beginning and no end. Somewhat like Melchi-Zadek (Who came to bless Abraham and to whom Abraham paid tithe) had no beginning and no genealogy! But like Newtonian time, Melchi-Zadek was also an idealization. We must think of Jacob, Abraham's grandson who had to operate in the phenomenal world. What about time around us?

All around us we see irreversible processes. Candles burn, food gets eaten and digested; and most of the phenomena around us are dictated by the generous supply of energy from the sun. Energy is being continually degraded; entropy is increasing and all the processes around us are maintained by this steady flow of solar energy.

Has it always been so and will it always be so? Surely not, if we recognize that the sun will burn down in a finite time. Even without knowing the mechanism of the sun's energy we can conclude, along with Olbers, that if sun and the stars are uniformly distributed throughout space and they had all existed for an infinitely long time then the night sky couldn't be dark. There would be equilibrium. The sun and stars would not emit or absorb. This simple but profound observation ties time to Cosmology.

As soon as we talk of cosmology we have to ask are the principles of homogeneity and isotropy, of time invariance and equivalence of uniformly moving physical systems really true? Could not, for example, physical laws depend on the cosmological epoch? Did the universe have a beginning of time? What does it mean? The present view generally held by cosmologists is that universe is evolving.

If things are changing in time the measurement of time is going to get tricky. Instead of considering time we can consider its square, its logarithm or any function that suits our fancy. Milne, in his kinematic relativity chooses the logarithm so that the origin of the new time has gone to minus infinity. More generally in relativistic cosmology space and time are not fixed but become dynamical variables: the space-time manifold obeys equations of motion; and the origin of our present version of the universe could be explosive singularity called the "Big Bang".

How does quantum mechanics alter all this? In quantum dynamics also one distinguishes the reversible evolution for isolated systems and the irreversible processes of external interference on the quantum system. The measurement of time becomes somewhat more subtle but it can be done. One conclusion was already mentioned only cyclic time can be strictly measured by a quantum clock, but survival probabilities do give a measure of linear time in an approximate manner.

2.6 Causation and Time Sequence

Closely related to the idea of temporal succession and temporary duration is the notion of causation. Causes and effects are interrelated; this interrelation is the essence of dynamical dependence, of the very notion of describability. But while this relation is symmetric in reversible processes it is asymmetric and directed in irreversible processes; the effect is dependent on the cause and later while the cause is earlier and alterable. It is this scheme of describing nature and the correspondence with our memory in normal waking state, that makes it natural for us to view time as being directed and historical.

In this vein, let us ask if our awareness alters the structure of time, clearly when we are in deep sleep we have no components to our awareness and hence no configuration. Therefore time itself is not! In normal waking state we are generally aware of historical time but there are contexts in which we are aware of duration but not of historicity. Times of intense creativity or total absorption in the task, of deep peace in which we do things like breathing or walking or even driving without the instruction of historical time, being immersed in music or times of meditative awareness in which texture of time seems to alter historical and durational times seem to coexist. And in dreams our experience of time is such that linear and cyclic times, reversible and irreversible time all coexist. Sometimes it is as if the irreversible sequence of events have been reversed.

There are some people who say that the "arrow of time" (the directed sense of time) stems from the expanding universe. The "Big Bang" and the consequent expansion of spacetime dominates the functioning of the physical law and all the universe and hence each part of it feels this all-pervading time sense. Since the creation of the perceived physical structures and even the synthesis of chemical elements is subsequent to "Big Bang" we may state this as saying the arrow of time is as old as matter itself; that rather than irreversible time originating in the interactions of complex systems they all had the same origin, the "Big Bang". It is reversible mechanics and its durational time that is the idealization.

2.7 Perception of Time: Archetypes and Artifacts

So far we have talked about the time in the physical sciences. When we come to the perception of time our archetypes and the very nature of our awareness are relevant. Three of these archetypes have already been alluded to: That of a "uniformly flowing" linear time and both durational and historical processes embedded in it. This is at the base of our waking awareness and is the one used in physical science. The second is closed cyclic loops of time which contain aspects of the waking state but in which time loses its "sense". The topology of time and space is altered. This is the time of our dreams and of our poetry and the fine arts. Third is the structureless duration of deep (dreamless) sleep in which there are no configurations to demarcate time. But there is a transcendent fourth, in which all the previous “times” coexist without clashing and all seen as artifacts. This is the creative time of contemplative awareness in which the rising and dissolution of historical time, the multiple cycles of cyclic time and duration itself maybe comprehended. While this is part of every person’s awareness it has not yet found a place in physical science. To freely adapt a stanza from Ramayana:

Transcendence of the limited renders time a chariot;
In limitation, are causes and effects;
Know that in harmony is pristine existence;
Go forth in well being and joy!

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