Time and Causality

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Humans are both agents and recipients of actions within space-time. Specifically we are influenced by events in the past, which can not be changed; we act in the present to influence the future events which are not yet a reality. Humans experience causal chains moving forward in time: past to present to future. *Becoming* in nature is the process of a causal chain. An *event* is a reality localized in space-time. All events must be part of causal chains. Causal chains are a series of contiguous events, which must be true because special relativity restricts causality traversing space-time at less than the speed of light. Later in this essay the non-locality in quantum mechanics will be explained.

Special relativity presents time as the 4th coordinate in our 4 dimensional space-time universe and in this picture time lacks the attribute of flow. Human's sense of time flow is actually a causal flow, which moves through time via contiguous events. A good analogy is a flowing river. The location along the river bank is analogous to the time coordinate. The water flowing down the river is analogous to the causal chains moving forward in time. A place where the water is stagnating is analogous to a lack of causal chains, and therefore a lack of events. Such regions of space-time must be completely isolated from events and causal chains occurring around them. We can expect such regions to be of microscopic dimensions and this brings us to quantum mechanics.

Before looking at quantum mechanics, I want to contrast my model with the block universe model in which reality, both past, present, and future already exists as static moments. In the block universe model there is no true process of becoming. The history of the universe is analogous to a completely written book in which humans, who are experiencing it, are simply turning the pages of the completed book. In contrast I do not allow a single static event, which is not part of a dynamic causal chain. However, even within a completely stagnating region of space-time there is a reality without events. This reality is a result of conservation laws. A good way to view this stagnating reality is with Noether's theorem. According to Noether's theorem translational invariance in space and time account for the conservation of momentum and energy respectively. This means that total energy and momentum, among other things, within a region of space-time must be a reality even without the existence of motion. The symmetries in our universe require this, quite apart from any causal chains. The proof of Noether's theorem requires the existence of a so-called Lagrangian, which contains mathematical expressions of the spatial dependence of kinetic and potential energy.

There are numerous isolated stagnating regions of space-time in our universe, and in quantum mechanics these are known as *stationary states*. A stationary state is generally the complete description of the internal behavior of a bound system, which lacks any influence from specific happenings in its surrounding environment. By the word *complete* the claim is that quantum mechanics gives a full description of the system's reality. Quantum mechanics tells us that such systems are time independent. An example of a stationary state is the ground state of hydrogen. A Hamiltonian of the hydrogen atom can be defined and likewise its Lagrangian can be defined consistent with Noether's theorem. Noether's theorem tells us that the energy of the ground state must be both defined and conserved. This assumes the atom is isolated such that there can't be any energy transfer with the surrounding environment.

Although the ground state hydrogen binding energy between the electron and proton is well defined as -13.6 eV, it doesn't take any specific form. The electron doesn't have a specific position or momentum in hydrogen, but only a probability distribution of possible values, if measured. Without a position or momentum the electron's potential and kinetic energy lack specific values, and instead vary over the spatial region. Remember that the hydrogen ground state is time independent and nothing is varying with time. Quantum mechanics makes these statements definitive and the only way to alter this is to claim quantum mechanics is incomplete. If the electron had position and momentum its motion would define a causal chain and the hydrogen atom would not be a stagnating time-independent system. [1]

To drive this viewpoint home let us compare the hydrogen atom's bound states to the single particle bound states of protons and neutrons inside the nuclei of atoms. There are numerous low lying energy states in atomic nuclei where the least bound proton or neutron is predominantly in a state (so-called orbit) nearly identical to a corresponding electron state. These states are defined by four quantum numbers. A comparison of electron and nucleon bound states with identical quantum numbers shows similar shapes of the probability distributions of their positions. Their angular distributions (dependence upon orientation around the center) are identical. The radial distributions have somewhat similar shapes with the same number of nodes. The only significant difference is the scale. Because of the small size of the nucleus the nucleon inside has a distribution that is compressed about one hundred thousandth of the electron's distribution in its atomic orbit. In 1963 Maria Goeppert Mayer and J. Hans D. Jensen won the Nobel Prize in physics for making early discoveries of these single particle orbits in nuclei. This became known as the shell model. What makes the similarity between the electron's orbits in atoms and the corresponding nucleon orbits in nuclei so remarkable is the huge difference in space available for each to move in. In atoms the electrons are very sparsely populated with plenty of room to move without hindrance from other particles. In contrast the average separation between nucleons in nuclei is only slightly larger than the nucleon's size. Furthermore any two nucleons are prohibitively restricted from overlapping because of the enormous very short range repulsive force between them. This means that nucleons have almost no free space to move within the nucleus and yet their orbits are nearly identical in shape with the orbits of the free moving electrons in atoms. The only reasonable conclusion to this paradox is that bound particles inside stationary states do not have a position, do not have motion, and therefore no collisions to alter their orbits. Another way to say this is that stationary states don't have any causal chains.

There are of course countless examples of microscopic particles in motion. Newton's first law states that an object free of external forces will move at a constant velocity through space. Its straight-line path through space-time represents a causal chain composed of a potentially infinite number of contiguous events in Newtonian mechanics. The event initially determining its velocity would be the first cause in the chain. On the other hand, in QM we are usually unable to see all of the events in a causal chain. We can observe only separated events. It is only a matter of interpretation whether or not a causal chain connects the separated events; even if it can be shown the events are correlated with each other. Stephen Hawking in *The Universe in a Nutshell* [2] rejects the notion of causal chains. He shows a picture where one particle is observed consecutively at two nearby locations and considers how the particle got from one location to the other. In his figure of this process

Hawking shows a crude pictorial of Feynman's path integral in which the particle takes every possible path between the two detected locations. Using the analogy of rolling dice in a casino he compares this to a universe experiencing multiple histories each with its own probability. In summary Hawking is trying to replace causal chains between two observed events with a web of all possible reality. While the mathematics of Feynman path integrals is very successful in predicting the probability of some future unrealized event, using it to make inferences about the past of the second measurement is unjustified. There is absolutely no experimental evidence that the particle takes more than a single path between two points. Any interaction identifying a path would nullify all paths inconsistent with the observation, meaning that separate distinct paths can never be verified. We will assume that the two measurements are so close to each other that it is impossible to put in a barrier with two slits to observe interference between separate paths. We want to keep this discussion to the simple basics.

To allow for a unique path between the two measurements of Hawking's particle, consistent with quantum mechanics requires the introduction of backward causation. Quantum mechanics does not allow for a unique path created by a causal chain going forward in time. Here I am assuming quantum mechanics is an ontological theory and not simply epistemology. If a causal chain emanates from the second measurement going backward in time, it can combine with a forward moving causal chain from the first measurement to define a definite path for the particle. This does not violate quantum mechanics. In quantum mechanics the second measurement collapses the particle's wavefunction by assigning it the measured value which replaces a distribution of possible values. If this collapse only pertains to future times after the measurement an unpleasant time-asymmetry is introduced. By including the affect of the collapse on the particle's wavefunction earlier in time, through backward causation, time symmetry is restored. Any past, which could conceivably be attributed to a future event, is inaccessible to experimental study. This inaccessibility is built into the nature of quantum mechanics, by which systems are uncontrollably altered by making an observation on the system. If we try to observe the past effects of a future event we will necessarily destroy the possibility of a backward moving causal chain from the future event before the future event can cause it. This effect of measurement, which is built into quantum mechanics, is known as the "inaccessible past" [3].

One of the most puzzling features of quantum mechanics is the appearance of non-locality defined as causation traveling faster than the speed of light. This non-locality is widely discussed for measurements occurring close in time but with a large spatial separation on two entangled particles. These particles are initially in close contact, where they become entangled, and then are widely separated when the measurements are made. Statistical correlations between pairs of repeated measurements on an ensemble of identical two particle systems indicate a causal connection between the two measurements. No local hidden variable theory can account for these experimental correlations, which are predicted by quantum mechanics. Without backward causation this result appears to violate special relativity. Backward causation from one of the measurements would travel backward in time with the particle until it made contact with the other particle. The causal chain could then continue forward in time with this other particle out to where the measurement on it is performed. Whatever the timing between the pair of measurements on the two particles locality is restored. The causal chains between the measurements traverse space-time at the speed of the particles, which is less than the speed of light. Using the river analogy backward causation is crudely analogous to eddy currents swirling around behind a big boulder in the river.

In closing, special relativity makes very clear that causation has a close connection with the time coordinate, unlike the spatial coordinates. There is no lower limit to the speed at which a causal chain can traverse space-time between two events. This means the two events can be at the same spatial location at different times. However the two causally connected events can not be at different spatial locations at the same time, because the maximum speed at which the causal chain traverses space time is the speed of light, c. Causal chains must traverse time but not necessarily space. Human experience is restricted to the macro-world where causation only flows forward in time giving us the distinction between past and future. This is what gives us the impression that time flows.

Our universe appears to have time symmetry, which is tied to energy conservation using Noether's theorem. The apparent lack of time symmetry associated with causal flow must come from the starting conditions of the causal chains. One way to understand this asymmetry of flow forward in time is to say that the Universe began in a low entropy state. The 2nd law of thermodynamics can then explain this forward flow in time as an unceasingly increase of the entropy of the universe into the future. If the low entropy initial state doesn't have an identifiable cause we can attribute it to either chance or design.

Every causal chain must have a first cause. In quantum mechanics it appears that any measurement on a system, forcing it to acquire a specific value for the measure quantity, becomes a first cause in newly created causal chains. This measurement can also be considered a boundary condition on the mathematical formulation of the quantum mechanical wavefunction. It would be the final boundary condition for the wavefunction existing before the measurement and the initial boundary condition for the wavefunction existing after the measurement. The actual measurement creates a discontinuity between the before and after wavefunctions. Science can not deal well with first causes especially if they appear arbitrary and lack symmetry. I interpret these measurements as first causes, and with backward causation we can restore the time symmetry of these first causes. Hawking's aversion with first causes is what motivates him to reject causal chains. There is irony here because the long history of success in science comes from describing and predicting phenomena in terms of causal chains.

References:

[1] William R. Wharton, "The Importance of Causality in Quantum Mechanics", *Perspectives on Science and Christian Faith*, **57**, (December 2005).

[2] Stephen Hawking, "The Universe in a Nutshell", New York: Bantam Books, 2001.

[3] Huw Price, "Time's Arrow and Archimedes Point", New York: Oxford University Press, 1996.