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THE CAUSAL CLOSURE PRINCIPLE OF THE PHYSICAL DOMAIN AND QUANTUM MECHANICS

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I. The Causal Closure Principle

Simply stated, the Principle of Causal Closure states that any physical event must have a physical cause. In his article entitled "The Myth of Nonreductive Materialism," Jaegwon Kim says, "This is the assumption that if we trace the causal ancestry of a physical event, we need never go outside the physical domain" (Kim 1989, 43).

There is also the implied assumption that if this is not true, there can in principle be no complete and self-sufficient physical theory of the physical domain. Again Kim says, "If the causal closure failed, our physics would need to refer in an essential way to nonphysical causal agents, perhaps Cartesian souls and their psychic properties, if it is to give a complete account of the physical world. I think most physicalists would find that picture unacceptable" (Kim 1989, 44).

I shall argue that this is exactly the situation in particle physics today, only the violators of the causal closure principle are not referred to as Cartesian souls[1], but virtual particles and forces. Specifically, the phenomenon of nucleon fluctuations provides a counterexample to the causal closure principle of the physical domain. The explanation of nucleon fluctuations offered by physics is inconsistent with the principle of the conservation of energy, which is essentially an expression of the causal closure principle. Physics cannot, even in principle, provide an

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[1] For more on the justification of dualism and its problems see Smith, P. and O.R. Jones (1986); Broad (1925); J.J.C. Smart (1963); Cornman (1981); Rorty (1965); Fodor (1981).

explanation for nucleon fluctuations which is also consistent with the principle of the conservation of energy.

II. Quantum Mechanics and Causal Closure

One of the most celebrated laws of quantum mechanics is the uncertainty principle which was discovered by Werner Heisenberg in 1927.[2] This law states that there are situations in the subatomic world where it is not possible, even in principle, to know the exact values of two different quantities relating to an elementary particle because the act of measuring the first interferes with our ability to measure the second. The uncertainty principle is stated as follows:

> If we denote ΔX the uncertainty in the position of an object and ΔP the uncertainty in its momentum, then in any attempt to measure these two quantities, the product of the uncertainties is given by $\Delta X \times \Delta P > h$, where h is Planck's constant (Trefil 1980, 45).

Because Planck's constant is a very small number,[3] this provides a justification for ignoring the interaction of observer and observed in the macroscopic world. But, if the object we are considering is a proton, then this principle becomes very important.

The uncertainty principle applies to a number of pairs of variables. The most familiar involve that of position and momentum. However, in the development of the ideas of elementary particles, the most important variables are energy and time. The uncertainty principle stated in terms of energy and time is as follows:

> If we denote ΔE the uncertainty in the energy of a quantum system and ΔT the uncertainty about the time at which it has a given energy, then in any attempt to measure these two quantities, the product of the uncertainties is given by $\Delta E \times \Delta T > h$, where h is Planck's constant (Trefil 1980, 47).

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[2] Today there is still much debate on the philosophical meaning of the uncertainty principle. For more discussion on this see Penrose (1989) pp. 225-296; Healey (1989); Trefil (1980) pp. 35-53.

[3] In units where mass is measured in grams and length in centimeters, h has the value $h = 6.62 \times 10^{-27}$. Also see Serway, Moses, and Moyer (1989) p. 48.

This means that the shorter (more exact) the measurement of time; the more imprecise the measurement of energy. If we want to know the exact time, then ΔE would, in this case, be infinite. If we want to know the exact energy, then this would require ΔT to be infinite. You cannot exactly measure both the energy and time. In quantum mechanics, it is this energy-time uncertainty relation that leads to the concept of the virtual particle.

Recall Einstein's now famous mass-energy equivalence equation:

$$E = mc^2$$

This relation shows that mass is a form of energy. Moreover, this also shows that a small mass corresponds to an enormous amount of energy. Conversely, mass can be created from energy, but this requires an enormous amount of energy.

The energy associated with the rest mass of a particle[4] can be included in the uncertainty relation along with any other energy. If we attempt to measure the exact amount of energy in a particle at a certain time, there is an uncertainty in the mass of the particle. If M represents the mass of the particle and Δt represents the time at which the measurement is taken, this is represented by the following equation:

$$\Delta M > \frac{h}{c^2 \, \Delta t}$$

(Trefil 1989, 49).

If the time interval is small enough, it is possible that the uncertainty in the mass may be large enough such that during the time Δt, we will not be able to determine whether there is a single particle of mass M or several particles with the total mass of $M + \Delta M$ at the particular location. There is no measurement that we can make by which we can determine whether or not this is happening. In this instance, the original particle "fluctuates" into two particles and the extra particle is called a virtual particle.

In 1935, the Japanese physicist Hideki Yukawa, proposed that the strong nuclear force between the neutrons and the protons in an atomic

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[4] Serway, Moses, and Moyer (1989) p. 442; 444.

nucleus was caused by the exchange of virtual particles. During the brief moment of the existence of the virtual particle, each nucleon would be attracted to it, thereby creating the strong force. In 1947, Cecil Frank Powell and Guiseppe P.S. Occhialini confirmed Yukawa's idea with the discovery of the meson.[5] Yukawa was awarded the Nobel Prize in Physics in 1949 for this theory.

Similarly, virtual photons account for the electromagnetic force between electrons. In fact, each of the four basic forces are now regarded as an exchange of virtual particles.[6] The Feynman diagram showing how a meson mediates the strong force between a proton and a neutron is shown below in figure A.

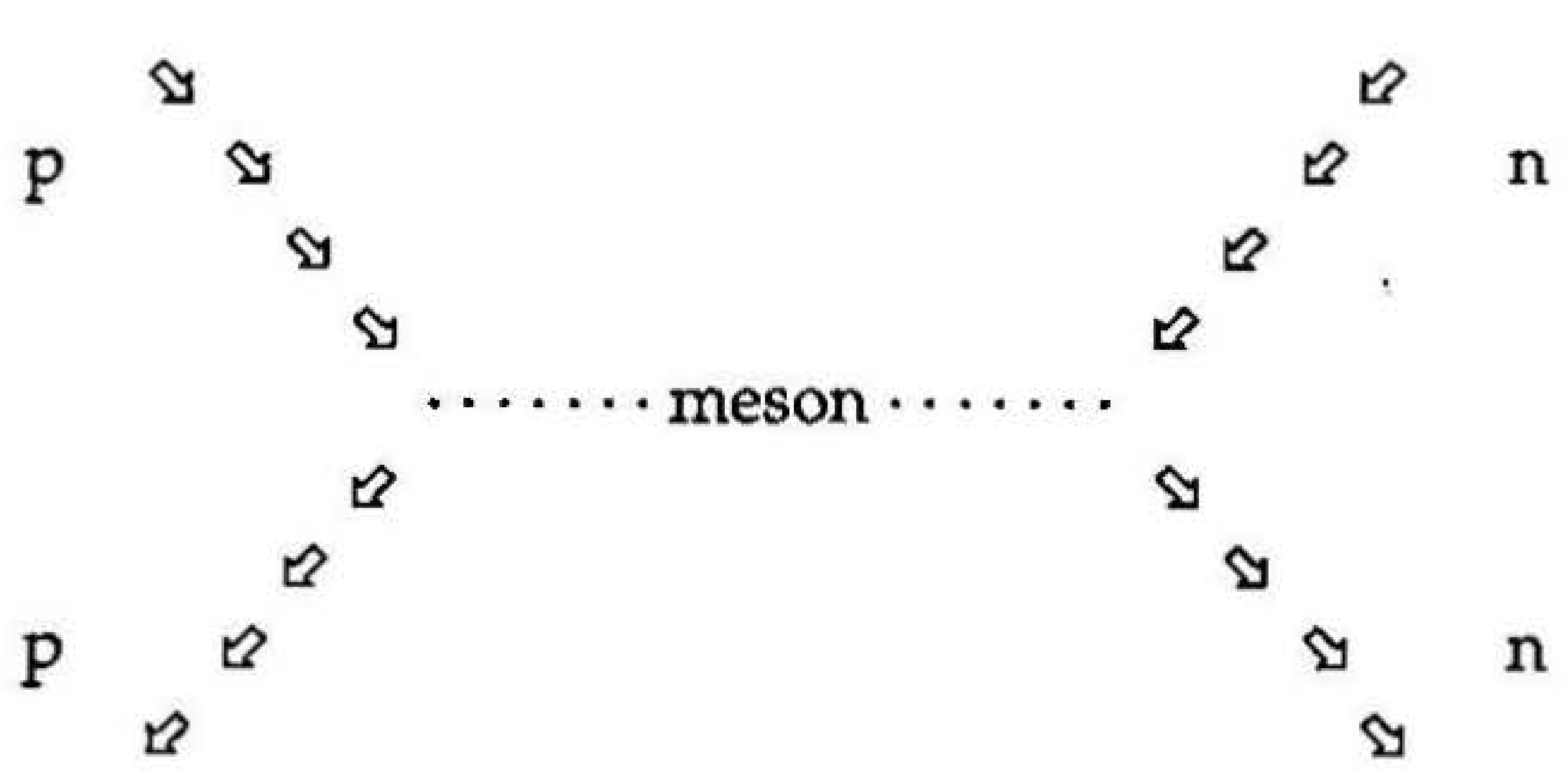

Figure A.

This diagram shows how a proton can change into a proton plus a meson, as long as it returns to its original state in the time allowed by the uncertainty principle. When mesons are emitted and absorbed this is referred to as nucleon fluctuation.

III. Violation of the Causal Closure Principle

Does this provide evidence for the violation of the causal closure principle of the physical domain? Do these fluctuations in the amount of energy of a physical particle violate the principle of the conservation of

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[5] Serway, Moses, and Moyer (1989) pp. 438-456.

[6] Serway, Moses, and Moyer (1989) p. 443.

energy? In their college textbook on modern physics entitled *Modern Physics*, Raymond Serway, Clement Moses and Curt Moyer say,

> Again, the very existence of the pion violates energy conservation by an amount ΔE, which is permitted by the uncertainty principle only if this energy is surrendered in a time Δt, where Δt is the time it takes the pion to transfer between nucleons (Serway, Moses, and Moyer 1989, 443).

For example, if we consider a proton fluctuating into a proton and a virtual particle that has the same mass as a proton, Δt would be 4.3×10^{-24} seconds and the distance it could travel approximately 1.3×10^{-13} cm.[7] Imagine the virtual particle as "sneaking out" while no one is looking, and as long as it gets back home before Δt has elapsed, the uncertainty principle guarantees that no one will know the difference.

If virtual particles only existed for the time allowed by the uncertainty principle without producing any effects upon physical reality, they would not necessarily constitute a violation of the causal closure principle. But, this is clearly not the case. David Bohm, in his book entitled *Quantum Theory*, points this out. He says, "Sometimes permanent (i.e., energy-conserving) transitions are called real transitions, to distinguish them from the so-called virtual transitions, which do not conserve energy and which therefore must reverse before they have gone too far. This terminology is unfortunate, because it implies that virtual transitions have no real effects. On the contrary, they are often of the greatest importance, for a great many physical processes are the result of these so-called virtual transitions" (Bohm 1989, 415).

Further, according to modern physics, the four basic forces of nature are due to the exchange of virtual particles. The strong nuclear force is mediated by pions; the weak nuclear force is mediated by the W+, W-, and Z particles; the electromagnetic force is mediated by photons; and the gravitational force is mediated by the graviton, which has yet to be observed.

We see that the same energy that is "allowed" by the uncertainty principle is also the same energy that mediates the basic forces of nature. It is inconsistent to hold the position that it is simply a matter of

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[7] The mass of a proton is 1.7×10^{-24} g., and the speed of light is 3×10^{10} cm/sec. Therefore, $\Delta t > (6.6 \times 10^{-27}) \div (9 \times 10^{20}) \times (1.7 \times 10^{-24}) = 4.3 \times 10^{-24}$ seconds. The distance the virtual proton can travel is limited by the speed of light. Therefore, $d = c\, \Delta t = 3 \times 10^{10} \times 4.3 \times 10^{-24} = 1.3 \times 10^{-13}$ cm.

physical law that particles just are associated with clouds of virtual particles accounting for the various interactions in which they engage because these clouds of virtual particles are not energy conserving. Furthermore, these virtual particles are responsible for causal interactions, yet their causal ancestry cannot be traced to any ultimate cause which is consistent with the conservation of energy. The fluctuations which are said to be responsible for their creation, in fact, violate the principle of the conservation of energy.

I maintain that this is a clear violation of the causal closure principle of the physical domain because if we trace the causal ancestry of a nucleon fluctuation, we cannot find a physical cause which is consistent with the principle of the conservation of energy and the fundamental principle of empirical science that there are no uncaused physical events. Energy is created out of nothing. We are forced to conclude that physical causal explanation cannot account for the totality of physical events in the world. Therefore, the causal closure principle of the physical domain is violated by the quantum mechanical explanation of the basic natural forces through the existence of virtual particles.

It is incumbent upon those who disagree with my analysis to provide an explanation as to how nucleon fluctuations and virtual particles can occur without violation of the principle of the conservation of energy. We have seen that recourse to the uncertainty principle does not provide an adequate explanation.

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