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Action Physics

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Special relativity unite space and time into space-time. Quantum theory extends relativity from space-time to state of being. A further extension of relativity to observer and law seems necessary and is described.

1. ACTION PHYSICS

Although the quantum theory is now over 65 years old it is still important to discuss its interpretation, for even a valid interpretation must evolve as long as the theory itself is still evolving. I will present only one interpretation here, the one I believe most. It entails a deeper transformation of our mental life than Einstein's relativity. Special relativistic mechanics is a special case of pre-relativity physics (namely, with Poincaré-invariant action principle); quantum physics is not a special case of pre-quantum physics.

By interpretation I do not mean an attempt to cut quantum theory to fit the Procrustean bed of prequantum or classical physics. Quantum theory was born with an interpretation. To change it is to change the theory. Any theory must have a syntax for forming sentences, a semantics to connect them with experience, and a logistics to compute which experiences are possible. By the interpretation of quantum theory I mean simply its semantics, an integral part of the theory. Quantum physics uses certain new symbols. What do they mean in practice?

Since it is clear that quantum theory is closer to nature than classical physics, I wish to understand it in its own terms, to think quantum and speak quantum. I understand this quantum semantics thus.

Classical physics starts from beings, and quantum physics starts from actions.

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First the symbols to be defined. All quantum kinematics is a grand variation on the theme of Malus' law for the probability that a photon from a polarizer will pass through an analyzer turned relative to the polarizer by an angle about the ray axis. The paradigm of such a vector is an arrow sign scratched upon a polarizer used in an optics experiment. The basic logistical formula of the quantum theory of any system (say an atom) has the syntactic form

$$A = \langle \mathrm{Out} | \mathrm{In} \rangle \tag{1.1}$$

It contains three key symbols A, $\langle \mathrm{Out}|$, and $|\mathrm{In}\rangle$.

Now their interpretation:

The sequence of symbols $\langle \mathrm{Out} | \mathrm{In} \rangle$ is a flow chart of a sequence of actions performed by us upon the atom, forming an atomic experiment (or experience; the words are the same in some languages). We read this sequence from right to left.

In a typical experiment on an atom, first we perform an input action or injection which imports or prepares an atom. This is represented by an "injective" vector $|\mathrm{In}\rangle$.

Then we attempt an out-take action or extraction which (if it succeeds) registers or counts the atom. $\langle \mathrm{Out}|$ is a dual "extractive" vector that represents the extractive action.

Finally, the symbol A stands for a number called the transition amplitude, the contraction of $\langle \mathrm{Out}|$ with $|\mathrm{In}\rangle$. When A is zero this means that the transition is forbidden, is predictably not going to happen.

These injective and extractive actions are theoretical elements of a kind that is alien to classical physics. They play the same fundamental theoretical role for quantum physics as the force concept for pre-quantum physics, and they meet resistance from Newtonian physicists much as forces did from Cartesian physicists.

A force is a push or a pull roughly as much as an injection vector $|\mathrm{In}\rangle$ is an input of a quantum. There is a physical relation between injection vectors and force vectors, but I do not dwell upon it here. Suffice it to say that both are vectors.

This means that in quantum physics, though not in pre-quantum physics, action symbols like $|\mathrm{In}\rangle$ can be added and the sum is an action symbol; this radically new process is called quantum superposition. An atom makes spontaneous transitions. It carries little memory of its past or precognition of its future. That is, these injective and extractive action vectors are not carried by the atom and cannot be learned from it. They describe us more than they describe the atom.

This is a good reason not to call them states; for in pre-quantum physics one imagined that the system under study truly carried a state, a complete determination of its responses to past and future actions, within itself.

Each injective vector $|I\rangle$ stands for how the metasystem (including ourselves) produces the system, much as a force stands for how the surroundings of a particle push on the particle.

2. THE END OF THE STATE

Heisenberg's original insight was basic: Suppose an atom had a complete description or state, as Descartes and Newton thought. Then even so, according to Bohr's provisional quantum theory, we observe the atom only in a transition from one atomic state to another, when it emits a photon that produces such a transition in us. Even if states existed, we would never see them.

This changes our epistemology. In one ancient conception, knowledge was a state of the knower that correlates with the state of the known. Bohr raised the question: What can it mean to know something that is always in transition during the process of knowing? The answer seems to be that knowing is a transition in the knower that produces or is produced by a transition in the known. We never see a state, but only a transition.

This answer also shows the two modes of knowing that I have mentioned, the injective and extractive. "*Non fingo hypothesis*," Newton put it, or words to that effect. Einstein, following the long line of Newton, Francis Bacon, and Ockham before him, taught us yet again that we should not take for granted the existence of what we can never see, whether it be the ether, absolute time, or the Stoic pneuma. I suspect that Heisenberg followed Einstein's line of thought one step further: Since we never see states, we should not invent them. We should pay attention to what physicists do, not what they say.

In pre-quantum physics we expected different atoms to do the same thing under the same circumstances. We implicitly assumed that individual behavior was already determined at the collective level. In pre-quantum physics, the injective and extractive actions of an allowed transition uniquely determine each other and can be identified. The resulting entity is the state. Different atoms act alike when they have the same state.

In quantum physics, individual behavior is determined at the individual level. Different atoms generally behave differently. They have no state in the original sense. In an allowed transition, the injective and extractive actions are independent variables and cannot be identified.

Often the word "state" is applied to an injective vector, and this has caused much confusion, for it lacks the most basic feature of the state we know from classical physics. It is not there in the system.

This statelessness expresses the incompleteness of quantum theory. Quantum theory and arithmetic are both incomplete in the same sense, though for different reasons: their postulates do not decide all their propositions.

I would rather speak of quantum spontaneity than quantum incompleteness, however. Calling quantum physics "incomplete" is a negative way to express its greater richness and openness, and contrasts it with a pre-quantum completeness that never existed. After all, pre-quantum mechanics, too, was incomplete. Its initial data were not even imagined to be specified by the theory. It is merely that it lumped this incompleteness at a beginning in the remote past, the creation of the universe. In quantum theory spontaneity is distributed throughout all time and space.

The fundamental processes of quantum physics are stateless acts, actions without passive objects. What Heisenberg discovered in 1925 he called a nonobjective physics, borrowing the term that Wasily Kandinsky had coined for his art in the same city in the previous decade. There is a prominent nonobjective tendency in mathematics, for example, in group theory and category algebra, and it appears in physics in Copenhagen quantum theory, though it encounters serious resistance.

At first glance, quantization does not seem to simplify. The unitary group of the quantum theory (which must be taken modulo the center) and its limit as $\hbar \to 0$, the canonical group of the classical theory, are both irreducible. The transition to quantum theory does not seem to simplify the canonical group, which was already simple.

To recognize quantization as simplification we must enlarge our transformations to include measurement processes. It is then a semigroup, not a group.

Classical mechanics evolved from astronomy. When we perceive a star classical thought neglects the change in the star, and then tacitly infers that any other object is equally unchanged by ideal observations. Classical physics naively omits measurement processes from the theory, as though we saw things as they "really are," as though that expression had meaning.

In the classical case the selective acts (filter processes, states, projection operators) form a semigroup that is an invariant subsemigroup of the dynamical semigroup of all possible actions on the system.

In the quantum case the dynamical semigroup is still not simple; it has invariant subsemigroups of determinant 0 and 1, for example.

But the projections no longer form a subsemigroup, let alone an invariant one. Thus quantum theory simplifies the dynamical semigroup. It unifies measurement (projection operators) and dynamics (automorphisms). It unifies knowing and doing. It fuses state and action by relativizing the state within the semigroup of actions, just as special relativity fused Galilean time and space/time by relativizing time within space-time.[2]

3. THE RETURN OF THE STATE

I call the doctrine that every system is an object with a state of being, in the prequantum sense already specified, and that all transitions are between these states "ontism." The doctrine advanced here is that the fundamental entities of nature are actions, whose entities actually have no state. I call this doctrine "praxism."

The primacy of operations is a crucial and salient feature of quantum thought and there have been many attempts to flatten it. Let me heighten it. By an object (or being) I will mean an entity that is completely defined by what it is, its state of being. The state of an object may be completely defined by a suitable injective action upon the being, and also by a suitable extractive action upon it. The collection of all the possible states an object can have is called its state space.

It was once imagined that the universe is an object composed of objects. It seems that it is not.

Heraclitus understated the case. We cannot step into the same river once; our step changes the river. And while all is flux, as he said, this holds not in the sense that everything changes its state, but in the sense that everything is nothing but change.

Some go further and say the atom does not exist. If by existence is meant having only the poor kind of being that objects have, I concur. But in fact we do see the atom, and more and more clearly with improving microscopy, only never completely. And we see it by its actions and reactions. It exists in the existential sense. Heisenberg dispensed with the state, not the atom. In atomic physics we prepare and observe atoms, not states.

Whence the "illusion" of being in pre-quantum physics, then? In pre-quantum physics all the injective and extractive actions under consideration are either the same or are orthogonal (have vanishing transition amplitude). This degenerate case is useful because for macroscopic systems two randomly chosen quantum actions are almost always orthogonal. To carry out a transition experiment on a macroscopic body that is neither compulsory nor forbidden involves such precision and such a removal of entropy that it becomes practically impossible, and so pre-quantum physics works, approximately. But there is no critical number of parts where suddenly an object materializes.

[2] I use the fraction bar for a nonsimple fusion, for example, for a fiber bundle whose fiber is the numerator and whose base is the denominator. I reserve the hyphen for simple fusions. Galileo already eliminated absolute space, but retained absolute time. Galileo had space/time, but space-time begins with Einstein.

It simply becomes harder and harder to notice the absence of one as the number of parts grows.

A maximal orthogonal collection of injective actions is called a frame. Since transitions within each frame are either compulsory or forbidden, just as in pre-quantum physics, each frame may be regarded as defining a limited or relative concept of being, relative to one experimenter. In pre-quantum physics there is only one frame for the system, composed of all its states, but in quantum physics there are many frames, each expressing some experimenter's choice of what experiments to do. Crescas and Giordano Bruno relativized the center of space, Galileo and Newton relativized the rest state, and Einstein relativized time; Heisenberg (and later, most explicitly, Dirac) relativized the frame, and thus being. Quantum theory extended relativity to a domain where Einstein refused to follow.

4. SOME REMAINING OBJECTS

This process is not over. The semisimplicity argument of Inonu and Wigner [1] is still a powerful one. It suggests now that all is quantum. Any element of quantum theory that seems to be an object will eventually resolve under closer scrutiny into a complex of nonobjective quantum actions.

The most conspicuous classical objects left in quantum physics today are the observer, the spacetime pointset, and the physical law. Today at the beginning of a calculation one usually postulates, mostly implicitly, that these are known in all their relevant properties, or may be known as completely as desired by physicists provided with enough time and capital.

4.1. Observer

Our concept of a theory is still based on an essentially objective conception of a symbol and its states. When we must take into account the spontaneity of everything, surely we must allow some to the experimenters in it. Quantum theory is remarkable in mentioning the metasystem (the system that studies the system under study), but providing no operations upon it, in mentioning the system–metasystem boundary and providing no way to move it. A still more quantum theory would seem to call for an at least partially quantum experimenter using at least some quantum symbols. Such an extension of quantum relativity may also occur in quantum computation and in cosmology.

4.2. Space-time

Space-time spoils the field bundle just as time spoiled the space/time bundle of Galilean physics. All field and string theories suffer from this fatal ailment. The result is a curious inconsistency with general relativity.

Gravity and quantum theory provide a well-known qualitative lower bound to the size of a space-time cell over which an average field of any kind can be measured with arbitrary precision. More precise localization than the Planck length and time results in a black hole that destroys what was to be localized. That provides an estimate of the short-time limit to field theory from the side of field theory. If we take quantum theory and general relativity seriously, this estimate is much too low.

To put the argument most simply, let us use $\hbar c$ units. Then the rationalized gravitational constant

$$\kappa = \frac{8\pi G\hbar}{c^5} = 7.2 \times 10^{-86}\ \mathrm{s}^2 := T_P^2 \tag{4.1}$$

(the form of Newton's constant G that is natural in field theory) is the square of the (rationalized) Planck time

$$T_P = 2.7 \times 10^{-43}\ \mathrm{s} \tag{4.2}$$

and the rationalized Planck energy is

$$E_P = \hbar/T_P \sim 2.4 \times 10^{27}\ \mathrm{eV} \tag{4.3}$$

Suppose that the best possible space-time localization is within a cell of volume τ^4. We call the fundamental time τ the chrone.

This cell can be considered to be merely a semiclassical way of treating whatever quantum uncertainties in position arise from space-time quantum structure, analogous to the cell of volume h^N in N-dimensional phase space introduced in semiclassical approaches to quantum mechanics.[3]

If we localize a field-meter operation within a space-time cell τ^4, then by the quantum uncertainty relation we inject an uncertain energy $E \sim 1/\tau$ into the cell. This is not the zero-point energy of the vacuum; it is the energy of the field-meter itself.

To avoid creating a black hole and terminating the measurement we must ensure that the Schwarzschild radius of this energy is less than τ:

$$2\kappa E \sim \kappa/\tau \lesssim \tau \tag{4.4}$$

This provides the well-known qualitative lower bound to τ:

$$\tau \gtrsim \sqrt{\kappa} = T_P \tag{4.5}$$

Let us extend this familiar reasoning one step further. The main assump-

[3] In fact we have in mind a stronger cellularity in the spirit of Yukawa's atomistic proposal [2]. Quantum network structures for matter-space-time exist that are consistent with Poincaré invariance and lead to a suggestive model of the internal unitary groups [3]. There τ is the scale time for the links in the quantum space-time net. The present note is relevant to, but not limited to, that theory.

tion is that quantum theory describes only processes that are possible in principle.

In many applications of quantum field theory we combine field operators at all points; for example, in the Hamiltonian. Thus the validity of quantum field theory requires not merely that the field at one space-time point can be measured, but also that a complete set of commuting field variables can be measured.

Ideally we need to be able in principle to measure the field at *every* point of a space-volume at one time-instant.

Suppose instead that we in fact can measure the field averages over space-time cells of scale $\lesssim \tau$ filling a cube of scale $\gtrsim T$. Again an uncertain energy $\gtrsim 1/\tau$ is injected into each cell, but now the number of cells is $\gtrsim N \sim (T/\tau)^3$, so the total injected energy is now $E \gtrsim N/\tau$. This creates a black hole terminating the measurement unless the Schwarzschild radius of this energy is $\lesssim T$:

$$\kappa E \sim \kappa \frac{N}{\tau} \sim \kappa \frac{T^3}{\tau^4} \lesssim T \tag{4.6}$$

This provides a stronger lower bound for τ than (4.5):

$$\tau \gtrsim (T_P T)^{1/2} \tag{4.7}$$

We fall back to the weaker estimate (4.5) if we require only that quantum field theory be meaningful over one minimal space-time cell, for then $T = \tau$. In general, however, the cell size τ must be $\gtrsim$ the geometric mean between the Planck time T_P and the system time T.

Dually, the high-energy limit E_{hi} for quantum field theory is not the Planck energy as sometimes stated, but the geometric mean between E_P and the low-energy limit E_{lo}:

$$E_{\text{hi}} \lesssim (E_P E_{\text{lo}})^{1/2} \tag{4.8}$$

The unification of space-time and field-matter that heals this cut has been begun elsewhere [3].

4.3. Dynamic

Again, in present quantum physics the law is regarded as an object, which may be completely known. This absolute, too, will be relativized in quantum cosmology. The law must be a quantum variable.

That the law is variable was proposed long ago by Newton, Peirce, Mach, and Wheeler, and lately by Landauer [5] and Smolin [6]. But this still leaves the split between law and system.

The only way to eliminate this split that I can see is to identify the dynamical law with the system under study.

Together with an assumption about statistics, this suffices to uniquely define a simplest "universal" action algebra $\mathfrak{Q}$, a Cifford algebra [4]. This extends the space-time unity of special relativity and the space-time-matter unity of quantum network dynamics [3] to a space-time-matter-dynamics unity that for short I call the dynamic.

Just as our determinations of spacetime geometry modify it slightly, through gravity, our search for the law of nature actively modifies it slightly as well. At least in a small degree we are law-makers as well as law-seekers.

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