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Time Symmetry and Cosmic Age

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A time-symmetric version of quantum mechanics provides a tentative solution of the cosmic age discrepancy in current cosmology. Due to retrocausal effects, the age of old stars is greatly overestimated.

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1. INTRODUCTION

Many problems in life can be addressed in different ways, and, judging by the number of its interpretations, the same holds true for quantum mechanics (QM). A major subcategory of interpretations are the various brands of "quantum logic," developed because of the peculiar logical structure of the theory. Suppose, however, one wants to hold on to classical logic, then how far can one get?

Within a classical framework, one must conclude that the standard formalism of QM is incomplete (see below), and structure must be added. But how much, and what kind of structure? As a second major subcategory of interpretations, various types of "hidden variable theories" offer logically complete alternatives to QM. Usually, these theories aim at more than merely completeness, however. For instance, they want magnitudes to have well-defined values at all times, or they aim to restore determinism: "God is not allowed to play dice."

Suppose, however, one does not care about this. Let God play dice and let magnitudes be partial, but let us still demand QM to be complete. Then how far can one get? Is there a third subcategory of interpretations, yielding a logically complete theory remaining much closer to standard QM?

There may be many ways of trying to stay close to standard QM in some way, but there are also theorems about unavoidable minimal deviations.

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So-called "no-hidden-variable theorems," such as those of Gleason, Kochen and Speckers, and Bell, hold for any theory with a classical structure. They imply that, in any complete classical theory empirically equivalent to standard QM:

- Standard physical magnitudes must be split, i.e., standard magnitudes, like the one we call "energy," are in fact classes of many different magnitudes.
- Some form of nonlocality must be admitted.

The first and perhaps major conclusion to be drawn from these theorems should be that, at least from the point of view of classical logic, standard QM is itself not complete. Evidently, no completeness claim can be acknowledged without, at least, clarity about how magnitudes are split and how nonlocality is effectuated. Although the discussion about QM is so muddled that even straightforward conclusions like this cannot be drawn uncontroversially, existing approaches in standard QM do contain various suggestions for meeting the above requirements in ways that are quite different from the usual hidden variable approaches. For instance:

- In Bohr's complementarity approach, magnitudes are defined only within the context of a specific "quantum phenomenon." In a, perhaps slightly vicious, reinterpretation of Bohr one may regard this as a form of splitting magnitudes *avant la lettre*, because, e.g., energy as defined in different phenomena is not necessarily the same quantity.
- The quantum theory of open systems suggests a nonstandard interpretation of magnitudes, where they are no longer described by self-adjoint operators.
- A time-symmetric probability measure introduced by Aharonov *et al.* (1964) leads to retrocausality, which is a form of nonlocality in Bell's sense.

2. QUANTUM PROCESS THEORY

On the basis of such ideas I have formulated (Hoekzema, 1993a,b) a theory called "quantum process theory," with the following basic structure:

Any sequence of events in a given time interval is represented by a linear operator V on a Hilbert space $\mathcal{H}$. Further, past events are represented by a Hilbert-space vector $|\mathrm{in}\rangle$, and, likewise, future events have an associated state vector $\langle\mathrm{out}|$. A triple $\langle\langle\mathrm{out}|, V, |\mathrm{in}\rangle\rangle$ defines a process state, and the quantum process described by it has an associated amplitude $\langle\mathrm{out}|V|\mathrm{in}\rangle$. Within an ensemble of processes, the probability of any given process being realized is proportional to the amplitude squared.

The relations to standard theory are quite evident, and empirical equivalence would be straightforward but for the problem that probabilities, in this theory, depend as much on the future state $\langle \text{out} |$ as on the past state $| \text{in} \rangle$. Equating $| \text{in} \rangle$ to the usual state vector of standard QM, one may wonder what happens to the extra out-state dependence, which does not seem to be observed at all. Bluntly said: in the real world, information can be transmitted from past to future, but not the other way around, and from a time-symmetric perspective this fact needs explanation. Therefore, I shall look for cosmic conditions such that, although in quantum process theory information can be transmitted from future to past in principle, this is not feasible yet, due to conditions prevailing in our part of spacetime, and, in particular, to the small age of the universe.

As it turns out, appropriate assumptions about future cosmic conditions then also lead to a tentative explanation of the cosmic age discrepancy, i.e., the embarrassing fact that the oldest stars seem to be about twice as old as current estimates for the age of the universe, as obtained by the Hubble space telescope.

3. TIME SYMMETRY

Looking at the night sky, one sees mainly blackness, with occasional specks of light, emitted by the hot surfaces of stars. Our eyes, thus, can absorb light, but, obviously, only from directions where it was once emitted by hot matter. In the reverse direction of time one would therefore, from symmetry considerations, expect that light can be emitted only in directions where, at some future time, it will be absorbed by matter. In reality, however, light can be emitted in any direction, indicating that there should be matter in all directions. This leads to two questions:

- Is there, indeed, enough matter in the future universe?
- Is this matter hot enough, or rather retro-hot enough, in the sense of being able to absorb radiation? (Note that it is necessary here to distinguish between hotness, the ability to emit radiation, and retro-hotness, the ability to absorb radiation, because the thermodynamic properties of the in-state may be quite different from those of the out-state.)

These questions have been investigated before, in the context of Wheeler and Feynman's time-symmetric theory of electromagnetism. Their theory was shown to be empirically equivalent to standard EM precisely under this condition of "complete absorption." Cosmological calculations (Hoyle and Narlikar, 1974; Davies and Twamley, 1993), however, indicate that the universe is too empty. Nevertheless, experiments have failed to show any evidence of future dependence (Partridge, 1973).

Within the present quantum process theory, the incompleteness of the standard quantum state is crucial for explaining this apparent contradiction. Because in process theory in- and out-states represent independent degrees of freedom, different temperatures can be associated with their thermodynamic properties, and this has important implications.

The blackness of the night sky indicates a low average temperature T_{in} of the in-state, caused by the youth of the universe, so relatively little radiation has been emitted yet, and by its expansion, causing a redshift of the radiation that *was* emitted, thus lowering the radiation temperature. Time reversed, both conditions point the other way. The time-reversed universe is very old and radiation is blue-shifted. This indicates a high temperature of the out-state, i.e., a large ability of absorbing radiation.

However, although this may explain a high T_{out}, the low matter density of the future universe remains a problem, as there can be no absorption in a direction where there is no matter. Accordingly, the expected low matter density of the future universe should lead to observable consequences. On the other hand, these consequences may not be as conspicuous as one might think. The high T_{out} of the matter that *is* available makes the situation comparable to looking at the daytime sky rather than the nighttime sky. That no stars can be seen at daytime is caused by scattering of the high-temperature solar radiation, not by complete absorption of their light in the atmosphere. The night sky is a magnificent illustration of the fact that a cloudless atmosphere is quite transparent.

Only a small part of the matter in the universe has a high in-temperature. Therefore, we see stars unless we are blinded by sunlight. If all matter has a high out-temperature, however, then, in the other direction in time, we may be blinded in whatever direction we look, even though the condition of complete absorption is not satisfied at all. One might say that dark matter is shining everywhere, if only in a different direction of time.

4. STELLAR AGES

Nevertheless, in spite of this blinding effect, there may be more subtle observable consequences. With the increase of time, the layer of matter separating us from the eventual great void becomes thinner and thinner. This should produce an effect comparable to what one may see high in the mountains, or from an airplane. The higher one gets, the darker blue the color of the sky will be, because the layer of matter scattering sunlight becomes thinner. Likewise, with the increase of time, as the layer of future matter becomes thinner, emitting radiation should gradually become more difficult, because there is less matter left to absorb it.

By the same token, emission must have been easier long ago. Therefore, stars radiated more light, and, consequently, they aged more rapidly. Taking reasonable assumptions about the expansion of the universe, a rough estimate of the effect can be obtained by a simple calculation (see below), leading to an apparent age given by

$$t_{\mathrm{app}} = t \ln(t/t_0)$$

where t is the present age of the universe and t_0 the time at which the star originated.

Estimating the age of the universe at 8 Gyr, the value suggested by recent Hubble measurements, we find that a star of 7 Gyr would appear to be $8 \ln(8/1) = 17$ Gyr old.

Evidently, this is quite the right order of magnitude for explaining the cosmic age discrepancy. Indeed, the universe turns out to be only half as old as the stars would lead us to believe.

5. CALCULATION

Assuming a star with constant surface temperature and therefore, according to standard theory, a constant power output $P = \sigma A T^4$, the age of the star is given by U/P, where U is the total energy radiated in the past, which determines the chemical composition of the star. For a cluster of stars, this age can be estimated from the Herzsprung–Russell diagram of the cluster.

In the normal direction of time, a light beam propagating in an absorbing medium of constant density and temperature approaches the thermodynamic equilibrium intensity I_{eq} according to

$$I(x) = (I_0 - I_{\mathrm{eq}}) \exp(-x/d) + I_{\mathrm{eq}}$$

where the mean free photon path d is determined by absorption in the medium and is proportional to the matter density. In a thin layer ($x << d$) and for small I_0 one has

$$I(x) \approx \frac{x}{d} I_{\mathrm{eq}}$$

Let us assume that this formula applies to the propagation of advanced radiation, backward in time through the future absorbing medium. This amounts to assuming that the effective future layer of absorbing matter is optically thin, temperature variations can be neglected, and the intensity of advanced radiation in the far future is vanishingly small. If we now interpret

I as the ability of the out-state to absorb radiation, then the power output of a star at time t becomes proportional to $I(x(t))$, where $x(t)$ is the effective optical thickness at time t of the future absorbing layer. Accordingly, the power output of the star will be given by

$$P(t) = \frac{x(t)}{d} P_{\text{eq}}$$

where P_{eq} corresponds to the case of complete absorption.

As $x(t)$ gradually decreases, so does $P(t)$. The effective optical thickness $x(t)$ is determined mainly by the future matter density, i.e., it is roughly proportional to the integral $\int_t^\infty \rho(s)\, ds$. Assuming a $k = 0$ Robertson–Walker metric, with $R \propto t^{2/3}$, and therefore $\rho(t) \propto t^{-2}$, one gets $x \propto 1/t$, where t is the age of the universe. Accordingly, one has, for arbitrary t_1, t_2,

$$P(t_2) = \frac{t_1}{t_2} P(t_1)$$

Recalculating the total emitted energy of the star now yields

$$U(t) = \int_{t_0}^{t} P(s)\, ds = \int_{t_0}^{t} \frac{t}{s} P(t)\, ds = tP(t) \ln\left(\frac{t}{t_0}\right)$$

where t is the present age of the universe and t_0 the age at which the star came into being. Comparing the apparent age of the star, $t_{\text{app}} = U(t)/P(t)$, to its real age, $t - t_0$, one finds that

$$t_{\text{app}} = t \ln(t/t_0)$$

6. CONCLUSIONS

Quantum process theory has some nice features, such as:

- It provides an interesting solution to the logical incompleteness of QM.
- It has very good symmetry properties, e.g., time reversal is described (Hoekzema, 1993b) by a linear operator rather than an antilinear one such as in standard QM.
- It provides a plausible explanation for the observed time symmetry in the present universe.
- It provides an elegant explanation for the observed cosmic age discrepancy.
- It is a consistent bicausal theory, admitting causal influence back in time, which makes it interesting if only for the study of causality

and for improving the quality of science fiction phantasies about time travel.

- It provides various clues for improving the compatibility between QM and relativity theory.
- It is great fun.

The present degree of acquaintance with theory is lagging behind its glorious qualifications, presumably due to bad PR, as well as to the general level of confusion in the quantum debate. Let us hope and expect that the effect of such factors is only temporary.

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