AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

June 1993

TAUP N230-93

DOE-ER40200-325

DECOHERENCE PLUS SPONTANEOUS SYMMETRY BREAKDOWN
GENERATE THE "OHMIC" VIEW OF THE STATE-VECTOR COLLAPSE

Yuval Ne'eman

Beverly and Raymond Sackler Faculty of Exact Sciences*
Tel-Aviv University, Tel-Aviv, Israel 69978

and

Center for Particle Physics†
University of Texas, Austin, Texas 78712

RECEIVED
JUN 10 1994
OSTI

ABSTRACT

The collapse of the state-vector is described as a phase transition due to three features. First, there is the atrophying of indeterminacy for macroscopic objects - including the measurement apparatus. Secondly, there is the environmental decohering mechanism, as described by Zeh, Joos and others - dominant in macroscopic objects. As a result, the classical background, an input in the Copenhagen prescriptions, is generated as an "effective" picture, similar to the "effective" introduction of Ohmic resistance or of thermodynamical variables, when going from the micro to the macroscopic; in this case, the collectivized substrate is provided by the multiplicity of photon scatterings, etc., on top of the effect of the large number of particles in macroscopic objects. Thirdly, there is the Everett "branching", i.e. the materialization of one of the now decoherent states, accompanied by the destruction of the other branches. By definition, quantum indeterminacy represents a symmetry; in a measurement, or in a branching, this symmetry is broken "spontaneously", involving a Ginzburg-Landau type potential with asymmetric minima, thus concretizing the quantum "dice" without the burden of "many worlds". We review and systematize the various phase transitions relating quantum to classical phenomena.

* Wolfson Chair Extraordinary in Theoretical Physics

† Supported in part by US DOE Grant DE-FG05-85-ER40200.

MASTER

The collapse of the state-vector is paradoxical in that it postulates a separate dynamical process for the description of measurements ("process 1" in Everett's notation [6]), whereas everything else is described by the Schroedinger equation ("process 2") for the case of non-relativistic quantum mechanics (or by the appropriate Dirac or Klein-Gordon, etc., for relativistic situations)**. Everett's work launched a program in which the fundamental physics is entirely quantal and does not require the Copenhagen classical framework. Process 1 then becomes a special case of process 2, in a treatment involving "relative states", emphasizing the fact that any amplitude represents a subsystem of the "world function of the universe". Zeh and Joos [7-10] have improved on this program by showing how the classical framework input of the Copenhagen prescriptions emerges as a result of the interaction with the environment.

This picture has recently been given a path-integral formulation by Hartle and Gell-Mann [11]. What is still not resolved in this approach is the dice-throwing: the concretization of one of the decoherent components in the resulting universal amplitude, while the other branches appear to live on. This is the feature which causes the Everett scheme to be described as involving a "many-world" interpretation - the worlds in which the other branches become concrete instead.

I have suggested [4,12] that this involve a spontaneous symmetry breakdown mechanism (SSB). The measurement (or other branchings') Hamiltonians would then contain a potential with asymmetric minima. This formulation does away with the "many world" implications of the unrealized branches - thus answering the criticism expressed in the "Note added in proof" on p. 320 of ref. [6], without negating the Popperian falsification requirements for scientific theories, a weak

** The choice is unfortunate, since "process 2" is the basic modus operandi of Quantum Mechanics. We have however preserved the notation, to reduce confusion.

"a phenomenon is not yet a phenomenon until it has been brought to a close by an irreversible act of amplification, such as the blackening of a grain of silver bromide emulsion or the triggering of a photodetector"

thus generalizing the apparatus' dial. In a macroscopic object, the $(\Delta x, \Delta p) \leq h$ uncertainty is shared by N particles, thus reducing the uncertainty per particle. In the apparatus' amplitude (s is the action per particle, S the total action)

$$\chi = c e^{iS/\hbar} = c e^{iNs/\hbar} \quad (2.1)$$

the $N \rightarrow \infty$ limit yields the same effective results as $\hbar \rightarrow 0$.

The now effectively classical combined object, apparatus together with measured quantum system, is then exposed to decohering multiple scatterings.

For an apparatus $|\chi(0)\rangle$ and a system $|\Phi(0)\rangle = c_1|q(0)\rangle + c_2|q'(0)\rangle$, the Schroedinger common evolution runs according to

$$|\Phi(0)\rangle|\chi(0)\rangle \rightarrow c_1|q(t)\rangle|\chi^q(t)\rangle + c_2|q'(t)\rangle|\chi^{q'}(t)\rangle \quad (2.2)$$

The density matrix $\rho(q, q', t)$ is multiplied by the overlap of the two resulting states of the apparatus,

$$\rho(q, q', 0) \rightarrow \rho(q, q', t) = \rho(q, q', 0) \langle \chi^{q'}(t) | \chi^q(t) \rangle \quad (2.3)$$

with interference terms becoming unobservable if

$$\langle \chi^{q'} | \chi^q \rangle \approx \delta(q - q') \quad (2.4)$$

In the language of sums-over-histories this defines a decoherence matrix (for this fine-grained case)

$$D[q'(t), q(t)] = \delta(q - q') \exp 2\pi i \{ (S[q'(t)] - S[q(t)]) / \hbar \} \rho(q', q, 0) \quad (2.5)$$

which yields for coarse-grained histories, with the two paths $q(t)$ and $q'(t)$ allowed respective variation ranges $\Delta(t)$, $\Delta'(t)$,

$$D[q'(t):[\Delta'(t)], q(t):[\Delta(t)]] = \quad (2.6)$$

$$\int_{[\Delta']} \delta q' \int_{[\Delta]} \delta q \delta[q'(t_f) - q(t_f)] \exp 2\pi i \{ (S[q'(t)] - S[q(t)]) / \hbar \} \rho(q', q, 0)$$

The integration is over all that is unspecified: here, over the range of values of the $q(t)$ and $q'(t)$, with their final values coinciding.

As a result of (2.4), when the off-diagonal elements of (2.6) will be sufficiently small, the amplitude (2.2) decoheres and the two states it describes become approximately orthogonal, with $|c_{1d}|^2$ and $|c_{2d}|^2$ (the coefficients of the post-decoherence orthogonal states) providing the respective materialization probabilities.

3. SPONTANEOUS SYMMETRY BREAKDOWN FOR DICING

We now have to represent dicing, namely the realization of one state and the destruction of the amplitude for the other. Note that we have no such problem with classically derived probabilities, since they are a-priori derived as statistical probabilities. The quantum probability derives from the quantum postulates for the amplitude, with the definition strongly tied to process 1 (the state-vector collapse). With Everett, we assume that the quantum amplitude is the only existing "underlying reality", as resulting from the Bell inequalities and the Aspect experiment; note that we are using the EPR terminology, even though we imply its opposite, since EPR were assuming a deterministic causal and local underlying reality. Having adopted the view in which physics is indeed a-priori quantal, we now have to complete the "liberation" process of the emerging classical result by ridding it of the residual unrealized piece of the quantum amplitude.

We note that the "loss of uncertainty + decohering + dicing" combined process (=the collapse) occurs both in measurement and in all similar branchings.

Of course, we have just replaced the many worlds incongruity by the ad-hoc insertion of an SSB potential, every time there is a process involving a macroscopic body. The aim should be to derive the SSB potential from the environment-generated decoherence process itself.

We have dealt elsewhere with criteria of "macroscopicity" [18]. Suffice it to say that these are based on the superposing of Joos' derivation of some classical features observed in spacetime [9] (namely the lack of phases and thus of quantum interference) from decoherence processes caused by the environment (e.g. dust particles "falling" in a gravitational field) with the other quantum restriction on spacetime - namely the emergence of the Planck length - providing a limit on pointlike smoothness and continuity. Our result indicates that Planck mass is also the lower bound for macroscopic objects with spatial extension exceeding their DeBroglie-Compton wavelengths; it is the upper bound for quantum behaviour not involving long-range correlation.

4. CLASSICAL TO QUANTUM AND QUANTUM TO CLASSICAL

In this context, it is worth reviewing the class of phase transitions relating a classical to a quantal phase. Very roughly, we have the "recognized" transitions,

- a) the low temperature classical to quantum transitions
(superconductivity, superfluidity)
- b) the classical to quantum transitions induced by gravitational collapse
(white dwarfs, neutron stars, black holes)

to which we have just added the set,

generalized apparatus decreases its indeterminacy, with the $N \rightarrow \infty$ limit yielding similar results to those of $\hbar \rightarrow 0$. The now effectively classical object is then exposed to the decohering multiple scatterings, followed by the dicing transition. In this sequence, it is the quantum phase which is intrinsically symmetric, due to quantum indeterminacy. This symmetry is destroyed together with the phases, with dicing completing the transition to a less-symmetric (and more ordered) classical phase. As discussed in ref.[12], the symmetry-breaking arrow points here in a direction opposite to that of the classical to quantum macroscopic transitions (a-b). The order parameter in (c) is the measured variable $q(t)$. The number of particles N and the number of decohering scatterings $N'(N)$ determine the abstract temperature, which is their inverse (see (2.1)), very roughly

$$T(c) \approx 1/N \text{ or } 1/N' \quad (4.3)$$

so that the ordered phase, using (4.1), is indeed the classical phase. Note that it is in the dicing transition we described in sec.3 that $q(t)$ and its classical parallel σ play the role of $M(x)$.

5. Conclusions

This treatment of (c), the canonical quantum to classical transition, thus provides a sound qualitative and formal basis for a physics in which the quantum description is the only one at the fundamental level. It would be interesting to check whether this phase transition aspect - if pursued further in a more evolved treatment - might yield new relations and some experimentally testable results, perhaps in combination with our gravity generated criterion of macroscopicity [18].

The combined phase transition (c) thus yields an effective picture fitting the Copenhagen prescriptions. In this presentation, these prescriptions - including the necessary classical apparatus - are now

rabbi can do!" was the reaction.. If Ohm as a highschool teacher could do what he did, imagine what should be the required standards, here in Cologne.. This may explain why I have had such a fruitful collaboration with Friedrich Hehl and his group..

We thus contend that with the transitions (c), the Copenhagen systematics receive an Ohmic interpretation; improving this derivation as suggested could be described as the Cologne program (1993). Its completion would allow us to postulate an overall quantum foundation for physics, ruled by orthodox quantum equations ("process 2") and with no need for "prescriptions".

13. See for example Frederick Brown's "What Mad Universe", with General Eisenhower conducting the war against Arcturus..
14. Ghirardi, G.C., Rimini, A. and Weber, T., "Unified dynamics for microscopic and macroscopic systems", Phys. Rev. D34 (1986) 470-491.
15. Haake, F., "Decay of Unstable States", Phys. Rev. Lett., 25 (1978) 1685.
16. Wheeler, J.A., in Proc. Am. Phil. Soc. and Roy. Soc. Joint Meeting, 5 June 1980, Am. Phil. Soc. Pub. 1981, pp. 9-40.
17. Peierls, in Symposium on the Foundations of Modern Physics, P. Lahti and P. Mittelstaedt editors (Proc. Joensuu 1985 Symp.), World Scientific, Singapore (1985), pp. 187-196.
18. Ne'eman, Y.N., "Localizability and the Planck Mass", Phys.Lett.A, to be publ.
19. 't Hooft, G., NATO Adv. Study Inst. on Recent Developments in Gauge Theories, Series B, 59 (1980) 117.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**DATE
FILMED**

7/12/94

END