Book review

Maximilian Schlosshauer, Decoherence and the Quantum-To-Classical Transition
(Springer, Berlin, 2007, Corrected Second Printing, 2008), xv+416 pp., ISBN 978-3-540-35773-5, hardcover, 74.85 euro.

Decoherence is like capitalism. Its proponents regard it as obvious, given human nature, and its success seems overwhelming. Competitors largely belong to the past, or get the impression they do. Consequently, although serious analysis finds deep flaws in it, the promise of huge benefits continues to attract new adherents with the naivety of those who enroll in a pyramid scheme.

Indeed, although decoherence was originally proposed as a *solution* to the measurement problem of quantum mechanics, in actual fact it *aggravates* this problem (Bacciagaluppi, 2004). For, where previously this problem was believed to be man-made and relevant only to artificial laboratory situations, we now hear that 'measurement' of a quantum system *by the environment* (rather than *by an experimental physicist*) happens everywhere and all the time: new superpositions build up continuously and totally beyond human control, Schrödinger's Cat so to speak growing up to a monster the size of the entire Universe. Hence my comparison with pyramid funds, reinforced by the way decoherence theorists have raised the stakes even further (Zurek, 1991) in claiming that their approach not merely addresses the measurement problem but even explains the entire quantum-to-classical transition (as in the subtitle of the book under review), or, phrased differently, the appearance of the classical world in quantum theory (Joos et al., 2003). As a case in point, the author of the book under review is quite explicit in claiming that decoherence indeed performs this job: "For all practical purposes of the working physicist, decoherence provides a complete and self-contained framework for a qualitative and quantitative description of the quantum-to-classical transition." (p. 10), or even: "Why, then, did it take another forty years [after EPR] for researchers to recognize the crucial importance of environmental interactions and entanglement for the explanation of how the classical world emerges from the quantum domain?" (p. 6).

What, then, can be meant by this claim? According to Schlosshauer (p. 56), "the measurement problem (and the problem of the quantum-to-classical transition) is composed of three parts (...):

1. *The problem of the preferred basis* (...)
2. *The problem of the nonobservability of interference* (...)
3. *The problem of outcomes* (...)"

He then goes on to argue in great detail that decoherence solves the first two problems, notably through Zurek's notion of *einselected* states: these are states in the Hilbert space of the system that are robust under coupling with the environment. Wetting our appetite, Schlosshauer announces that the third problem will be discussed in the last two chapters of the book on interpretations and observations.

Before getting there, he takes his reader through a very fine tour of the decoherence program in all its facets. First, following a crash course on the elementary formalism of quantum theory he reviews the basic ideas of decoherence, including an interesting discussion of the two-slit experiment from the point of view of entanglement and decoherence. He then explains an early but still impressive and generic example of decoherence due to scattering of thermal photons and air molecules, continuing with the formulations of decoherence in terms of Master Equations. This also includes a brief discussion of the Lindblad formalism. Quantum Brownian motion, the Spin-Boson Model, Spin-Environment models, Buckey Balls (i.e. C_{70} molecules), SQUIDS, you name them, Schlosshauer explains them. Considerable attention is also payed to the (potentially detrimental) effects of decoherence on quantum computation and quantum error correction. This is a large amount of material, which due to its unity as well as the precision and clarity of writing should be more easily accessible to philosophers of physics than the original papers on which it is based. Also, the joint coverage and interplay of both theoretical and experimental aspects of decoherence is very welcome.

Here it has to be stated quite clearly that the successes of the decoherence program as described in these pages are not only predicated on a solution of the problem of outcomes (which are simply *assumed* to occur), but also on a certain tacit manoeuvre (Janssen, 2008). Namely, despite Schlosshauer's insistence that "the decoherence program is derived solely from the well-confirmed Schrödinger dynamics" and that accordingly this program "attempts to explain the emergence of classicality purely from the formalism of basic quantum mechanics" (p. 337), in actual fact the whole program hinges on an interpretational move that cannot be read off the Schrödinger equation or any other ingredient of the formalism. The move in question is the assumption that in the generic case that the einselected states form a basis (perhaps approximately), this 'preferred' basis is taken to be the one over which the theory is interpreted—in particular, with respect to which the Born probabilities are calculated. Nothing in the formalism dictates this procedure (whose empirical correctness is unquestionable, but that is not the point!).

My curiosity about Schlosshauer's solution to the problem of outcomes was only satisfied on the penultimate page of the main body of the book, where he actually has a 'coming out'. He argues that, provided it is underwritten by decoherence, the many-minds interpretation of quantum mechanics stands a chance of solving the third problem: "The conjecture is then that, because the different conscious versions of the observer would not be 'aware' of each other, from the inside perspective of the observer one should be able to account for the empirically required perception of definite measurement outcomes (...)." Since, according to Schlosshauer's overall analysis, no other interpretation successfully accounts for these outcomes (and right he is), depending on where one stands with regard to the many-minds interpretation one is implicitly left with the choice between:

- either seeing this combination of many-minds and decoherence as *the* explanation of the classical world from quantum theory,
- or else regarding Schlosshauer's analysis as a *reductio ad absurdum* proof against his own claim that decoherence explains the quantum-to-classical transition.

Leaving this choice to the reader (his as well as mine), it has to be stated first and foremost that as a detailed survey of the decoherence program as it originated with Zeh and has been greatly expanded by Zurek, Schlosshauer's book is highly recommended. As an account of the quantum-to-classical transition or the appearance of the classical world, however, it is fundamentally incomplete, like the entire body of work on which it is based. As I pointed out before (Landsman, 2007), this is because decoherence, combined with whatever interpretation of quantum mechanics, can only be part of the explanation why quantum systems under certain conditions behave classically. To achieve its goal, decoherence will have to be combined with the more traditional classical limit of quantum mechanics, be it either the $\hbar \to 0$ limit where Planck's constant becomes (effectively) small or the $N \to \infty$ one where the size of the system becomes large. Without such a limit (which, though mathematically formulated, simply singles out a certain physical regime) it is not possible to account for two aspects of the quantum-to-classical transition that are at least as important as the three points quoted above Schlosshauer does take into account, namely the dispersion-free nature (or commutativity) of classical observables and the convergence of quantum-mechanical time evolution to classical dynamics. I was, in fact, astonished that a book with such a subtitle puts $\hbar = 1$ already in the Preface and does not even mention Ehrenfest's Theorem, the WKB-approximation, or the notion of a macroscopic observable (not to speak of the modern mathematical implementations of these ideas in microlocal analysis and C*-algebras). It also fails to link decoherence with the Consistent Histories program, which seems a good vehicle for discussing dynamical issues in the context at hand. Indeed, one may even surmise that a combination of decoherence with the classical limit might eventually solve the problem of outcomes, removing the need for such desperate remedies as the many-minds interpretation. Thus the above-mentioned dilemma implicitly posed by the book may well turn out to be a false one.

In addition, the book contains a numer of inaccuracies one wouldn't expect of a former PhD student of Arthur Fine. For example, anticipating his praise of decoherence for its revolutionary move of abandoning the notion of an isolated system, Schlosshauer writes: "Yet, the ubiquitous and idealized notion of isolated systems remained a guiding principle of physics and was adopted in quantum mechanics without much further scrutiny." (p. 1). I would say that *all* of Bohr's writings on the foundations of quantum mechanics draw attention to the fallacy of assuming that isolated quantum systems exist (or even make sense conceptually). And later on, he claims that in the Copenhagen Interpretation “classicality ought to be viewed as an indispensable and irreducible element of a complete quantum theory” (p. 335). Indispensable? Yes. Irreducible? No: the spirit of the Copenhagen Interpretation is best captured by the well-known motto of Landau & Lifshitz (1977, p. 3): “Thus quantum mechanics occupies a very unusual place among physical theories: it contains classical mechanics as a limiting case, yet at the same time it requires this limiting case for its own formulation.”

To conclude, although a philosopher of physics would have appreciated a rather more critical stance towards decoherence (Bacciagaluppi, 2004; Janssen, 2008), and despite the fact that the program of deriving classical physics from decoherence along the lines discussed in the book is incomplete, Schlosshauer has written an excellent survey of a field that is of the greatest possible interest for the foundations of quantum physics. Like capitalism, decoherence seems here to stay.

References

Bacciagaluppi, G. (2004). The Role of Decoherence in Quantum Theory. *Stanford Encyclopedia of Philosophy*, (Winter 2004 Edition), Zalta, E.N. (Ed.). Online only at `http://plato.stanford.edu/archives/win2004/entries/qm-decoherence/`.

Janssen, H. (2008). *Reconstructing Reality: Environment-induced Decoherence, the Measurement Problem, and the Emergence of Definiteness in Quantum Mechanics* (M.Sc. Thesis, Radboud University Nijmegen). Available at `www.math.ru.nl/~landsman/scriptieHanneke.pdf`).

Joos, E., Zeh, H.D., Kiefer, C., Giulini, D., Kupsch, J., & Stamatescu, I.-O. (2003). *Decoherence and the Appearance of a Classical World in Quantum Theory.* Berlin: Springer-Verlag.

Landau, L.D. & Lifshitz, E.M. (1977). *Quantum Mechanics: Non-relativistic Theory.* 3d Ed. Oxford: Pergamon Press.

Landsman, N.P. (2007). Between classical and quantum, *Handbook of the Philosophy of Science Vol. 2: Philosophy of Physics*, pp. 417–554. Eds. J. Butterfield and J. Earman. Amsterdam: North-Holland/Elsevier.

Zurek, W.H. (1991). Decoherence and the transition from quantum to classical. *Physics Today* 44 (10), 36–44. Updated version available at `arXiv:quant-ph/0306072`.

N.P. Landsman
Radboud Universiteit Nijmegen
IMAPP, Heyendaalseweg 135
6525 AJ NIJMEGEN
THE NETHERLANDS
E-mail address: `landsman@math.ru.nl`