Review: Christopher G. Timpson, *Quantum Information Theory & the Foundations of Quantum Mechanics.* Oxford, UK: Oxford University Press (2013), 293 pp., $85.00 (hardcover).*

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A philosophical treatise of high calibre, Timpson's book draws on insights from the philosophy of language, from general philosophy of science, from epistemology, and from metaphysics to inform detailed analyses of the concept of quantum information, of its role in quantum informational protocols, and of its significance for the wider philosophy of quantum mechanics. Those with a philosophical interest in the concept of information (quantum or otherwise) and in information theoretic approaches to science are strongly encouraged to read this work. Those interested in the philosophy of quantum information theory in particular, and in its significance for the foundations of quantum mechanics, would be unwise not to.

The book is very well and clearly written: the prose is lucid and the structure is transparent, and despite the intricacy and complexity of the subject matter it is accessible to a wide audience. For the most part it is also self-contained, in the sense that one needn't draw on outside sources in order to comprehend, at least superficially, the contents and subject matter of the book. Thus in addition to being a scholarly work of high importance, it is suitable to read as part of a graduate (or advanced undergraduate) philosophy seminar dealing with these topics. Indeed any graduate course on the

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philosophy of quantum information whose syllabus did not include at least a portion of this book would, in this reviewer's opinion, be lacking.

Regarding the content, let me begin with a few words about what the book is not. First, those hoping to *learn* the science of quantum information should look elsewhere. Timpson's exposition of the technical machinery of classical (i.e., Shannon) and quantum information theory is done in a clear, careful, and accessible manner, and for its primarily philosophical purposes the book is for the most part self-contained. However Timpson's book is no substitute for a more thoroughgoing technical introduction to the topic such as Nielsen and Chuang's classic text. The book is also nowhere near to a comprehensive survey of all of the philosophically interesting research presently being done in quantum information theory. There is little or no mention, for instance, of information theoretic measures of quantum correlations, or of the resource theory of entanglement; nor of their potential (or lack thereof) for illuminating quantum foundations. Neither is the book devoted in any really significant way to quantum *computation*. Timpson's three-page discussion of quantum computation in his expository chapter on quantum information theory is largely superficial. His otherwise quite illuminating chapter on the status of David Deutsch's 'Turing principle', on the other hand, is neither an introduction to quantum computation, nor a detailed analysis of how quantum computers work, nor is it even (at least for this reviewer) a discussion of one of the more pressing philosophical issues related to the science of *quantum* computing in particular. Thus, those wishing to learn more about these topics are advised, again, to look elsewhere. But with respect to the book's actual goals: of clarifying the concept of quantum information, and of clarifying the relation of the theory of quantum information to the foundations of quantum mechanics, the book is highly relevant, wonderfully executed, and its claims are powerfully argued for.

'Information', for Timpson, is an abstract noun, and one can explicate it most generally in terms of the verb 'inform'. In the 'everyday' sense, to inform is to make known to someone something that was previously unknown; it thus involves and is closely associated with such concepts as knowledge, language, meaning, and the concept of a person. Not so for the *technical* sense of inform, which is the object of both the Shannon and quantum theories of information. The failure to recognise that there is a distinction between these two senses has, according to Timpson, led to a number of confusions in the philosophical literature on information (such as Dretske's 'semantic naturalism', discussed in Chapter 2). As for the main topic of concern of the book, it is information in its technical sense; i.e., what Timpson refers to as 'information$_t$'.

Timpson defines information$_t$ as "what is provided by an information$_t$ source that is required to be reproducible at the destination if the transmission is to be counted a success" (p. 22). Just what this something provided by an information$_t$ source—what a piece of information$_t$—is, for Timpson, is most correctly thought of as a type. For instance, a sequence such as $x_2x_4x_1x_9 \ldots x_6x_8x_3x_1x_2$ (in the quantum case the x_i will be quantum state descriptions) is a type that is capable of being instantiated by various concrete tokens (one of which is the particular collection of markings printed on this page). It is not these tokens which are required to be transmitted if the communication is to count as being successful. Rather, what is required is only that another token of this type be produced at the destination. Thus it is the *type* which must be transmitted. Once we are clear on this, i.e. on the fact that information$_t$ transfer does not essentially consist in the flow of some spatiotemporally located *thing* called 'the information$_t$', then we see, according to Timpson, how to dissolve many of the mysteries associated with quantum informational protocols like quantum teleportation (Chapter 4). And just in case one thought the approach of Deutsch and Hayden might be used to explicate a notion of quantum information 'flow', Timpson's fifth chapter should convince one that this approach is not a viable one for that purpose.

So much for what (quantum) information *is*. In the last part of the book, Timpson takes up the relation between quantum information theory and the foundations of quantum mechanics, and along the way evaluates a few of the more important extant information theoretic approaches to quantum foundations. These include, most notably, the information theoretic axiomatisation of quantum mechanics due to Clifton, Bub, and Halvorson (CBH), as well as the quantum Bayesianism of Caves, Fuchs, and Schack. Timpson's discussion of the latter in particular is remarkable for its clarity and magnanimity. The proponent of quantum Bayesianism is no 'straw man' under Timpson's treatment, and Timpson dismembers many of the more common objections to the view (Chapter 9), before presenting a number of other more serious (though not insurmountable) challenges (Chapter 10). In the end, however, the question of the viability of quantum Bayesianism is, for Timpson, largely orthogonal to the question of the relevance of information theory to the foundations of quantum mechanics. For the quantum Bayesian, the quantum state description is nothing more than a representation of our subjective degree of *belief* regarding the probabilities of various experimental outcomes. Information, however, is *factive*, and hence inherently objective. Thus whatever we think of the merits of the view, the quantum state description cannot represent information for the quantum Bayesian (p. 203). Timpson's evaluation (Chapter 8) of Clifton, Bub, and Halvorson's axiomatic approach to the link between information theory and quantum mechanics is also negative. It is not the case, Timpson argues, that the the CBH characterisation theorem shows us that the aim of fundamental physics is to represent and manipulate information, nor is it the case that the CBH characterisation theorem shows that quantum mechanics must be interpreted as a principle theory like Special Relativity.

Without doubt, Timpson's deflationary explication of information$_t$ represents an important positive contribution to the philosophy of (quantum) information. Nevertheless the overall thrust of Timpson's monograph (in the second half especially) is negative. Thus, regarding the relation between quantum information theory and fundamental physics: quantum information theory does not, for Timpson, add a new kind of stuff to our catalogue of physical concepts; nor, for Timpson, does it demand that we reinterpret our existing physical concepts in light of it. But what can we say that is *positive* about the relation between quantum information theory and quantum mechanics? Timpson does make a few gestures in this direction: quantum information theory contributes to our understanding of the foundations of quantum mechanics by encouraging us to ask new kinds of questions and by suggesting new frameworks for inquiry; moreover it highlights the fact that progress in theoretical physics needn't always be made by successfully postulating new kinds of stuff (p. 239). This is all very well said. However, apart from an all too short discussion of generalised probability theories in §8.4, Timpson does very little more than make gestures at these potential positive contributions. Yet it is precisely these which this reviewer, and I am sure many others, would have preferred to read about. In fairness to Timpson, however, it is sometimes necessary to clear the road of obstacles before one ventures to travel down it.

In any case, let me reiterate that Timpson's book is a must read for those interested in the topic of quantum information theory. Moreover it is an important contribution to the philosophy of information theory in general, and I have no doubt that it will be much discussed in the years to come.