



Quantum Computing without Magic Devices. Zdzislaw Meglicki. The MIT Press, 55 Hayward Street, Cambridge, MA 02142, USA. 2008. 422 pp. Price: US\$ 35.

Quantum computation has generated tremendous interest among scientists and general public, and several books have been written on this subject. This book has unique feature that it attempts to alleviate the aura surrounding quantum mechanics, even after almost a century of its success. The provocative title of this book is therefore quite appropriate. It has an interesting preface and tells us that 'quantum mechanics is a probability theory'. Rightly so the book takes probability as a starting point, which is lucidly introduced in Chapter 1. This chapter lays the groundwork and introduces the reader to probability as practised in everyday life, i.e. in classical physics. Introduction of 'fluctuating registers' is a clever ploy to lay the foundation of probability in quantum mechanics. Introduction to mixed and pure states follows in a logical manner.

Chapter 2 again provokes the reader by referring to the 'evil quanta'. Convincing arguments are put forward for the omnipresence of quantum mechanics by showing that if the laws of classical physics were to hold for the microscopic world, 'we would not be here'. This view is further corroborated by stating the well-known fact that the Boltzmann distribution can, under certain conditions, be derived from Fermi-Dirac and Bose-Einstein statistics, but not the other way round. The magic is further demystified by explaining that the measurement of the microscopic world needs a macroscopic apparatus. This raises a can of worms, such as 'what does it mean to "observe"'. The idea that observation or measurement of a quantum state will destroy it is explained by the following argument. If instead of light, we needed an exploding bomb to observe the classical world, then also the act of observation

would have destroyed the observed object. The author emphasizes this by stating that the microscopic world is so delicate or fragile, that even bouncing a single photon can change its state dramatically. Non-locality of the quantum world logically follows using Heisenberg's uncertainty principle. The well-known paradox in quantum mechanics that 'it is not just the act of shining light onto an object that affects it, but when the observer detects it', is discussed in some detail. This paradox led Einstein to describe it as an 'evil quanta'. That the result of measurement in the microscopic world must be interpreted in a probabilistic manner is well brought out, concluding that 'even Einstein had to accept it'.

Introduction to qubit states that a 'qubit' can be described in terms of a 'fiducial vector', which is then used to illustrate the fundamental difference between classical and quantum systems. A detailed description of the Stern-Gerlach experiment leads to polarized states and onto the Bloch sphere. The Bloch sphere highlights the quantum nature well, since every point on its surface represents a pure state, which are infinite in number and demonstrates the infinite ways a quantum bit can exist, unlike a classical bit which can exist in only two states. The concept of mixed states follows logically from the Bloch sphere as a point inside the sphere, with the centre of the sphere representing a completely mixed state such as an unpolarized photon.

Chapter 3 introduces Hamiltonian and density matrices through the concept of quaternions. Pauli spin matrices are used to bridge the two and expectation values give way to probability measurement. This is one of the best introduction to density matrices and certainly removes some of the 'magic' associated with these quantities. Once these two concepts are introduced, unitary transforms and results of measurements in quantum mechanics are clearly understood. Basis vectors and Hilbert space are the media through which quantum systems are described. Some interesting facts pop-up while thumbing through this book. The von Neumann equation, which describes the evolution of density matrices, is equated to the 'qubit' evolution equation. (Do not miss the brief description of von Neumann's personality at the bottom of p. 104.) The magic of quantum mechanics is simply overcome in this chapter by equating the evolution of the density

matrix under a Hamiltonian to the evolution of quaternions as a straight-forward mapping and then asking 'why does it work'. The author answers it by asking: 'when can an arbitrary complex matrix be a density operator' and proceeds to show that it must be Hermitian, must have a trace of equal to 1, and must be positive because he further shows that for pure states the density operator must be idempotent ($\rho^2 = \rho$). The 'magic' is removed by showing the same proof for 'quaternions' on p. 151. A reassuring statement follows; that the above properties of the density operator of a pure state extend to quantum systems of dimensionality higher than single qubits, to multi-qubit systems and even to infinite-dimensional systems. The Schrödinger equation is presented as a special case of the von Neumann equation, rather than the other way round.

Single-qubit gates are introduced using a NOT gate and demonstrating that the NOT gate applied to a coherent superposed state reproduces the state within an overall phase factor of (± 1). While the NOT operation is shown as a 180° rotation of the Bloch ball around e_x , the Hadamard gate is introduced as a square root of NOT, i.e. a 90° rotation about e_x , demonstrating that starting from a state $|0\rangle$ it produces a coherent superposition state of $(|0\rangle + |1\rangle)/\sqrt{2}$. Berry phase is introduced with a nice title, 'Taking qubit for a ride', but do not get carried away that this will read like a story. Elaborate mathematical proof is given for the Berry phase in its adiabatic journey. Later, the author gives examples of experimental observation of Berry phase using ultra cold neutron. A nice demonstration of the Berry phase by NMR was done by Alex Pine's group in UC Berkeley, which in my opinion deserves mention. What about non-adiabatic transport over a closed loop? Aharonov and Anandan (*Phys. Rev. Lett.*, 1987, **58**, 1593) demonstrated that this also gives a geometric phase similar to the Berry phase. Several NMR groups have demonstrated the observation and use of such a phase in NMR quantum computing, which deserve mention.

Chapter 5 introduces a two-qubit system named 'biqubit', which forms the heart of a quantum computer. Using again probability arguments, the author systematically guides the reader through an elaborate algebra towards entanglement and Bell states. He then clarifies that the

verb 'entanglement' has two meanings, both leading to paradoxical situations which were recognized way back by Einstein, Podolsky and Rosen in 1935, also known (according to the author 'affectionately') as the EPR paradox. At this point the author asks the question 'how do we know that entangled states exist at all?' He proceeds to demonstrate that in the helium atom the two electrons, obey Pauli's exclusion principle, that antisymmetrizes the multi-electron wave function, which in turn implies entanglement. This property is of course obeyed by Fermions. At this point the author becomes eloquent and states that

'in lay man term, Fermions hate being like the other guys, are individualistic; if there is a Fermion nearby that does something and we happen to be an identical Fermion, we will do our best to be different, dress differently, drive a different car, look the other way and preferably get out of the neighborhood as soon as possible. On the other hand Bosons love to be together and to be alike; 'I am having what she is having'. If a Boson is driving on a freeway, a whole pack of Bosons soon will be driving in the same direction, right next to each other – this is how super fluidity works: cats are Fermions and dogs are Bosons; beautiful, eloquent.

The author examines in detail the question 'Are the qubits really entangled' and after detailed discussion of non-locality and separate-ability criterion, comes to the conclusion that to entangle two qubits we must have a non-trivial rank two coupling between them. Such a coupling is indeed provided in NMR as the J-coupling. Non-unitary evolution giving rise to depolarization or decoherence is discussed in detail. The colourful story of the Schrödinger's cat, whether 'dead' or 'alive' is explained in a manner that takes the 'magic' out of it.

Chapter 6 deals with controlled-NOT gate, which is the heart of most quantum computing. The author points out that the controlled-NOT gate, sometimes called the 'measurement' gate, since it can be used to measure a qubit while looking at the other, is only true in classical digital computing. In quantum systems it does not allow us to carry out non-demolition measurement. Furthermore, the controlled-NOT creates entanglement if the control qubit is in coherent superposition state (eq. (6.15)). Later, the author describes

general bi-qubit unitary gates. Three qubit gates and the Deutsch gate lead to the Toffoli gate, all of which are discussed in great detail. Experimental demonstration of controlled-NOT operations is discussed with reference to linear Paul trap of ions (Cirac-Zoller gate) using laser cooling, Doppler cooling, and superconducting controlled-NOT gate by the Japanese group and Dutch group.

In the final chapter, use of the controlled-NOT gate in quantum computations is described. First the Deutsch oracle is discussed in great detail and its experimental implementation using ion trap is described. Deutsch-Jozsa oracle is also discussed in great details. The later part of the chapter in which the author defends 'NMR quantum computing', is most enjoyable (to me). The author systematically defends NMR quantum computing as 'quantum', even though it uses a classical apparatus. The nuclear spins individually behave as quantum objects and even their collective behaviour is quantum in nature. They can be placed in coherent superposition state. The coherent superposition state in NMR (the free induction decay) is long-lived, and can even be 'controlled' and allowed to dephase slowly using error correction routines. The Hadamard gate in NMR is just a 90° pulse and can be selectively applied to one, two, any or all qubits. The controlled-NOT gate uses refocusing pulses for controlling the number of qubits participating in the Hamiltonian evolution and each gate can be selectively applied. Several algorithms such as the Deutsch-Jozsa, Grover's search and Shor's prime factorization algorithms have been demonstrated by NMR, and by implication the author admits that NMR quantum computing has demonstrated maximum progress.

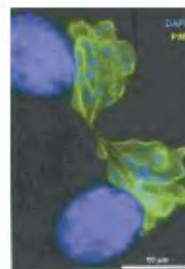
In conclusion, this is an excellent book. However, in an attempt to demystify the 'magic' from quantum computations, it creates its own web of arguments which are tedious and will need a whole semester, to work through its many equations. It is an enlightening book to read, but let me warn you, not an easy one to read.

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Annual Review of Microbiology, 2008. Susan Gottesman and Caroline S. Harwood (eds). Annual Reviews, 4139 El Camino Way, P.O. Box 10139, Palo Alto, CA 94303-0139, USA. Vol. 62. 491 pp. Price not mentioned.

This volume covers 23 diverse topics, representing a broad spectrum of themes ranging from basic aspects (RNA polymerase elongation factors) to population microbiology (population structure of *Toxoplasma gondii*). Among these, the one that attracted me at the outset was 'The Fortunate Professor', the prefatory chapter by Stanley Falkow (one of the editors). He begins like a best-selling novelist. He mentions, 'Well, I guess they wanted to invite me before it is too late', alluding to the fact that he was diagnosed with a bone marrow disease. His personal reminiscences have a lot for everyone and the scholarly style of writing is a refreshing reading.



Falkow's thoughts about biotechnology are: 'I have always thought that biotechnology was the direct result of the research funding philosophy of 1950–1980, which was to encourage individual creativity and to invest in the best people no matter what their precise area of scientific expertise might be'. The first chapter on intracellular pathogens sets the tone for newer concepts from various authors in the other chapters. Arturo Casadevall states that 'classifying organisms as intracellular and extracellular may be ultimately a futile exercise fraught with error and misconception'. The article by Mark Achtman on genetically monomorphic pathogens reviews an exciting new concept, which clearly shows that monomorphic pathogens have reached the limit of genome reduction, and hence the current strains arose from a minimal genome of their ancestor. The existence of clinical isolates of monomorphic pathogens argues for setting up high-throughput sequencing for SNP discovery in human pathogens, including *Mycobacterium tuberculosis*, which is also