Preface

Masatsugu Sei Suzuki
Department of Physics, SUNY at Binghamton
(Date: December 23, 2014)

Quantum mechanics is one of the most significant physics courses at both the undergraduate and graduate levels. The microscopic world can be explained with fantastic accuracy. The fruits from its insights have created technologies such as computers, lasers, mobile telephones, optical communications and so on. Nevertheless, most physicists admit that in their scientific career, they have had difficulties understanding the foundations of quantum mechanics. They feel some impressions that a really satisfactory and convincing formulation of the theory is still lacking.

Here is a brief history of the remarkable progresses in the quantum mechanics (which I selected on the basis of my judgment), including the fundamentals of quantum mechanics, solid state physics as applications of quantum mechanics. Such a choice may be different for different people.

1910-1920's	Development of the quantum mechanics (N. Bohr, W. Heisenberg, E. Schrödinger, P.M. Dirac, M. Born, W. Pauli et al.).
1929	Introduction of density operator (J. von Neumann).
1935	EPR (A. Einstein, B. Podolsky, N. Rosen) paradox.
1956	BCS theory for superconductivity (J. Bardeen, L. Cooper, J.R. Schrieffer).
1962	Josephson effect (B.D. Josephson): tunneling of Cooper pair.
1965	The Bell’s inequality (J. Bell).
1969	CHSH inequality (J. Clauser, M. Hone, A. Shimoney, and R. Holt).
1980	Quantum computer (Y. Manin).
1981	Experimental verification of violation of the Bell's inequality by photon (A. Aspect):The quantum entanglement validity.
1981	Development of STM (scanning tunneling microscope) (G. Binnig and H. Rohrer).
1982	Quantum computer (R.P. Feynman).
1986	Discovery of high T_c superconductor (Bednorz and Műller).
1989	GHZ (D.M. Greenberger, M.A. Hone, A. Zeilinger) experiment for the quantum entanglement.
1995	Bose-Einstein condensation of alkali atoms (E. Cornell, C. Wiemann, W. Ketterle).
2012-14	Experiments of quantum teleportation (several groups over the world).

The first quantum revolution occurred in the 1920's, with overwhelming success not only to atom and particle physics but also to nearly all other science branches as chemistry, solid state physics, biology or astrophysics. Because of the success in solving essential problems in these fields, fundamental open problems concerning the quantum theory itself (for example, EPR paradox in 1935) were approached only in rare cases. It was thought that after the first quantum revolution, the quantum mechanics was already established subject. At 1966 John Bell's famous inequality broke the ice. As shown in the above list, it seems that the second quantum revolution occurred with the experimental verification of quantum entanglement in 1980’s (A. Aspect et al.). The experimental confirmation of quantum entanglement leads to the essential change in our understanding of quantum mechanics (the nature of non-locality, spooky action at a distance). Consequently, new topics in quantum mechanics emerge, such as quantum teleportation, quantum computing and quantum information. This also leads to a deeper understanding of quantum mechanics itself as well as the applications in quantum engineering.

There are so many textbooks of quantum mechanics. In the old good textbooks of quantum mechanics which were published before 1980's, of course, there are few descriptions on the new topics. If we use such textbooks, students may not notice the situation of the rapid progress (so-called, quantum jump) in quantum mechanics. In fact, as is described by the preface of the textbook by Townsend (revised version, we use as textbook in my class), there are so many important topics added. I found an interesting preface which was written by Prof. J.M. Ziman in his famous book on Solid State Physics. It is clearly predicted that the content of the textbook of the quantum mechanics will change with the rapid progress.

The Frontiers of knowledge are always on the move. Today's discovery will tomorrow be part of the mental furniture of every research worker. By the end of next week it will be in every course of graduate lectures. Within the months there will be a clamor to have it in the undergraduate curriculum. Next year, I do believe, it will seem so common place that it may be assumed to be known by every schoolboy (Ziman, Principles of the theory of solids, Cambridge University Press, 1964).

Here I have to say something about Mathethatica as a mathematical tool for the calculation of quantum mechanics. It is assumed that students of quantum mechanics will avail themselves of the most advanced arsenal of Mathematica for solving problems and visualizing the propositions of quantum mechanics. The history of Mathematica is listed below.

1988	Launching of Mathematica 1.0 (S. Wolfram).
2013	Mathematica 10 (Mathematica celebrateed 25th Anniversary).

It was generally thought that being able to do long calculations by hand was an essential skill in the quantum mechanics. So now that Mathematica exists, what does it mean for physics students and physicists? In the years since the first version of Mathematica became available (version 1.0 was released on June 23, 1988), a vast amount of new physics has been done with it. Indeed, for example, if one looks today at any of the leading physics journals, one can tell that a large fraction of the calculations and pictures in them were done with Mathematica. Since then so much has happened with Mathematica in the quarter century. We can see how many contributions Mathematica has made to. It is not just at the level of research that Mathematica affects the way physics is done. Anyone who learns today can do so in a very different way because of Mathematica (S. Wolfram).

It is no doubt that the quantum mechanics plays a significant role in unifying principles in contemporary physics. The central role of this physics course is reflected in the training of students who are expected to specialize in solid state physics, atomic physics, elementary particle physics, nuclear physics, quantum optics, quantum chemistry, and so on. The textbooks must be written for such a course as a comprehensive introduction to the principles of quantum mechanics and to their application in the subfield of physics.

I have been teaching the course of quantum mechanics at undergraduate level at the SUNY at Binghamton for consecutive three years since Fall 2013, although I also often taught the quantum mechanics at the graduate level since 1986. This course consists of two courses: Phys.421 for the Fall semester and Phys.422 for the Spring Semester. Pre-requisite of this course is the Modern Physics (Phys.323) and general physics (Phys.131 and 132, calculus based). Students have completed a course of Modern Physics which includes an introduction to quantum mechanics, such as wave mechanics, the duality of wave and particle, Bohr model, Schrödinger equation, quantum tunneling effect, α-decay, the angular momentum, and so on. They are assumed to know how to solve the Schrödinger equation using the separation variable method.

In my class, I use a textbook of John S. Townsend, A Modern Approach to Quantum Mechanics, second edition (University Science Books, 2012). In the past, we used, Liboff's textbook, Shankhar's textbook, Merzbacher's textbook, Griffiths's textbook, Sakurai's textbook, and Cohen-Tannoudji's textbooks. In Phys.421 (the Fall semester), the topics for Chapters 1 – 7 are covered, while in Phys.422 (the Spring semester), the topics between Chapter 8 – 14 are covered. As is noticed, the content of Townsend is similar to those of Sakurai and McIntire. We need to give some comment on the contents between Chapter 1 and 5. These chapters are rather different from those of old good textbooks. The chapters between 6 and 14 are similar to the contents of good old textbooks.

In Chapter 1 we learn the physics on the Stern Gerlach experiment for the spin 1/2 particle and later spin 1 particle. In Chapter 2, we learn the quantum mechanics of photon polarization, including the right-hand polarized photon and the left-hand polarized photon. These photons have the angular momentum with spin 1. The rotation operator is discussed in connection with the angular momentum. The spin 1/2 system and photon polarization provide us with many beautiful but straightforward illustrations of the essentials in quantum mechanics, in particular the Bell's state in the quantum entanglement.

In Chapter 5, newly topics are added, including the density matrix, quantum entanglement quantum teleportation, no-cloning theorem, and so on. First we study the Dirac spin exchange interaction in order to get the two spin states. One of these two-spin state is the spin zero state and is called the Bell's states. Next we discuss the EPR paradox, the Bell's inequality, the appearance of quantum entanglement, quantum teleportation, and quantum computer. Such contents are rather different from those of the old good quantum mechanics (I used the books of D. Bohm, L.I. Schiff, and P.M. Dirac when I studied the quantum mechanics). In Chapter 6, there is a description of x-p representation, one dimensional square well potential, which our students are very familiar with in Phys.323 (Modern Physics).

Here I present my lecture notes on Phys.421 (Quantum Mechanics I) and Phys.422 (Quantum Mechanics II) which are mainly prepared during the classes. Although these are less complete than a textbook, I think that these are deserved for putting my web site so that students may use these as a part of references. The advantage of such lecture notes on the Web site is that one can revise some descriptions which are not appropriate or add to new topics on a daily basis. In classes, if students have some difficulty in understanding the physics, they can ask questions.

This situation is also true for the lecture notes. If they do not understand, they can ask it by using the e-mail. Science evolves; during that period, there appeared numerous crucial experimental and technological steps forward. My lectures also evolved quite a lot in 30 years. Actually, they were never the same from one year to the next. So each lecture itself must be considered as a superposition of text books and topics, which I could not have covered completely in class rooms.

Here we note that these notes are written only for my convenience, but not for the students themselves, since some topics are much more complicated than one expects. In our classes we discuss only important topics which I selected. The Mathematica programs was immensely helpful in preparing this lecture notes. In these lecture notes, many kinds of Mathematica programs and their results, which I made during the classes, are presented here. I think that the use of the Mathematica is significant for deeper understanding of the quantum mechanics. In my lecture notes I show a variety of Mathematica programs which may be useful for the calculations in quantum mechanics, including (i) eigenvalue problems, (ii) calculations on matrices and Kronecker product (denoted by $\otimes$), (iii) Clebsch-Gordan coefficients for the addition of angular momentum, and so on. In particular, the use of Kronecker product is essential to solving the eigenvalue problems for two-spins, three-spins, as well as four spin states, and (iv) the operation method for the quantum computation. I have been doing my research on the solid state physics, while teaching the quantum mechanics course. So I chose several topics on solid state physics, including the Bloch theorem, Kronig-Penny model, Landau level, Aharonov-Bohm (AB) effect, and so on. In our classes, we picked up selected problems from several books including Zettili and Peleg, and showed how to solve them.

It is our hope that these lecture note may be useful and helpful for the students who want to know the essential of the quantum physics. Finally we note that quantum computing is still in its infancy but experiments have been carried out in which quantum computational operations were executed on a very small number of qubits.

ACKNOWLEDGEMENT

I am grateful to Dr. Itsuko S. Suzuki (my wife) in providing me useful suggestions and putting all my lecture notes in my web site.