Leonard Susskind’s Quantum Mechanics course

I’ve heard a few times about quantum mechanics, from friends and TV show/series (Bing Bang Theory, Fringe …) that make references about this weird subject. Since this time, I put quantum mechanics on my “to-learn” list. I also wanted to know quantum mechanics in order to understand the developments of **quantum computing which is likely to be the future of IT** (it will be one of my next articles).

I first tried to learn it by reading articles on Wikipedia but I quickly stopped because the subject is spread on too many articles and some pages are (very) hard to understand for a non-physicist. This is why I watched a 10-lecture course on YouTube about Quantum Mechanics by Leonard Susskind. Those videos are records of a continuing education course from 2008 at Stanford. I’ve chosen this course because of Leonard Susskind’s reputation and the fact that it’s a community course and therefore not destined to physics (under)graduate students.

But for a “simplified” course it’s a pretty tough one! Indeed, this course involves:

- advanced linear algebra (matrix and vector, inner/outer product, Eigen value and Eigen vector , complex numbers)
- mathematical analysis (vectorial/Hilbert space, Hermitian operators, Hamiltonian operators, dual space, integration, Fourier transform, Dirac function)
- good notions of classical physics (Newton’s laws, phase, phase space, waves, photons, electrons, electromagnetic fields, polarization)

Though Leonard Susskind (quickly) explains all those concepts, if you’ve never learned/seen most of them before (especially the mathematical ones and some physical ones like polarization) it will require a lot of work and re-watching to really understand the lectures. You can still skip the parts you don’t understand but if you skip too many parts without getting at least the overall idea you won't understand the course.

Course overview

The course is divided into 10 two-hour lectures. Each lecture starts with a review of the previous one. Here is a summary of the 10 lectures:

- The first one is the most accessible: Leonard Susskind gives some concrete and physical ideas of what quantum mechanics is and the differences with classical mechanics
- The second one is a reminder of mathematical concepts: vector space (orthogonal and orthonormal bases, scalar product, linear operators), complex number, ket and bra vectors, He also gives some concrete examples of linear operators.
- The third one continues on mathematical concepts: Hermitian operators, Eigen vector/value. It follows with the (mathematical) postulates of quantum mechanics with a physical interpretation. The rest of the course is about the position and momentum mathematical/physical operators with a focus on the position operator (and its physical interpretation).
- The fourth one introduces the Dirac function and focus on the mathematical momentum operator. Susskind ends with a physical example of what this operator means.
- The fifth one presents 2 mathematical concepts: the outer product between 2 vectors and the Fourier transform that links the position with the momentum. Then the lecturer recalls some physical concepts: electromagnetic fields, photons and polarization, and ends with a definition of the quantum polarization state and the quantum polarization operator.
- The sixth one continues on (linear) photon polarization and photon circular polarization that involves complex numbers. The course ends with the concept of expected values (the average value of an observable).

- The seventh one starts with a comparison between a classical mechanics problem and a quantum one. Susskind introduces the concept of phase. The rest of the lecture is about how quantum states change with time and change with each other (quantum entanglement). This part introduces new math concepts: Hermitian conjugate and unitary operator.
- The eight one continues on how the quantum states changes with time using a new mathematical concept: Hamiltonian operators. It also introduces Schrödinger's equations.
- The ninth one starts with a (very good) speak on the history of QM and then continues with Schrödinger's equations. It ends with studying how a wave packet moves in time that links QM with classical mechanics.
- The last one is an application of the concepts learned during the course by analyzing the quantum harmonic oscillator.

Review of the course

I took this course to have a good understanding of quantum physics and I'm satisfied. Before this course, I knew nothing about quantum mechanics. Now, I can read technical papers/articles on this subject and understand the ideas. The last time I studied advanced physics and mathematics was in 2007 and the "light" explanations from Leonard Susskind were enough to make me remember most of my old courses. Concerning the difficulty, I watched another online course from Stanford (Coursera) on machine learning (that also involves heavy mathematics) and the difficulty of Leonard Susskind's course is way above Andrew Ng's famous course. I had to watch some part multiple times to understand them (or just get the overall idea), especially in the last lectures.

In my opinion, the advantages of this course are:

- Leonard Susskind is a good speaker (it's not boring)
- Though I didn't carefully understand every mathematical proof, I got the overall idea thanks to Leonard Susskind's explanations.
- It's a very detailed course and not a "it's too difficult, but trust me this is the truth" course. If you follow it carefully you'll have a deep understanding of the subject (but won't be an expert).
- Each lecture starts with a summary of the previous lecture so that you can

watch the course on multiple months without forgetting the previous concepts.
- It’s free (the “live” course cost 350$).

The drawbacks are:

- Leonard Susskind is not rigorous when it comes to mathematics and sometimes it’s difficult to follow his mathematical proofs. For example, he sometimes
    - uses the same notation for Eigen values and Eigen vectors,
    - uses different notations for the same mathematical object,
    - makes no difference between a function f and f(x) which is the function f at “x”
    - …
- In my opinion, this course focuses too much on the (heavy) mathematical part of quantum mechanics and not enough on the physical interpretation. This course has approximately a 85/15 ratio. Although QM involves a lot of math, I wonder if a 70/30 would have been possible (especially for a “simplified” course).
- The course requires a high level of abstraction (I can’t tell if it’s because of the teacher or the subject itself).
- The questions from students are sometimes difficult to hear since the micro is on the teacher.
- The video has a low resolution (240p) and is too dark. However, It doesn’t prevent from reading the whiteboard.

For physics enthusiasts with a good knowledge on physics and mathematics this course is good, but not great due to a (too) strong focus on the mathematical parts. If you don’t know more than 70% of the concepts I used in the course overview, you should learn more about physics and/or mathematics before watching this course.

For physicists (or physics students), this course can be helpful to have another point of view of quantum physics but I don’t think that it is sufficient to be a stand-alone course.

Quantum confusion

Concerning quantum mechanics, I'm more confused than before starting the course. Unlike all the physics subjects I learned when I was student (Newton's laws, electricity, electromagnetisms, thermodynamics …), it is counter intuitive and the physicals results are just consequences of mathematical theories applied on a set of axioms. Though some results can really be observed since the end of the 20th century (like the dual particle-like and wave-like behavior that works only at quantum level or the quantum entanglement) they don't make sense to me. I feel like there is a missing piece in this theory, the one that would explain why the quantum world behaves like it does. Like Richard Feynman -one of the greatest minds in QM- said "If you think you understand quantum mechanics, you don't understand quantum mechanics.".