Quantum Mechanics
Lect. I

I What is quantum mechanics?

II Go over Syllabus

III Could it be different?

I. Q.M was discovered in the context of atomic physics, but unlike many of the named classes in our curriculum it is not a subfield of physics in the same way that atomic physics or optics or particle physics are. Instead it encompasses (almost) all the known subfields of physics and <u>provides a new understanding of two of the pillars of physics</u>:

- What it means to describe a physical system (a system's configuration, or more formally its <u>state</u>)

and

- What is possible when you measure a system (its measurement outcomes).

The exception here is gravity; many of us are trying to sort out what that means.

I quite like Scott Aaronson's analogy that quantum mechanics is like a computer's operating system (OS). You can run optics or atomic physics as software on this OS, but fundamentally, it determines what is possible

Q.M. determines what you can compute/predict and what you can measure.

It is a new framework. Think back to when you first learned Newtonian mechanics. Forces are by no means intuitive and they don't help you think about every physical scenario or problem. Nonetheless, the Newtonian ~~perspective~~ framework provides an irreplaceable perspective on how to predict and understand physical motions. Q.M. revolutionizes this understanding and framework.

The analogy with an OS is also useful in thinking about the sort of mental shift you need to make as a student of quantum mechanics. If you pick up a friend's computer running an unfamiliar OS you will often find it challenging to do simple operations. Despite these difficulties you know quite well what a computer does; similarly, you know quite well what quantum m. does — it provides a quantitative framework for predicting the outcomes of measurements — so don't lose track of this picture as you are familiarizing yourself with its operational procedures.

Many people bring a great attitude to learning a new OS; they simply muck around with it until they get the hang of it. When they screw up they simply say "oops" and try again. I strongly encourage you to bring this mindset to learning quantum. After all, it's a new OS, you should expect to turn many wrong robe and totally misinterpret some relationships until you are more familiar with it. Don't believe the hype — quantum mechanics is not overly difficult, just unfamiliar and surprising at times.

II Go over syllabus

III What would happen if Quantum were not as it is? We'll spend some time with this question during this first week.

Let's overview some of the unusual features of the quantum operating system, we'll meet them again and again.

• The outcome of a ~~quantum~~ measurement of a quantum system is often, but not always, one of a discrete set of possibilities. (It's like digital computing.)

If you setup and run an experiment multiple times, then, despite having ~~taken~~ every care to set it up in exactly the same way, you will often get different results. In sharp contrast to the saying that defines insanity, it is now quite reasonable to do exactly the same thing and to expect different results.

Quantum theory tells you how to compute the probabilities of these measurement outcomes.

It has nothing to say about the exact outcome you'll get during an individual trial run.

Ex. Since Q.M. is often digital, let's look at the simplest quantum digital system, one with just two states; it's called a qubit.

A nice implementation of this is an optical interferometer — here with just a single photon in it.

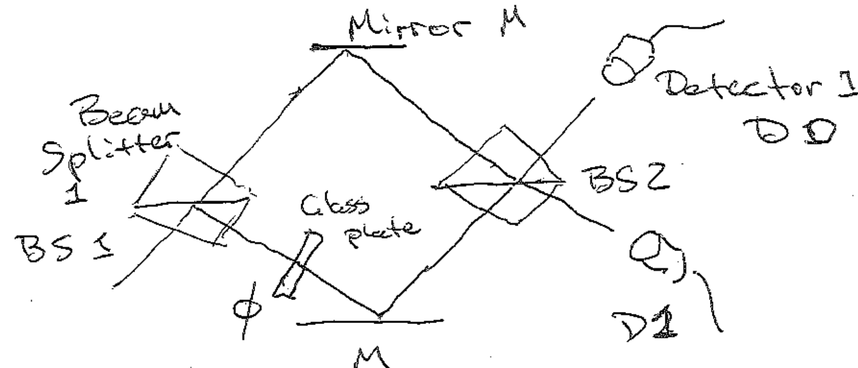
The outcome of the experiment

and no photon was measured.

Just two possible outcomes.

These outcomes can occur with different probabilities, p and $1-p$.

We often say probabilities can't be negative — this is very sensible. What would it mean ~~that~~ for there to be a -20% chance of



Mach-Zehnder interferometer

~~The probability of mea~~

at detector D0 is either a click — a photon was measured — or, no click —

Snowmugedon?

Let's restrict to real numbers for the moment. Certainly the probabilities should satisfy

$$p_1 + \cdots + p_N = \sum_i p_i = 1$$

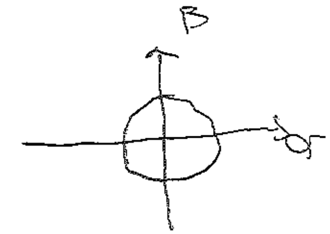
Of all possible outcomes, certainly one must happen.

But this uses the 1-norm, essentially the sum of absolute values.

What if we also allowed the 2-norm, that is, a norm ~~based~~ like ~~on~~ that used in the pythagorean theorem?

We can do this if we interpret the squares as the probabilities ~~Tha~~ Take (α, β) as variables, we want

$$\alpha^2 + \beta^2 = 1$$



Why not just forget about α and β and only consider α^2 and β^2?