# Seminar 6

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# Measurement and Bases

Week 5 | October 23rd, 2022

## High-level Overview:

- **Measurement**
    - What is it?
    - How does it affect quantum states?
- **Bases**
    - What are they?
    - How does this relate some different states?

### Quantum Measurements:

1. The outcome of a q-measurement is often random
2. By observing (measuring) a q-state, we can change it

**Measurement = extracting information**. Measurement extracts information from systems (key concept). The final step is measurement. This is crucial since without it we would be running gates all day without actually knowing the value of the outcomes.

**Measurement gives classical states:**

When we measure a qubit, we get out either 0 or 1. 0 q-state will always collapse to classical and 0 state and similarly for 1 state. The results of measurements are always classical states. Therefore, we need to store the classical state results in some way.

When we measure the + or - states, there is a 50% chance of getting 0 versus 1. We have no way to predict anything beyond. the outcome is truly random. Measurement is random for any of the possible superposition states.

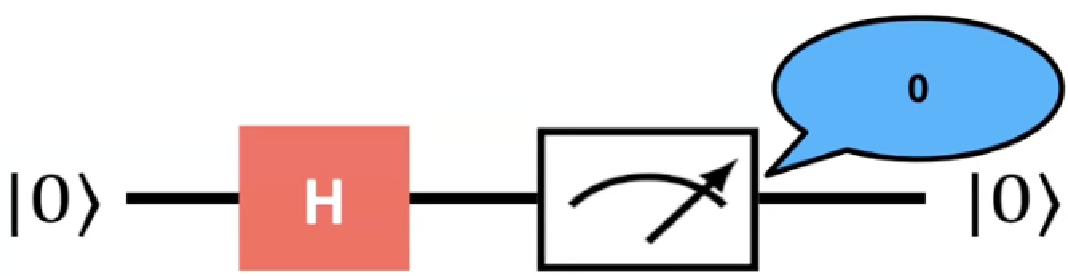
**Random Outcomes:**

If I am only making the measurement once on my circuit, you cannot tell the difference between a H-gate or a just a regular 0 state qubit. Therefore, we need to run this circuit and make measurements many times, We then look at the pattern of outcomes.

Given the inherent randomness, we have to perform many measurements to try to arrive at the right answer. We can use these measurements to derive the probability that a qubit will behave one way versus another. The more measurements we make, the more confident we can be in our results. (**MORE IS BETTER)**

M**easurements change states!**

If we happen to measure 0 in the circuit below, the qubit will end up in the |0> state instead of the |+> state.




After the initial measurement, the second measurement, assuming no further gates are applied, will always read whatever value the state collapsed to (q-circuit's state is changed once the measurement is made!)

Measurements take that information away from the qubit, often destroying or collapsing superpositions (notion of projections in linear algebra)

**The Paradox of Quantum Measurement:**

- We need to make measurements to know what our q-system is doing.
- But the moment we make a measurement, we’ve destroyed the q-properties that made the system so special.
- To get the many outcomes necessary to understand our q-system, we need to completely rerun it every time.

**Harnessing Q-Randomness:**

- Researchers have built a device that can derive truly random sequences of numbers form photons, a q-particle. This is a a crucial advancement because random number generation is the foundation of cybersecurity/cryptography
- We can use properties of q-measurement to implement secure cryptography schemes! learning how measurements work this week will help us learn these q-cryptography schemes in a few weeks

## Bases

### Basis

A basis is the specific point of view or frame of reference you are using to look at a state. It is another word for coordinate system. Basis allow us to describe all possible points in a given area/grid-system.

It is possible to keep the exact same point and switch the coordinate system, which will mean using different bases will result in different results. Each basis is equally valid so long as we can describe all possible points using it.

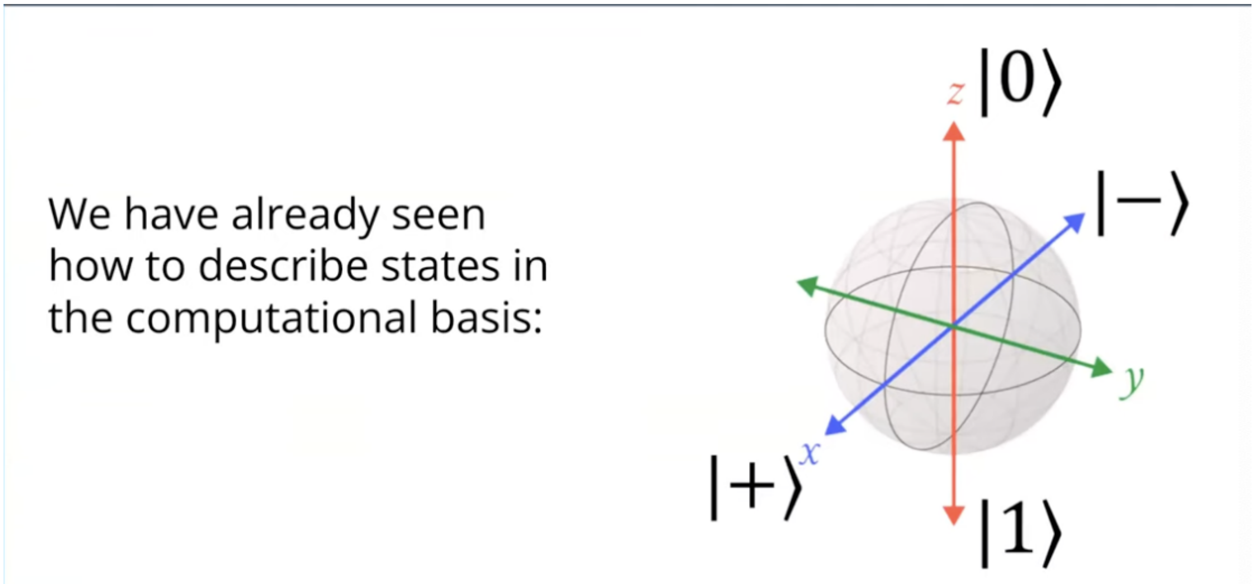
### Bases are Coordinate Systems

There is no such thing as a “correct” basis. Each one has its advantages and disadvantages. Qubits can be described and measured in different bases too! Instead of rotating a graph like we just did, we rotate the whole Bloch sphere.

The Bloch sphere as the x, y, z basis.

Z Basis - The z basis describes states wit z axis pointed up. This is commonly called the computational basis and it is the standard basis to talk about qubits in.

**Computational Basis**




**How can we mathematically describe the + and - states?**

|+> = (1/root(2))|0> + (1/root(2))|1>

|-> = (1/root(2))|0> - (1/root(2))|1>

Notice that (1/(root(2))^2 = 1/2 which gives us the probability for each of the qubit states (Born’s Rule)