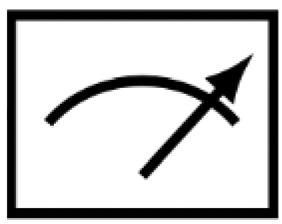
Week 5 summary of key concepts

Lecture

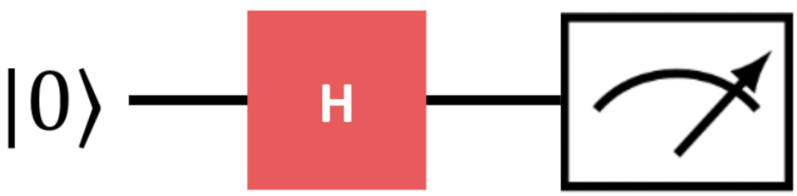
In lecture this week, we explored the role of **measurements in quantum circuits** and the idea of **bases**.

1. **The Quantum Circuit model** captures the **3 major parts of any quantum circuit: the qubit states, gates, and measurements.**
    a. **Measurement is the final step of any circuit.** It is how we extract information about the state of our qubits in the actual circuit. Without measurements, we would never know what state our qubits were in and we would not get the results of our computations.
    b. The symbol for measurement in a circuit that we used is:



2. When we make measurements on a circuit, we always get classical information out. In other words, we get the answer to the question: **"Is the state of the qubit $|0\rangle$ or $|1\rangle$?" These are the only two answers we can get!**
    a. **For some circuits**, such as the one shown below, t**here is a definite answer to this question**. In the circuit shown below, the X gate changes the qubit from $|0\rangle$ to $|1\rangle$. So, when we make a measurement, we will always get $|1\rangle$. **We can predict this result before we make the measurement.**

b. **For other circuits**, such as the one shown below, **there isn't a definite answer to this question**. In the circuit below, the H gate changes the qubit from $|0\rangle$ to $|+\rangle$, which is a superposition of $|0\rangle$ and $|1\rangle$. When we make a measurement on this circuit, we will get random results - sometimes we will get $|0\rangle$, and sometimes we will get $|1\rangle$. T**here is no way to predict before making the measurement if we will get $|0\rangle$ or $|1\rangle$ - the results of the measurement are truly random.**



c. **This is generally true for superposition states.** When a qubit is in a superposition state, the results of measurement are fundamentally random and cannot be predicted.

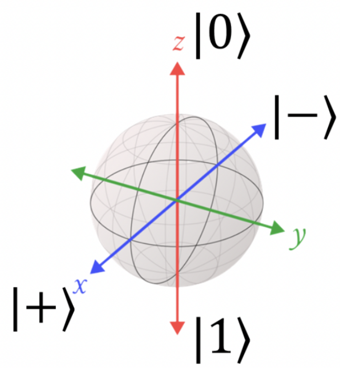
d. After the measurement, the state of the qubit changes to the state that it was measured in. Therefore, if the result of the measurement was $|1\rangle$, the qubit will be in state $|1\rangle$ after the measurement. **Measurement can change the state of the qubit. This change is also known as collapse.**

3. If the results of measurement can be random, how do we find out what state the qubit was in?
   a. **We can run the circuit and measure the state of the qubit many, many times.** Repeated measurements increase the precision of our knowledge about the qubit. For example, if the qubit was in the $|1\rangle$ state at the end of

the circuit, the result of measurement will be $|1\rangle$ every time. If it was in the $|+\rangle$ state, the results of measurement will be $|0\rangle$ roughly half the time, and $|1\rangle$ roughly half the time.

   b. **Although we cannot always predict what the exact result of an individual measurement will be, we can always predict the probability of different possible results of a measurement.** We will learn how to do this in a few weeks!

4. 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**.
   a. There is no such thing as a "correct" basis so long as it is able to describe all possible points. Each one has its advantages and disadvantages.
   b. The **z basis** describes states with the z axis pointed up. This is commonly called the **computational basis** and it is the standard basis to talk about qubits in.



   c. The states corresponding to the up and down directions in a given basis are called the **basis states**. These are $|0\rangle$ and $|1\rangle$ in the computational basis.
   d. As a sneak peak of what's to come, the $|+\rangle$ and $|-\rangle$ states in the computational basis are:

$$|+\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

$$|-\rangle = \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle$$

Lab

In lab this week, we learned how to add measurements to our Qiskit circuits and run circuits with measurements. The major steps for creating and running circuits remain the same, but we modify the code at each step.

Step 1: Creating an empty circuit

1. In this step, we now have to **add classical bits** in our circuit. These classical bits store the results of measurements on qubits.
2. The code for creating a quantum circuit named ***qc*** with 1 qubit and 1 classical bit is:

qc = QuantumCircuit(1,1)

Here, the first 1 is the number of qubits in our circuit, and the second 1 is the number of classical bits.

Step 2: Adding gates to our circuit

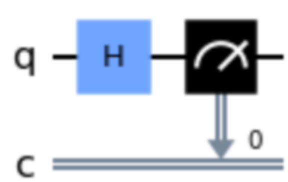
1. The code for adding gates stays the same! So, for example, if you wanted to add an H gate to the circuit, the code would be

qc.h(0)

2. In addition to adding gates, we also have to add measurements to our circuit in this step. The code for adding measurements to the circuit is as follows:

qc.measure(0,0)

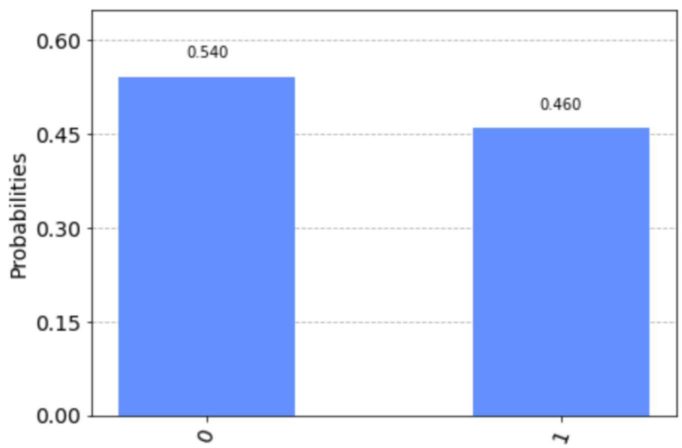
In this code, the first 0 is the index of the qubit being measured, and the second 0 is the index of the classical bit in which the results of measurement will be stored.
3. As before, we can draw our circuit using **qc.draw().** Here's what a circuit with an H gate and a measurement would look like:



Step 3: Run the circuit

1. After adding gates and measurements, we run our circuit. To run circuits with measurements, we use the **QASM simulator.**

2. **A simulator is a classical computer that uses math to figure out the results of a quantum circuit.** We will learn more about different simulators on Qiskit, as well as the code for using them next week! This week, the code was pre-written in our notebook, and we ran it and analyzed the results.
3. For the circuit shown above, the QASM simulator returns results that look like the following histogram:



We can make two major observations about this result:

a. **The circuit gives us 0 and 1 roughly equal number of times.** This is expected, since an H gate puts the qubit into an equal superposition of the $|0\rangle$ and $|1\rangle$ states.

b. **The number of times we get 0 and 1 is not exactly equal.** You can think of this as similar to tossing a coin 100 times. We will not always get exactly 50 heads and 50 tails. Similarly, when we measure an equal superposition state, we will not always get an equal number of $|0\rangle$ and $|1\rangle$ measurements.

c. **If the circuit is run again and the measurement is repeated, we get a different number of 0s and 1s.** Again, we can think of this like tossing a coin - repeating the experiment of tossing the coin 100 times will probably give us a different number of heads and tails as the first time.