Quantum Computing for the Quantum Curious

1.0 Superposition

1.0 Objectives

- Explain what it means for an object to be in a quantum superposition.
- Identify the measurement outcome of a system in a classical vs. quantum superposition.

Key Terms: quantum system, quantum state, quantum superposition

1.1 Classical Superposition

In classical physics, the principle of superposition is used to describe how physical quantities can be combined to form new quantities.

This principle is evident in wave interactions and the calculation of forces.

1.1 Classical Superposition

Example: Wave Interference

When two waves interact, their amplitudes add together according to the principle of superposition. This interaction can result in constructive or destructive interference:

•**Constructive Interference**: When two waves meet in phase, their amplitudes add up, creating a larger wave.

•**Destructive Interference**: When two waves meet out of phase, their amplitudes cancel each other out, reducing the overall wave amplitude.

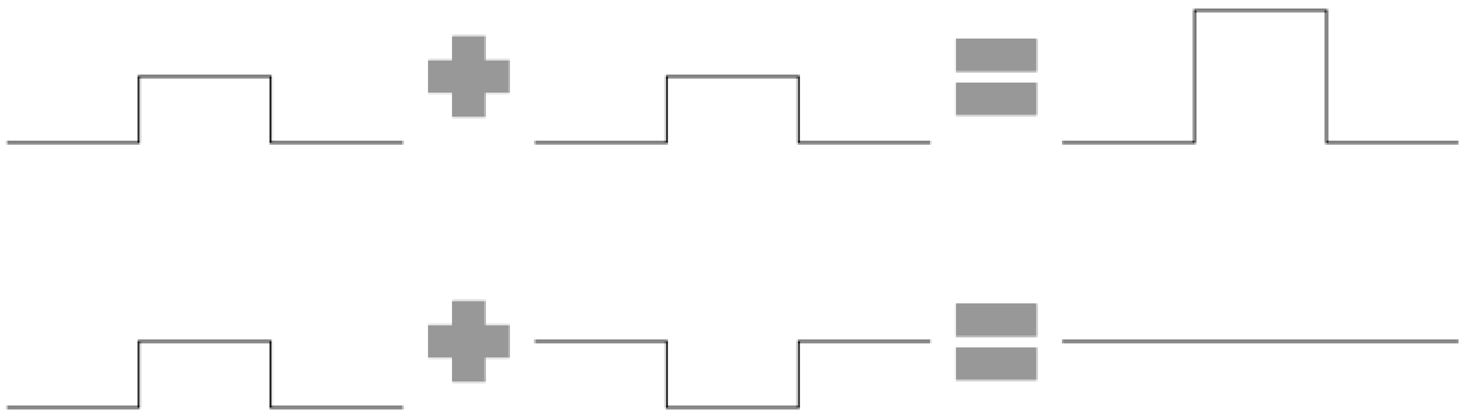


Fig. 1.1 Examples of constructive and destructive interference due to the classical superposition principle

1.1 Classical Superposition

Example: Vector Addition

Finding the total magnitude and direction of quantities such as force, electric field, magnetic field,etc.

In classical mechanics, forces are vectors and follow the principle of superposition. To calculate the total force on a charge q_2 due to other charges q_1 and q_3, one must sum the individual forces vectorially:

$$\mathbf{F}_{\text{total}} = \mathbf{F}_{12} + \mathbf{F}_{32}$$

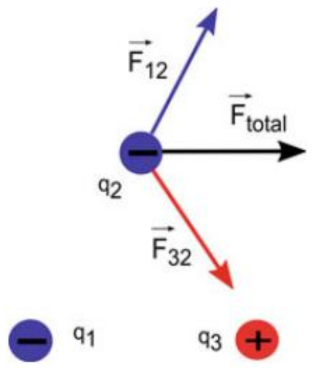


Fig. 1.2 A classical superposition is used to calculate the total electric force on a charge q_2 due to charges q_1 and q_3

1.2 Quantum Superposition

Quantum superposition is a fundamental concept in quantum mechanics, where a quantum system can exist **in multiple states** simultaneously **until it is measured.**

We Will Be going through:

- Energy Quantization
- Coin Toss Analogy
- Schrödinger's Cat

1.2 Quantum Superposition

Energy Quantization

In classical physics, energy can take any value within a range. For example, you would normally expect that an object can have an arbitrary amount of kinetic energy ranging from 0 to infinity (∞) Joules, i.e. a baseball could be at rest or thrown at any speed. However, according to quantum mechanics, the ball's energy is **quantized**, meaning it can only have certain values.

A specific example of **energy quantization** is when energies can **only have integer** values E = 0, 1, 2, 3,..., but not any numbers in between. This is counterintuitive, as we cannot observe it with our classical eyes. The gaps in energy are too small to be seen with the human eye and as such can be treated as continuous for classical physics.

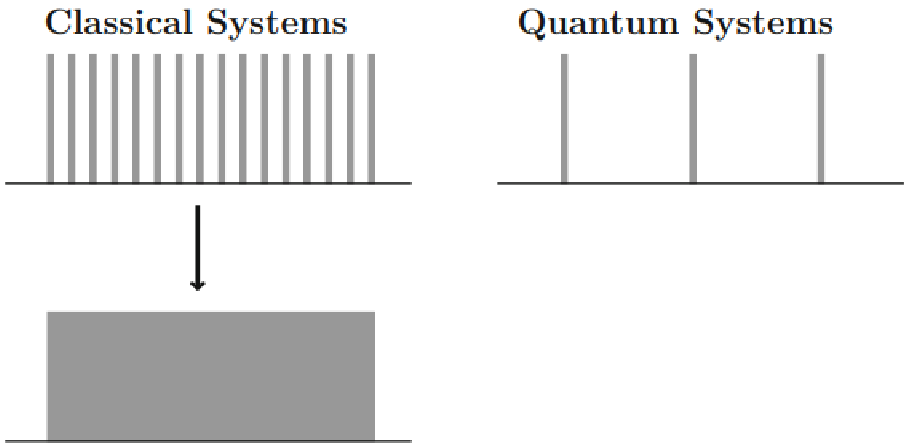


Fig. 1.3 Quantum effects associated with energy quantization are important at the atomic and subatomic distances. In this figure, the grey lines represent allowed energies. In quantum systems, the energies are quantized. As we zoom out of the quantum system to see it through a classical lens (represented by the downward arrow), the energies become more dense and appear continuous. This is the reason quantization is not noticeable in everyday objects

1.2 Quantum Superposition

Coin Toss Analogy

One aspect of quantum superposition can be explained using a coin analogy.

Question 1 *What state is the coin in while it is in the air? Is it heads or tails?*

While it is in the air: We can say that the coin is in a **superposition** of both states (heads and tails). When it lands (Measured), it has a **definite state**, either heads or tails

When we observe the coin, we are making a measurement which destroys the superposition to a definite quantized values (either in a heads state or a tails state).

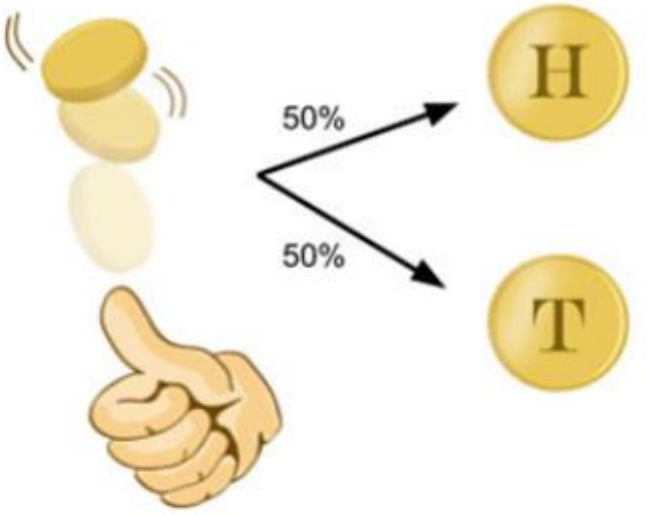


Fig. 1.4 A tossed coin has a 50% chance of landing on heads or tails

1.2 Quantum Superposition

Schrödinger's Cat

In Schrödinger’s famous thought experiment, Schrödinger’s cat is placed in a closed box with a single atom that has some probability of emitting deadly radiation at any time. Since radioactive nuclear decay is a spontaneous process, it is impossible to predict for certain when the nucleus decays. Therefore, you do not know whether the cat is alive or dead unless you open and look in the box.

Video: Schrödinger's Cat

1.3 Big Ideas

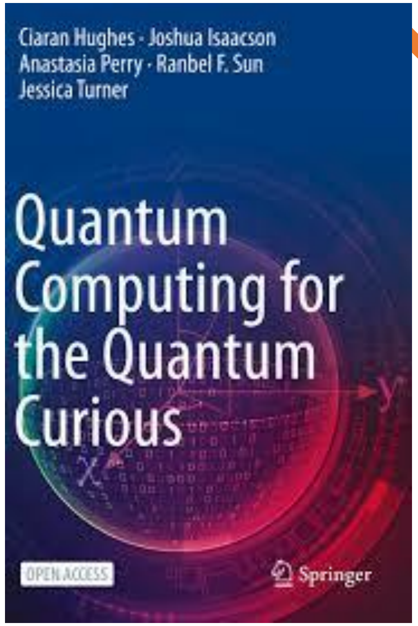
1. A particle in a quantum superposition exists as a combination of different states at the same time.

2. Each possible state has a given probability of being observed, but measurement destroys the superposition because only one definite state is seen.

Reference Book

Quantum Computing for the Quantum Curious

This open access book makes quantum computing more accessible than ever before. A fast-growing field at the intersection of physics and computer science, quantum computing promises to have revolutionary capabilities far surpassing "classical" computation. Getting a grip on the science behind the hype can be tough: at its heart lies quantum mechanics, whose enigmatic concepts can be imposing for the novice. This classroom-tested textbook uses simple language, minimal math, and plenty of examples to explain the three key principles behind quantum computers: superposition, quantum measurement, and entanglement.



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