Applications of Quantum Mechanics in Electronics under Research

Quantum mechanics’ strange consequences and “spookiness” are often the subject of popular science writings (Jenner). However, fewer people are aware of the practical implications of the principles of quantum mechanics. In spite of the quantum’s strange behaviors, the subject’s practical implications have enabled lasers and the manufacturing of silicon-based semiconductors. Moreover, quantum mechanics has many potential new applications in the area of electronics that are currently under research. These include low drift atomic clocks, highly secure encryption techniques, and high-speed quantum computers.

Traditional clocks in use today rely on quartz crystals to produce a regular oscillation, allowing them to keep time. Quartz crystals are piezoelectric devices meaning that they create an electric potential when they are deformed, and applying an electric potential causes them to deform. Quartz crystals inside electronic devices oscillate between deformed and undeformed states, and the changing electric charge generated by these oscillations simultaneously drives the cycle and is measured to produce beats at highly regular and precise intervals (Woodford). However, Quartz crystals only oscillate so fast, meaning they have limited precision and they are subject to drift over time especially due to changes in temperature and humidity. These factors can be controlled, but in applications requiring a high degree of precision over timespans on the order of years, such as telecommunications and GPS, this drift becomes a problem. Drift can cause wireless communication frequencies to pass outside their acceptable bandwidths or it can cause communicating computers to become out of sync with one another. Atomic clocks offer a potential alternative that will stay accurate over a longer time span.

Atomic clocks, such as the Strontium clock developed by a joint institute of CU Boulder and the National Institute of Standards and Technology, use the oscillations of electrons between different energy levels in Strontium atoms to produce regular time-keeping beats (Hernandez). According to the Bohr model of the atom, electrons occupy discrete energy levels, corresponding to their state of excitation. Electrons spend most of their time in the lowest energy ground state. However, they can be excited by absorbing the exact amount of energy corresponding to the higher energy levels. This energy is absorbed from incoming photons, whose energy is proportional to their frequency. An individual photon with the specific frequency, giving the photon the energy equal to the distance between two electron energy levels, will cause the electron to jump from the ground state to a higher energy level. However, the electron is highly unstable in its excited state and will quickly jump back to the ground state. The electron will then emit a photon of the same energy as its jump (that is, of the same wavelength as the photon it initially absorbed). By repeatedly absorbing and emitting photons, the electrons oscillate between their ground and excited states (Hernandez). In a carefully controlled environment, the electrons can be made to undergo highly regular oscillations by shining laser lot on the strontium atoms. These oscillations are then measured and used to keep track of time (Jenner).

Quantum mechanics’ applications in cryptography are being researched with the goal of making eavesdropping more difficult in encrypted electronic communication channels. In cryptography, a key is used to generate an encrypted message, which is then sent to a recipient who decodes it to obtain the original plain text message. However, the recipient must also have the key to decode the encrypted message. Sending the key to the recipient poses a security risk because malefactors can also receive the key by eavesdropping on the communication channel.

Current research seeks to make it impossible to covertly intercept the key during transmission using quantum entanglement (Jenner). Using this method, the key is transmitted as randomly polarized photons over fiberoptic cables (Ma et al.). These photons are read by the recipient using a series of polarizing filters, which allows their angle of polarization to be determined. For each photon sent to the recipient, an entangled photon is kept by the sender and monitored. Since observing a photon affects its state, measuring one of the transmitted photons would instantly cause its entangled twin to also change. Thus, eavesdropping is instantly detectable by the key’s sender (Greenemeier).

Quantum computers can theoretically outperform conventional supercomputers in certain tasks, such as pattern recognition used in machine learning, thanks to qubits and quantum tunneling (Cho). Qubits are similar to normal bits, except they exist in a superposition between one and zero until measured (Jenner). This is because the position of electrons in a quantum model are not strictly deterministic. Instead, their position, until measured, is represented by a probability distribution. Due to quantum tunneling, this probability distribution stretches outside the bounds of what would be possible for a Newtonian particle, allowing the electron to tunnel from one energy to a lower one while passing straight through a high potential energy region. This allows a quantum computer to solve an encoded problem by all of its qubits reaching their lowest possible energy states. Tunneling should allow quantum computers to accomplish this faster than traditional computers and should prevent operations with very large numbers from bogging down calculations (Cho).

The electronics industry stands to benefit from new advances in network connectivity and performance thanks to research that applies the principles of quantum mechanics. Quantum energy levels, entanglement, and tunneling all have useful applications which are currently being utilized.

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