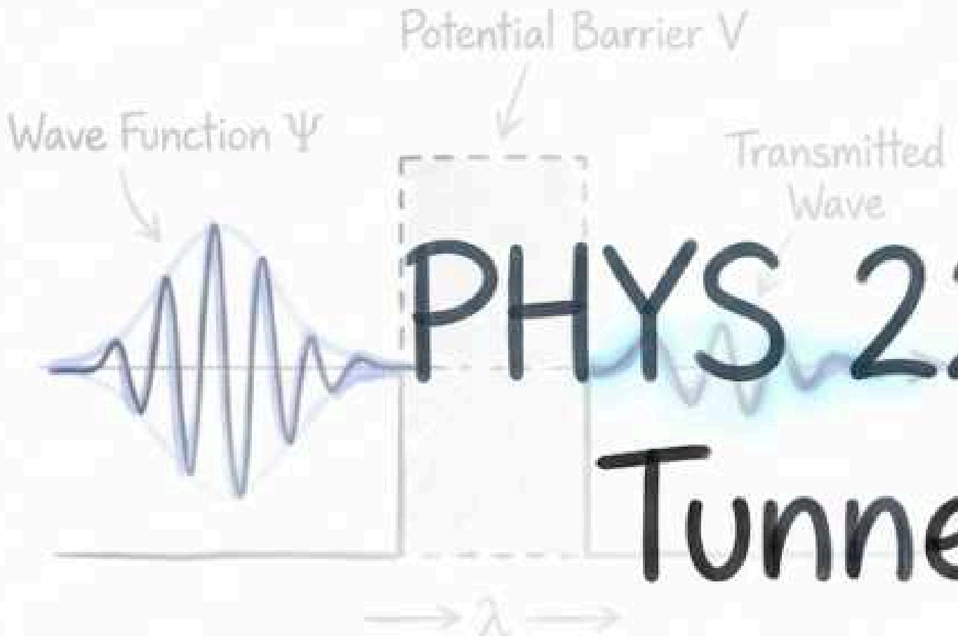
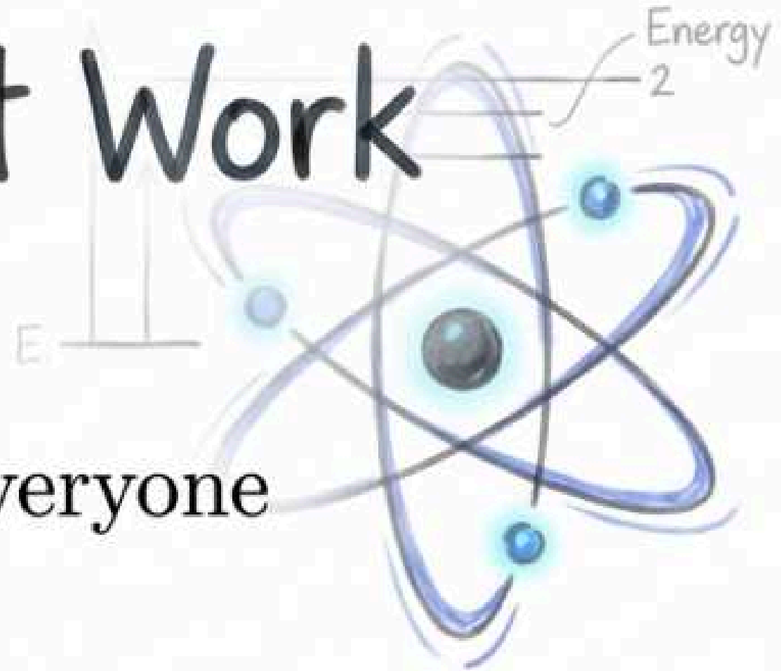


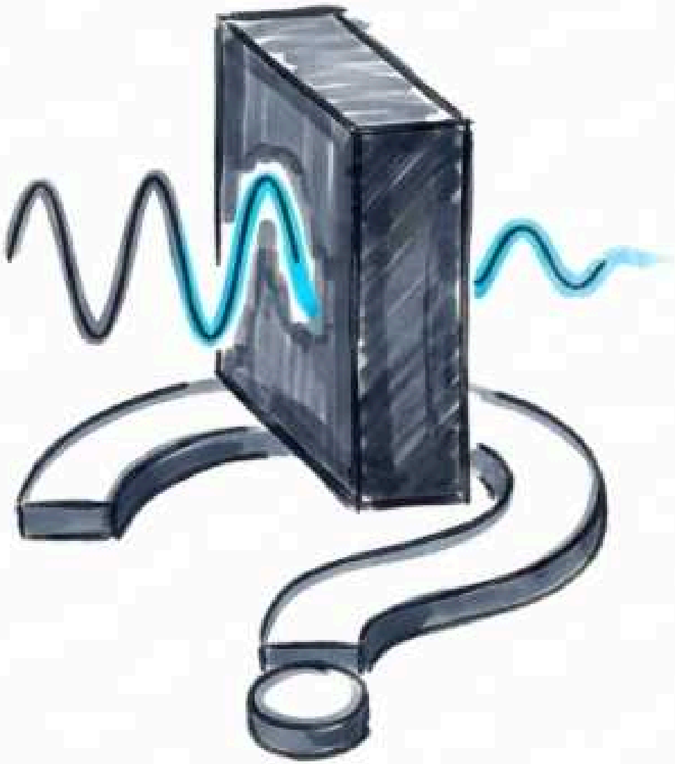
PHYS 220 B: Lecture 6 Tunneling and the Quantum World at Work



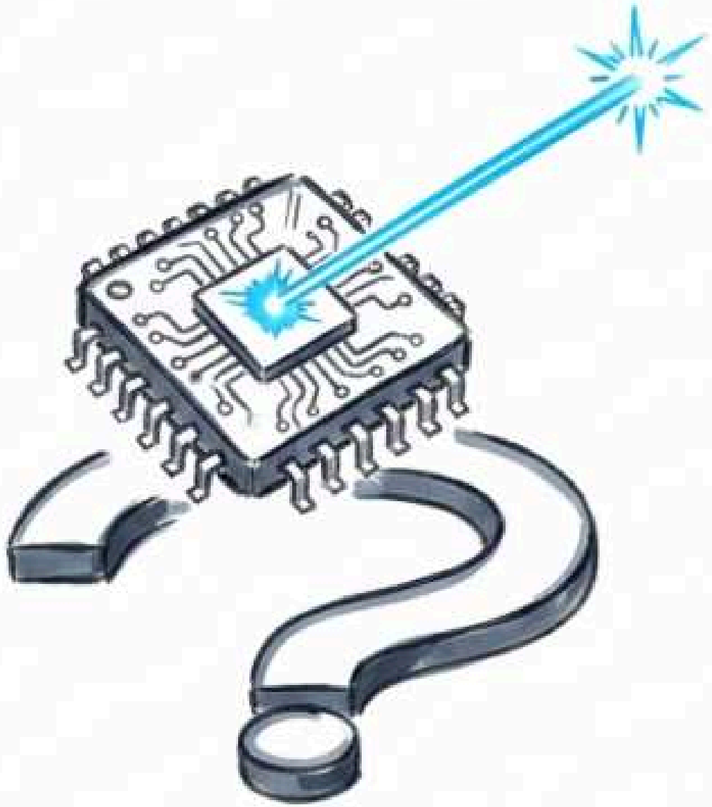
Anderson Academy

Quantum Mechanics for Everyone

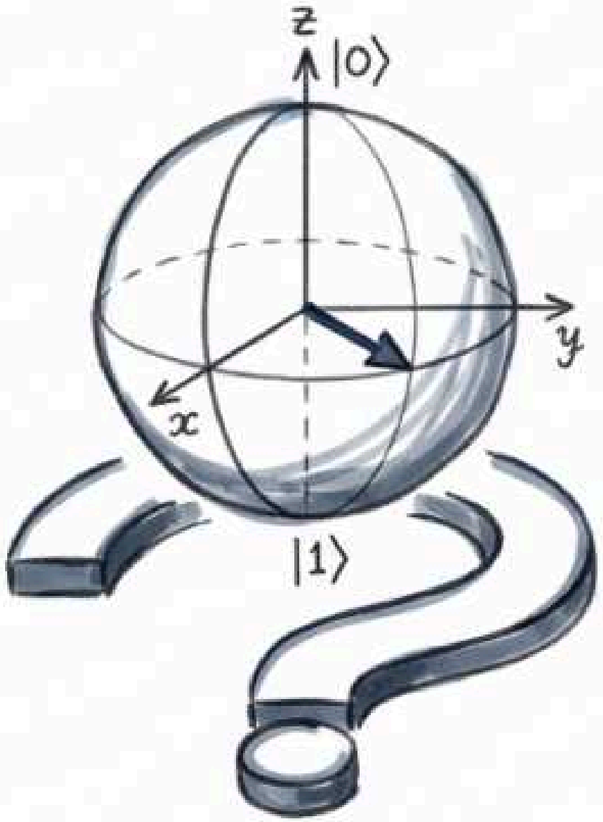
6.1 | The Three Questions



1. How does a particle cross an unscalable barrier?



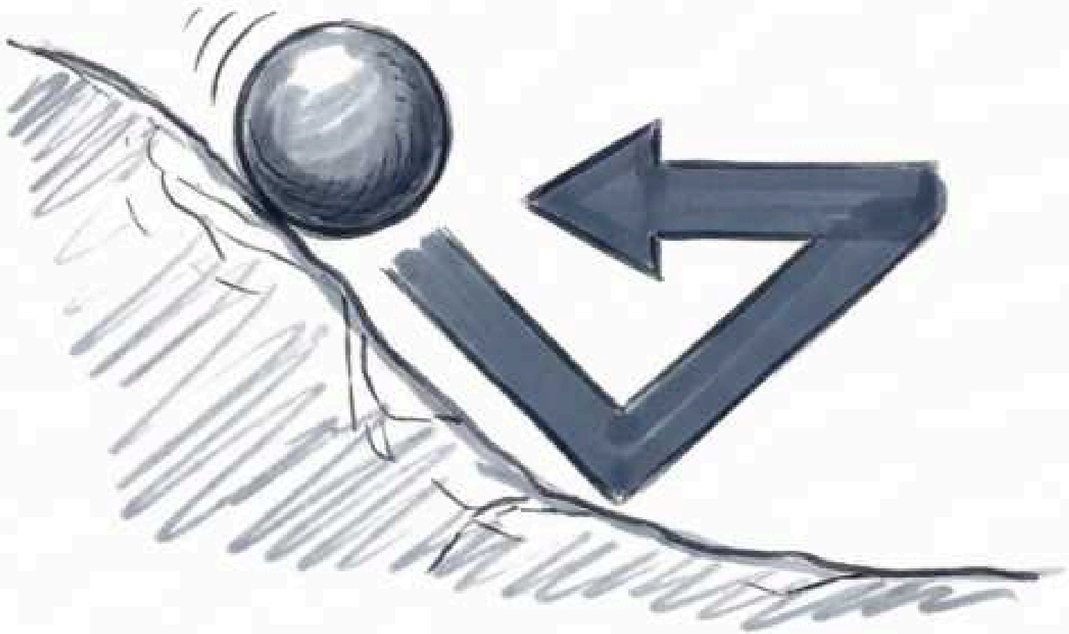
2. How did quantum theory give us lasers, chips, and MRIs?



3. What can quantum computers actually do?

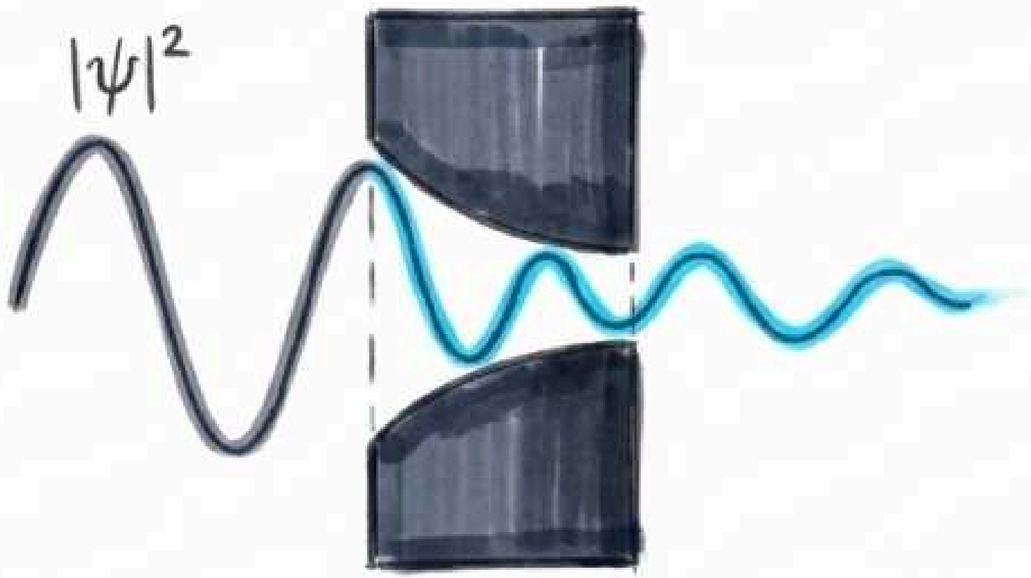
6.2 | Quantum Tunneling Explained

Classical Physics



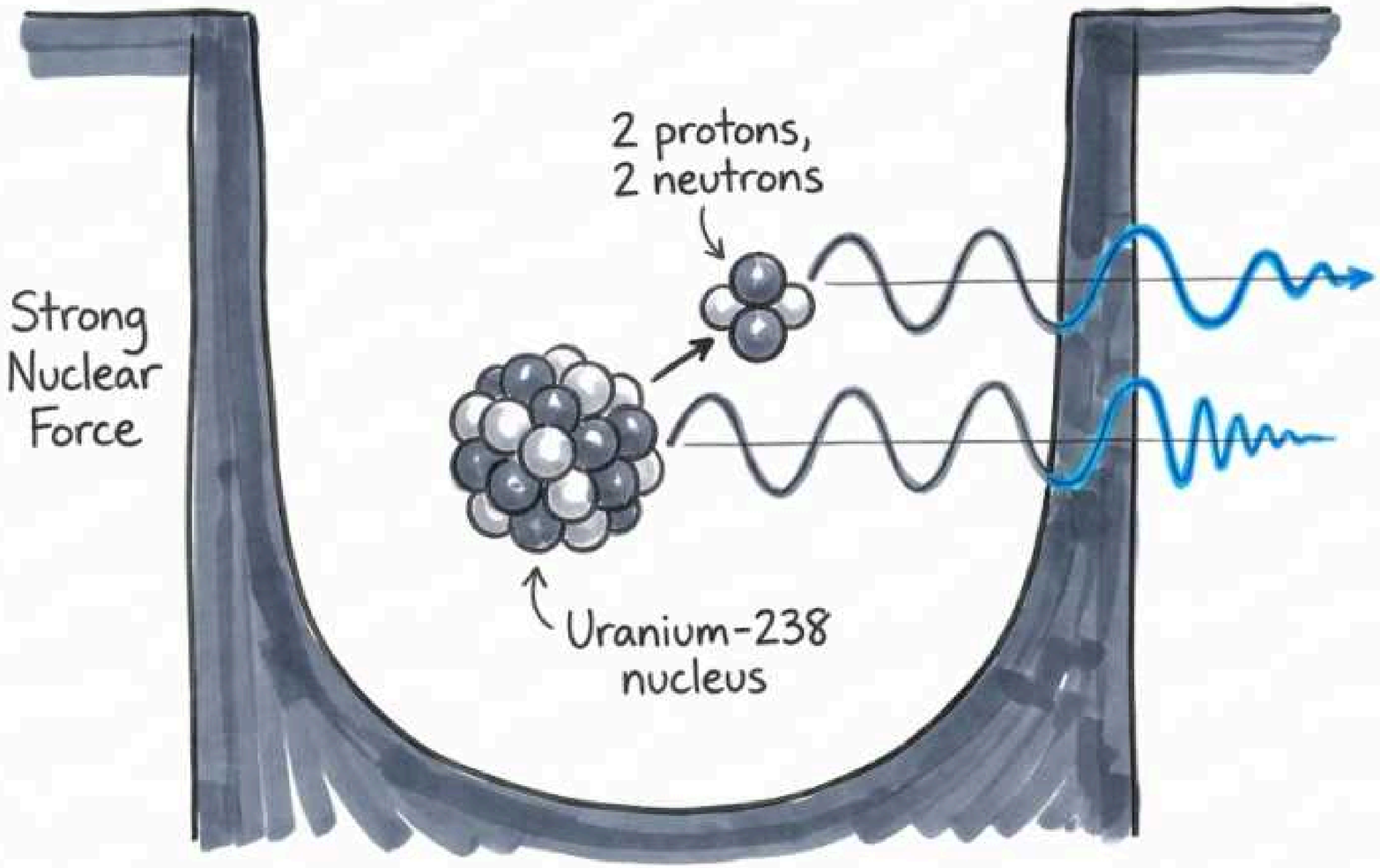
Insufficient energy = absolute stop.

Quantum Physics



The wave shrinks inside the barrier but does not stop dead. Through a thin barrier, there is a definite probability of crossing.

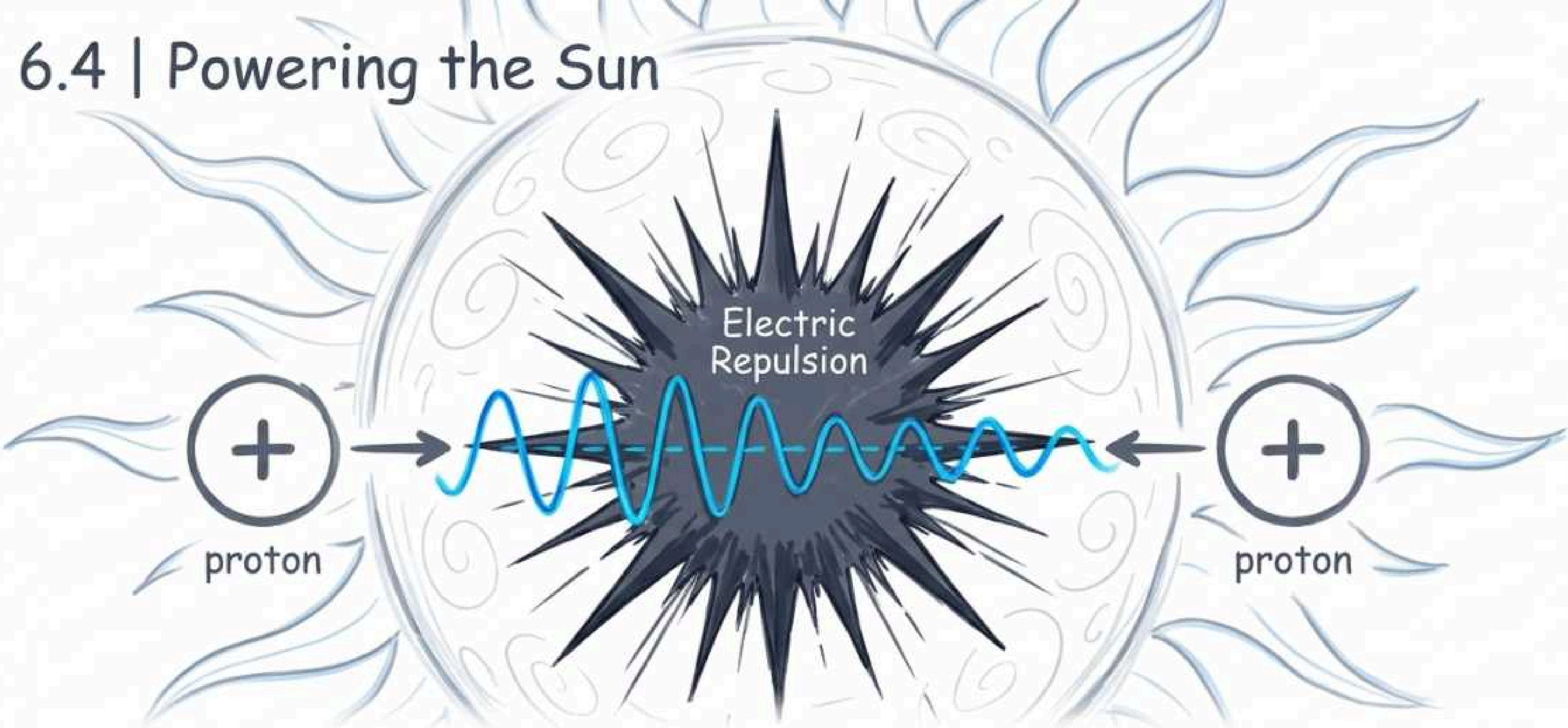
6.3 | Alpha Decay



Gamow, Gurney, Condon (1928)

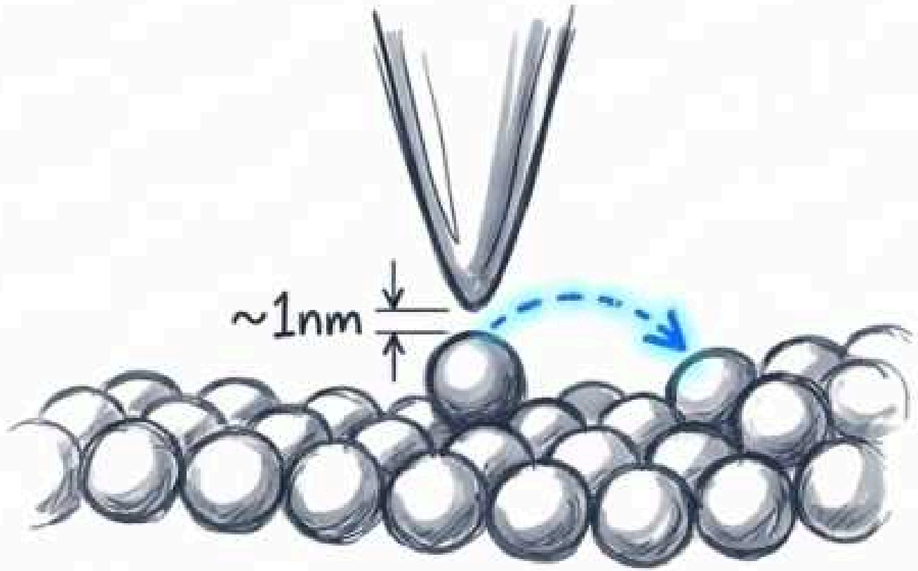
The alpha particle lacks the energy to climb out of the nucleus, so it tunnels. Because tunneling probabilities fall steeply, tiny energy differences result in massive half-life differences—from fractions of a second to 4.5 billion years for U-238.

6.4 | Powering the Sun

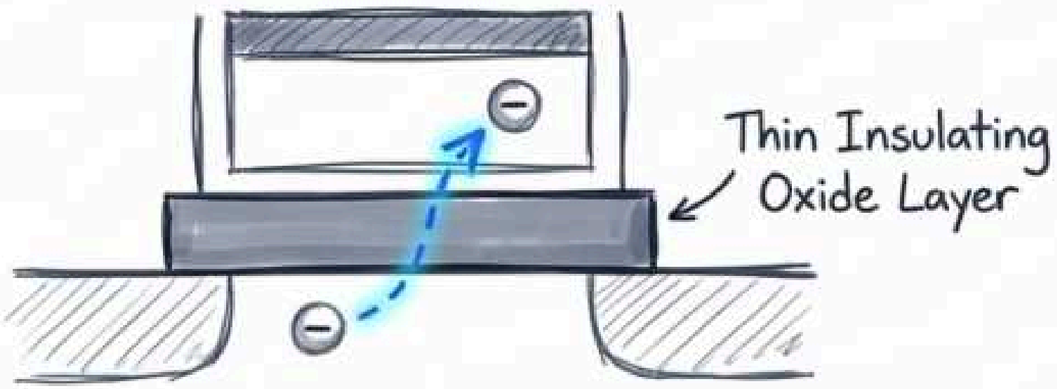


Inside the solar core (15 million degrees), classical physics dictates that protons cannot get close enough to fuse. Quantum tunneling allows a small fraction to bypass the repulsion barrier, powering the Sun steadily for billions of years.

6.5 | Engineering Tunneling

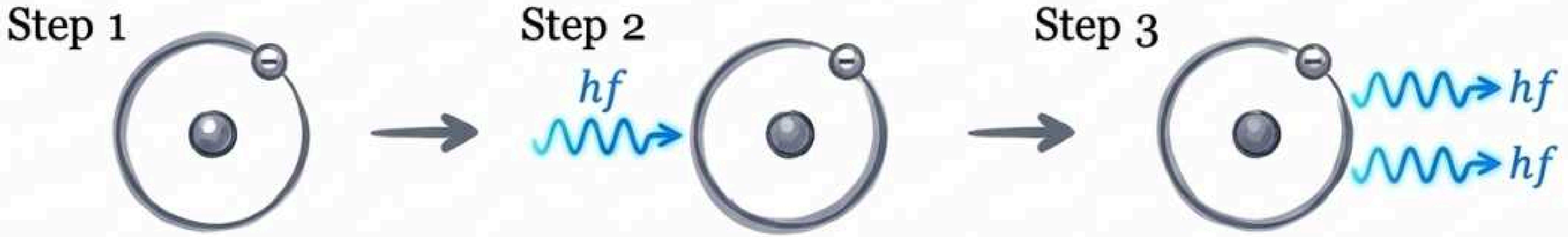


Scanning Tunneling Microscope (Binnig & Rohrer): Maps individual atoms by measuring the tunneling current across a nanometer gap.

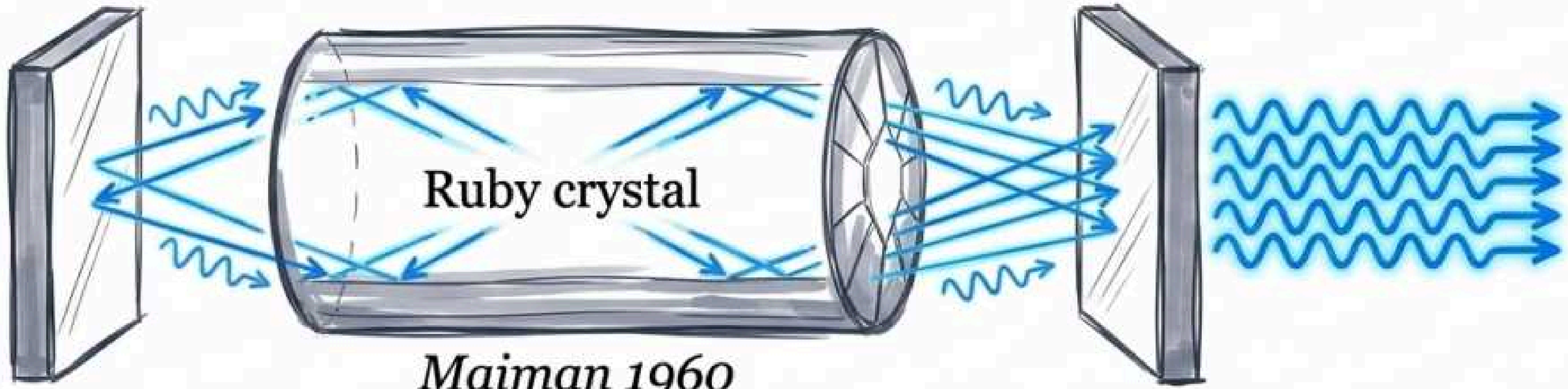


Flash Memory: Stores data in your phone by deliberately pushing electrons through an insulator via tunneling.

6.6 | The Laser: Light Amplification

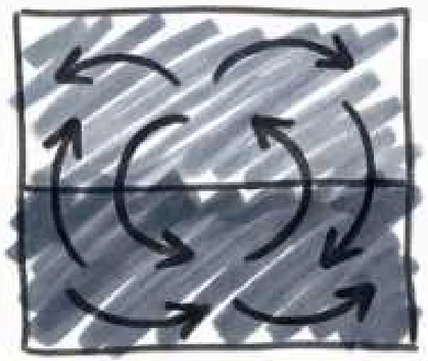
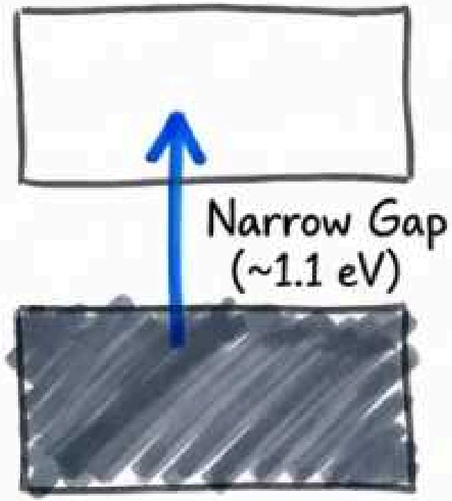


Einstein (1917) showed that a passing photon can trigger an excited atom to emit a second, perfectly identical photon. Through Population Inversion, one photon becomes two, two become four, creating a perfectly synchronized beam.



Maiman 1960

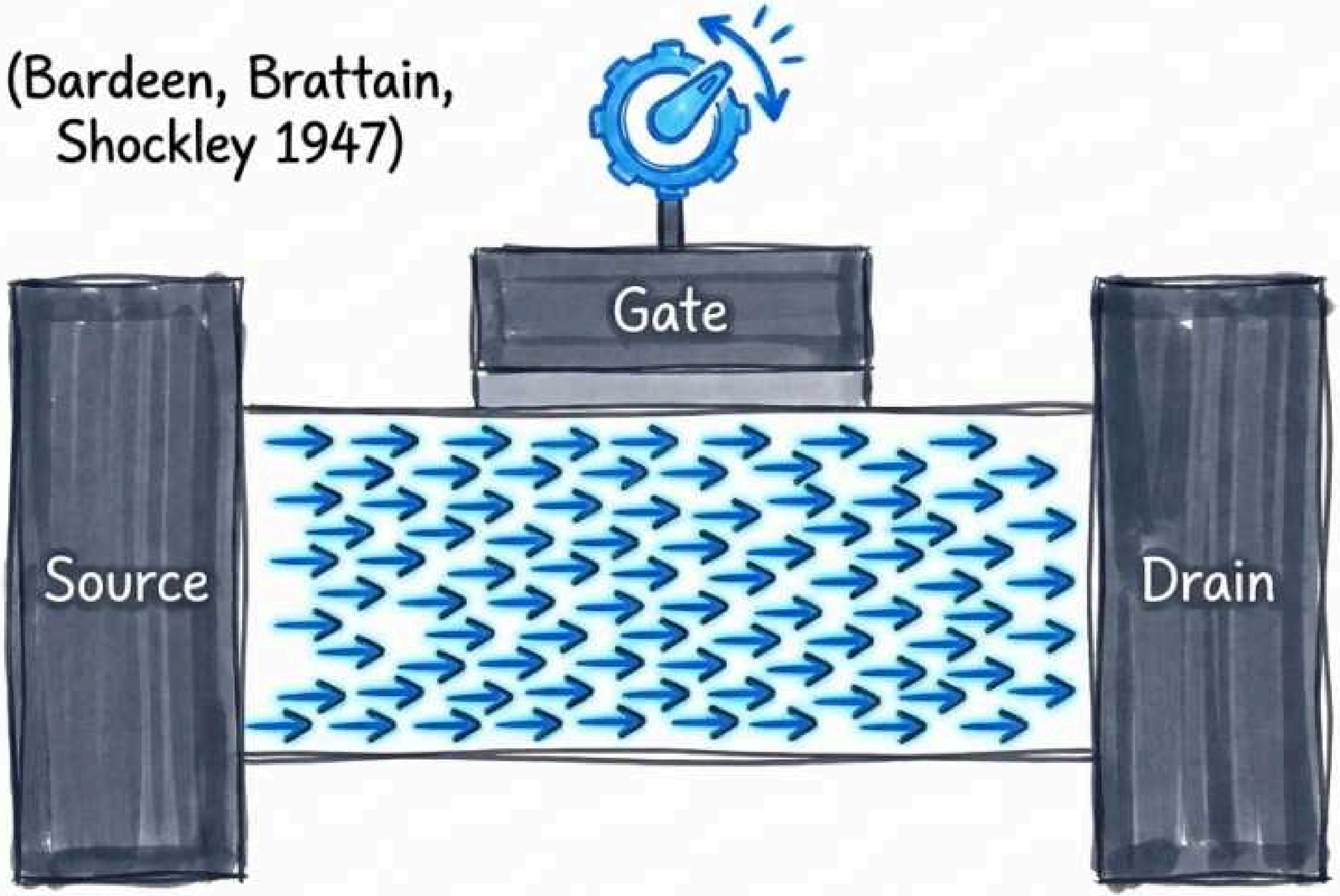
6.7 | Energy Bands in Solids

Metal	Insulator	Semiconductor (Silicon)
		
Overlapping Bands, Free Electrons	Large Energy Gap, No Conduction	Small Gap, Tunable Conductivity

Countless atomic energy levels merge into broad bands. The size of the band gap determines conductivity. Silicon's narrow gap allows scientists to precisely control its conductivity by doping it with other elements.

6.8 | The Transistor

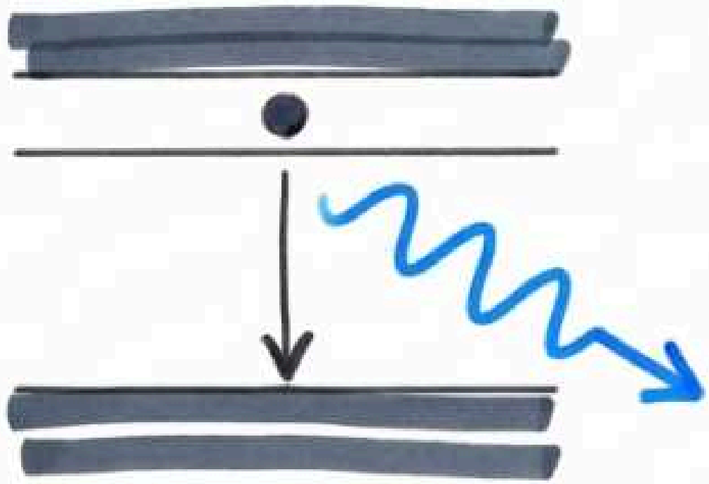
(Bardeen, Brattain, Shockley 1947)



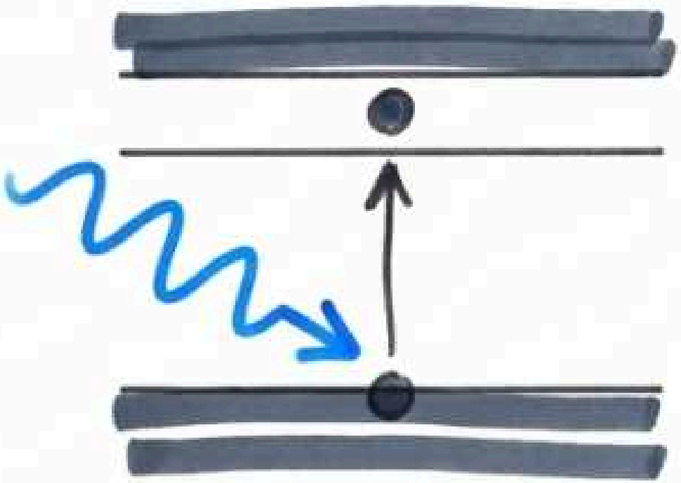
- A switch with zero moving parts.
- A tiny voltage applied to the Gate controls a much larger current.
- Modern processors pack billions of these switches, each tens of atoms across.

6.9 | Two Sides of the Same Quantum Coin

LED



Solar Cell

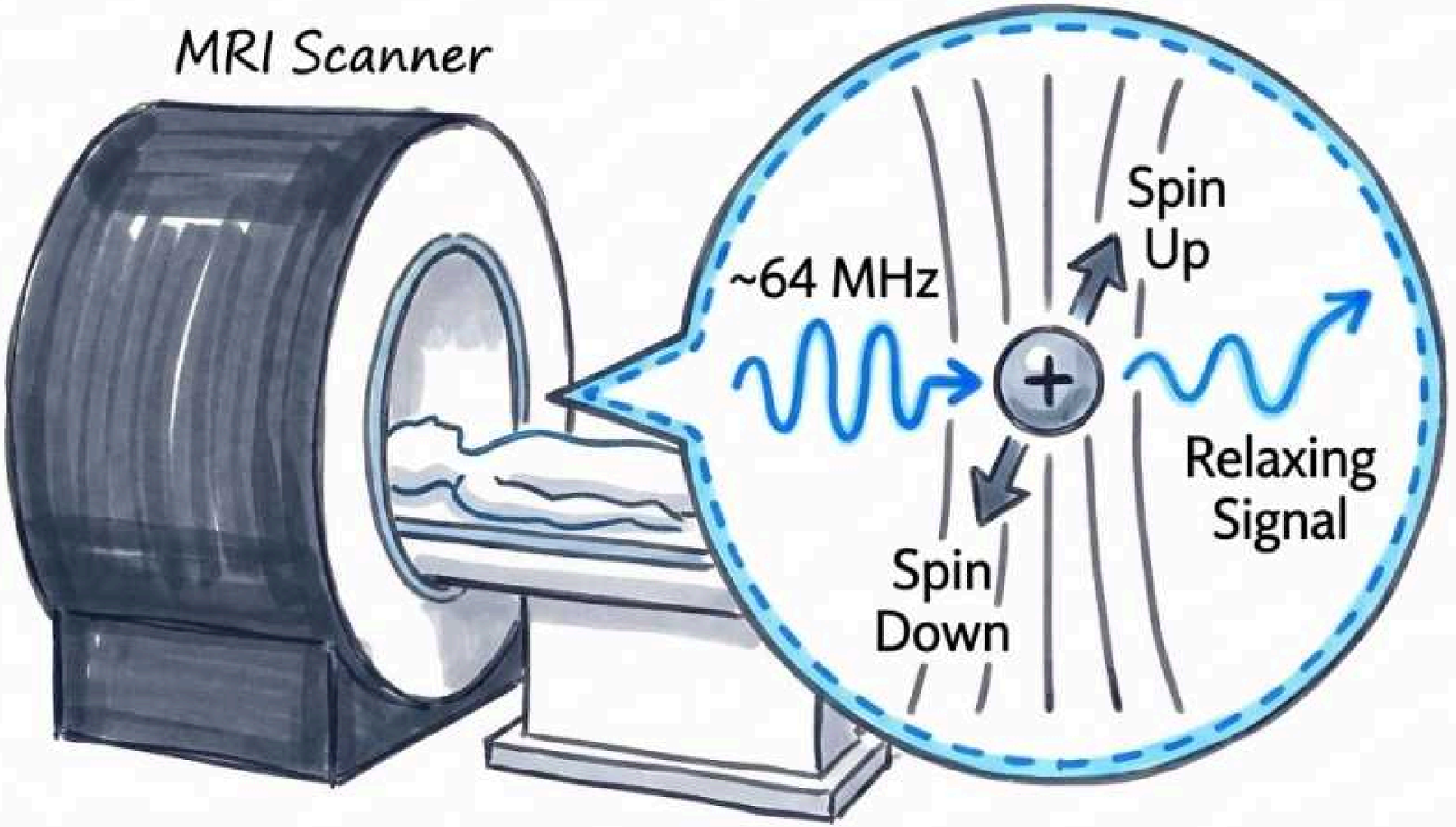


$$E = hf$$

LEDs emit a specific color when an electron drops across a band gap.

Solar cells drive electric current when an absorbed photon lifts an electron across the gap.

6.10 | Magnetic Resonance Imaging (MRI)

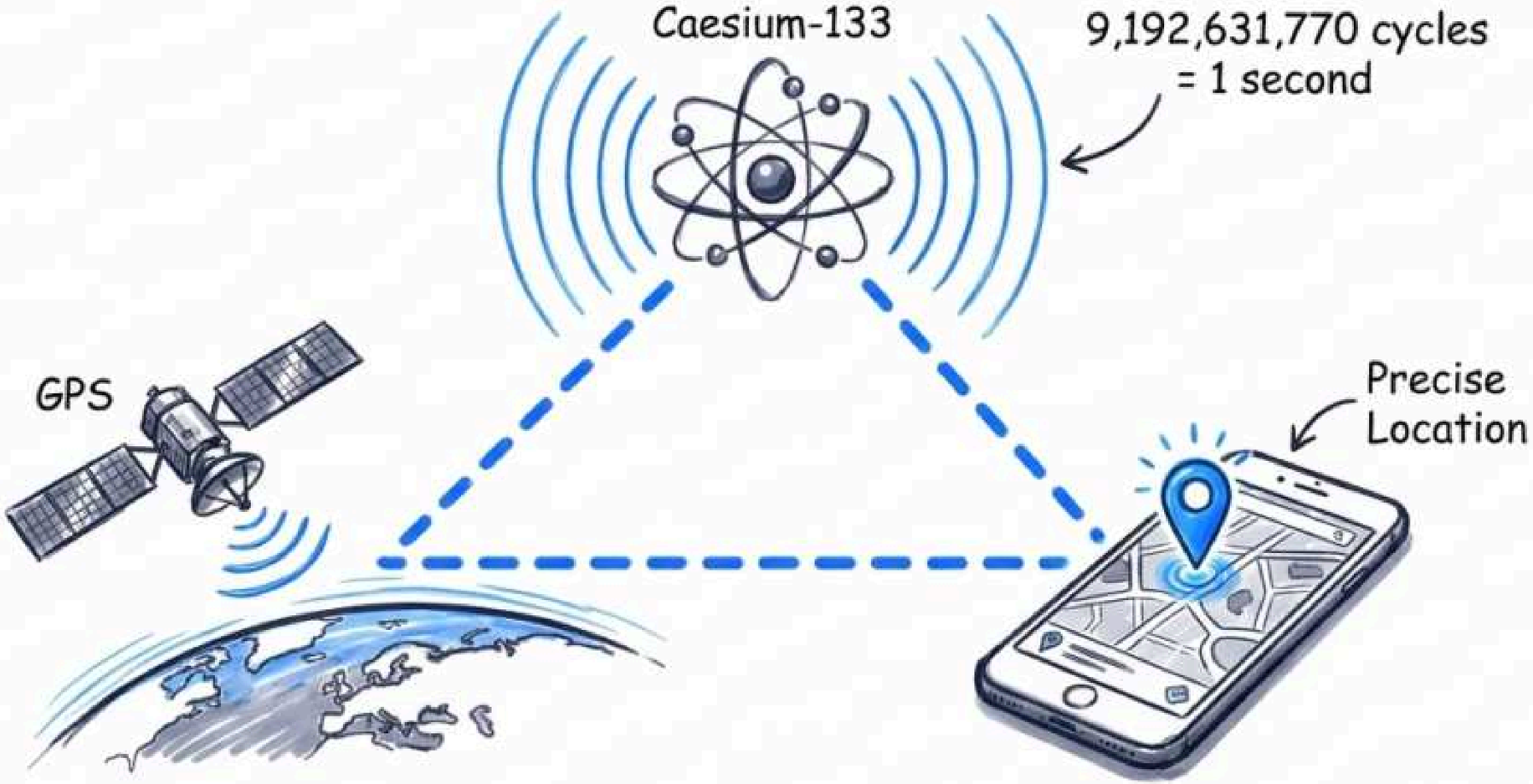


Hydrogen nuclei (protons) act as tiny magnets.

In a strong magnetic field (1.5–3 Tesla), precise radio waves flip their spins.

As they relax, they emit signals that create highly detailed images of soft tissue without harmful X-rays.

6.11 | Atomic Clocks and GPS



Fixed atomic energy levels act as nature's perfect pendulums. Without this quantum precision, a timing error of just one millionth of a second would throw your phone's GPS off by 300 meters.

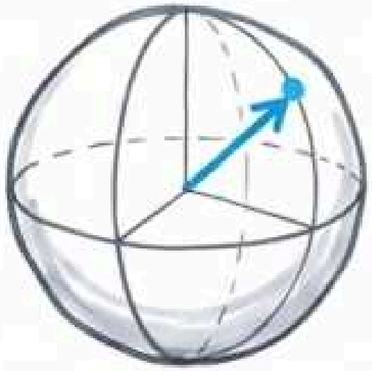
6.12 | The Qubit

Classical Bit

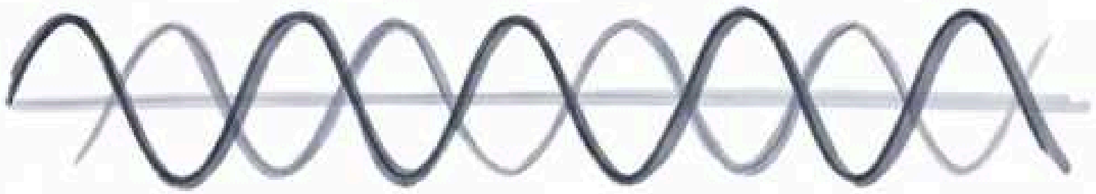


0 OR 1

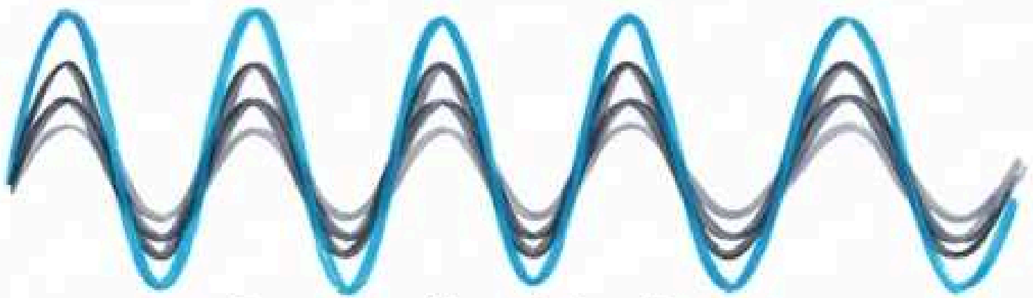
Qubit



Superposition of 0 AND 1



Destructive Interference



Constructive Interference

- n qubits = 2^n amplitudes.
- A quantum computer doesn't just try every answer at once. It acts like a double-slit experiment, carefully arranging for wrong answers to cancel out and right answers to add up.

6.13 | Quantum Speed-Ups



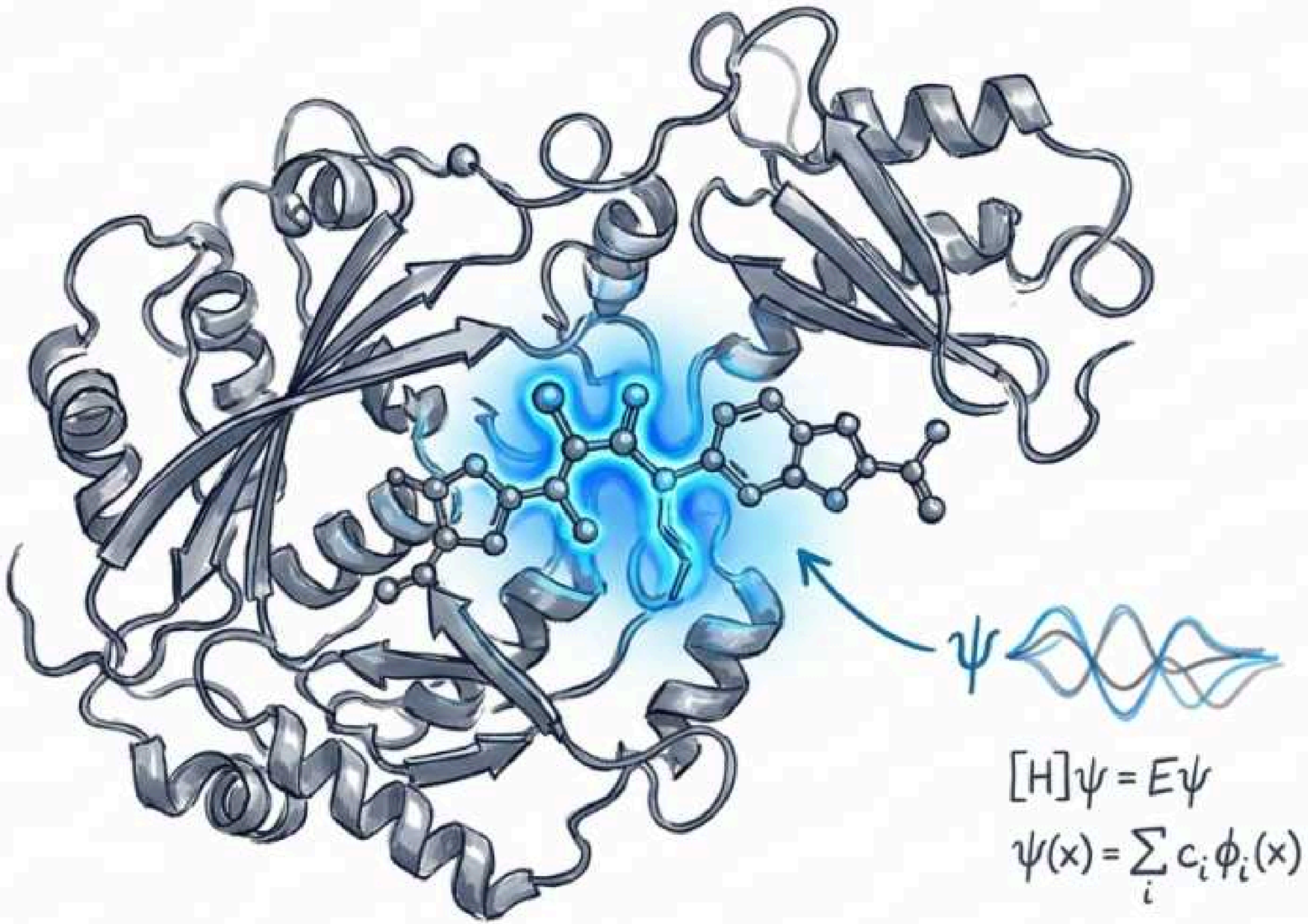
Shor's Algorithm
Breaking Encryption

Grover's Algorithm
Searching Lists

Quantum Supremacy (Google 2019)

Enormous potential for specific tasks. While error-corrected machines capable of breaking modern encryption haven't been built yet, governments are already designing post-quantum cryptography to survive them.

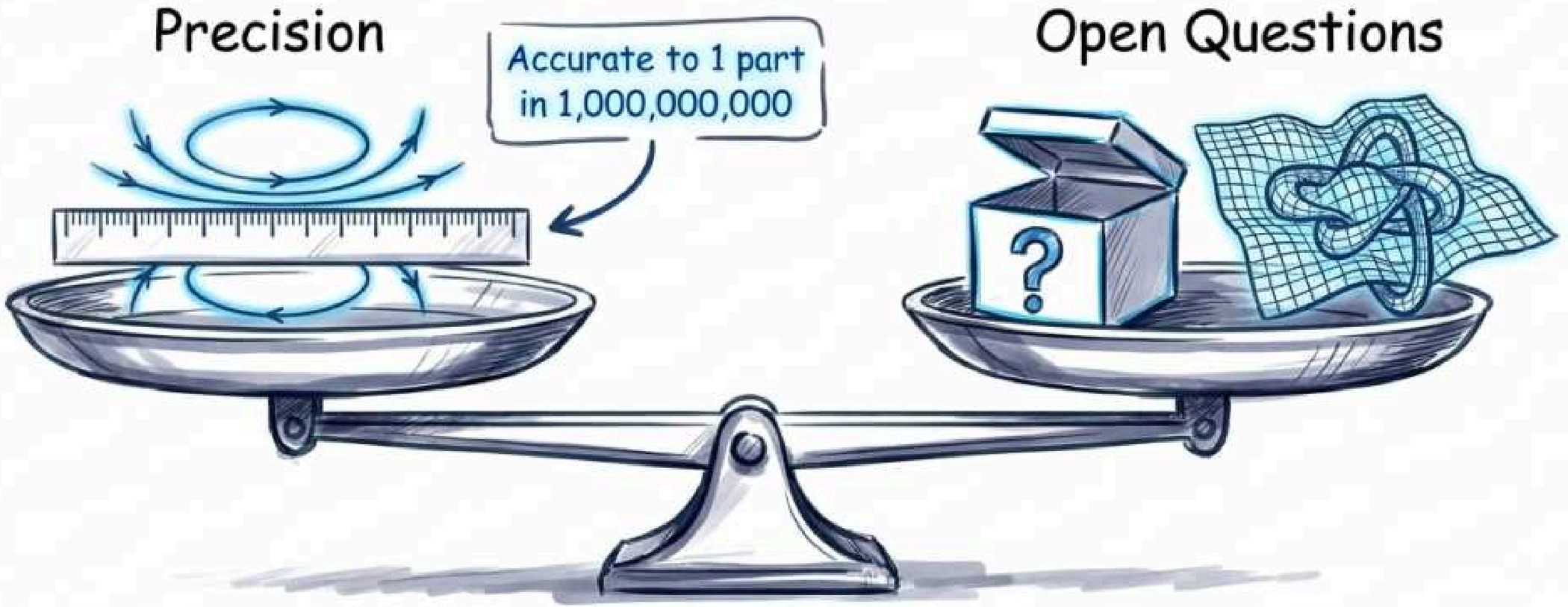
6.14 | Simulating Nature



Quantum mechanics underlies all of chemistry.

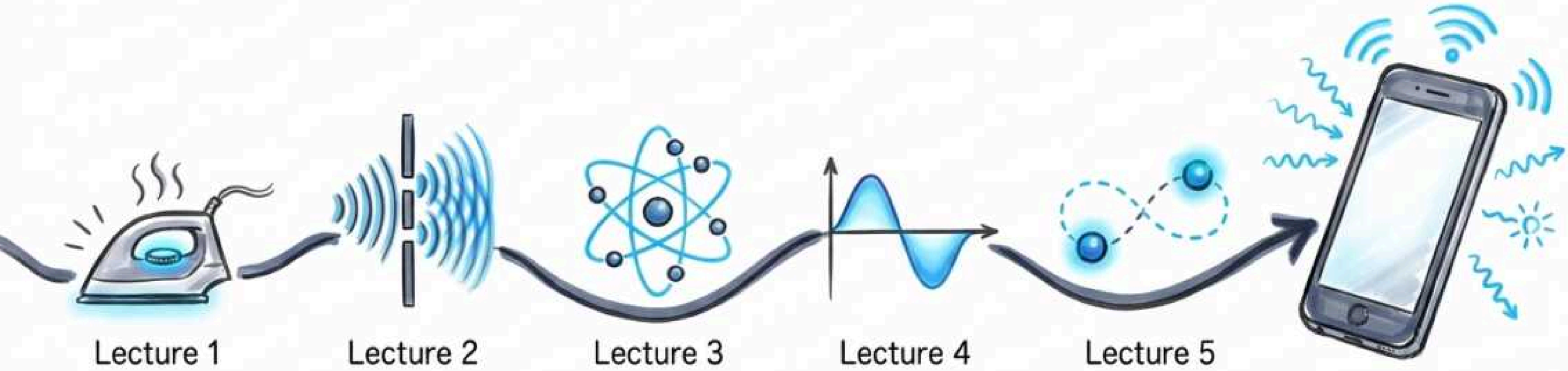
As Richard Feynman noted in 1981, the most promising use for quantum computers is simulating molecules and materials—because nature itself is a computable quantum system.

6.15 | Precision and Open Questions



The most successful theory in science. Yet, the true physical nature of measurement remains fiercely debated, and gravity remains entirely unintegrated. Live research problems await.

6.16 | Course Summary



From Planck's abstract lumps of energy to the technology in your pocket.

Tunneling, lasers, semiconductors, MRI, and GPS—all built on the strange, precise laws of the quantum world.