# Visualizing Quantum Mechanics

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SCIENCE MELTING POT

# My Journey

B.Sc, M.Sc. Physics
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Science Educator & Communicator, India

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Quantum Games and Simulations, Marie-Curie EU project, Denmark

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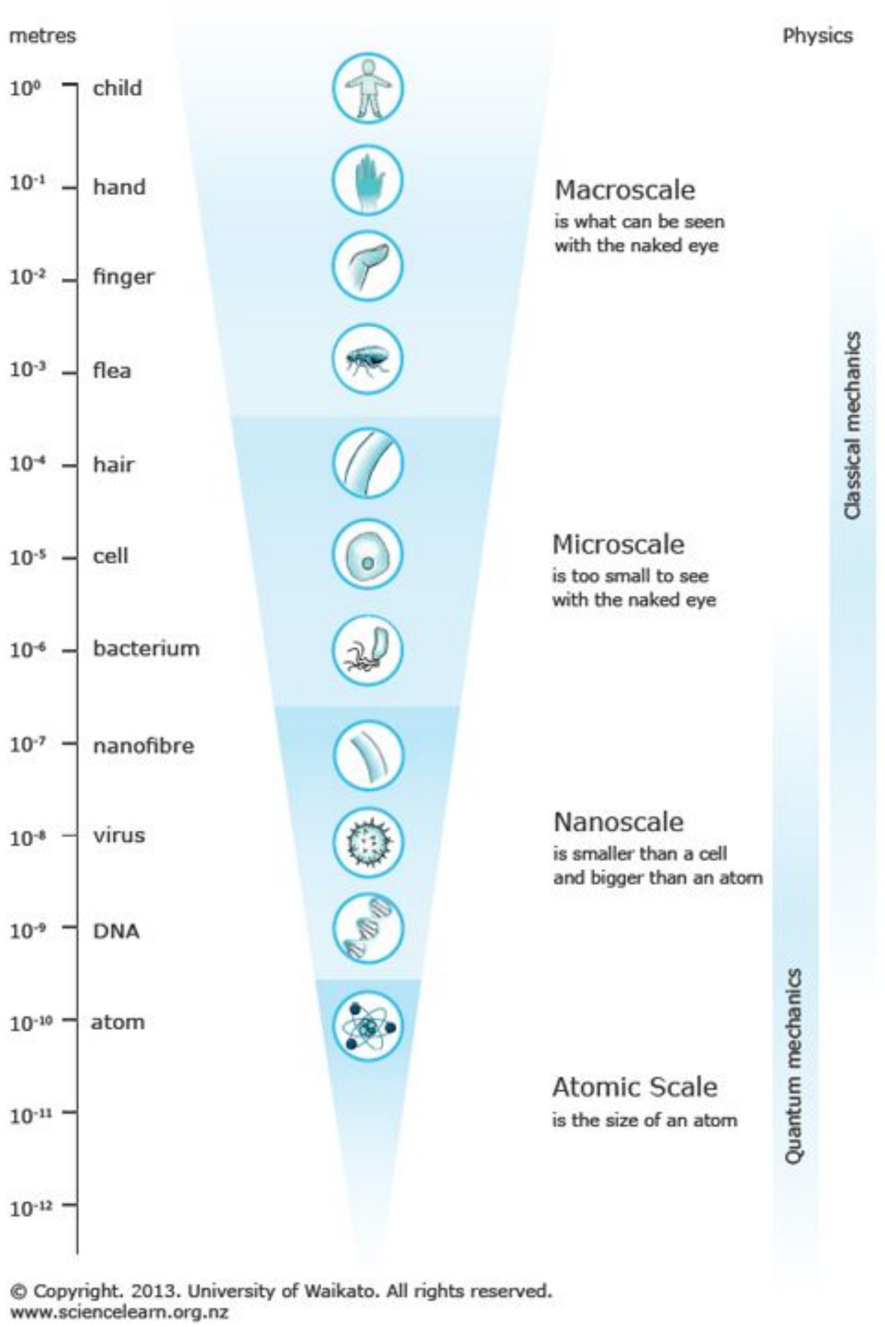
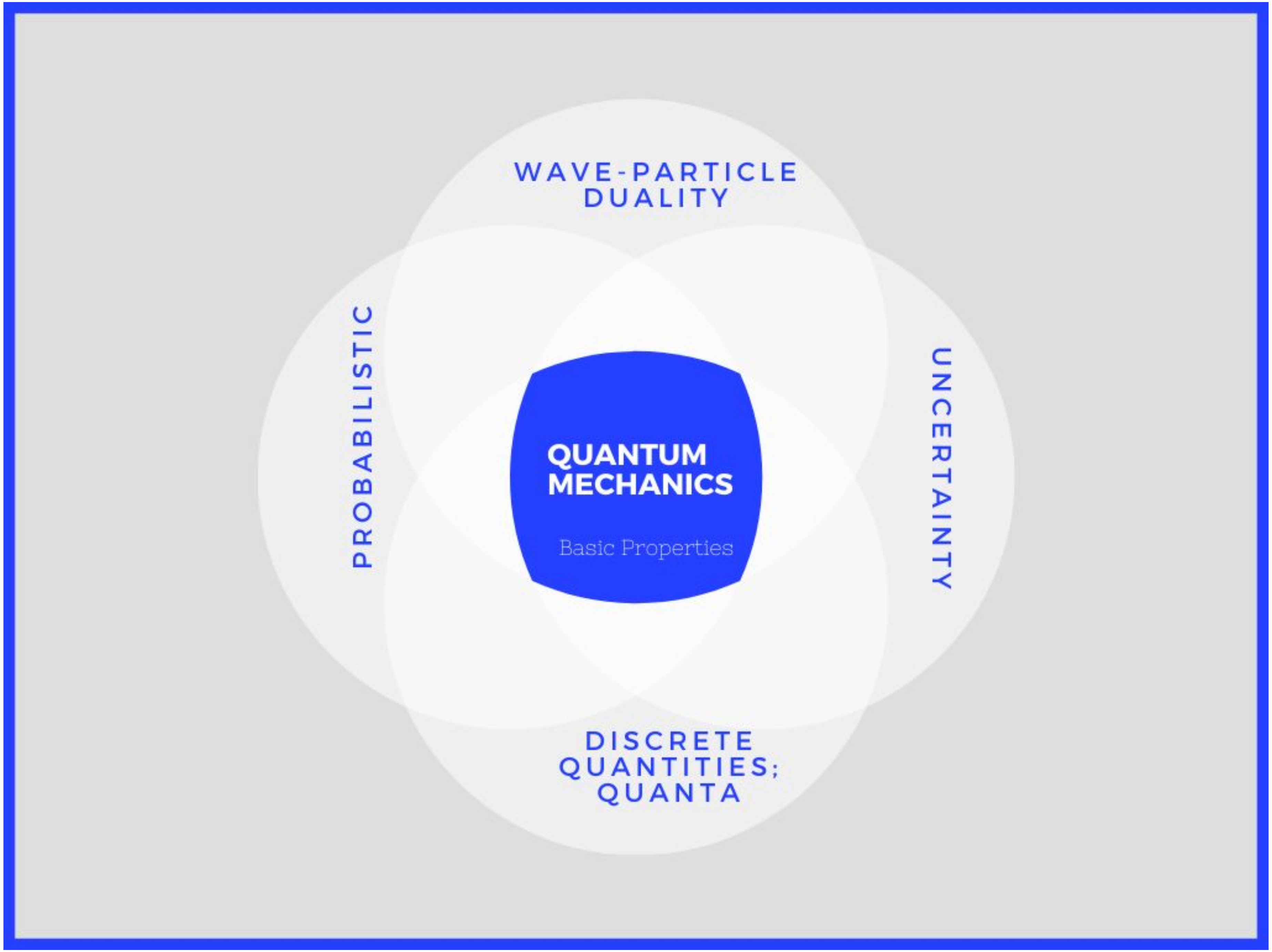
Science Education, Outreach, Diversity

# Outline

- What is quantum mechanics?
- Properties of a quantum system
- Quantum mechanics terminology
- Quantum harmonic oscillator



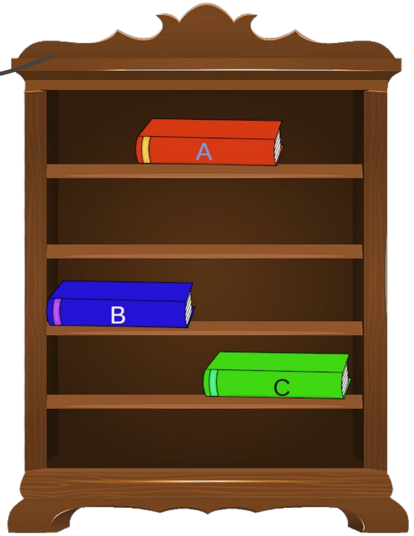

# Quantum Mechanics describes the physics at the atomic scale

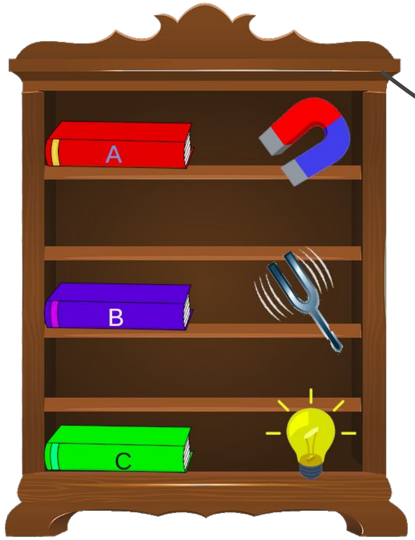

WAVE-PARTICLE DUALITY
PROBABILISTIC
QUANTUM MECHANICS
Basic Properties
UNCERTAINTY
DISCRETE QUANTITIES; QUANTA

# What makes a quantum system so special?

**Different levels:**

Like books on a shelf we can place electrons at different energy levels of an atom.




**Physical properties:**

Some of these levels may react to different parameters (like electromagnetic fields or vibrations).


**Superposition:**

The same book (particle) can be spread simultaneously through multiple levels.

**State collapse:**

When we observe the system, the particle appears instantly in just one of the levels where it was.

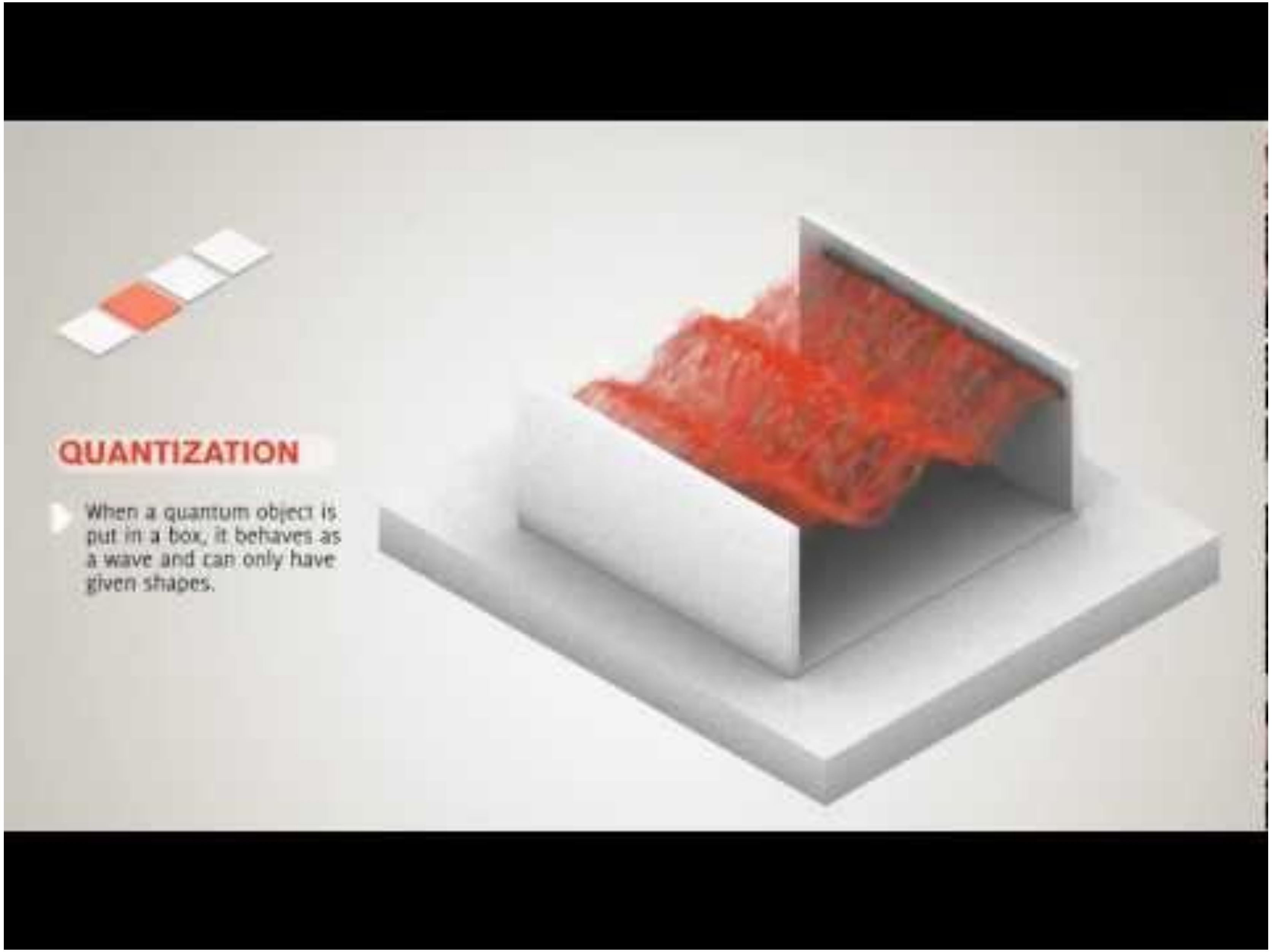

Source: Adapted from Fernando Gago-Encinas, PhD student, FU Berlin

# Double-Slit Experiment

Source: Quantum Kate, SDU Denmark

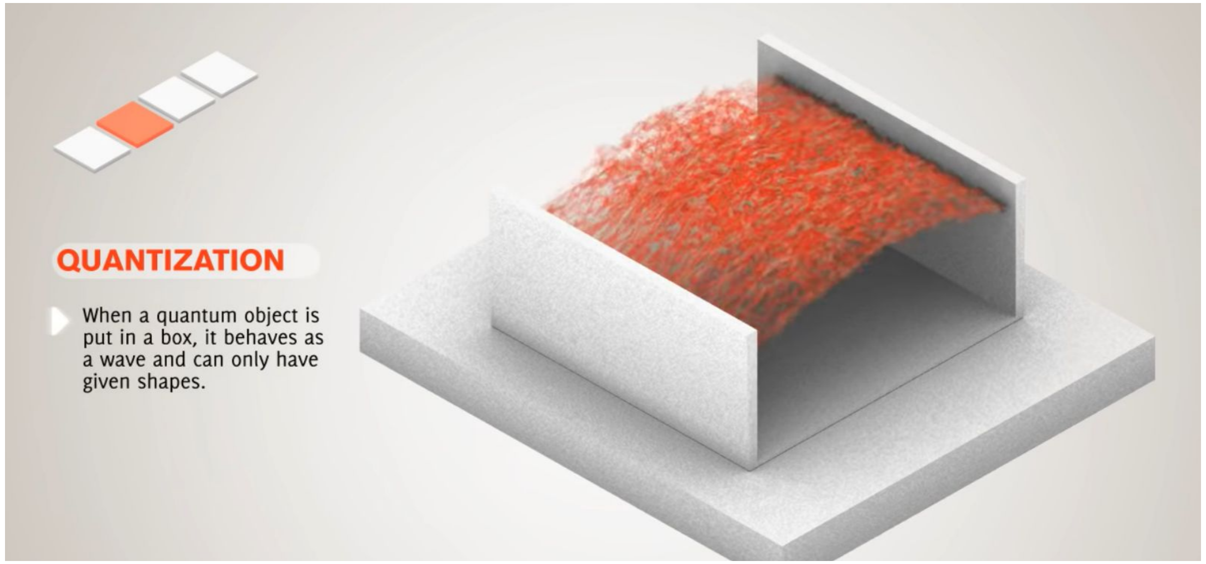
# Key Points

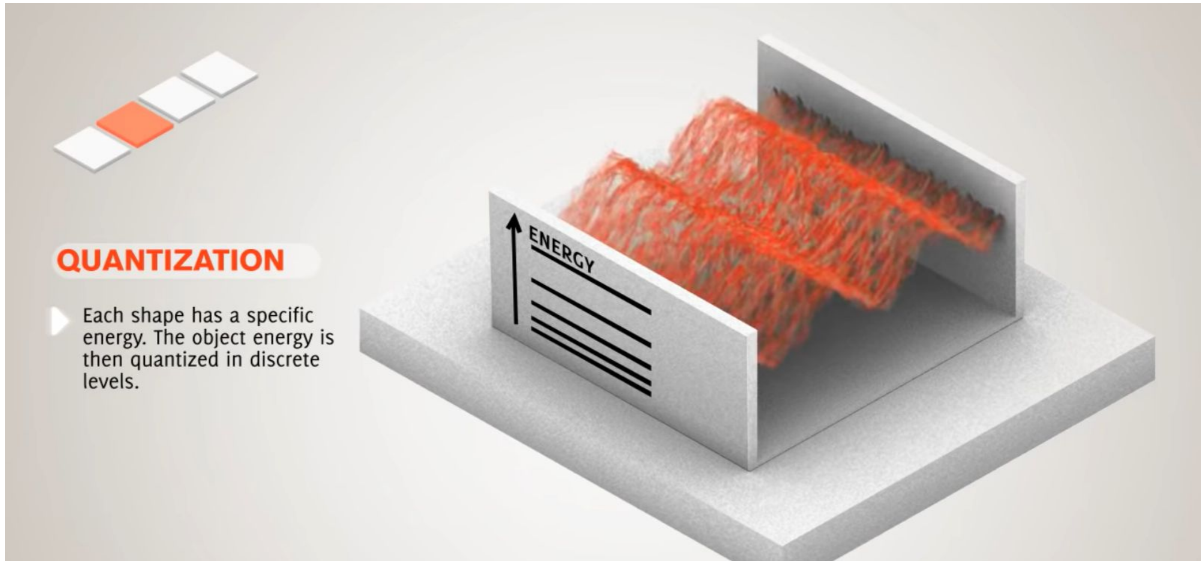
- Superposition:
  - Being in two places at once/multiple quantum states at once!
- Wave-Particle Duality:
  - Electrons can be both waves and particles
- Role of Observer:
  - If we want to observe if it’s a wave or particle, then it chooses to be one !
  - Not observing 2 states at the same time, but one of these states with e.g. 50% chance




Source: Physics Reimagined (Univ. Paris-Saclay, CNRS)

In 1925, Erwin Schrödinger designed an equation that enabled him to find the energies of any quantum particle. Such particles display a "quantized" behavior: they can only have certain energies and they jump suddenly from one energy level to another.





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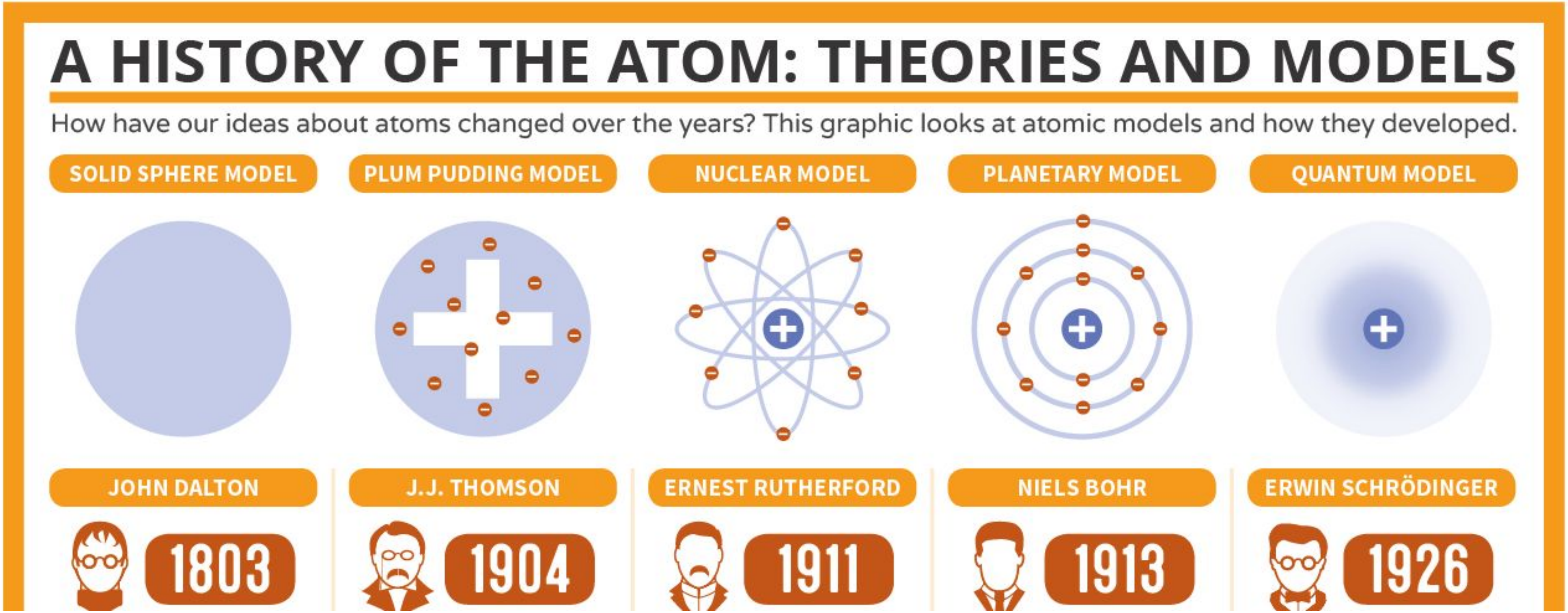


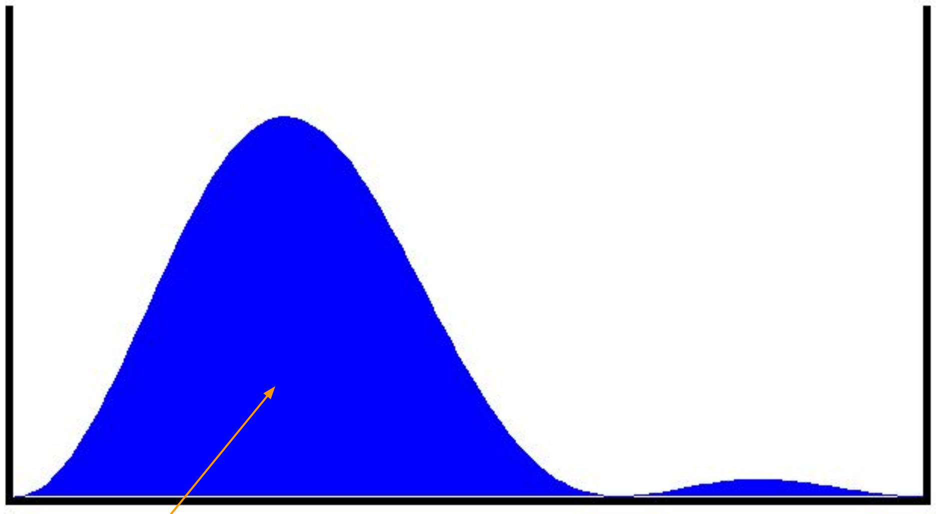

Source: Adapted from Compound Chem

# Quantum Basics: Mathematical Terminology

$x$ Spatial dimension

$V$ Potential (For example: hard walls of a box )

$H$ Hamiltonian (Total Energy)



Source: Pieter Kuiper, Wiki Commons

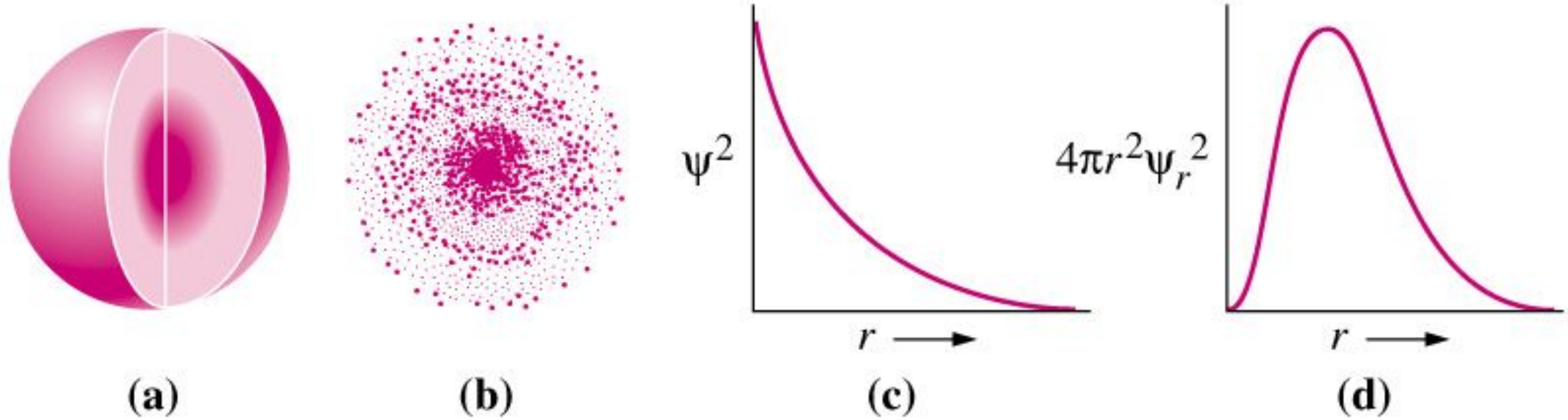
$\psi$ Wavefunction:
Describes the state of a quantum object.

# Quantum Basics ...

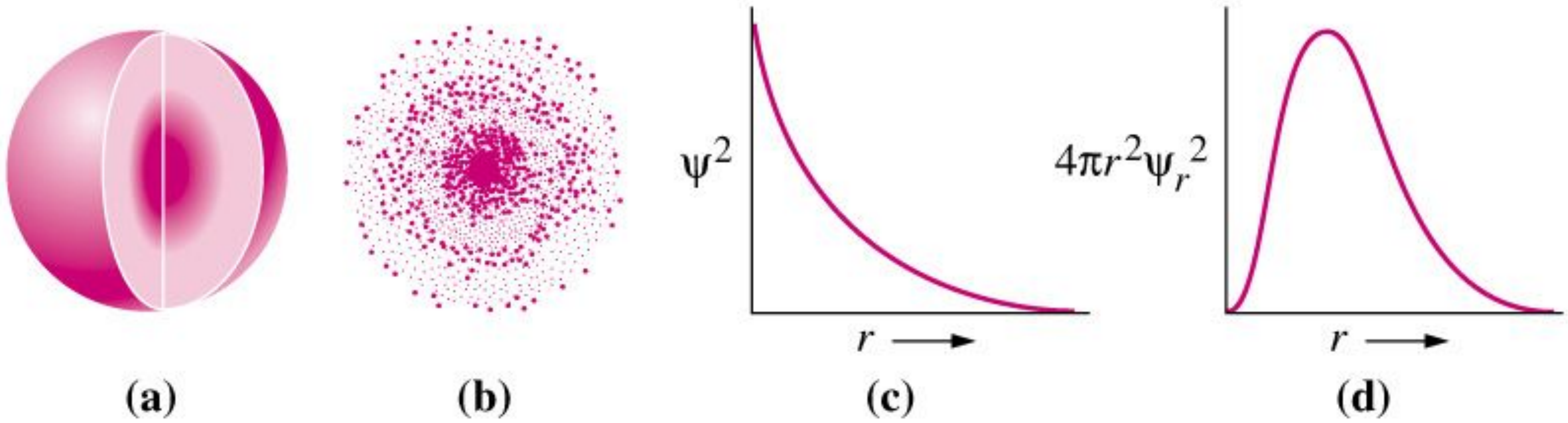
$|\psi|^2$

Probability density

Gives us the probability of finding a particle at a given time and place



# Wave Function & Probability Density




(a) 1*s* electrons can be "found" anywhere in this solid sphere, centered on the nucleus

(b) The electron density map plots the points where electrons could be. The higher density of dots indicates the physical location in which the electron cloud is most dense

(c) Electron density is shown as a function of distance from the nucleus (r) as a graphical representation of the same data used to generate figure b.

(d) The total probability of finding an electron is plotted as a function of distance from the nucleus (r).

# How do we know

$\psi$

Wavefunction describes the state of a quantum object

Planck's constant

Called the 'del-squared operator', this quantity describes how the wavefunction, $\Psi$, changes from one place to another

A mathematical quantity called an 'imaginary number'. It is equal to the square root of minus one

$$-\frac{\hbar^2}{2m}\nabla^2\Psi + V\Psi = i\hbar\frac{\partial\Psi}{\partial t}$$

The mass of the particle being described

Describes the forces acting on the particle

Describes how $\Psi$ changes its shape with time

Plays the role of Newton's 2nd laws in classical physics

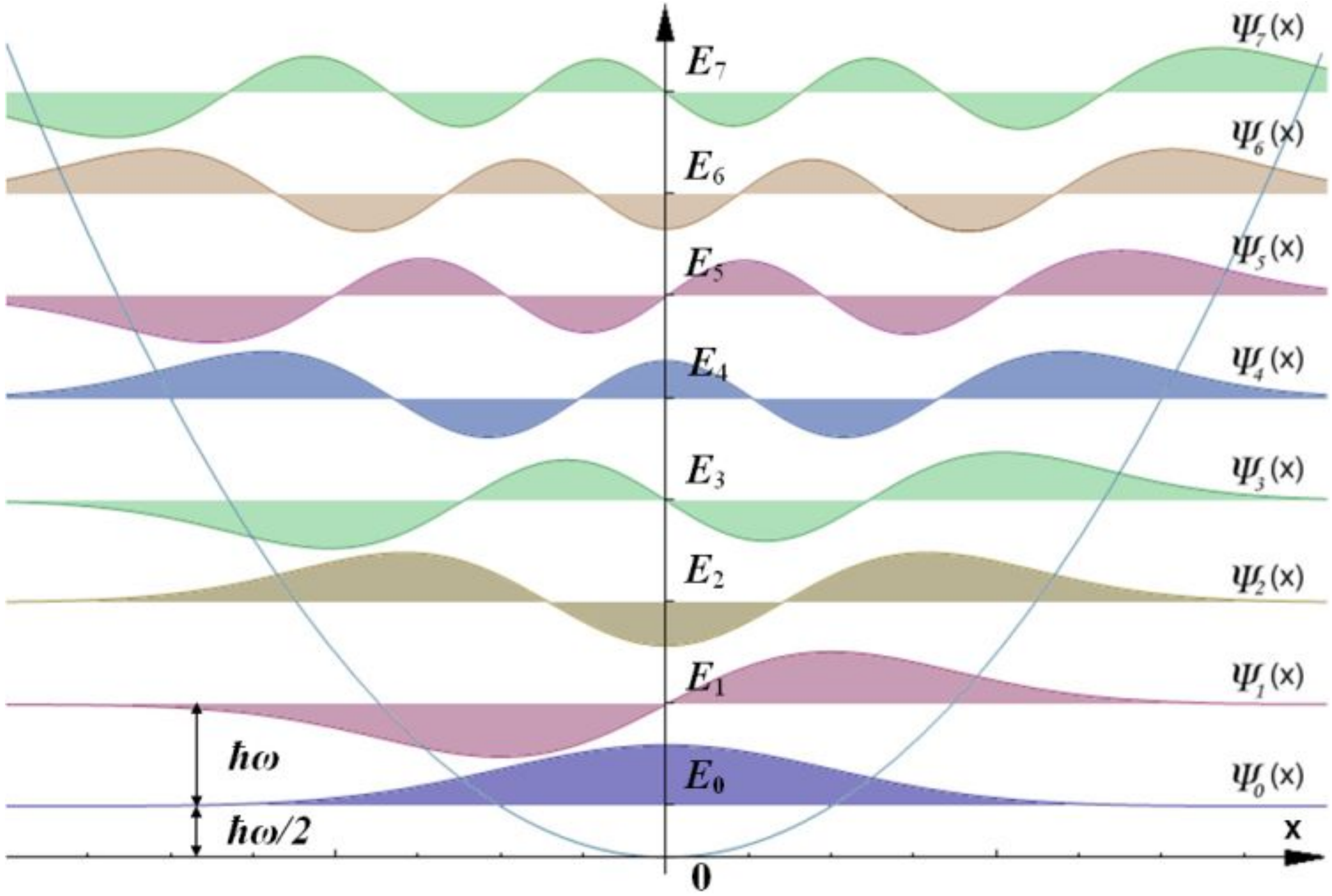
(F = ma)

## Schrödinger Equation

# Quantum Basics

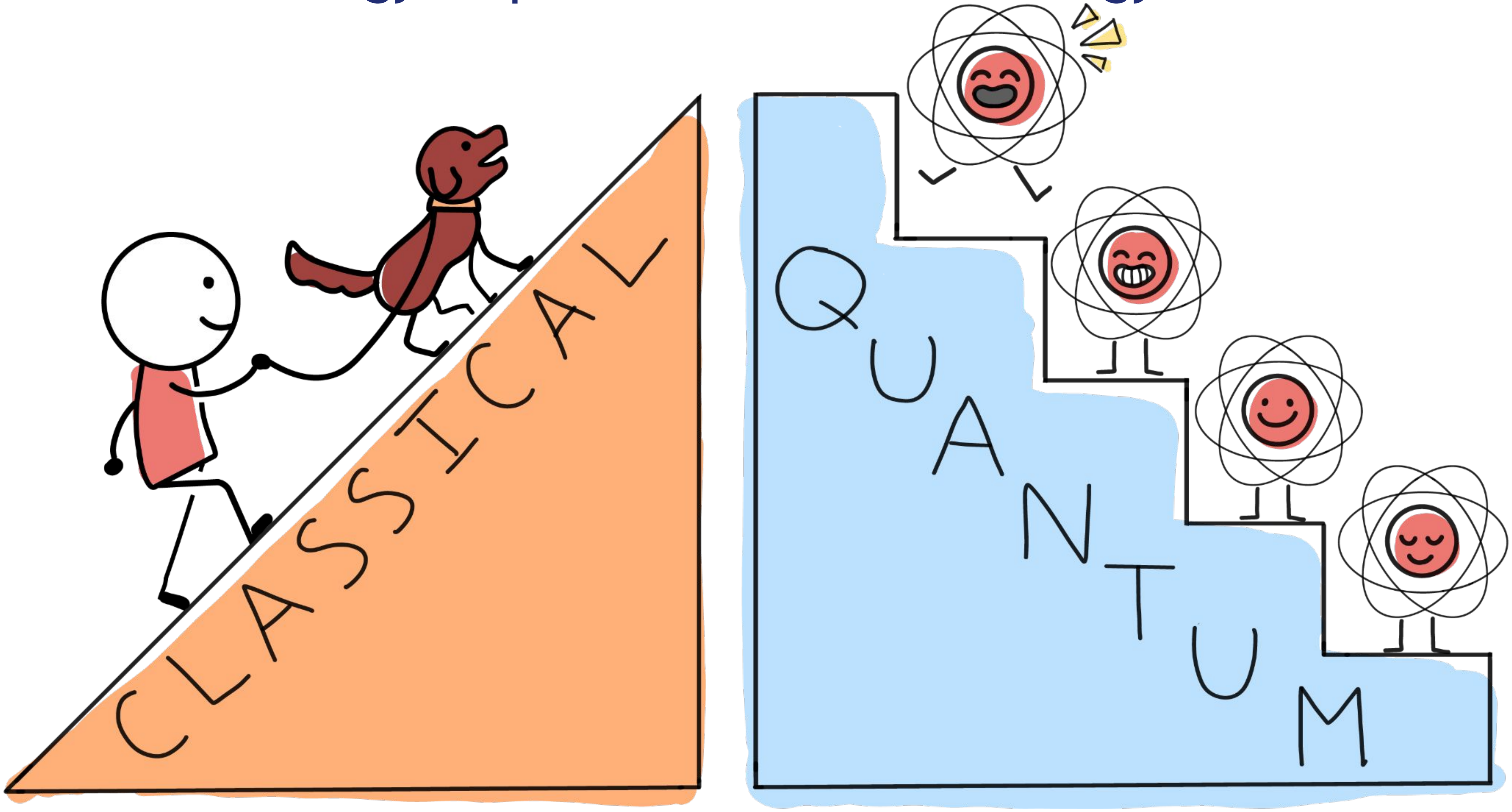
Spectrum $\{\psi_n, E_n\}$

Each potential will give us a set of energy states and energy values that a quantum particle can have




Source: Wikimedia Commons

# Energy is quantized: Discrete energy levels

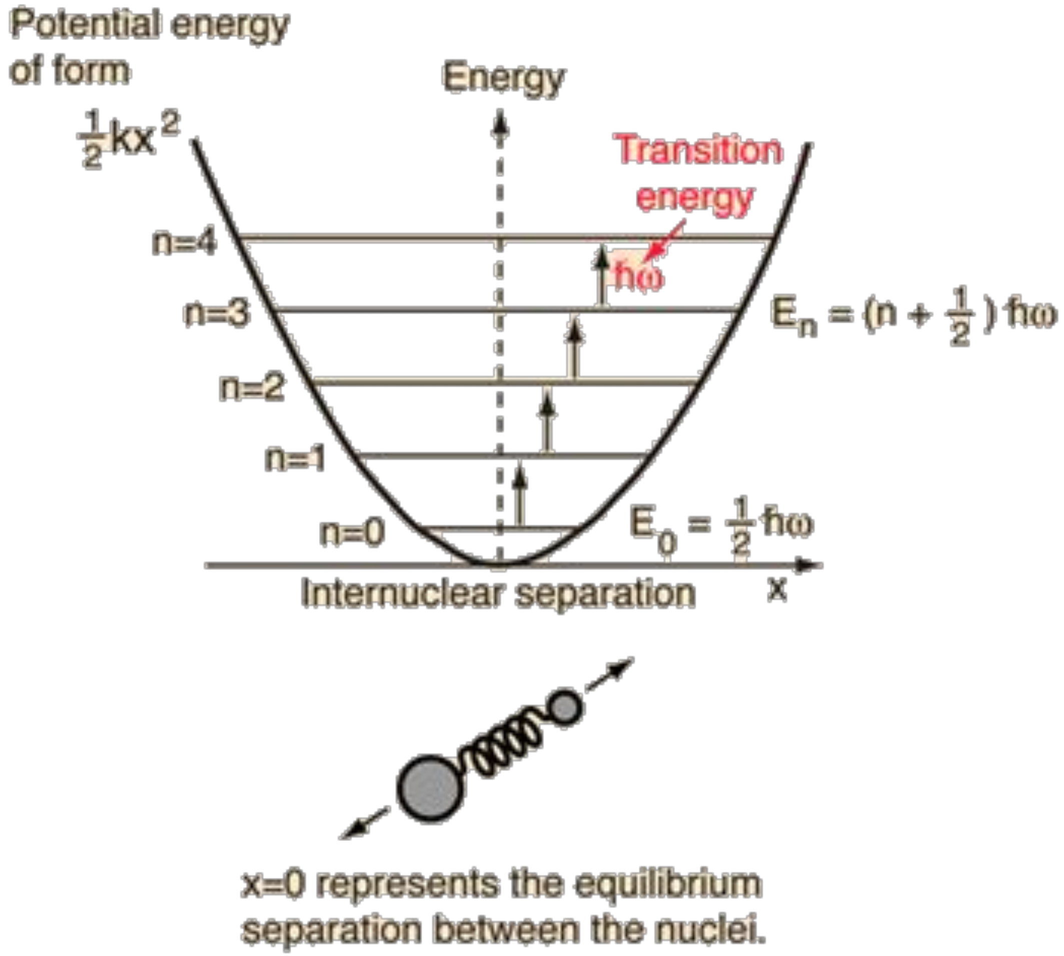



Source: The Quantum Atlas

# An example: Quantum Harmonic Oscillator

- Important model systems in quantum mechanics

- The vibrations of a diatomic molecule are an example of a version of the quantum harmonic oscillator.

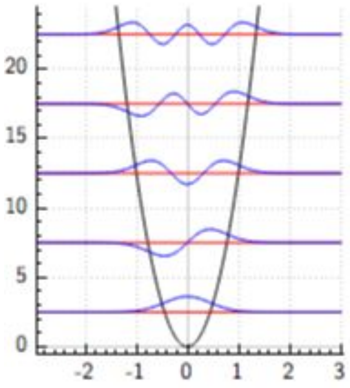



Source: http://hyperphysics.phy-astr.gsu.edu/

# Energy spectrum in different potentials

Each potential has its own spectrum of energy levels and their corresponding wave functions

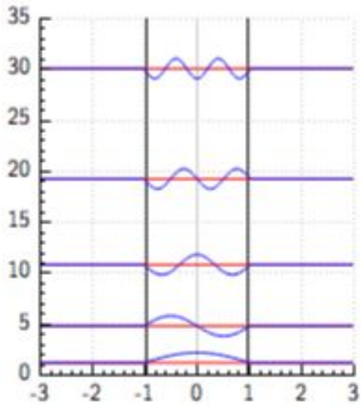
$$V(x) = \frac{1}{2}a^2x^2$$




(a)

Spacing between energy levels is equal

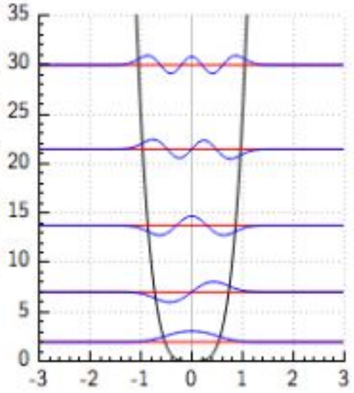
$$V(x) = \begin{cases} 0 & |x| < a \\ \infty & \text{otherwise} \end{cases}$$




(b)

Spacing between energy levels is increasing

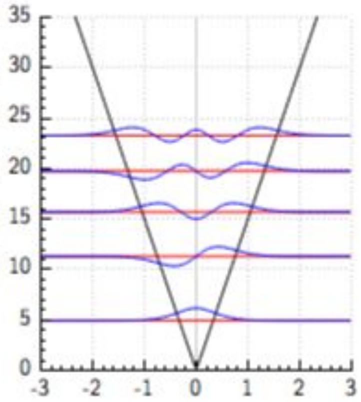
$$V(x) = a^2x^4$$




(c)

?

$$V(x) = a|x|$$

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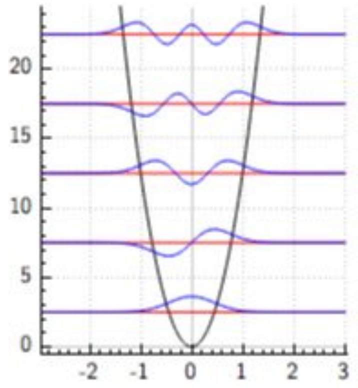


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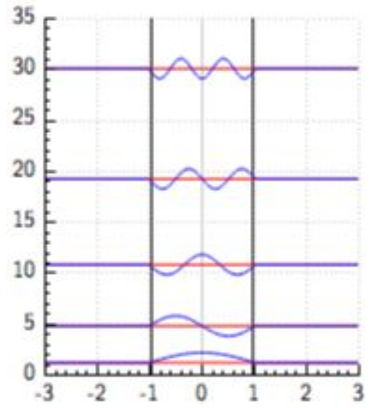


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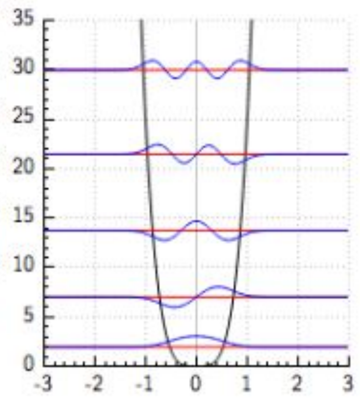


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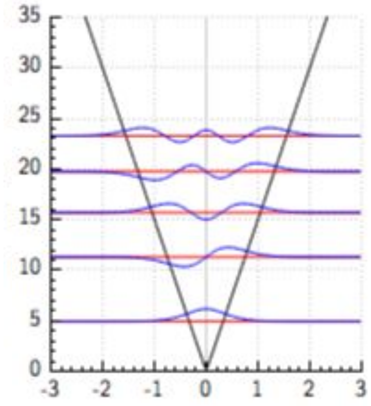


(d)

spacing between energy levels is decreasing

# That’s all for today-Thank you!

For questions, reach out to me on Discord or email me at info@sciencemeltingpot.com

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