If the object light interacts with is about the size or smaller than the wavelength of light, it acts like a wave and exhibits diffraction and the Ray model no longer holds.
Polarization

The EM fields are aligned in specific directions.

Unpolarized light intensity = $S$

Polarizing material

Polarized light intensity = $\frac{1}{2}S$
Polarization of Light

- Plane Polarized
- Circular Polarized
- Polarization upon Reflection
Circularly Polarized EM Wave
Elliptically Polarized EM Wave
Light is in a Superposition of Polarization States!
This is a Quantum Effect.
Diffraction depends on SLIT WIDTH: the smaller the width, relative to wavelength, the more bending and diffraction.
Another Way to Bend Waves
Interference
Double Slit is VERY IMPORTANT because it is evidence of waves. Only waves interfere like this.
Dispersion: Diffraction Gratings

Waves can be bent by diffraction.
Light can be dispersed by diffraction.
The greater the wavelength, the greater the angle.
How does this compare to dispersion with a prism?

![Diagram showing diffraction gratings and dispersion](a)
Dispersion: Diffraction Gratings

How does this compare to dispersion with a prism?
Longer wavelength light is bent more with a grating.
Shorter wavelength light is bent more with a prism.
Each chemical element produces its own unique set of spectral lines when it burns.
Incandescent Light Bulb
Hydrogen Spectra
Helium Spectra
Mercury Spectra
Neon Spectrum
Continuous vs Discreet

This is a continuous spectrum of colors: all colors are present.

This is a discreet spectrum of colors: only a few are present.
Electrons exist in quantized orbitals with energies given by multiples of Planck’s constant. Light is emitted or absorbed when an electron makes a transition between energy levels. The energy of the photon is equal to the difference in the energy levels:

\[ E = nhf, \quad n = 0, 1, 2, 3, \ldots \]
\[ h = 6.626 \times 10^{-34} \text{ Js} \]

\[ E_\gamma = E_i - E_f = hf \]
Light is emitted or absorbed when an electron makes a transition between energy levels. The energy of the photon is equal to the difference in the energy levels:

\[ E_\gamma = E_i - E_f = hf \]
Light Emission & Absorption

\[ E_\gamma = hf \]

Electron gains potential energy and moves farther from nucleus. A photon of light is absorbed.

Electron loses potential energy and moves closer to nucleus. A photon of light is emitted.
Light Emission
Light Emission
Hydrogen Spectra

Transition probabilities correspond to the intensity of light emission.
Hot blackbody

Cloud of cooler gas

Prism

Absorption line spectrum

Prism

Continuous spectrum

Emission line spectrum
Absorption Spectrum of Hydrogen Gas
Hydrogen Emission Spectra
• Cosmological Redshift: Expanding Universe
• Stellar Motions: Rotations and Radial Motions
• Solar Physics: Surface Studies and Rotations
• Gravitational Redshift: Black Holes & Lensing
• Exosolar Planets via Doppler Wobbler
Spectral lines shift due to the relative motion between the source and the observer.
• **Red Shift**: Moving Away
• **Blue Shift**: Moving Toward
Fluorescence

UV in, vibrant color out.
Phosphorescence
Time Delayed Fluorescence
Glow in the Dark: Day Glow
Iridescence: Diffraction
Transition probabilities correspond to the intensity of light emission.
Stimulated Emission

$hf_{in}$

$E_2$

$2hf_{out}$

$E_1$

= photon
Lasers

Light Amplification by Simulated Emission of Radiation

"A splendid light has dawned on me about the absorption and emission of radiation..."

Albert Einstein, 1916
Stimulated Emission
Classical vs Modern

Classical

- Laws of Physics are deterministic.
- Space and time are absolute.
- Particles are *Localized* in Space and have mass and momentum.
- Waves are *non-localized* in space and do not have mass or momentum.
- **Superposition**: Two particles cannot occupy the same space at the same time! But Waves can! Waves add in space and show interference.

Modern

- Laws of Physics are statistical.
- Space and time are relative.
- The speed of light is absolute.
- Particles are wave-like
- Waves are particle-like
Unsolved Mysteries of 1900’s that gave birth to Modern Physics

• Is light particle or wave?
• What is matter made of?
• How and why do atoms radiate discrete spectra?
• Are nebulae within our galaxy or are they other galaxies?
• Black Body Radiation?
The Quantum Revolution

Photons can be particles, Electrons can be waves.
Electrons are *STANDING WAVES* in atomic orbitals.
The Dawn of Modern Physics!
Particle Wave Duality
Is Light a Particle of a Wave?

Flashlight

$E = hf$

$E' = hf'$

Depends on How you LOOK at it!
1800’s: Spectroscopy was the Game

But nobody could explain it!
Fraunhofer Lines: 1814

The English chemist William Hyde Wollaston was in 1802 the first person to note the appearance of a number of dark features in the solar spectrum. In 1814, Fraunhofer independently rediscovered the lines and began a systematic study and careful measurement of the wavelength of these features. In all, he mapped over 570 lines, and designated the principal features with the letters A through K, and weaker lines with other letters.
Kirkoff’s Rules for Spectra: 1859

German physicist who developed the spectroscope and the science of emission spectroscopy with Bunsen.

* Rule 1: A hot and opaque solid, liquid or highly compressed gas emits a continuous spectrum.
* Rule 2: A hot, transparent gas produces an emission spectrum with bright lines.
* Rule 3: If a continuous spectrum passes through a gas at a lower temperature, the transparent cooler gas generates dark absorption lines.
James Clerk Maxwell
1860s

Light is wave. The medium is the Ether.

\[ c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3.0 \times 10^8 \text{ m/s} \]
Ångström measured the wavelengths on the four visible lines of the hydrogen spectrum, obtained with a diffraction grating, whose dispersion is linear, and replaced Kirchhoff’s arbitrary scale by the wavelengths, expressed in the metric system, using a small unit \((10^{-10} \text{ m})\) with which his name was to be associated.

<table>
<thead>
<tr>
<th>Line color</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>6562.852 Å</td>
</tr>
<tr>
<td>blue-green</td>
<td>4861.33 Å</td>
</tr>
<tr>
<td>violet</td>
<td>4340.47 Å</td>
</tr>
<tr>
<td>violet</td>
<td>4101.74 Å</td>
</tr>
</tbody>
</table>
Balmer Series: 1885

Johann Balmer found an empirical equation that correctly predicted the four visible emission lines of hydrogen

\[ \lambda = B \left( \frac{m^2}{m^2 - n^2} \right) = B \left( \frac{m^2}{m^2 - 2^2} \right) \]

Johannes Robert Rydberg generalized it in 1888 for all transitions:

\[ \frac{1}{\lambda} = R_H \left( \frac{1}{2^2} - \frac{1}{n^2} \right) \]

\( R_H \) is the **Rydberg constant**

\( R_H = 1.0973732 \times 10^7 \text{ m}^{-1} \)

\( n \) is an integer, \( n = 3, 4, 5, \ldots \)

The spectral lines correspond to different values of \( n \)

- \( \text{H}_\alpha \) is red, \( \lambda = 656.3 \text{ nm} \)
- \( \text{H}_\beta \) is green, \( \lambda = 486.1 \text{ nm} \)
- \( \text{H}_\gamma \) is blue, \( \lambda = 434.1 \text{ nm} \)
- \( \text{H}_\delta \) is violet, \( \lambda = 410.2 \text{ nm} \)
Albert Einstein

Born 1879
Democritus
460-370 BC

Atomic Theory
Thermal Excitation: $f \sim T$

Incandescence

Color shifts to shorter wavelengths (higher frequency) as an object is heated.

*increasing temperature*
Late 1800's: Black Body Spectrum Mystery & The Ultra Violet Catastrophe

Why this shape? Why the drop?
Atomic Energy is *quantized.* It comes in chunks of Planck’s constant, \( h \).

\[
E = nhf, \quad n = 0, 1, 2, 3, \ldots
\]

\[
h = 6.626 \times 10^{-34} \text{ Js}
\]
Joseph John Thomson
“Plum Pudding” Model 1904

- Received Nobel Prize in 1906
- Usually considered the discoverer of the electron
- Worked with the deflection of cathode rays in an electric field
- His model of the atom
  - A volume of positive charge
  - Electrons embedded throughout the volume
Problem: changing the intensity of the incident beam didn’t effect the ENERGY of ejected electrons, just the NUMBER of ejected electrons. Didn’t agree with wave picture of light.
1905: Einstein's Photon Hypothesis

Light is quantized.
The energy of a photon is frequency times Planck’s constant, h.

\[ E = hf \]

\[ h = 6.626 \times 10^{-34} \text{ Js} \]
Problem: changing the intensity of the incident beam didn’t effect the ENERGY of ejected electrons, just the NUMBER of ejected electrons. Didn’t agree with wave picture of light.
1911: Rutherford’s Planetary Model of the Atom

- A beam of positively charged alpha particles hit and are scattered from a thin foil target.

- Large deflections could not be explained by Thomson’s model.

(Couldn’t explain the stability or spectra of atoms.)
Electrons exist in quantized orbitals with energies given by multiples of Planck’s constant. Light is emitted or absorbed when an electron makes a transition between energy levels. The energy of the photon is equal to the difference in the energy levels:

\[ E = nh\hbar, \quad n=0,1,2,3,... \]

\[ h = 6.626 \times 10^{-34} \text{ Js} \]

\[ E_\gamma = E_i - E_f = \hbar f \]
Bohr’s Assumptions

1. Electrons in an atom can occupy only certain discrete quantized states or orbits.
2. Electrons are in stationary states: they don’t accelerate and they don’t radiate.
3. Electrons radiate only when making a transition from one orbital to another, either emitting or absorbing a photon.

Postulate:
The angular momentum of an electron is always quantized and cannot be zero:

\[ L = n \frac{h}{2\pi} \]

\( (n = 1, 2, 3, \ldots) \)
Bohr Line Spectra of Hydrogen

Bohr’s Theory derived the spectra equations that Balmer, Lyman and Paschen had previously found experimentally!

\[ \frac{1}{\lambda} = RZ^2 \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right) \]

\[ R = 1.097 \times 10^7 \, m^{-1} \]

Balmer: Visible
Lyman: UV
Paschen: IR
Problems with the Bohr's Model

1. Bohr model does not explain why electrons don’t radiate in orbit.
2. Bohr model does not explain splitting of spectral lines.
4. Bohr model does not explain ionization energies of elements.
If photons can be particles, then why can’t electrons be waves?
Electrons are *STANDING WAVES* in atomic orbitals.

\[ \lambda = \frac{h}{p} \]
De Broglie's Waves

De Broglie Wavelength

\[ \lambda = \frac{h}{mv} \]

\[ h = 6.626 \times 10^{-34} \, J \cdot s \]
deBroglie's Waves

Electron De Broglie Wavelength for electron \( v = 0.1c \)

\[
\lambda = \frac{h}{mv}
\]

\[
\lambda = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{(9.1 \times 10^{-31} \text{ kg})(3 \times 10^7 \text{ m/s})}
\]

\[
\lambda = 2.4 \times 10^{-11} \text{ m}
\]
Lynda’s De Broglie Wavelength

\[ \lambda = \frac{6.626 \times 10^{-34} \, J \cdot s}{(75 \, kg) \, 2 \, m / s} \]

\[ \lambda = 4.4 \times 10^{-36} \, m \]
Double Slit for Electrons shows Wave Interference
In reality, electrons do show an interference pattern, like light waves.
If electron were hard bullets, there would be no interference pattern.
Interference pattern builds one electron at a time.
Electrons act like waves going through the slits but arrive at the detector like a particle.
Heisenberg Uncertainty

Trying to see what slit an electron goes through destroys the interference pattern.

Electrons act like waves going through the slits but arrive at the detector like a particle.
Measurement Problem in Quantum Mechanics

before observation

photon

electron

observer

after observation

the act of observing effects the position and energy of electron
Which Hole Did the Electron Go Through?

If you make a very dim beam of electrons you can essentially send one electron at a time. If you try to set up a way to detect which hole it goes through you destroy the wave interference pattern.

Conclusions:
• Trying to detect the electron, destroys the interference pattern.
• The electron and apparatus are in a quantum superposition of states.
• There is no objective reality.
Quantum Uncertainty
*A Watched Kettle Never Boils*

When we observe very tiny things, they often seem to somehow 'know' that we are observing them. Maybe they are always looking back!

How frustrating!
Feynman’s version of the Uncertainty Principle

It is impossible to design an apparatus to determine which hole the electron passes through, that will not at the same time disturb the electrons enough to destroy the interference pattern.
WAVE?
Particle?
BOTH?

\[ E = hf \]
\[ E' = hf' \]
Proof the Light is a Wave?
The Double Slit
Proof that Light is a Particle?
Photoelectric Effect
Wave Packet: Making Particles out of Waves

Superposition of waves to make a defined wave packet. The more waves used of different frequencies, the more localized. However, the more frequencies used, the less the momentum is known.
Wave Packet: Making Particles out of Waves

Precisely determined momentum

A sine wave of wavelength $\lambda$ implies that the momentum $p$ is precisely known: $p = \frac{\hbar}{\lambda}$.

But the wavefunction and the probability of finding the particle $\psi^*\psi$ is spread over all of space.

Adding several waves of different wavelength together will produce an interference pattern which begins to localize the wave.

$\lambda_{avg}$

but that process spreads the momentum values and makes it more uncertain. This is an inherent and inescapable increase in the uncertainty $\Delta p$ when $\Delta x$ is decreases.

$\Delta x\Delta p > \frac{\hbar}{2}$
You make a wave packet by wave superposition and interference. The more waves you use, the more defined your packet and the more defined the position of the particle. However, the more waves you use of different frequencies (energy or momentum) to specify the position, the less you specify the momentum!
Richard Feynman:

Electron waves are probability waves in the ocean of uncertainty.
Strings & Atoms are Quantized

The possible frequencies and energy states of an electron in an atomic orbit or of a wave on a string are quantized.

\[ f = n \frac{v}{2l} \]

\[ E_n = n hf, \quad n= 0, 1, 2, 3, \ldots \]

\[ h = 6.626 \times 10^{-34} \text{ Js} \]
Quantum Theory

Assume electrons are represented by waves.

A wave function is derived that contains all the information about the electron: position, momentum & energy.

The wave function is a superposition of all possible states.

The probability of finding an electron in a particular state is given by the square of the wave function.

All we can know are probabilities.

\[ \Psi(x, t) = \frac{1}{(2\pi\hbar)^{3/2}} e^{i(p\cdot r - \omega t)/\hbar} \]

Probability = \( \Psi^2(x, t) = (\text{possibility})^2 \)
We know that the electron in an atom is allowed to exist ONLY in the discrete energy states. So where is it when it transitions between n=5 and n=1?
Super Simplified Quantum Theory: Spectra

The intensity of each spectral line of hydrogen is related to the rate and/or probability of that transition to occur. Again, each transition is ‘weighted’ and given a probability amplitude. The Red transition happens most often and is thus weighted more and so on. For example:

\[ a_{\text{red}} = 0.591, \quad a_{\text{cyan}} = 0.566, \quad a_{\text{violet1}} = 0.48, \quad a_{\text{violet2}} = 0.316 \]

The wave function is in a superposition or sum of all these possibilities:

\[ \Psi = 0.591_{\text{red}} + 0.566_{\text{cyan}} + 0.48_{\text{violet1}} + 0.316_{\text{violet2}} \]

The total probability of some transition happening is given the square of the entire wave function added up over all the possible transitions. This sum equals 1 which is 100% probability.

\[ \Psi^2 = 0.35 + 0.32 + 0.23 + 0.1 = 1 \]

Warning! This is a GROSS mathematical oversimplification BUT is the basic idea of the ‘mechanics’ of quantum.
The Quantum Jump: Where is the electron when it jumps between allowed states?

It is in a superposition of all the possible states!

It exists in “Potentia” not in Reality!

\[ \Psi = 0.591\text{red} + 0.566\text{cyan} + 0.48\text{violet1} + 0.316\text{violet2} \]

Only when a measurement is made (red light is detected) does the electron exist in a defined state. We say that the wave function “Collapsed” from a superposition of states to a definite state.
NOTE: A Quantum Jump
Is not necessarily a LARGE Jump!
It can be quite a small jump.
The weirdness of the Quantum Jump is that it goes from one place (state) to another without traveling in between!!!
Wave Function Collapse

The system stays in a superposition of states until it is observed. This is the “Collapse” of the wave function.
Many Worlds Hypothesis

Hugh Everett

under the many—worlds hypothesis, each quantum event splits the Universe into $U_1$ and $U_2$

No collapse is necessary!

and each Universe follows its own path into the future

all the possible Universe’s exist, but none can communicate with another.
Many Worlds Leads to Parallel Universes and a *Multiverse*
Improved technology will not save us from Quantum Uncertainty! Quantum Uncertainty comes from the particle-wave nature of matter and the mathematics (wave functions) used to describe them!
Schrödinger's Cat Paradox  *Is the cat dead or alive?*

The cat is in a superposition of dead and live states until we open the box and make a measurement (observation), collapsing the wave function!

\[ \Psi_{\text{total}} = \Psi_{\text{Dead}} + \Psi_{\text{Alive}} \]

This paradox shows the limits of quantum superposition applied to macroscopic systems. Or does it?
Heisenberg Uncertainty
Energy and Time

Particles can be created with energy $\Delta E$ can that live for a time $\Delta t$. They are called virtual particles but they can become real.

Virtual Particles...

$\Delta E \cdot \Delta t < \frac{\hbar}{2}$
Quantum Foam

Virtual Particles are constantly popping in and out of the quantum vacuum, making a Quantum Foam. In QED, virtual particles are responsible for communicating forces.
Making Matter out of Nothing
Matter-Antimatter Pair Production

Antimatter: Same mass, different charge.

When matter and antimatter collide they annihilate into pure energy: light.
Quantum Fluctuations

Quantum Vacuum

the quantum vacuum cannot be perceived or measured directly since it appears to be empty, in fact it is filled with potentiality

within the quantum vacuum, pairs of virtual matter and anti–matter particles are continually created and destroyed, borrowing their mass/energy by the uncertainty principle. They do not exist as observable entities, but their existence is exerted on other particles as a subtle pressure (called the Casimir effect)
Casimir Effect: The Zero Point Energy of the Quantum Vacuum
Quantum Cosmology
BIG BANG!
The Universe Tunneled in from Nothing
In Sum: The Quantum Vacuum

Due to Quantum Uncertainty, the nothingness of empty space is actually full of energy!

*Virtual Particles* pop in and out of the Quantum Vacuum in matter-antimatter pairs. If they have enough energy they can become real!

The Universe came from nothing and is being accelerated by nothing!
God does not play dice with the Universe!

Why doesn’t Einstein like Quantum?
• Reality should be deterministic and not based on probabilities.
• Reality should be objective and not dependent on an observer!
Einstein, Podolsky & Rosen
EPR Paradox

Measurement of Correlations between Components of Nuclear Spin
The Rules: Conservation Laws

Conservation laws are empirical laws that we use to "explain" consistent patterns in physical processes. Typically these laws are needed to explain why some otherwise possible process does not occur. Current Conservation Laws are:

• Energy
• Momentum
• Angular Momentum (Spin)
• Electric Charge
• Color Charge
• Lepton Number
EPR Paradox
Quantum Non-LocalitY

• Two particles are ‘entangled’ quantum mechanically – that is, they are described by one wave function.
• Suppose they have total zero spin.
• Then they are separated. If the spin of one is flipped in flight to the detector, the other one flips *instantaneously, faster than light*.
• This violates the speed limit of light.
• OR, somehow the particles are connected across space – they are *NONLOCAL*. This is a big no-no to Einstein and his Quantum Pals.
EPR Particles: Entanglement

EPR particles are particles that are ‘entangled’ that is, there is a single wavefunction that describes both particles. Until a measurement is made, the particles remain in an entangled state. While entangled, the particles are connected in a ‘nonlocal’ way so that even if they are separated over great distances they can communicate faster than light.
I don’t like this spooky action at a distance!
At the heart of the realm of quantum computation is the qubit. The quantum bit, by analogy with the binary digit, the bit, used by everyday computers, the qubit is the quantum computer's unit of currency. Instead of being in a 1 or zero state, a qubit can be in a superposition of both states.
Physicist Eugene Wigner's representation of quantum superposition state (the two lumps) showing interference fringes in the center. Image also corresponds to a qubit in a superposition state of 0 and 1.
Quantum Teleportation

Entangled photons are used to teleport other photons.

Quantum Encryption
Quantum Teleportation??

Quantum Uncertainty will make it very difficult to teleport a complex organism since there is always uncertainty in the position of its atoms!
Quantum Consciousness

Why are we not zombies?

What Causes our Subjective Experience of Inner Being?

Each caged electron is a qubit in a nanoscale quantum dot. We have a billion billion of them enslaved by coherent near electromagnetic brain fields of low frequency. This forms a mind-brain hologram. There is direct back-reaction of the coherent phased array of single electron dipoles on their mental pilot landscape field. This generates our inner conscious experience.

- Jack Sarfatti
THE PROBLEM
Coherence & De-Coherence

In order for particles to be entangled in a non-local way they must be in a coherent superposition. Observing the system collapses the wavefunction into a localized state. The problem is that it is very difficult to maintain coherent superpositions because the environment can collapse the wavefunction. In order for quantum phenomena to function in the biological realm, coherence must be maintained for at least a millisecond. This is not currently achievable and perhaps not even theoretically possible. Coherence is also the problem with quantum computers. It is also the problem with any claim of macrocosmic entanglement and quantum nonlocal effects - maintaining coherence is very difficult in any environment!!!
Quantum Quackery?
SPACE-TIME
AND
BEYOND

BEFORE SPACE-TIME Began
WE ARE INTIMATELY CONNECTED TO EVERYTHING IN THE UNIVERSE
CONSCIOUSNESS IS THE ORIGIN OF ALL SPACE-TIME
EVERYTHING IS THE SAME THING
EVERYTHING IS INTER-PERSONAL
THE UNIVERSE HAS BEGIN
THERE IS LIFE IN EVERYTHING

BOB TIEHAN
IN CONVERSATION WITH PHYSICISTS JAC. SARFFATTI AND FRED WOLF
For each of us, an indefinite number of universes exists simultaneously.

Typical universe layer

Each universe has its own time sequence

Each universe may be a slight variation of the next one or may be entirely unrelated.
ALL THINGS ARE POSSIBLE!
THERE IS AN INDEFINITE NUMBER OF HARMONIES
CONSTRUCTING AN INDEFINITE NUMBER OF POSSIBILITIES

WE EXIST IN ALL THE UNIVERSE LAYERS SIMULTANEOUSLY
ONE OF AN INDEFINITE NUMBER OF REALITIES

ANOTHER OF THE INDEFINITE NUMBER OF REALITIES
WE CONSTRUCT OUR OWN INDIVIDUAL REALITIES

ALL WE CAN THINK OR PERCEIVE IS BROUGHT INTO AWARENESS WITH OUR INDIVIDUAL THOUGHTS

Collapsing Wave Function

QUANTUM HEALING
EXPLORING THE FRONTIERS OF MIND/BODY MEDICINE
DEEPAK CHOPRA, M.D.
Entanglement

**Healing with the Hands**

Healer mentally constructs a union with the oneness of all.

Biogravitons mix with gravitons forming a solid bridge or connection allowing phase harmony entrainment.

A link is established between the patient and the harmony of the universe, which contains the knowledge, or "vibrations," to reestablish a normal state of health.
Every thought, every dream is an awareness of another reality which coexists.

This "thought" is actually in another universe layer.

This boy is actually flying to the moon in another universe layer!

The direct experience would come with a harmony among the layers.
A Theory of Everything (TOE)?

Quantum Gravity

Unification

all the forces of Nature should be capable of being described by a single theory. But only at high energies should the behavior of the forces combine, this is called unification

Supergravity (quantum gravity)

Electroweak force

Gravitational force

Weak force

Electromagnetic force

Strong nuclear force

more energy

before the unification point, the forces are indistinguishable and have symmetry. After the unification point, the forces act differently and the symmetry is broken.
Other Possible TOEs

Strings

String Theory

Particles

Supersymmetric "shadow" particles

Supersymmetry
I think I can safely say that nobody understands quantum mechanics.

Richard Feynman
Health Secretary
WARNING

Deep thinking on Quantum Mechanics brings about INSOMNIA