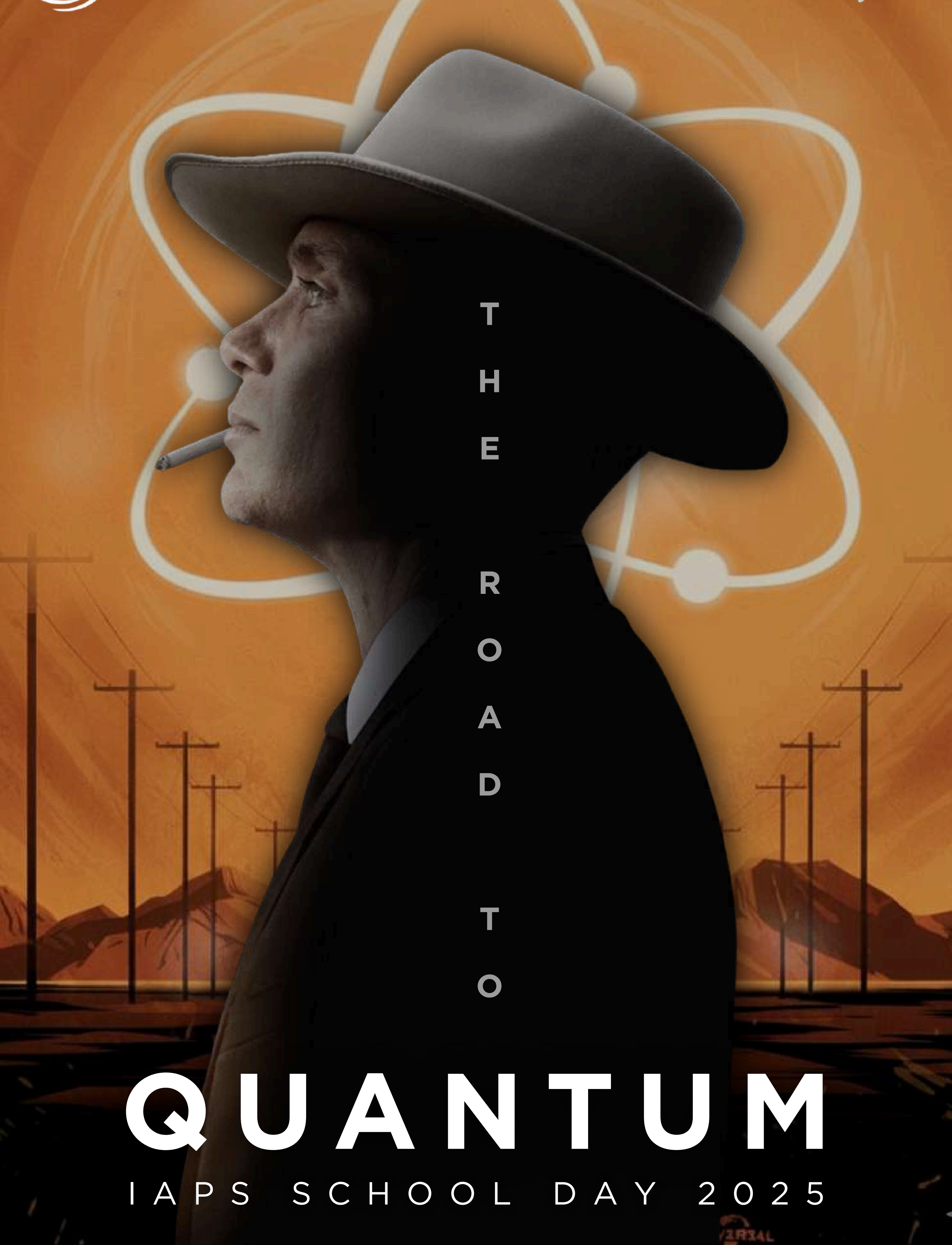
A GUIDE BY
INPS (TC - INDIA) & IAPS OUTREACH WG



THE ROAD TO QUANTUM

IAPS SCHOOL DAY 2025

Introduction

In the following pages, you'll find a series of experiments designed to spice up the IAPS School Day 2025, with the theme: Quantum Sciences and Technology! Any IAPS Committee or member is welcome to follow this guide, so let's get cooking! This guide came about after TC India whipped up the idea of combining this year's experiments done by the various RCs and Individual Members, with the combined and shared efforts of Anant Singh, Deepanshi Singh, Arjun Singh, Aditya Raj, Jayansh Dave and a few others. We believe that a colorful topic like this deserves a commitment to ensure there are no defects. All experiments have been curated by our members. To show science enthusiasts, that even with waste material, basic equipment and electronics, in their home, a colorful world of scientific wonders waiting to be explored in the field of Quantum!

Our main target is students aged 13 to 18, but we have made sure these activities are accessible to everyone, regardless of age or academic level. Most experiments can be constructed at home with everyday materials. Supervision is always a good idea, but some of these experiments are kid-approved for solo action—perfect for those committees with fewer members or when in-person gatherings aren't on the table. The hands-on nature of these activities encourages kids to dive into the scientific method: they can create their own hypotheses, perform experiments, and come to their own conclusions—all while using our straightforward guidelines. Without further ado, let's construct, learn, and most importantly, try not to blast something!

~Your friends from INPS (TC India) and IAPS Outreach WG

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Single Slit

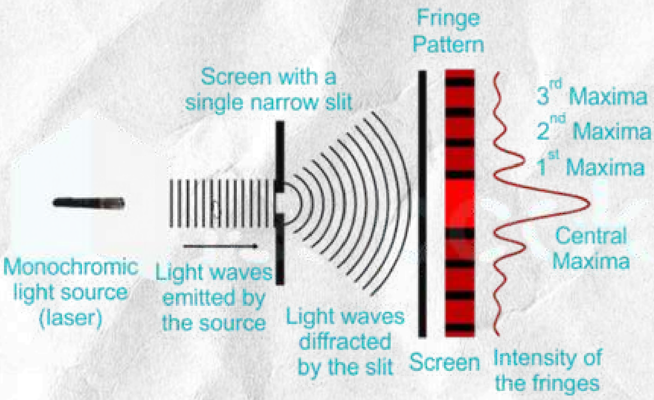
Wave or Particle ??

Objective

To demonstrate that light bends, or diffracts, when it passes through a narrow aperture.

Materials

- A laser source
- A slide containing a single, narrow vertical slit
- A mounting stand for the slide
- A flat, white screen for projection



Principle

According to a simple particle model of light, passing a beam through a single slit should result in a sharp, singular line projected onto the screen—an exact image of the slit. However, wave theory predicts that when a wave passes through an opening comparable in size to its wavelength, it will bend around the edges and spread out. This phenomenon is termed diffraction.

Procedure

1. The apparatus is arranged in a darkened environment..
2. The laser is positioned to project its beam directly through the single slit.
3. The resulting pattern is observed on the screen placed at a distance.

Observation and Explanation

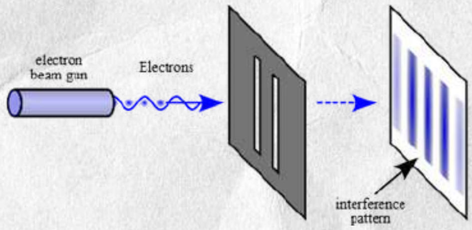
The pattern observed on the screen is not a single sharp line. Instead, it consists of a wide, bright central band of light. This central maximum is flanked on both sides by a series of alternating dark and progressively dimmer bright bands. This observed spreading of light and the creation of a pattern is a clear demonstration of diffraction, a behavior characteristic of waves.

Double Slit

Why did it spread ??

Objective

To demonstrate the principle of interference, where light waves interact with each other.



Principle

Extending the previous experiment, if light were composed of particles, passing it through two slits would simply produce two sharp lines on the screen. Wave theory, however, predicts a different outcome. The diffracted waves from each slit should interact, or interfere.

- Constructive Interference: Where crests of both waves align, they combine to produce a brighter region.
- Destructive Interference: Where the crest of one wave aligns with the trough of another, they cancel each other out, producing a dark region.

Materials

- A laser source
- A slide containing a single, narrow vertical slit
- A mounting stand for the slide
- A flat, white screen for projection
- A slide containing two narrow, closely spaced vertical slits

Procedure

1. A slide containing two narrow, closely spaced vertical slits
2. The laser is aimed so that its beam passes through both slits simultaneously.
3. The resulting pattern is observed on the screen.

Observation and Explanation

The screen does not show two simple lines. It displays a pattern of multiple, evenly spaced bright and dark vertical bands, known as an interference pattern. The bright bands correspond to points of constructive interference, while the dark bands are the result of destructive interference. This outcome, where the combination of light from two sources produces darkness, is definitive evidence of the wave nature of light.

The Diffraction Grating

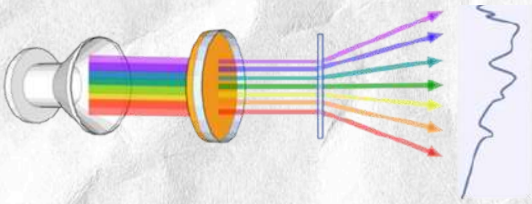
Where are the colors??

Objective

To observe the effect of a multi-slit apparatus on the interference pattern of light.

Materials

- A laser source
- A slide containing a single, narrow vertical slit
- A mounting stand for the slide
- A flat, white screen for projection
- A diffraction grating (a slide with a very large number of evenly spaced slits per millimeter)



Principle

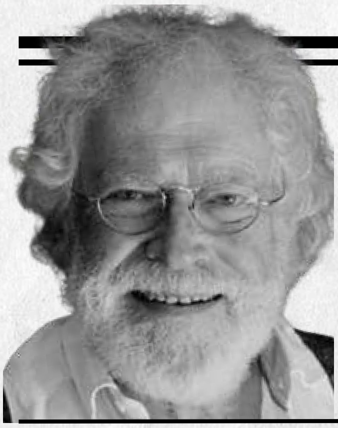
A diffraction grating applies the principle of multi-source interference. With thousands of slits, the conditions for constructive interference become much more precise. This results in an interference pattern that is significantly sharper and more widely separated than the pattern from a double slit.

Procedure

1. The double-slit slide is replaced with the diffraction grating.
2. The laser is projected through the grating.
3. The resulting pattern is observed on the screen.

Observation and Explanation

The pattern produced by the diffraction grating consists of a central bright point and a series of other bright points that are very sharp, distinct, and widely spaced. This highly defined pattern is a consequence of interference from a multitude of wave sources. A key application of this device is its ability to separate white light into its constituent spectrum of colors, as each color's wavelength is diffracted at a slightly different angle. A common, real-world example of this effect can be seen by looking at the reflective surface of a CD. The microscopic pits on the disc's surface, arranged in a spiral track, act as a natural diffraction grating, splitting ambient white light into a familiar rainbow of colors.



Qubits using Polarized Laser Light

Objective

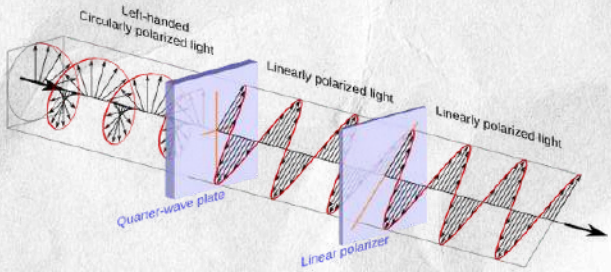
To observe the effect of temperature on the spectral distribution and intensity of light emitted by an ideal radiator.
To experimentally demonstrate the principles of Wien's Displacement Law and the Stefan-Boltzmann Law.
To understand the historical failure of classical physics ("ultraviolet catastrophe") and the necessity of Max Planck's quantum hypothesis.

Principle

What is Polarization? Polarization means restricting the light so that it vibrates in only one direction. Polarization Filter only allows light waves vibrating in one direction to pass. Horizontal(H) – only horizontal waves pass. Vertical(V) – only vertical waves pass.

Materials

- Laser pointer
- Polarizing filters
- Rotatable mount
- Screen.



Procedure

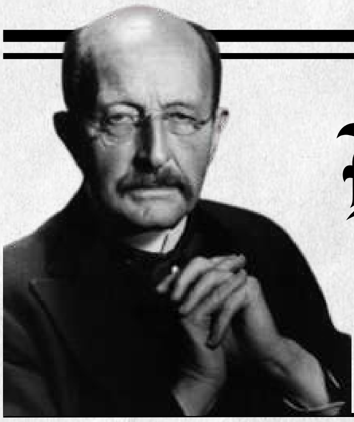
1. Mount the laser in front of a screen or wall.
2. Place the first polarizer at 0º (horizontal) to define state |0〉 (H).
3. Place a second polarizer (the analyzer) in front of the first one. Rotate it and observe how the brightness of light changes with the angle.

- At 0° - maximum brightness (same state).
- At 90° - no brightness (orthogonality of H & V).
- At 45° - partial brightness (superposition).

4. Now fix the second polarizer at the position where light passing through both polarizers gives zero brightness. This corresponds to state |1〉 (V), where second polarizer is at 90º (perpendicular to polarizer 1).
5. Now fix the second polarizer at the position where light passing through both polarizers gives zero brightness.

- Observe that light passes again, even though two polarizers at 0º and 90º would block it completely.
- This shows the importance of measurement order in quantum systems.

6. Add a third polarizer between polarizer 1 & 2, at an angle θ between 0º and 90º.
7. Observe that light passes again, even though two polarizers at 0º and 90º would block it completely. This shows the importance of measurement order in quantum systems.



Blackbody Radiation

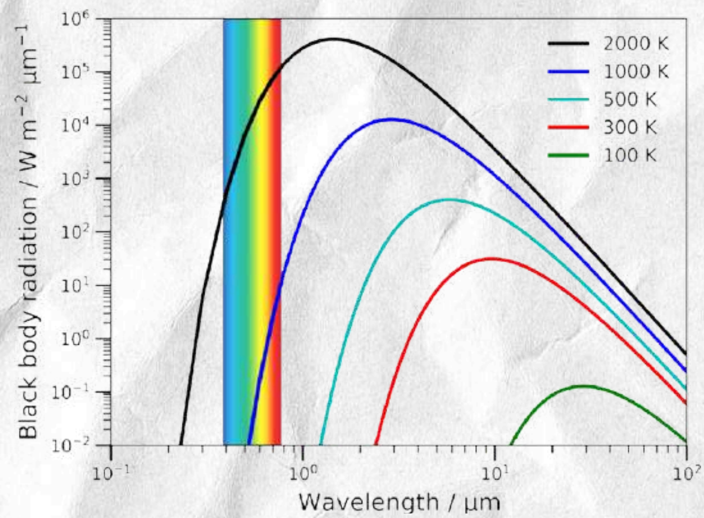
Hotter = Bluer

Objective

To demonstrate how the color and brightness of light emitted by a hot object depend only on its temperature.

Materials

- Computer or Tablet: Device with internet access.
- PhET Interactive Simulation: "Blackbody Spectrum"



Principle

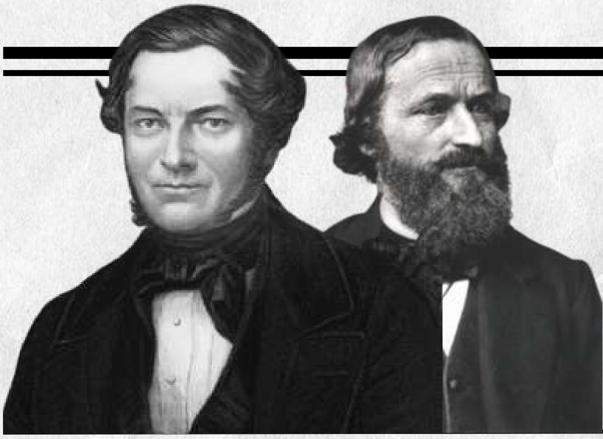
A "blackbody" is a theoretical object that absorbs all light that hits it[2]. When heated, it re-emits energy as light. Classical physics failed to predict this, leading to the "ultraviolet catastrophe"[3]. Max Planck solved it by proposing that energy is quantized, or comes in discrete packets ($E=hf$), marking the birth of quantum mechanics[4].

Procedure

1. Open the PhET "Blackbody Spectrum" simulation. Ensure the "visible spectrum" overlay is on.
2. Set the temperature slider to ~3000 K to simulate a "red hot" object.
3. Increase the temperature to ~6000 K (like the Sun).
4. Observe how the curve's shape, peak, and height change.

Observation and Explanation

As the temperature increases, two things happen: the object glows much brighter (the curve gets taller) , and the peak color shifts from red to yellow to blue (shorter wavelengths). This is why hot stars are blue and cool stars are red. This precise curve is direct proof that energy is quantized.



Atomic Spectra

Quantum 'Barcodes'

Objective

To demonstrate that excited atoms emit light only at specific, discrete colors, not a continuous rainbow. Principle Classical physics predicts a full rainbow. Quantum mechanics states electrons exist only at specific energy levels. When an electron 'falls' from a high to a low level, it emits one photon of a specific energy (color), creating the atom's unique 'barcode' or spectrum.

Principle

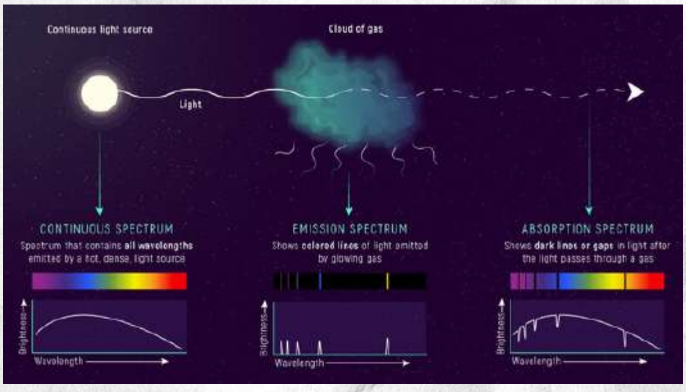
Classical physics predicts a full rainbow. Quantum mechanics states electrons exist only at specific energy levels. When an electron 'falls' from a high to a low level, it emits one photon of a specific energy (colour), creating the atom's unique 'barcode' or spectrum.

Materials

- Diffraction grating glasses (or a CD/DVD)
- Gas discharge lamp (e.g., neon sign)
- Incandescent bulb (for control)

Procedure

1. In a dark area, put on the diffraction glasses.
2. First, observe the incandescent bulb (the 'control').
3. Next, observe the gas discharge lamp (e.g., neon).
4. Compare the two resulting patterns.



Observation and Explanation

The incandescent bulb produces a full, continuous rainbow. The gas lamp produces sharp, distinct lines of color separated by darkness. These lines are the atom's 'fingerprint,' or spectrum, and are direct proof that electron energy levels are quantized.

Fluorescence

Energy Steps Down

Objective

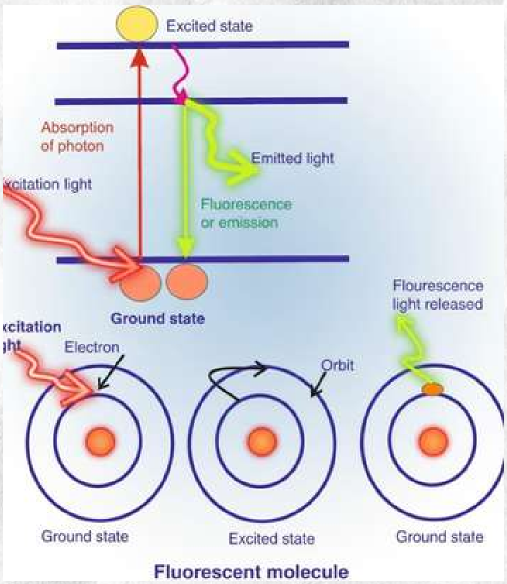
To demonstrate how certain materials absorb high-energy, invisible light and re-emit it as lower-energy, visible light.

Principle

Quantum theory explains this as a multi-step process. An electron absorbs a high-energy UV photon, jumping to a high state. It loses a little energy as heat (vibration), then falls the rest of the way, emitting a lower-energy (and thus visible) photon.

Materials

- A UV (blacklight) flashlight
- Tonic water (containing quinine)
- A clear glass
- (Optional) Highlighter ink on paper



Procedure

1. Assemble in a very dark room.
2. Pour the tonic water into the glass.
3. Shine the UV flashlight at the liquid.
4. Observe the colour.
5. Turn the UV light off and observe.

Observation and Explanation

The clear tonic water instantly glows a bright, visible blue when hit by the invisible UV light. The glow stops immediately when the light is removed. This shows the UV energy is being absorbed and transformed into lower-energy blue light, a classic quantum-step process.

LEDs & The "Price" of Color

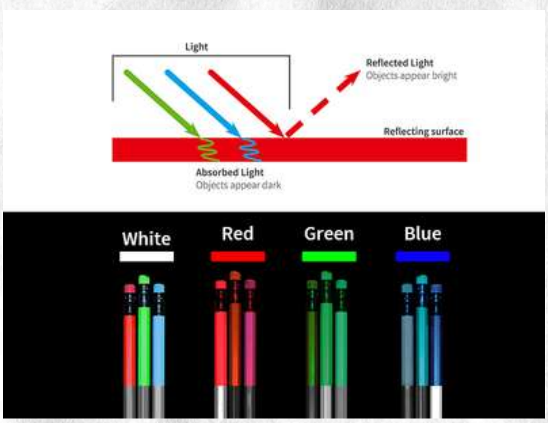
Quantum Band Gaps

Objective

To demonstrate that different colors of light require different, specific minimum amounts of energy (voltage) to be created.

Materials

- Variable DC power supply (0-5V)
- One red, one green, and one blue LED
- Alligator clip leads or breadboard



Principle

Quantum physics dictates that in an LED, an electron must be 'pushed' across an energy 'band gap'. The size of this gap determines the energy (and color) of the photon emitted. A blue LED has a large gap, requiring a large energy push. A red LED has a small gap.

Procedure

1. Set the power supply to 0V. Connect the Red LED.
2. Slowly increase the voltage until the LED just begins to glow. Note this voltage (~1.8V).
3. Repeat the process for the Green LED (~2.2V).
4. Repeat the process for the Blue LED (~2.7V).

Observation and Explanation

The turn-on voltage is different for each color. Red (low-energy light) requires the lowest voltage, while blue (high-energy light) requires the highest. This directly measures the quantum 'band gap' energy ($E=hf$) required to create each color of light.

The Uncertainty Principle

The Observer Effect

Objective

To create a classical analogy for Heisenberg's Uncertainty Principle, showing how the act of measuring a particle's position disturbs its momentum.

Materials

- A dark, open room
- A lightweight balloon
- Several ping-pong balls
- A blindfolded "Searcher"

Principle

In the quantum world, you cannot simultaneously know a particle's exact position and exact momentum. To 'see' a particle (measure its position), you must 'hit' it with another particle (like a photon), which inevitably changes its momentum (motion) in an unpredictable way.

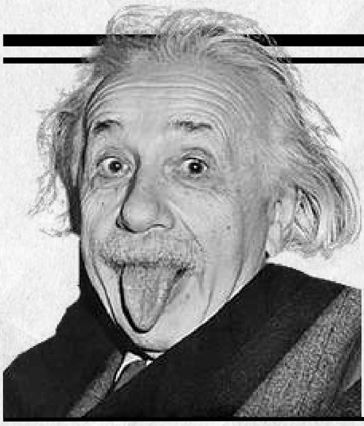
$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$

Procedure

1. The Searcher is blindfolded.
2. Another person silently tosses the balloon into the air.
3. The Searcher tries to find the balloon's location only by throwing ping-pong balls at it.
4. Listen for the "thwack" of a successful measurement.

Observation and Explanation

The Searcher can only find the balloon's position at the exact moment a ping-pong ball hits it. However, that very act of 'measuring' (the hit) transfers energy, sending the balloon flying. The instant its position was known, its momentum became completely unknown.



Photoelectric Effect

Light as a Particle

Objective

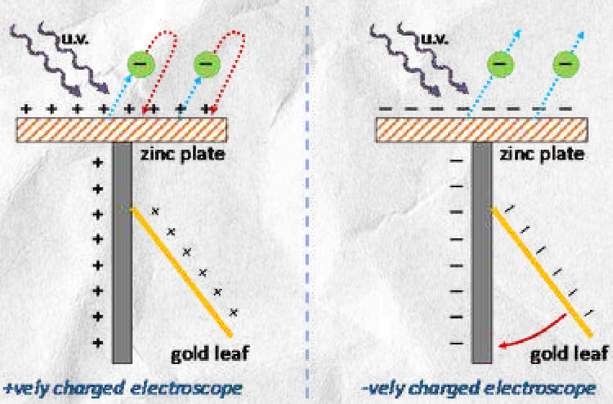
To demonstrate the photoelectric effect and prove that light's ability to do work depends on its frequency (color), not its brightness.

Materials

- Gold Leaf Electroscope
- Zinc plate
- Plastic/PVC rod & woollen cloth
- UV lamp

Principle

The photoelectric effect is the emission of electrons from a metal when light shines on it. Albert Einstein explained this by proposing that light is made of energy packets called photons. If a photon has enough energy (a high frequency), it can "knock" an electron out of the metal.



Procedure

1. Rub the plastic rod with the wool cloth to create a static charge.
2. Transfer this negative charge to the zinc plate, causing the electroscope leaves to spread apart.
3. Shine ordinary visible light on the plate. No change is observed.
4. Now, shine the ultraviolet (UV) lamp on the plate.

Observation and Explanation

When the high-frequency UV light hits the plate, the electroscope leaves quickly collapse back together. This is because the UV photons have enough energy to eject the extra electrons from the plate, neutralizing its charge. The visible light, no matter how bright, fails to do this. This proves that light's energy is quantized—it depends on its frequency, not its intensity

Further References

Here is a list of some more resources across the internet which might be of interest to the readers and help them with planning out their experimental demonstrations as well as the outreach sessions.

Double-slit (wave–particle duality)

- I did the double slit experiment at home
- Quantum Mechanics - Double Slit Experiment. Is anything real? (Prof. Anton Zeilinger)
- Simple Explanation of the Most Notorious Experiment | Double Slit and Delayed Choice Quantum Eraser

Single-photon / low-intensity interference

- Single Photon Interference
- One Photon In, TWO Photons Out

Stern–Gerlach spin demonstration (sim & hands-on analogs)

- The Stern-Gerlach Experiment
- 100 Years anniversary: Stern-Gerlach Experiment 1922 (U2-07-03)

Bell test / CHSH experiments (entanglement & local realism)

- Bell's Inequality: The weirdest theorem in the world | Nobel Prize 2022
- Experimental tests of local realism and the birth of quantum technology

Quantum eraser / delayed-choice experiments

- Delayed Choice Quantum Eraser Experiment Explained
- I did the quantum eraser experiment at home

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