Wonders of
Quantum Physics

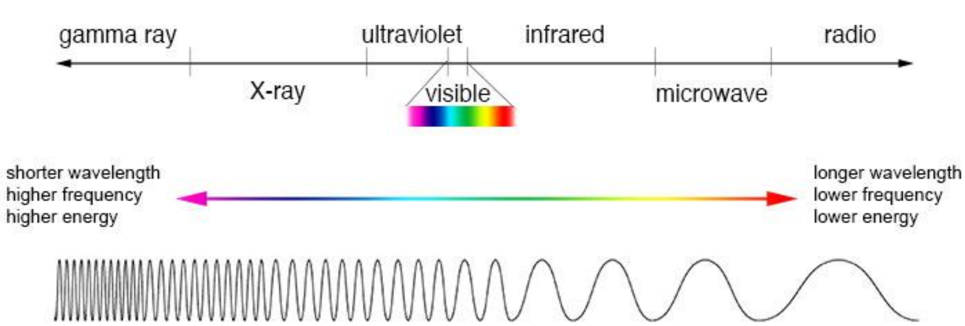
Introduction to Light and Quantum Computing

Light exhibits wave-particle duality, which means it has properties of both **waves** and **particles**. But what exactly does that mean?

In some ways, light acts like a **wave**. It spreads out or diffracts after passing through an opening; it bends or refracts when moving into a different medium, such as when light moves from air into water; it bounces back or reflects when it hits a barrier like a mirror; and it adds together or cancels out with other light waves of the same or different phases in a process known as interference. All of these properties are observed in other waves, and so light has wave-like properties.

Because light acts as a wave, it can be spread out into its component parts by passing it through a prism or diffraction grating. The spread-out light is called a **spectrum**, and it tells us how much light there is at a given energy, wavelength, or frequency on the electromagnetic (EM) spectrum. For example, when we put white light, such as light from an LED, through a prism or diffraction grating, we find that it is actually composed of all wavelengths of visible light. When light is in the visible part of the EM spectrum, it corresponds to a color of the rainbow.

The Electromagnetic (EM) Spectrum



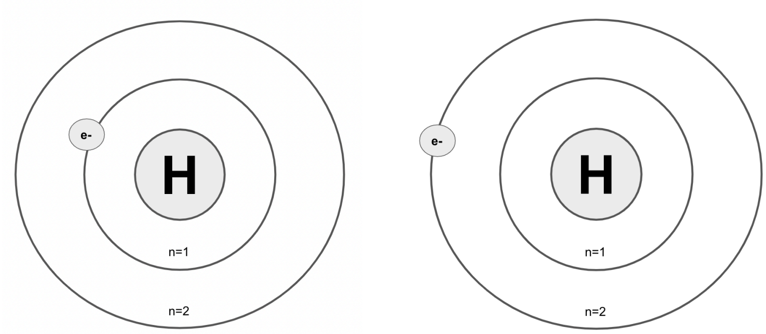
The electromagnetic (EM) spectrum divides different ranges of energies, wavelengths, and frequencies into categories. Image Credit: [NASA's Imagine the Universe]

Like a wave, light wiggles in a specific direction as it moves. Light emitted from sources like a flashlight or the Sun wiggles in all directions. A polarizer, like you might find in sunglasses, blocks out light that is wiggling in all directions except the direction that matches the polarizer. The light that comes out the other side of a polarizer is called polarized light, which means it wiggles in only one direction.

Some materials, like cellophane, have a special ability to change the polarization of light depending on the light's color. When white light, which is the combination of all colors, goes through the cellophane, it changes the polarization of each color slightly differently. That means that each color in white light will have a different polarization after it passes through the cellophane.

When light interacts with matter like atoms or molecules, it acts like a **particle**. For example, when an atom absorbs a particle of light, called a **photon**, one of the atom's electrons can be excited to a higher energy level. Then, when the electron returns to its ground state, it releases a photon of a particular energy. When an electron moves from one state to another, that is called an **electron transition**.

Hydrogen Atom - Ground and Excited States



In this diagram, the hydrogen atom on the left has one electron in its ground state, which we call n=1. The hydrogen atom on the right has absorbed a photon, which excited its one electron to the next orbital called n=2. When an electron in the n=2 state returns to the ground state, it releases a photon.

One consequence of light's particle-like behavior is that it can be absorbed by atoms or molecules when it has a specific energy (or wavelength or frequency). All atoms or molecules absorb and emit light only at a unique set of energies, which means that each atom and molecule has its own set of unique electron transitions that can be precisely measured. The light emitted and absorbed by these atoms are known as spectral lines, which act as a fingerprint on a spectrum for identifying the presence of certain atoms or molecules in or around an object. By observing the spectral lines of an object, you can identify what elements make up or are surrounding the object. Besides composition, a spectrum can also be used to identify other physical properties of an object, such as its temperature, classification, density, and, for far-away objects like stars, their distance.

Because photons of only certain energies can be absorbed and emitted by certain atoms, light is said to be quantized. That is, light has discrete, instead of continuous, values for properties such as energy. Light also has discrete values for wavelength and frequency, which are properties that are directly proportional to energy.

Precisely measuring the unique electron transitions of atoms is the cornerstone of many quantum technologies, including atomic clocks and quantum computers. For example, one method to create a quantum computer uses the unique electron transitions of certain atoms to store information in what are known as **qubits**. Instead of storing information as a 0 or 1, which is how regular computer bits work, quantum scientists create qubits by manipulating electrons with light so they are in a state of both 0 and 1 at the same time. Quantum researchers can also store and encode information into qubits using a photon's polarization.

Although they won't replace the computers we're used to, quantum computers have the potential to help scientists make calculations that would take regular computers thousands of years, as well as provide a way to send unhackable messages from one place to another.

Review Questions

- What is wave-particle duality?
- Describe one way that light acts as a wave, and one way that light acts as a particle.
- Fill in the blank: Light is _______, which means that it has discrete values for properties such as energy.
- What is a spectrum?
- How is polarized light different from unpolarized light?
- State one way quantum computers are different from regular computers.

Funding and support provided by

HQAN Hybrid Quantum Architectures and Networks

NSF

Department of Physics
UNIVERSITY OF WISCONSIN–MADISON