# Chapter 7 - Quantum Model of Atom

## Section 1 – Quantum Theory

*Dr. Sapna Gupta*

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## Introduction

Until now we have learned about the nuclear model of the atom, which is nucleus in the center of the atom and electrons all in the space around it. The nucleus has the protons and neutrons.

In this chapter we will learn where and how the electrons exist in the atom. The location of electrons could be learned only after scientists learned abut the electromagnetic spectrum and the quantum theory was proposed by Max Planck. Quantum theory brought about the proposal that light has a dual nature of wave and particle which was then used to understand the properties of electron.



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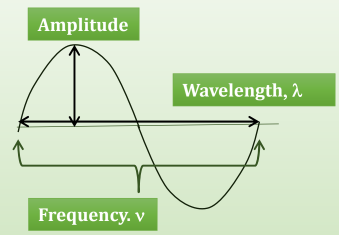
# Wave Nature

All waves travel in a particular cycle of certain length which determines properties of that wave. The properties that determine the quality of the wave are:

- **Wavelength**: λ (*lambda*) distance between identical points on successive wave/peaks.
- **Frequency**:ν (*nu*) number of waves that pass a particular point in one second.
- **Amplitude**: the vertical distance from the midline of waves to the top of the peak.

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Wavelength and frequency are inversely proportional to each other, hence when wavelength decreases frequency increases (more waves pass in one second).
**λ α 1/ν**.

Energy of wave is directly proportional to energy. This is understood after Planck's quantum theory. See later slides for this. **ν α E**



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# Understanding Wave Properties

Since wavelength and frequency are inversely proportional, their multiplication will always be constant, and that constant is speed of light.

**λ α 1/ν**.

**λν = constant**

Wave properties are mathematically related as:

$$c = \lambda\nu$$

Where,

$c$ = speed of light: 2.99792458 x $10^8$ m/s

λ = wavelength (in meters, m)

ν = frequency (reciprocal seconds, $s^{-1}$)



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**Solved Problem: Relationships in a wave**

Answer the following questions related to quantum theory.
What is the relationship of the properties below of the wave to each other. If there is none then write no relation.
Wavelength, frequency, energy and amplitude.

Wavelength and frequency – inverse relationship
Wavelength and energy – inverse
Wavelength and amplitude – none

Frequency and energy – direct

Energy and amplitude – none





**Solved Problem: Calculating frequency of a wavelength**

The wavelength of a laser pointer is reported to be 653 nm. What is the frequency of this light?

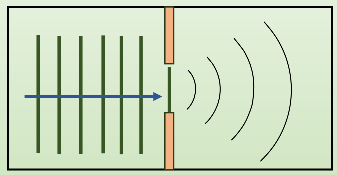
$$\nu = \frac{c}{\lambda}$$

$$\lambda = 553 \text{ nm x } \frac{1\ x\ 10^{-9}}{1\ nm}$$

$$\lambda = \frac{3.00\ x\ 10^{8} m/s}{5.53\ x\ 10^{-7} m} = 5.42\ x\ 10^{14}\ s^{-1}$$

# Nature of Light

- In 1801, Thomas Young, a British physicist, showed that light could be diffracted; which is a wave property.



- The **photoelectric effect,** first observed by Heinrich Hertz1887 is the ejection of an electron from the surface of a metal or other material when light shines on it.
- The wave theory could not explain the photoelectric effect because this discovery means that light has energy also.



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# The Electromagnetic Spectrum

The electromagnetic spectrum is part of the radiation that is all around us. When the cosmic radiation, which travels in waves, interacts with the earth's atmosphere, it splits into different types of radiation.

The electromagnetic spectrum (em) is arranged according to wavelength and frequency of radiation. The radiations are labelled as radio waves, microwaves, X rays.

All parts of electromagnetic spectrum are used in our lives

- Radio waves were the first to be used as part of devising a communication method.
- Microwaves are ubiquitous in our kitchens that use microwave radiation.
- Infra-red radiations are used in night vision goggles and heat lamps.
- Visible radiation is the smallest part of em spectrum but makes us see our world in colour.
- Ultraviolet radiation is harmful to us if we stay out in daylight too long.
- X-rays are high energy radiation and are used to visualize inside our bodies.
- Gamma radiation is extremely high in energy and is very dangerous for us even in small doses.



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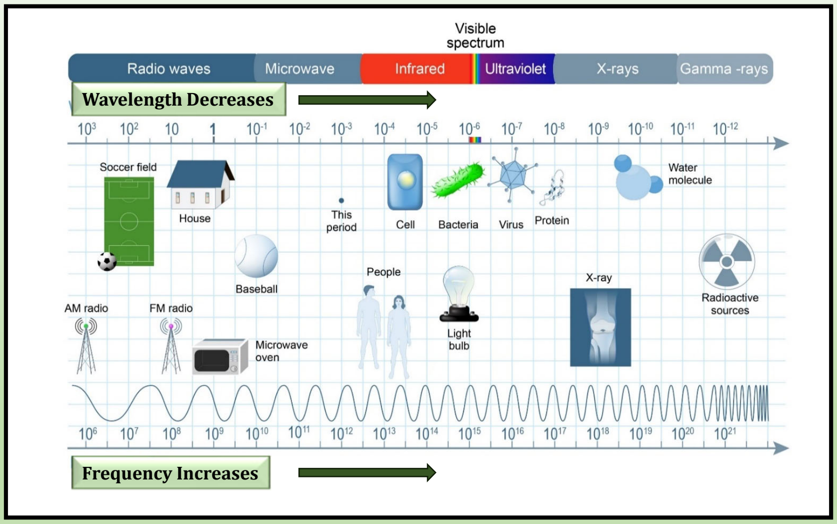
# The Electromagnetic Spectrum

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# Quantum Theory by Max Planck

Max Planck around 1900 proposed that energy in radiation could only be emitted or absorbed in discrete quantities called quanta. This quantum are packets of energy.

It revolutionized way of thinking since it meant that radiation, which travels in waves also has particles (dual nature of light). This is what explains how different frequencies can have different energies. The higher the frequency, the more the quanta in the wave and thus, the higher the energy.

Energy of a single quantum of energy is given by the Planck's equation.

$$E = h\nu$$

Where,

$E$ = energy (in Joules)

$h$ = Planck's constant $6.63 \times 10^{-34}$ J · s

$\nu$ = frequency



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**Solved Problem: Calculating energy from wavelegth**

Calculate the energy (in joules) of a photon with a wavelength of 600.0 nm

$$\lambda = 600.0\ \text{nm} \times \frac{10^{-9}\text{m}}{\text{nm}} = 6.00 \times 10^{-7}\text{m}$$

$c = \lambda\nu$

$$\upsilon = \frac{3.00 \times 10^{8}\text{m/s}}{6.00 \times 10^{-7}\text{m}} = 5.00 \times 10^{14}\text{s}^{-1}$$

$E_{photon} = h\nu$

$$E = (6.63 \times 10^{-34}\text{J} \cdot \text{s})(5.00 \times 10^{14}\text{s}^{-1})$$
$$= 3.32 \times 10^{-15}\ \text{J}$$





# Key Points

- Electromagnetic spectrum
- Wavelength, frequency, energy (calculate)
- Quanta (of light - photon)