# Radiation Physics

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**Lecture 2: Wave-Particle Duality and Electromagnetic Radiation**

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## Electron Transitions, Characteristic and Auger Emission

To move an inner-shell electron to an outer shell, some external source of energy is required. On the other hand, an outer-shell electron may drop spontaneously to fill a vacancy in an inner shell. The transition energy is released as a photon. Because the binding energy of electron shells is a unique characteristic of each element, the emitted photon is called a characteristic photon. The emitted photon may be described as a K, L, or M characteristic photon, denoting the destination of the transition electron. For transitions to shells beyond the M shell, characteristic photons are no longer energetic enough to be considered x rays.

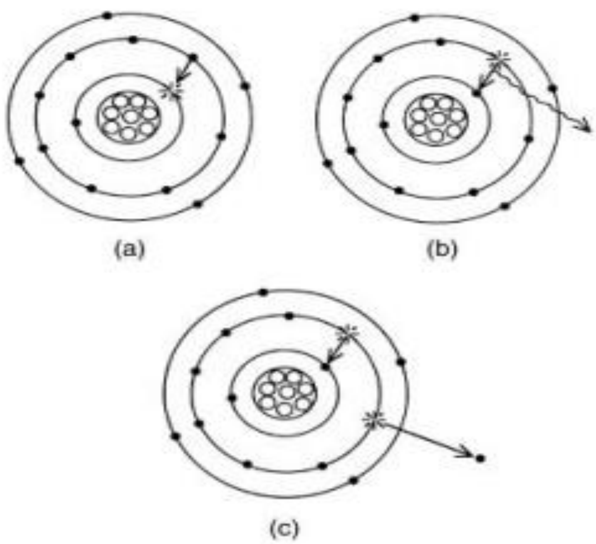


**Figure 1: (a) Electron transition from an outer shell to an inner shell.**
**(b) Electron transition accompanied by the release of a characteristic photon.**
**(c) Electron transition accompanied by the emission of an Auger electron.**

Figure shows an alternative process to photon emission. In this process, the energy released during an electron transition is transferred to another electron. This energy is sufficient to eject the electron from its shell. The ejected electron is referred to as an Auger (pronounced “aw-jay”) electron. The kinetic energy of the ejected electron will not equal the total energy released during the transition, because some of the transition energy is used to free the electron from its shell. The Auger electron is usually ejected from the same shell that held the electron that made the transition to an inner shell, as shown in Figure.

## Wave Characteristic

At any point, the graph of field strength against time is a sine wave, depicted as a solid curve in Figure 2. The peak field strength is called the amplitude (A). The interval between successive crests of the wave is called the period (T).
The frequency ($\nu$) defined as the number of cycles per unit time ( $sec^{-1}$) introduced into the medium each second is referred to as the frequency of the wave, expressed in units of hertz, and $\nu = 1/T$. The dashed curve refers to a later instant, showing how the wave has travelled forward with velocity (c).
The distance between successive crests of the wave is called the wavelength ($\lambda$).

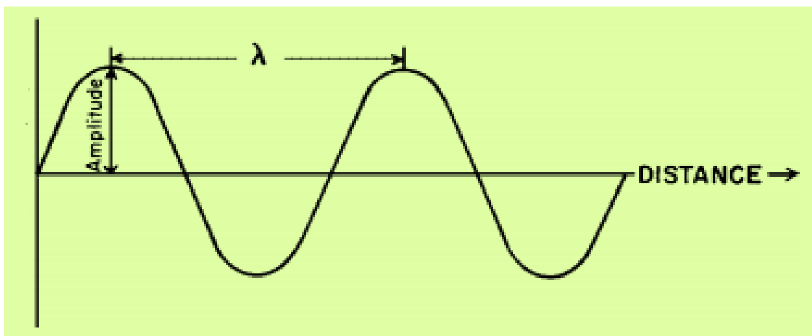


**Figure 2: Characteristics of wave.**

## Wave-Particle Duality

There are two aspects for Electromagnetic radiation can be regarded as a stream of ‘packets’ or quanta of energy, called photons (i.e. quantum aspects), traveling in straight lines. The photon is the smallest possible packet (quantum) of light; it has zero mass but a definite energy. Electromagnetic radiation can also be regarded as sinusoidally varying electric and magnetic fields (i.e. wave aspects), traveling with light velocity when in vacuum. They are transverse waves: the electric and magnetic field vectors point at right angles to each other and to the direction of travel of the wave.

Einstein is most famous for saying "mass is related to energy":

$$E = mc^2$$

Because of the wave-particle duality of light, the energy of a wave can be related to the wave's frequency by the equation:

$$E=h\upsilon$$

Planck constant: $h= 6.626 \times 10^{-34}$J.s

There are three measurable properties of wave motion: amplitude, wavelength, and frequency, the number of vibrations per second. The relation between the wavelength λ (Greek lambda) and frequency of a wave ν (Greek nu) is determined by the propagation velocity (v);

$$\upsilon = c/\lambda$$

This relation is true of all kinds of wave motion, including sound; although for sound the velocity is about a million times less. More usefully, since frequency is inversely proportional to wavelength, so also is photon energy: E (in keV) =1.24/λ (in nm)

For example:

| | | |
|---|---|---|
| Blue light | λ=400 nm | E=3 eV |
| Typical X- and gamma rays | λ=0.1 nm | E=140 keV |

Example: A sodium surface is illuminated with light of wavelength 300 nm

$$E= h\upsilon= hc/\lambda = (6.626 \times 10^{-34}\text{J.s})(3 \times 10^{8}\text{m/s}) / 300 \times 10^{-9}\text{m}$$

$$= 6.63 \times 10^{-19}\text{ J}$$

$$E = 6.63 \times 10^{-19}\text{ J} /1.6 \times 10^{-19}\text{ J. eV}$$

$$= 4.14\text{ eV}$$

## Calculate The Energy of Radiation in The Electron Volt

Electron Volt (eV) is the amount of energy by the charge of a single electron moved across an electric potential difference of one volt. A more fundamental unit of energy is the Joule (J). That means, a particle with charge *q* has energy

$$E = qV$$

$$E = h\upsilon = J.s \times Hz$$

after passing through the potential V. Therefore, one electron volt is equal to

$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

can be converted to other units of energy:

$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

$= 1.6 \times 10^{-12} \text{ erg}$

$= 4.4 \times 10^{-26} \text{ kW-hr}$

Note:

$10^3$ eV = 1 keV , $10^6$ eV = 1 MeV

The electron volt describes potential as well as kinetic energy. The binding energy of an electron in an atom is a form of potential energy. An electron that is accelerated by an electric potential of one volt will acquire energy to one eV. Most x-ray used in diagnostic radiology have energy up to 150 KeV, where as those in radiotherapy are measured in MeV. Other radiological important energies, such as electron and nuclear binding energies and mass-energy equivalence, are also expressed in eV.

## Radiation

Radiation is a fact of life: all around us, all the time. Radiation is energy moving in the form of waves or streams of particles. Understanding radiation requires basic knowledge of atomic structure, energy and how radiation may damage cells in the human body. The radiation has many other forms. Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation (that produces a suntan), infrared radiation (a form of heat energy), and radio and television signals.

## Electromagnetic Radiation

It is the process by which heat energy is transmitted from one place to another without the aid of any material medium. When a body has internal energy, its atoms and molecules vibrate and emits electromagnetic radiation, which can transport energy across a vacuum, e.g. heat reaches the earth from the sun.

Electromagnetic radiation consists of oscillating electric and magnetic fields (see Figure 3). An electromagnetic wave requires no medium for propagation; that is, it can travel in a vacuum as well as through matter.

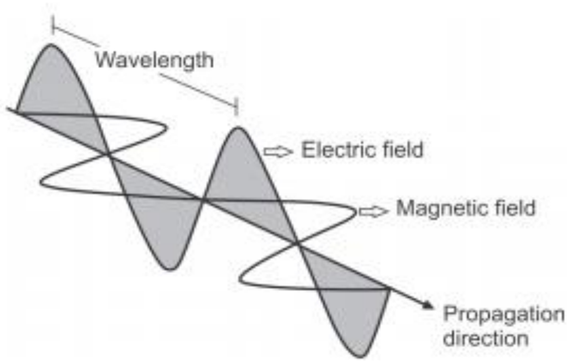


**Figure 3: Electromagnetic wave**

Electromagnetic radiation is a form of energy. Electromagnetic energy is the term given to energy traveling across empty space and used to describe all the different kinds of energies released into space by stars such as the Sun. These kinds of energies include some that you will recognize and some that will sound strange. They include:

- Radio Waves
- TV waves
- Radar waves
- Microwaves, like in a microwave oven
- Heat (infrared radiation)
- Light
- Ultraviolet Light (This is what causes Sunburns)
- X-rays (emitted by X-ray tubes)
- Gamma Rays; gamma rays (emitted by radioactive nuclei) have essentially the same properties of X-rays and differ only in their origin.

**Table 1: Electromagnetic spectrum**

| Electromagnetic | Wavelength | Frequency | Energy |
|---|---|---|---|
| **Radio waves** | 30-6 m | 10-50 MHz | 40-200 neV |
| **Infrared** | 10-0.7 µrn | 30-430 THz | 0. 2-1.8 eV |
| **Visible light** | 700-400 nm | 430-750 THz | l.8-3eV |
| **Ultraviolet** | 400-100 nm | 750-3000 THz | 3-12 eV |
| **X- and gamma** | 60-2.5 pm | 5× I0$^{6}$– 120× 10$^{6}$THz | 20-500 keV |

## Electromagnetic spectrum

Electromagnetic spectrum includes radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays and cosmic rays (Figure 4). All of them travel at a velocity ‘c’(3×108 m.s $^{-1}$) in a vacuum. The wavelength and photon energy of the whole range of electromagnetic radiation are summarized in Table 1.

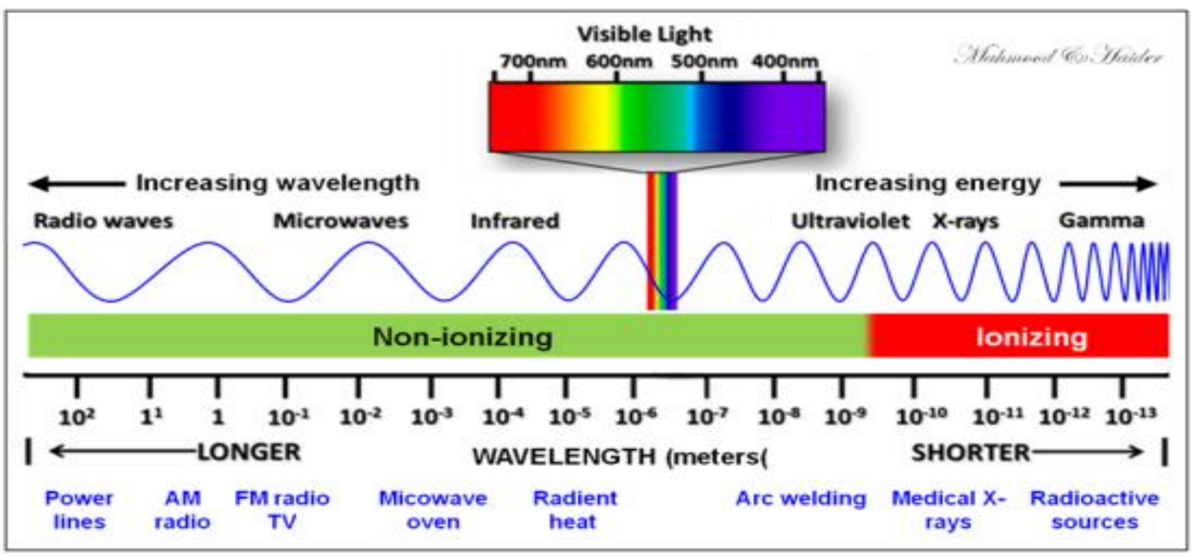


**Figure 4: The electromagnetic spectrum**

## Types of Radiation

Not all radiation interacts with matter in the same way. There are two forms of radiation:

## 1-Non-Ionizing Radiation

Non-ionizing radiation is the radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove electrons. That mean it does not possess enough energy to produce ions.

- Non-ionising radiation consists of parts of the electromagnetic-spectrum (Figure 4), which includes radio waves, microwaves, infra-red, visible and ultraviolet light, together with sound and ultrasound. Cellular telephones, television stations, FM and AM radio, and cordless phones use non-ionizing radiation.
- Other forms include the earth's magnetic field, as well as magnetic field exposure from proximity to transmission lines, household wiring and electric appliances. These are defined as extremely low-frequency (ELF) waves and are not considered to pose a health risk.

## 2-Ionizing Radiation

Ionizing radiation is a special type of radiation (in the form of either particles or waves) that has enough energy to remove tightly bound electrons out of their orbits around atoms, thus creating ions, the atom is said to be ionized. This process is called ionization.

- Ionizing radiation includes the radiation that comes from both natural and man-made radioactive materials. Examples of this kind of radiation of interest for the purpose of this curse are gamma (γ) and x-rays. Gamma radiation consists of photons that originate from within the nucleus, and X-ray radiation consists of photons that originate from outside the nucleus, and are typically lower in energy than gamma radiation. We take advantage of its properties in diagnostic imaging, to kill cancer cells, and in many manufacturing processes.
- Ionizing radiation can occur in one of two forms: particulate or electromagnetic . Particulate ionizing radiation is emitted when components of the structure of an atom are ejected, artificially or naturally.