X-RAY SPECTROSCOPY

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X-ray spectroscopy is a form of optical spectroscopy that utilizes emission, absorption, scattering, fluorescence, and diffraction of X-ray radiation

X-ray was discovered in 1895 by Roentgen where he was observed emission of unknown rays from the cathode tube penetrates the glass as well as many non-transparent materials for normal light.

Roentgen discovered that X-rays penetrate some substances more than other materials and provided for a few weeks, the first radiographic image taken back to Rontgen's wife hand.

The properties and nature of these rays were explained in 1932 by scientists Peece, Hethler and Sooti.

Production of X - rays

X-rays are generated in a tube that has been historically known as the Coolidge tube.

This consists of quartz tube vacant to a very large degree (10-3 – 10-4 mmHg) for Two reasons:

1- To avoid the oxidation of filament by air.

2- To avoid the collision of electron with air and lost its energy.

and two electrodes forming the cathode and anode

In this tube, the cathode consists of an electron-rich material also called heating filament which is the source of the electronic beam, cathode is manufactured by a spiral of tungsten for two reasons:

1-Tungsten has a large atomic number (Z=74)

2- Tungsten has a very large melting point (T = 3370 °C)

The heating filament is surrounded by a cylinder called a focusing cup to avoid the spacing of emitted electrons from the filament as a result of the crowding of the electrons among them.

The anode is a metal plate that is often made of tungsten.

The electronic beam is produced by heating the filament by a few amperes current (I_C) (electrochemical effect).

The electron beam of the filament is then accelerated towards the anode under high-voltage effect (200 kv) applied between cathode and anode .

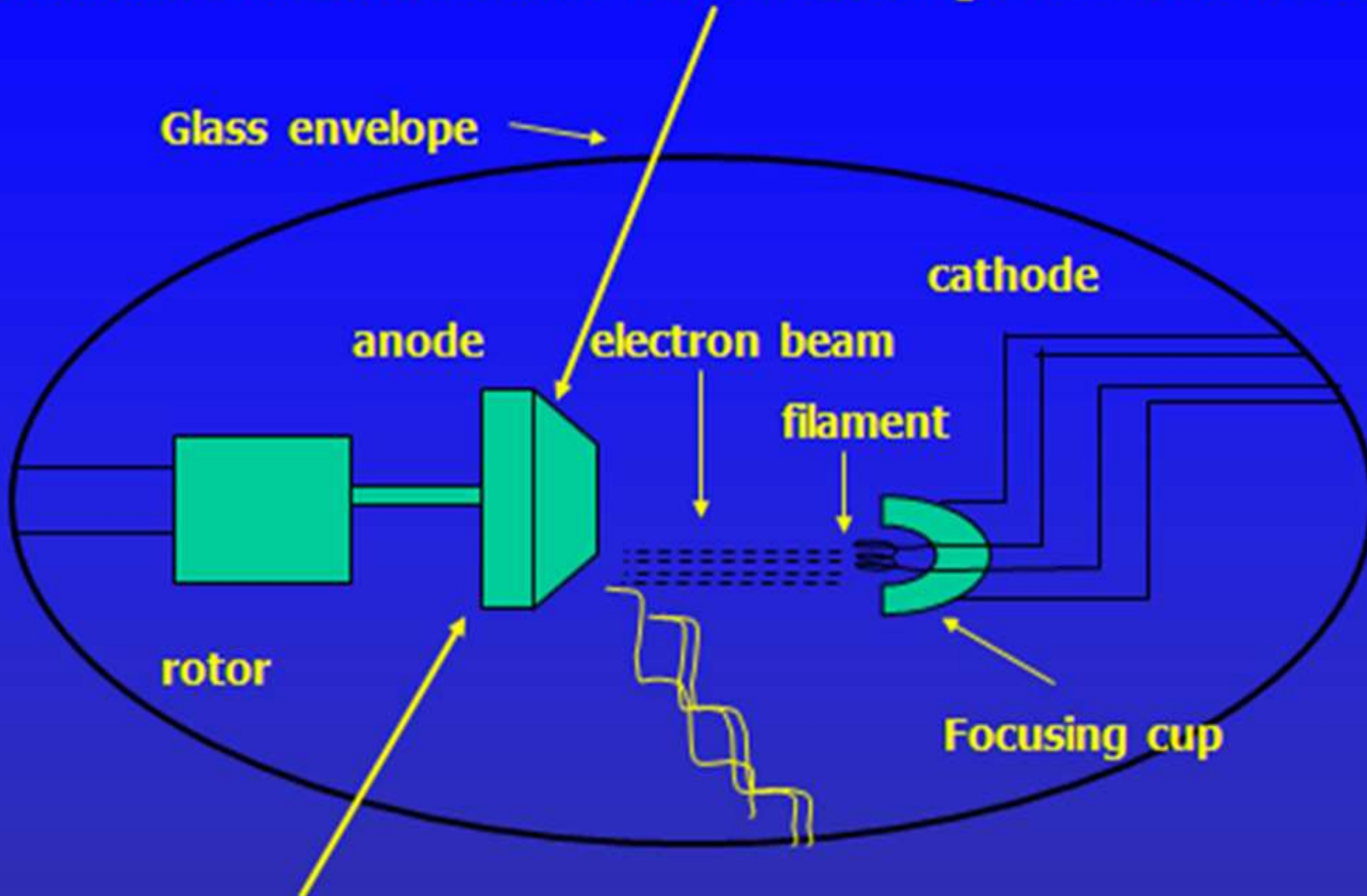
As a result, the accelerated beam of electrons collides up the anode which is beveled for the electronic beam path (small angle 12° - 17 °) resulting in a reciprocal effect between the falling beam electrons and a substance of anode (target) which eventually leads to the emission of X-rays from the characteristic area of the anode called a focal spot.

*When the electrons from the cathode are accelerated at high voltage to the anode:

99% of the energy is dissipated as heat (anode materials are selected to withstand the high temperatures , which is connected to a fine copper tube for anode cooling because copper has good conductivity of electricity and heat)

while 1% is given off as X-rays.

•The anode is bevelled at an angle of 12 to 17 degrees in order to maximise the contact area while focussing the resultant beam



•The anode is usually composed of tungsten or molybdenum as it must withstand very high temperatures (>3000 degrees C)

Notes

1. The heating filament is designed in a spiral with the aim of being highly resistant and slightly temperature increasing.

2 .The width of the beam is depend on the width of the focal spot. If the focal spot is wide (large), we get a large rate of X-ray, but if the focal spot is small (narrow) we get a small rate of X-ray.

In addition, the width of the focal spot is depend on the tilt of the anode, which is as small as the tilt small.

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3. X-ray Tubes employ special anode (Mo, Cu, Fe, Co and Cr) to produce the correct type of characteristic radiation

4. The Coolidge tube is surrounded by a lead shield to protect researchers and workers of exposure to this hazardous radiation ,because lead is highly dense and absorbs this radiation.

5. Special windows are employed such as Beryllium, mica or low absorption glass to minimise loss of low energy radiation

Emission of X – rays

The spectrum of X-ray produced in the Coolidge tube is due to two conditions:

1- Ionization (Excitation) : produces a characteristic spectrum called the spectrum of lines.

2- Braking : produces a Continuous spectrum called braking spectrum (Bremsstrahlung).

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From this we conclude that the resulting X-ray spectrum is a sum of Two spectra :

1- A continuous spectrum called the braking spectrum (Bremsstrahlung) makes up approximately 80% of the X-ray beam.

2- A discrete spectrum called the characteristic spectrum makes up approximately 20% of the X-ray beam.

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X-ray spectra are composed of:

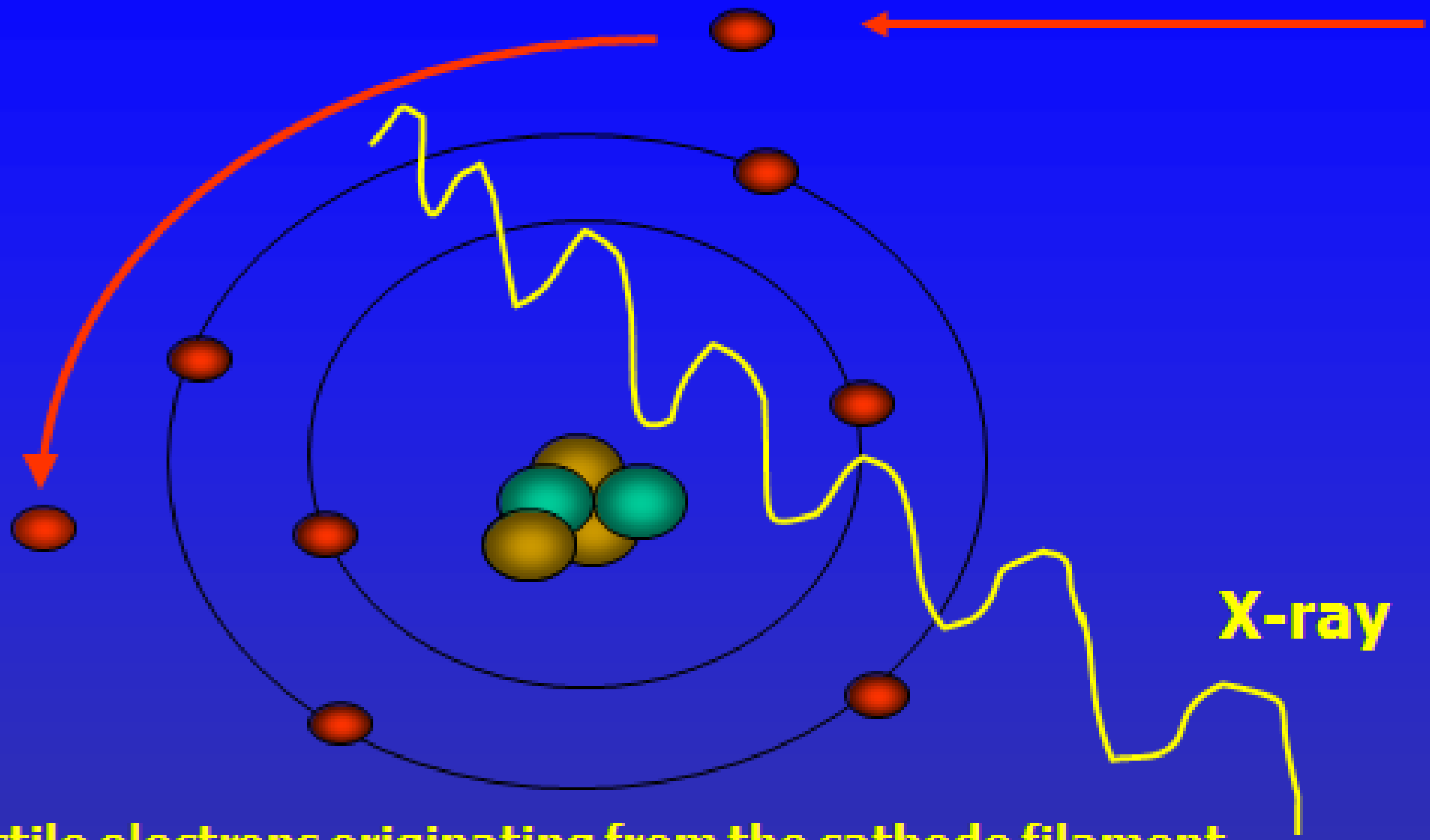
1. Continuous bremsstrahlung spectra

2. In most cases, **discrete** spectra peaks known as **characteristic x-rays**.

Continuous spectrum

Assume that one of the electrons produced by the heating filament has kinetic energy Ec enables it to be nearby to the nucleus , the electron will then be attracted to the nucleus under the influence of attractive forces by positive protons effect , However, it will bent from its trajectory when it is sufficiently close to the nucleus because of the influence of nuclear forces (repulsion forces), leading to far away from the nucleus with a much lower kinetic energy Ec′

Bremsstrahlung radiation



Projectile electrons originating from the cathode filament impinge on atoms in the anode and will often pass close by the nucleus of these atoms.

As the electrons pass through the target atom they slow down, with a loss in kinetic energy. This energy is emitted as x-rays. The process is known as *bremsstrahlung* or "braking energy".

In this case, the kinetic energy that the electron lose it during its trajectory is continuously released as X-ray radiation with energy :

$$h\upsilon = Ec - Ec'$$

which represent braking energy .

X-ray energy takes its values from zero to a maximum value E_{max}, when the electron lose all its kinetic energy to be emit in the form of X-ray photon

Duane and Hunt's law

Assuming that the kinetic energy of the electron has been completely transformed into continuous X-ray radiation. in this case we can determine the minimum wavelength (λ_{min}) For the emitted X-ray from the tube in the following mathematical equation:

$$\lambda_{min} = \frac{h \times c}{eV}$$

Where:

h: Represents Blank constant.

c : Represent velocity of light.

e : Represent an electron charge.

V: Represent the applied voltage.

To compensate for these constants we find that:

$$\lambda_{min}\left(A^{o}\right)= \frac{6.62\times 10^{-34}\times 3\times 10^{8}}{1.6\times 10^{-19}\times V\left(KV\right)}=\frac{12.4}{V\left(KV\right)}$$

This relationship is called :

Duane and Hunt's law

Notes

1. The spectrum of the continuous X-ray is independent of the nature of the anode (target) and is only depend on the accelerated voltage, and is used in the field of medical imaging and radiotherapy.

2. X-rays resulting from braking are called continuous (white) radiation or Bremsstrahlung.

3. Short-wavelength X-rays with large penetrating abilities called hard X-ray, (produce by heavy elements) , while X-ray with a large wavelength and small penetrating abilities called soft X-ray

The hardness or softness of X-rays is controlled by changing the accelerated voltage value V.

The hard X-ray, is weaker absorption and greater the penetration through the specimen. While the soft X-ray, is stronger absorption and weaker penetration through the specimen.

- 4.The continuous radiation does not have a value unique to an element , it is excluded for quantitative analysis

Returns of X-rays tube

Returns of X-rays tube (r) is the dividing of the radiated energy(R) to the energy(E) consumed in X - ray tube .
or it is the dividing of the radiated power (R·) to the electric power (P) consumed in X - ray tube .
It is determined according to the following equation :

$$r = \frac{R}{E} = \frac{\dot{R}}{P} = \frac{k \times I \times Z \times V^2}{V \times I} = k \times Z \times V$$

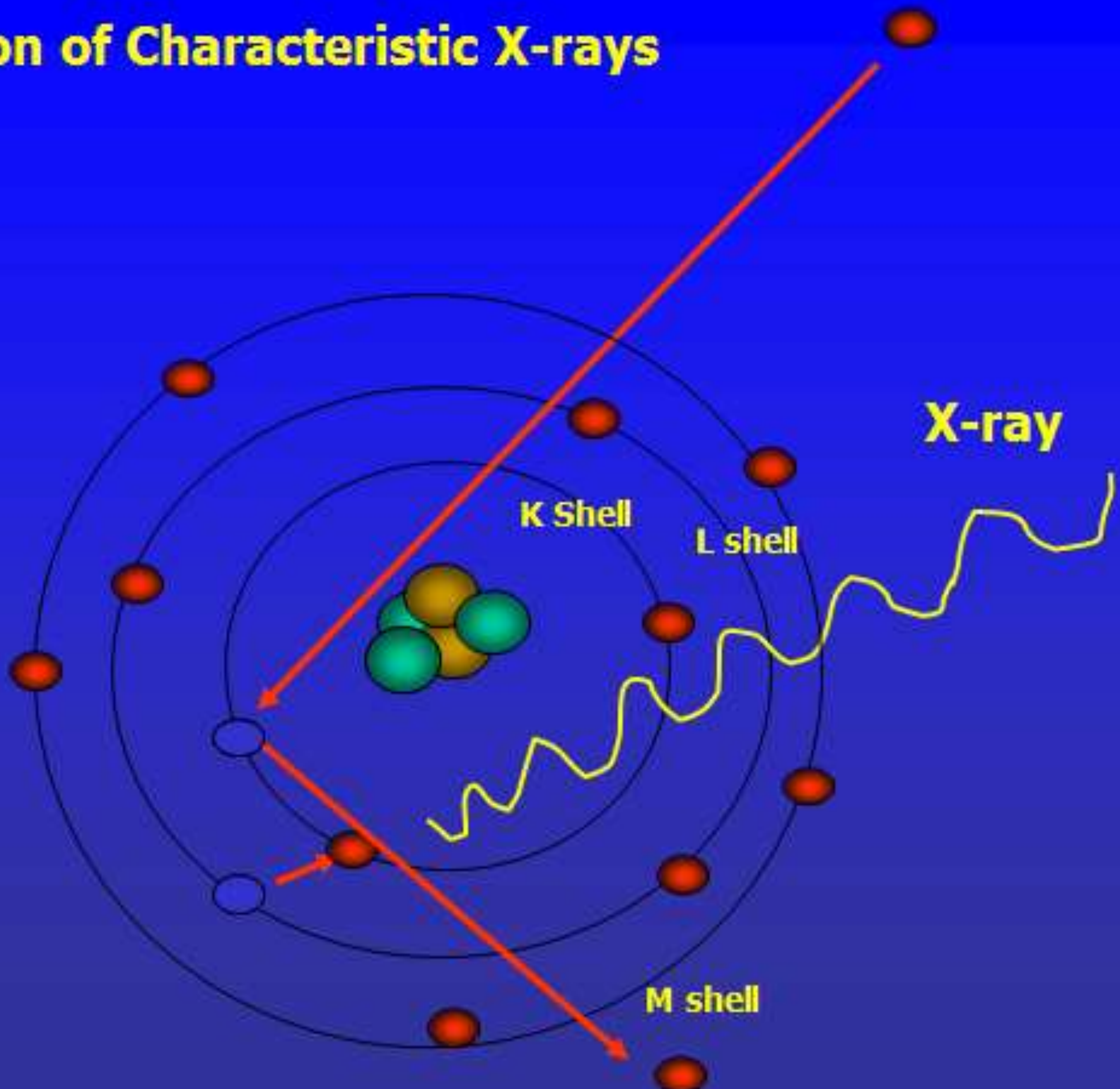
The return X-ray generated by Coolidge tubes is very poor and does not exceed at best 2% this results in a large amount of release temperature, that can cause the device to malfunction and lead to damage the anode material. In order to avoid this, a rotary anode can be used.

Characteristic spectrum (lines spectrum)

When the applied high voltage becomes sufficient, we observe some lines that are mounted on the continuous spectrum, these lines are characteristic of the anode material , this can explained as following: An incoming high-energy electron dislodges an inner-shell electron in the target, leaving a vacancy in the shell, then the atom becomes excited (unstable state), an outer shell electron then "jumps" to fill the vacancy to restore the previous stability of atom , a characteristic X-ray (equivalent to the energy change in the “jump”) is generated with frequency (υ) . The characteristic X-ray energy given by the following equation:

$$\Delta E = h \times \upsilon$$

Production of Characteristic X-rays



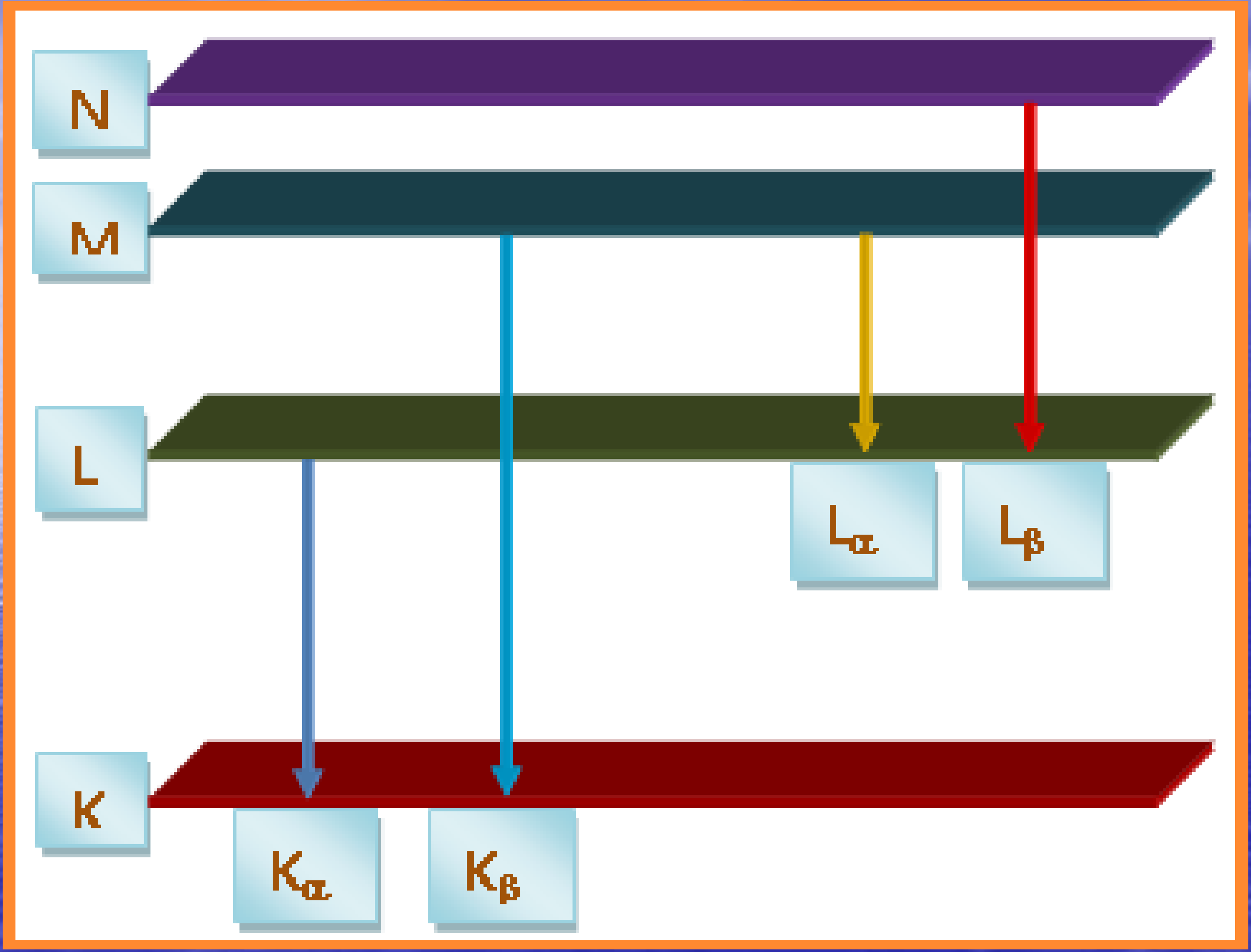
Naming of the characteristic lines

The naming of the characteristic lines was agreed with the same Latin letters as the main atomic shells that the electron fall on it to fill the vacancy , and the shell that electron come from it is indicated by one of the Greek letters α , β , γ ,…..

It is written in the form to indicate that the filler electron come from the top shell directly or from the shells which followed.

For example, electron come from the top shell directly or from the followed shells Assume an electron come from L shell to fill the vacancy in K shell ,As a result, the electron energy will be lost appear as characteristic (line) X-ray (Kα) with energy $E_{k\alpha}$ where:

$$E_{k\alpha} = h\upsilon = E_L - E_K$$


N
M
L
K
L_α
L_β
K_α
K_β

Notes

1. Characteristic X-rays spectrum are most commonly used in the scientific field (Crystallography)

2. Characteristic X-rays spectrum are used in the elemental identification and quantitative analysis

3. Characteristic lines spectrum does not appear at a small accelerated voltage , but these lines start to be appear by increasing the accelerated voltage.

X-ray properties

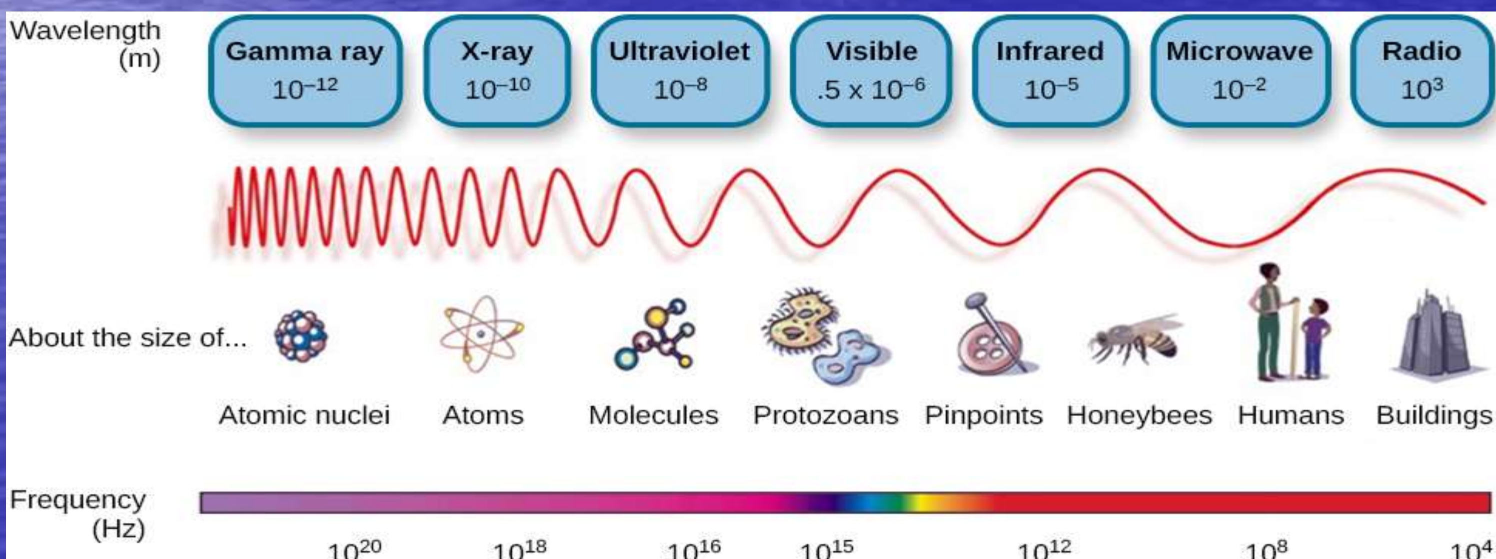
1- X-ray is an electromagnetic nature.

2- X-ray energy are ranged between

$10^2 - 10^5$ eV

and wavelengths are limited to

$10^{-12} - 10^{-9}$ m



3- Spread equal to the light speed as straight lines and in all directions.

4- Do not deviate under the influence of the fields of electric and magnetic.

5- Ionize gases that pass through it, and this feature used to measure the amount of X - ray using the ionization chamber.

6- Lead to the fluorescence of some mineral salts.

7. Able to penetrate the human body and be easier when its penetration are more .

8. It becomes depleted when it penetrate the material and becomes more depletion as both the thickness of the material and its density are high.

9.Lead to the chemical and biological reactions occurrence within the living tissue, leading to ionization and deflection of the cellular metabolism.

10- Cause the blackness the photography emulsion.