Section 6: EMISSION/ABSORPTION OF EM RADIATION

In this section, we describe ways atoms respond to being excited and how they then undergo de-excitation. They link directly to how we detect radiation, modify and analyse materials using radiation and how radiation interacts with matter.

Emission/absorption of EM radiation

THE PHOTOELECTRIC EFFECT:

Emission of electrons from a material bombarded with em radiation.
The classical and quantum mechanical views of this phenomenon are very different.

Classical electromagnetic-wave picture:

- Electron gains energy continuously from the radiation at a rate proportional to the radiation intensity and the electron is liberated when it has acquired sufficient energy to escape.
- When this occurs depends on the electron binding energy and the radiation intensity.
- The greater the binding energy the *longer* will be the time taken to liberate the electron.
- Conversely, the greater the intensity, the *shorter* will be the time required to liberate the electron
- The time should be independent of the radiation frequency.

Experimental observation:

- There is a threshold frequency ν_0 that depends on the material, below which no electrons are liberated at all, regardless of the intensity.
- If $\nu \geq \nu_0$, electrons are liberated **immediately** with a maximum kinetic energy given by

$$E_{max} \propto \nu - \nu_0 . \tag{4.2}$$

The constant of proportionality is Planck's constant *h.*

- As the electromagnetic intensity is increased, there is no change in the emitted energies, but the **rate** of electron emission increases.

Quantum-mechanical picture

Energy is absorbed by the electrons in **quantized** amounts $h\nu$ equal to the energy of a photon.

- There is a threshold photon energy ($h\nu_0$), which is the binding energy (BE) of the most weakly-bound electron.
- It is the **minimum** energy needed to remove an electron.
- If $h\nu < h\nu_0$, the electron **cannot** be liberated from the atom.
- The electron can be excited **only** if $h\nu$ corresponds **exactly** to an allowed electron transition in the atom.
- If $h\nu > h\nu_0$, the electron **can** be liberated with maximum kinetic energy (KE) given by

$$E_{\text{max}} = h\nu - \text{BE} = h\nu - h\nu_0. \qquad (4.3)$$

- This is the observed KE of the most weakly-bound electron. The more strongly-bound electrons appear with lower kinetic energies.
- The intensity of the radiation is proportional to the number of incident photons per m^2 per second. Therefore, the electron flux (per m^2 per second) $\propto$ intensity.

The quantum-mechanical picture completely explains the experimental results and was one of the crucial pieces of evidence supporting the new quantum theory.

EMISSION SPECTRA

Suppose one of the two K-shell electrons is removed from an atom leaving a vacancy in the K-shell.

- This is rapidly filled by an electron from a higher shell (energy E_n) `dropping down' into the K-shell (energy E_K).
- At the same time a photon is emitted with energy

$$E_{ph} = h\nu = E_n - E_K \qquad (4.4)$$

Since shell energies are characteristic of a particular element, the frequencies (or wavelengths) of the emitted photons are also characteristic of the element involved.

- Transitions from higher shells to the K-shell are called K transitions.
- A subscript is added to the transition name to identify the upper level from which the transition originated:

Transitions with final states in the K-shell are denoted K_α, K_β, K_γ etc.

Higher shell	Δn	Transition
L (n = 2)	-1	K_α
M (n = 3)	-2	K_β
N (n = 4)	-3	K_γ
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If an L-shell electron has de-excited to fill a K-shell vacancy (emitting a K_α photon), a vacancy will exist in the L-shell.

- This vacancy will be rapidly filled by an electron from a still higher shell.
- Such transitions are called L transitions.
- Again, a subscript is added, which identifies the higher shell.

Higher shell	Δn	Transition
M (n = 3)	-1	L_α
N (n = 4)	-2	L_β
O (n = 5)	-3	L_γ
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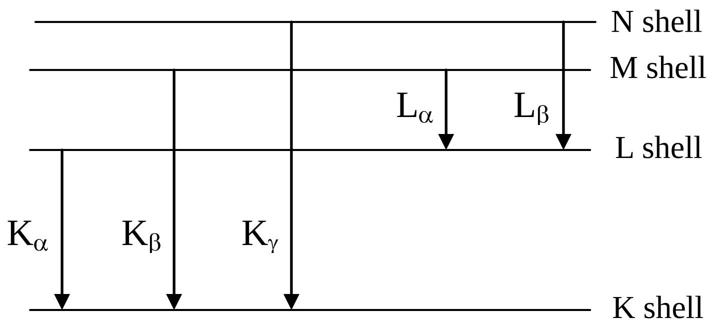
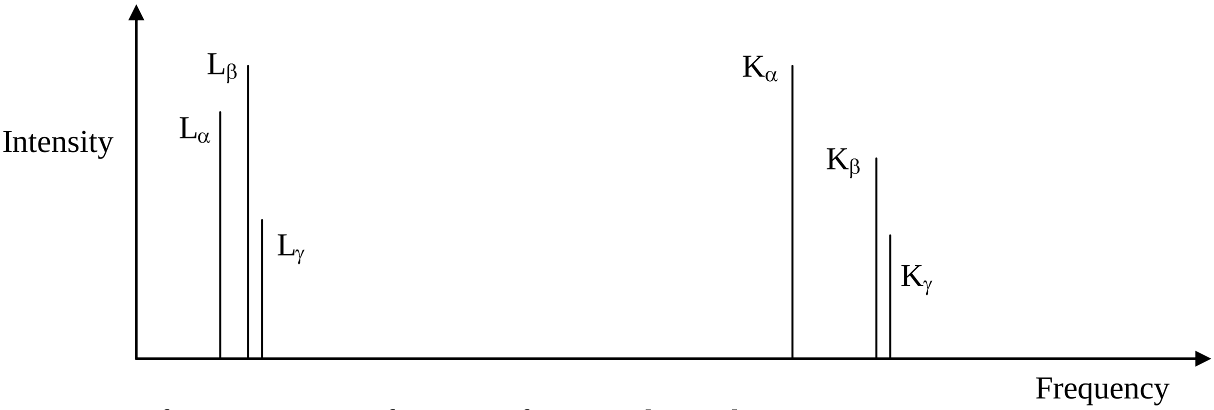


Energy level diagram showing several K and L transitions.

Emitted radiation is a series of sharp lines, corresponding to the frequencies of the characteristic radiation of that element.

It is called an **emission spectrum** and the emitted frequencies are called **spectral lines.**

- They occur only at certain discrete values.
- In general, the intensities of the lines vary from element to element.

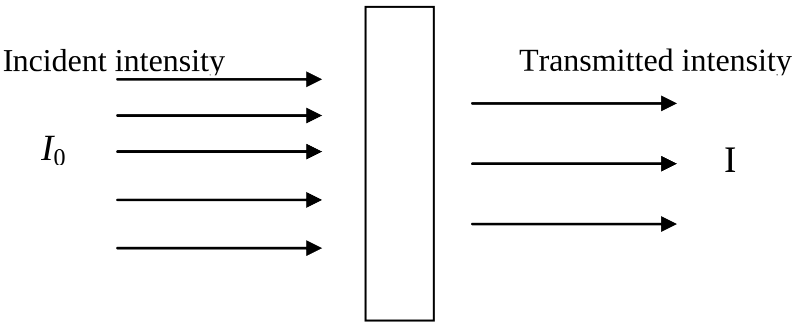


Spectrum of intensity versus frequency for several K and L transitions.

- For hydrogen, the K series is just the **Lyman Series** (ultra violet).
- The L series is the **Balmer series** (visible).
- For other light elements, the characteristic spectral lines also lie in the visible or ultra-violet regions.
- For heavier elements (large Z) the lines are in the X-ray region, with energies E_X up to many keV. E_X is approximately proportional to Z^2.

ABSORPTION SPECTRA

Consider a beam of **monoenergetic** (or monochromatic) X- rays incident upon a slab of a heavy element (e.g. lead).



Some photons are absorbed by the material - mainly by the photo-electric effect. Therefore, the transmitted intensity, I is less than the incident intensity I_0.

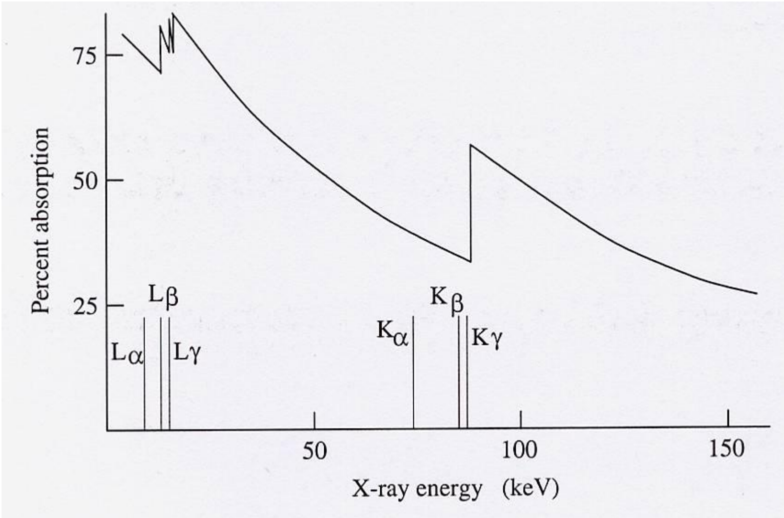
$$\% \text{ absorption} = \left(\frac{I_0 - I}{I_0} \right) \times 100. \qquad (4.5)$$

Each additional slab will reduce the intensity by the same factor as the first, leading to an exponential decrease of intensity with absorber thickness.

Absorption decreases with beam energy - i.e. it becomes more penetrating.

Low-energy photons can only eject electrons from the outer shell but eventually, photons have sufficient energy to ionize electrons from the next more tightly-bound shell and so on, to the L- and finally, the K-shells.

As the photon energy successively exceeds the different shell energies, the percentage absorption increases sharply in what are known as **absorption edges.**



- The L-edge consists of several closely-spaced edges corresponding to the the L subshells, which have slightly different energies.
- Energies of the emission lines lie just below the energy of the corresponding edge.
- The edge energy is the energy required to ionize electrons and is equal to the binding energy of that shell.
- The emission-line energy is less than the binding energy of the lower shell.

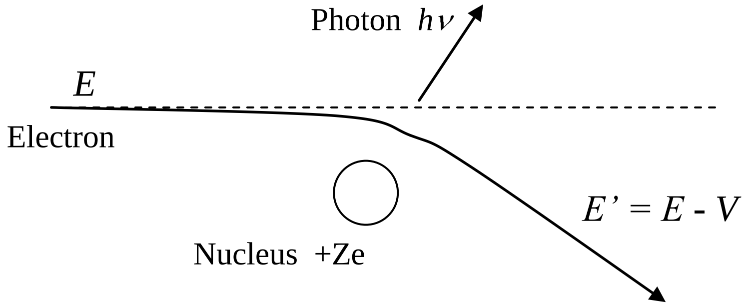
X-RAYS

X-rays are produced by bombarding a heavy element target with a beam of high-energy (few keV to few MeV) electrons.

There are two main processes:

1) Photon emission, following the excitation and ionization of bound electrons.
   - Electrons in the beam collide with target electrons causing **excitation** or **ionization** and creating vacancies in the inner shells.
   - Characteristic X-rays are emitted as the vacancies are filled.

2) Inelastic electron scattering by target nuclei.



EM radiation (photon) can be emitted when a charge, such as an electron is accelerated (i.e. goes off in a different direction) when it is scattered by passing close to a nucleus.

The emitted radiation is called **bremsstrahlung** radiation (`braking' radiation). It has a continuous range of energies from approximately zero to a maximum value (= beam energy). Most electrons are scattered through small angles and lose little energy (emitting low-energy bremsstrahlung photons).

- Most of these low-energy (or `soft') photons are absorbed.
- Electrons scattered through larger angles lose more energy and emit higher-energy photons up to the maximum energy.
- This part of the X-ray spectrum is independent of the target material.

The observed X-ray spectrum is the sum of the two contributions:

- The sharp emission lines - **characteristic** of the target material.
- A continuous spectrum - **independent** of the target material.

Note that K (and L) lines are seen only if the beam energy is sufficiently high to excite or ionize electrons from the K- (and L) shell.