بسم الله الرحمن الرحیم

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Faculty of Materials Science and Engineering

Materials Characterization Methods

Sixth Session
(Interaction of Electrons with Samples)

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Interaction of Electrons with Samples

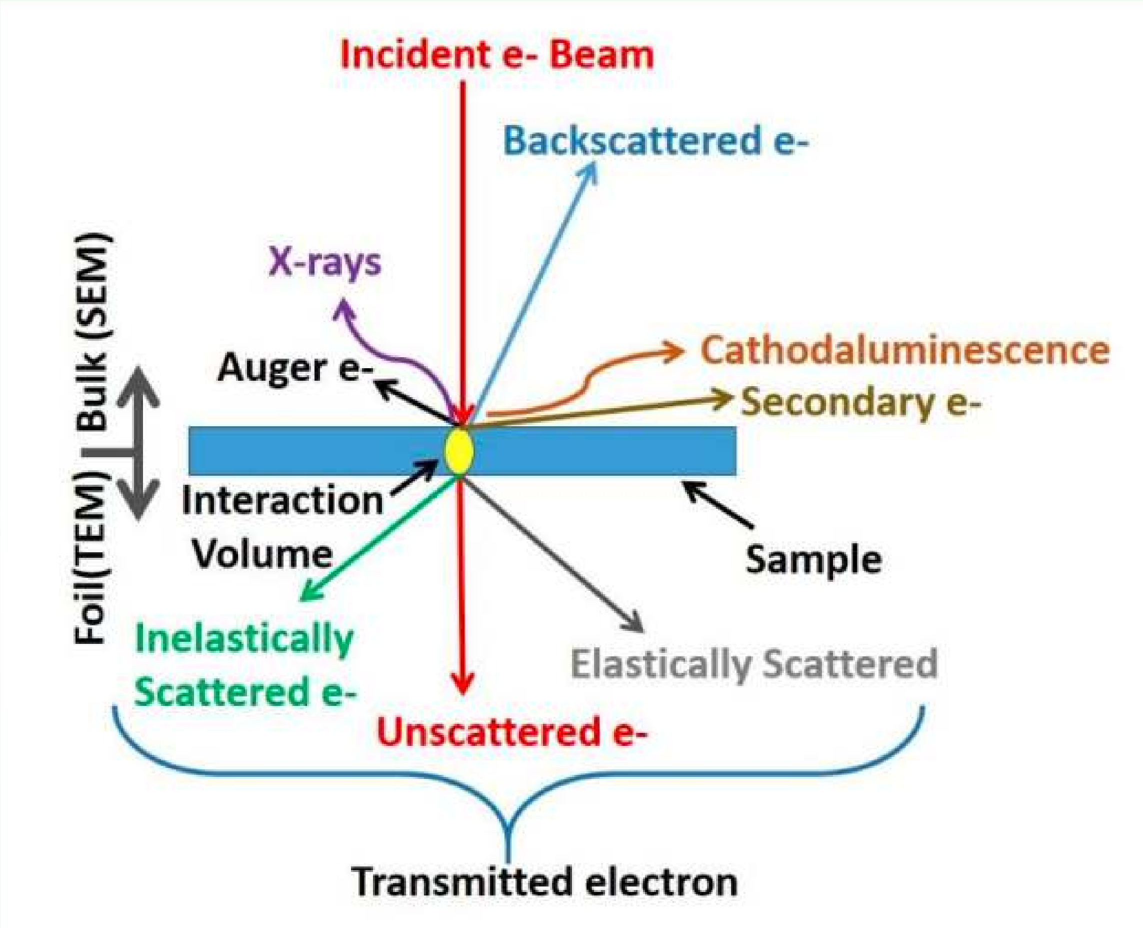
- ✓ Electron interaction with samples refers to the products or signals of electron radiation on the object.

- ✓ Due to the collision of the electron beam with the surface of objects, various phenomena occur, each of which provides valuable information.

- ✓ This information can be about the sample composition, surface roughness, crystal structure and other properties of the material.

Interaction of Electrons with Samples

Signals generated by the collision of an electron beam with a sample



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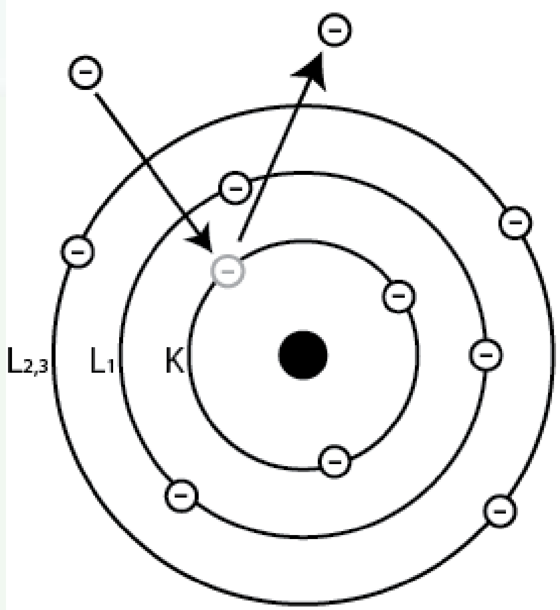
Secondary Electrons

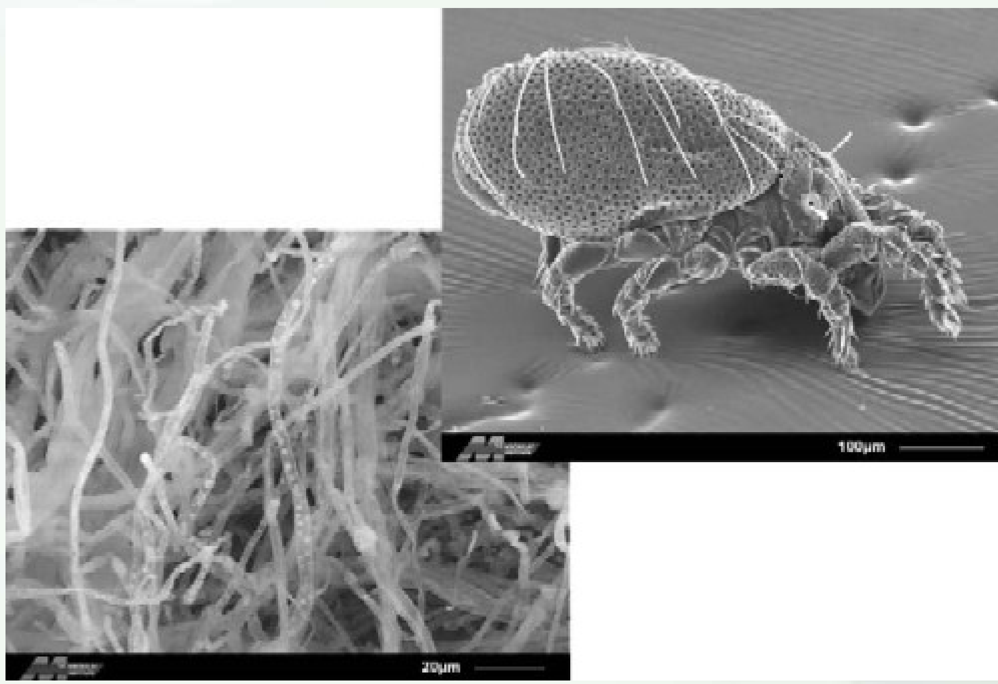
An electron beam after collision to the surface may penetrate into the structure and cause electrons to leave the surface atoms, which are called secondary electrons.



Secondary Electrons

Secondary Electrons

- ✓ Electrons leave the outer electron layers of the atom (valance layer) and have low energy (less than 50 electron volts).
- ✓ An image composed of secondary electrons is suitable for surface topography (fractography imaging).



Secondary Electrons

- ✓ The information depth of the secondary electrons is about 5-50 nm. In some cases, these electrons are also called slow secondary electrons (SSE).
- ✓ If the electron beam separates the electrons from the internal layers of the atom, the output electrons have a high energy and velocity and can have an energy of about 50-300 electron volts.
- ✓ These electrons have no special application in electron microscopes and can even interfere with X-ray analysis.

Back-Scattered Electrons

- ✓ Some primary electrons can be reflected off the surface of the sample before losing all their energy. They are much more likely to leave when they have not yet lost much energy.

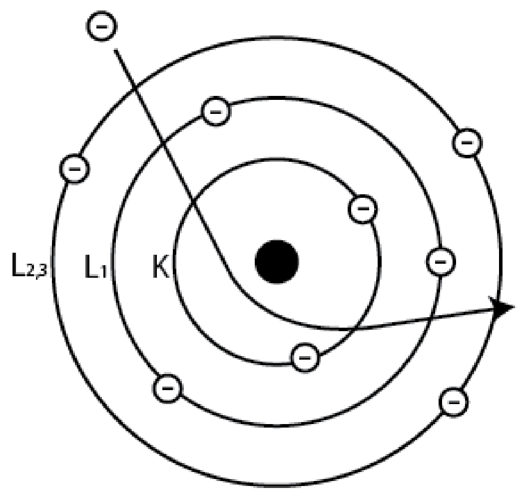
Back-Scattered Electrons

- ✓ These electrons are less than the secondary electrons, but have a high energy and are used for imaging, diffraction, and analysis in SEM.
- ✓ Due to the high energy, these electrons can also come out of great depths.

Back-Scattered Electrons

- ✓ The depth of information by the back-scattered electrons is 2-5 microns.

- ✓ These electrons are also called fast secondary electrons (FSE).



Backscattered Electrons

Auger Electrons

- ✓ If an electron is ejected from an atom by the radiation of an electron to a sample, the atom is placed in an energetically excited state. Then the electron vacancy is filled and the atom reaches a state of equilibrium and relaxation and its excess energy is released as a secondary effect.

- ✓ If there is a vacancy in the inner layer, the energy released is greater and a characteristic X-ray or characteristic Auger electron can be emitted.

Auger Electrons

Instead of emitting an X-ray, an electron may be ejected from the external layer, which carries this extra energy as kinetic energy. This process is called Auger emission. In this case, four electrons are involved:

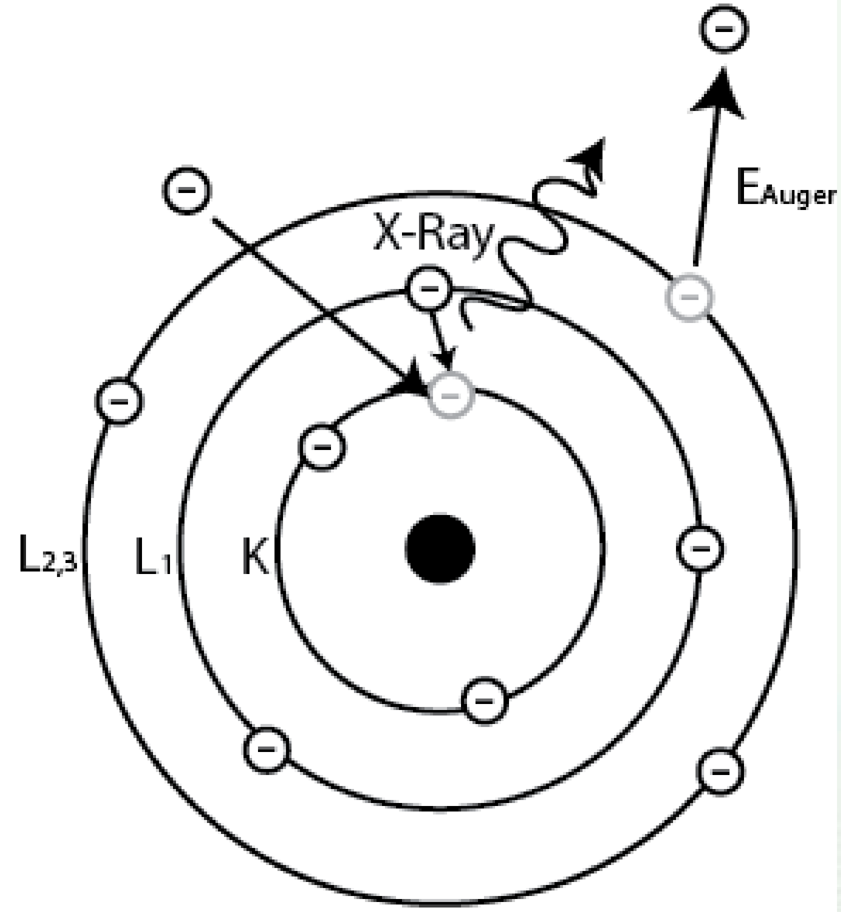
1- Primary electron (which removes the electron from the internal layer)

2- An electron that leaves the layer

3- An electron that fills its vacancy and

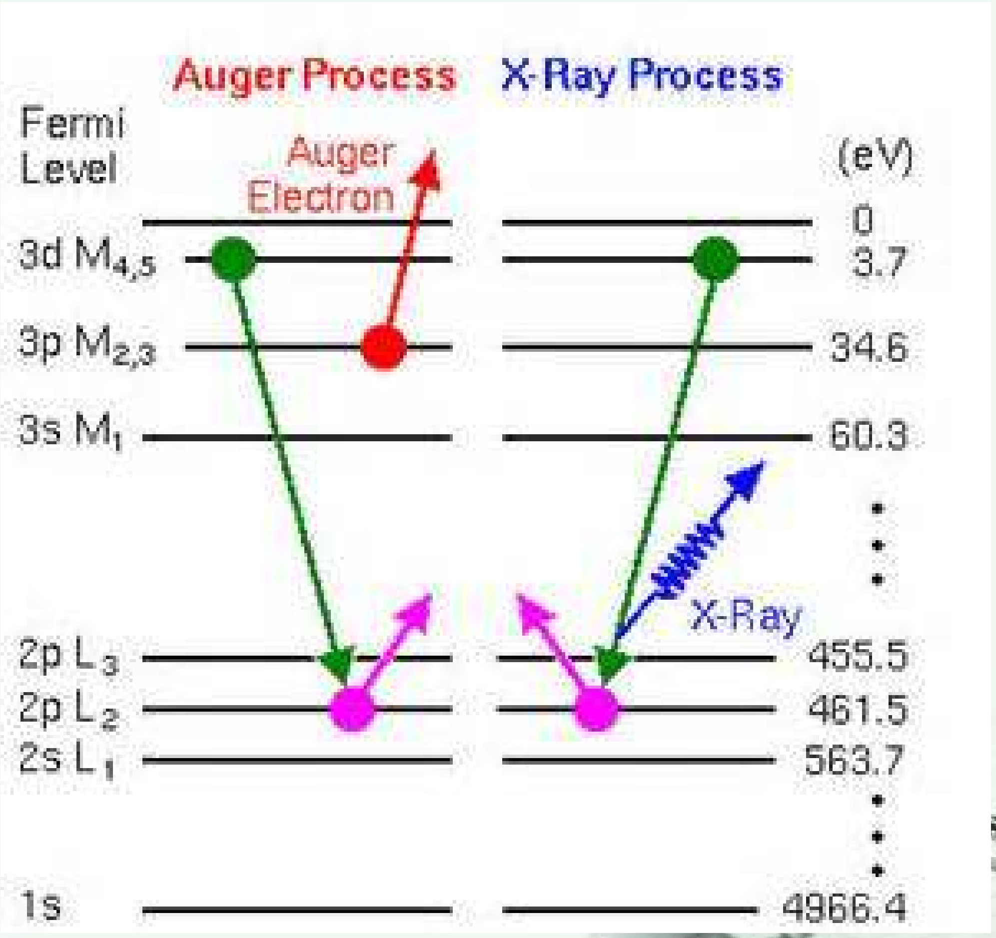
4- Another electron from the external layer that leaves the atom with extra energy (Auger electron).

Auger Electron and Characteristic X-Ray



Auger Electrons or
X-Ray Fluorescence

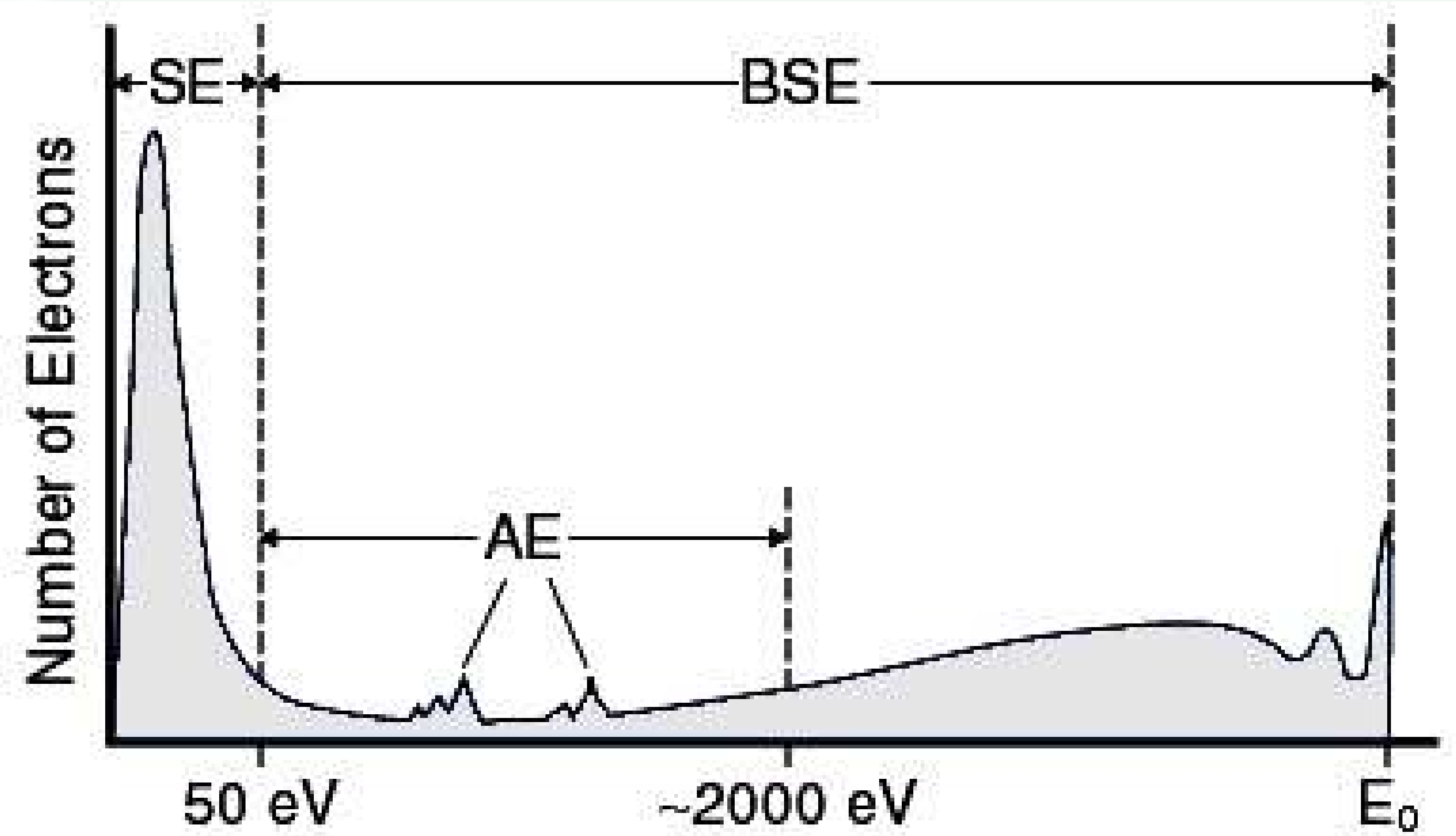
Auger Electron and Characteristic X-Ray



Auger Electrons

- ✓ Measurement of characteristic Auger electron energy form the basis of Auger electron spectroscopy. The energy of these electrons is very low and they can only come out of completely surface layers (1 nm), such as oxide or coating layers.
- ✓ The probability of occurrence of Auger electron emission and characteristic X-rays in a material is not the same.
- ✓ For light elements (with a small atomic number), the number of emitted Auger electrons is much greater than for an X-ray, and for heavy atoms (with a higher atomic number) it is quite the opposite.

The Relative Abundance of Three Types of Electron Emission



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Characteristic and Continuous X-Ray Spectrum

Characteristic X-Ray Spectrum

- ✓ If an electron jumps from an external orbit to an empty one in an internal orbit, the energy of the X-ray is equal to the difference in energy of the atom excited in the two states that characterize the atom.

- ✓ In other words, the energies and wavelengths of the resulting X-rays are different for each type of atom, and by measuring them, the type of elements in the sample can be identified.

Characteristic and Continuous X-Ray Spectrum

Continuous X-Ray Spectrum (White or Braking Radiation)

Primary electrons can also emit X-rays without expelling electrons from the internal layer. In this case, the electron can lose any amount of energy (up to all its kinetic energy) and this energy produces an X-ray. This X-ray will not be characteristic of a particular atom and has a range of wavelengths. These electrons are also back-scattered electrons, if they leave the same input surface.

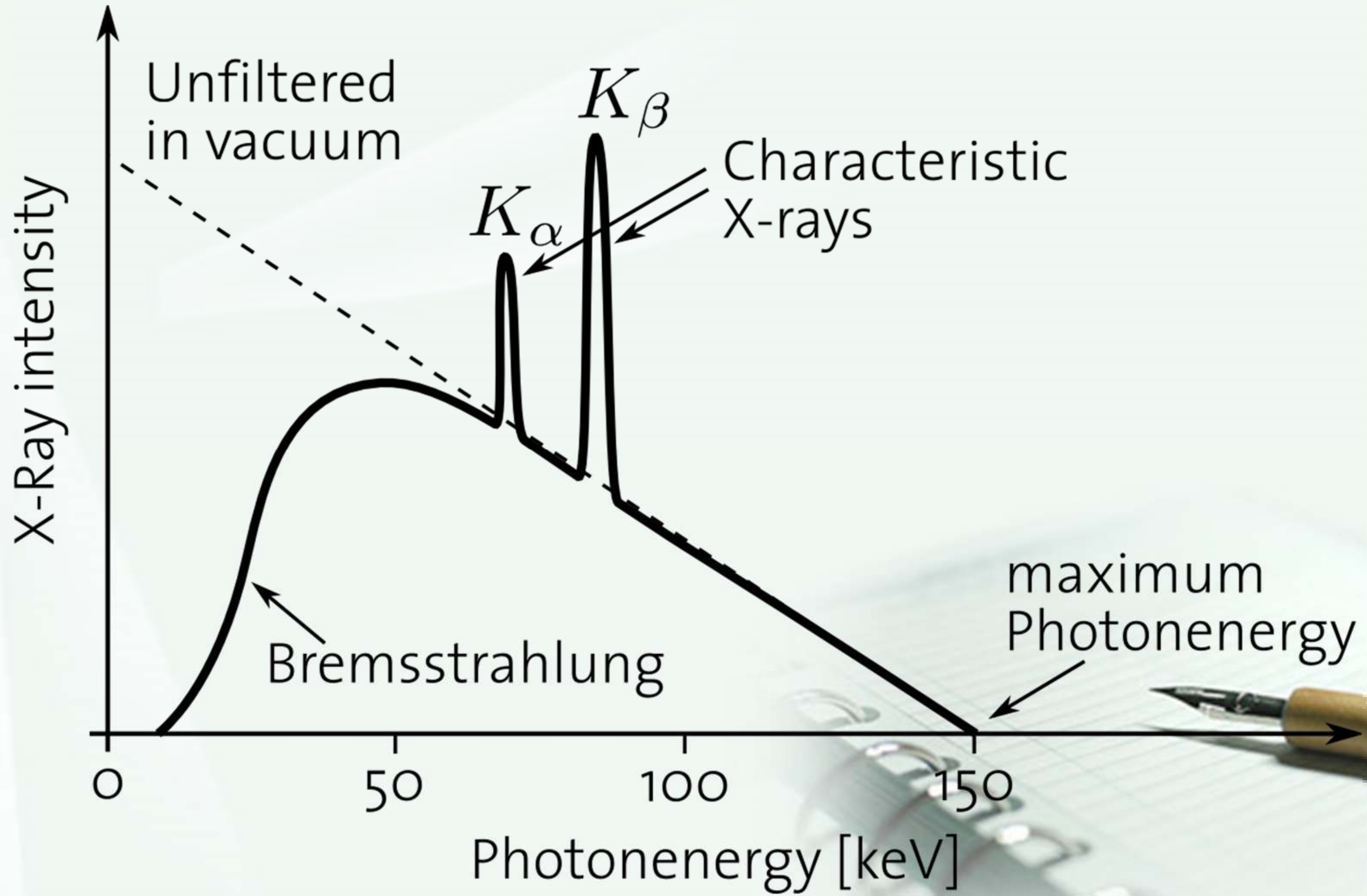
Characteristic and Continuous X-Ray Spectrum

Continuous X-Ray Spectrum (White or Braking Radiation)

- ✓ The process of producing continuous X-rays is called Bremsstrahlung (German equivalent of Braking Radiation).
- ✓ This process creates an X-ray background with a white (continuous) spectrum in the characteristic X-ray spectrum generated by the electron.

Characteristic and Continuous X-Ray Spectrum

A common spectrum that includes characteristic radiation and the white spectrum of X-rays.



Cathodoluminescence (Visible Light)

- If the electron is in an external orbit, the energy released is low and usually emits photons, which can be in the visible light range. This effect is called cathodoluminescence.

- Because the difference in energy released in this case is small, it is limited to the emission of visible light.

Transmission Electrons

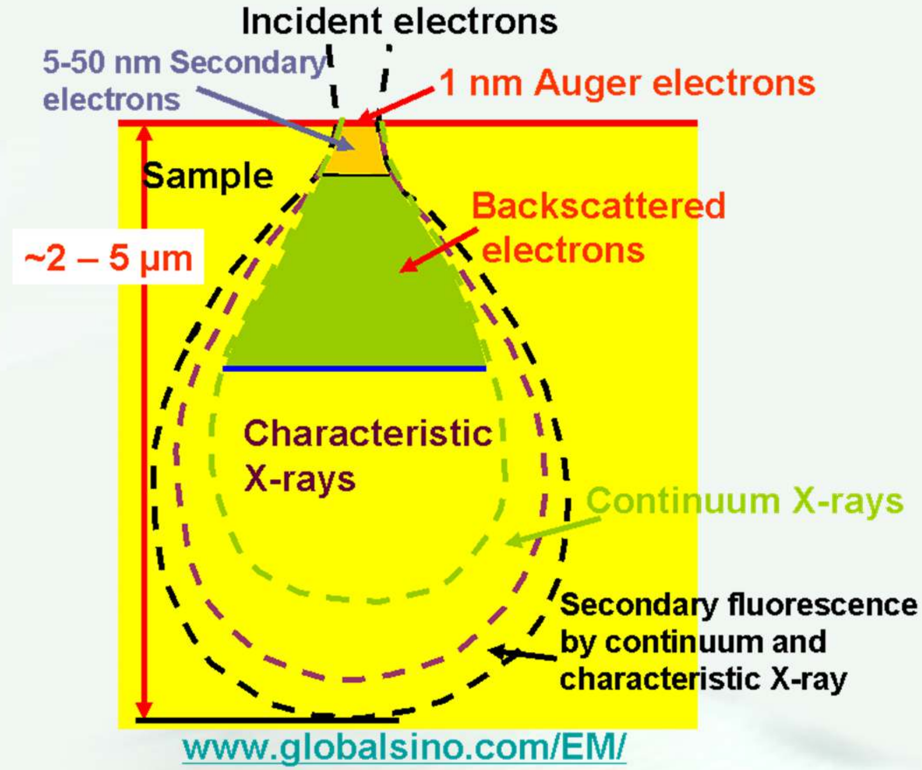
- ✓ Some of the electrons emitted to the sample pass through the interior of the material in the direction of the thickness of the sample. These electrons can be in the same direction of radiation or deflected.
- ✓ The smaller the sample thickness, the higher the probability and rate of electron beam transmission. This transmission beam is also used for microscopic and structural analysis of the materials.

Electric Currents and Heat

- ✓ Electric currents are generated on the surface due to the accumulation of beam electrons on the surface of the sample.
- ✓ When an electron beam strikes a sample, part of its energy is used to generate heat.

Diffraction Pear

The figure below shows the volume of the reaction and the areas where the secondary, back-scattered and Auger electrons c, and X-ray can be detected. Characteristic and continuous X-rays can produce X-ray, which is called secondary fluorescence, by the same mechanism of X-ray production by electrons.



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