S.O.S. IN ENVIRONMENTAL CHEMISTRY
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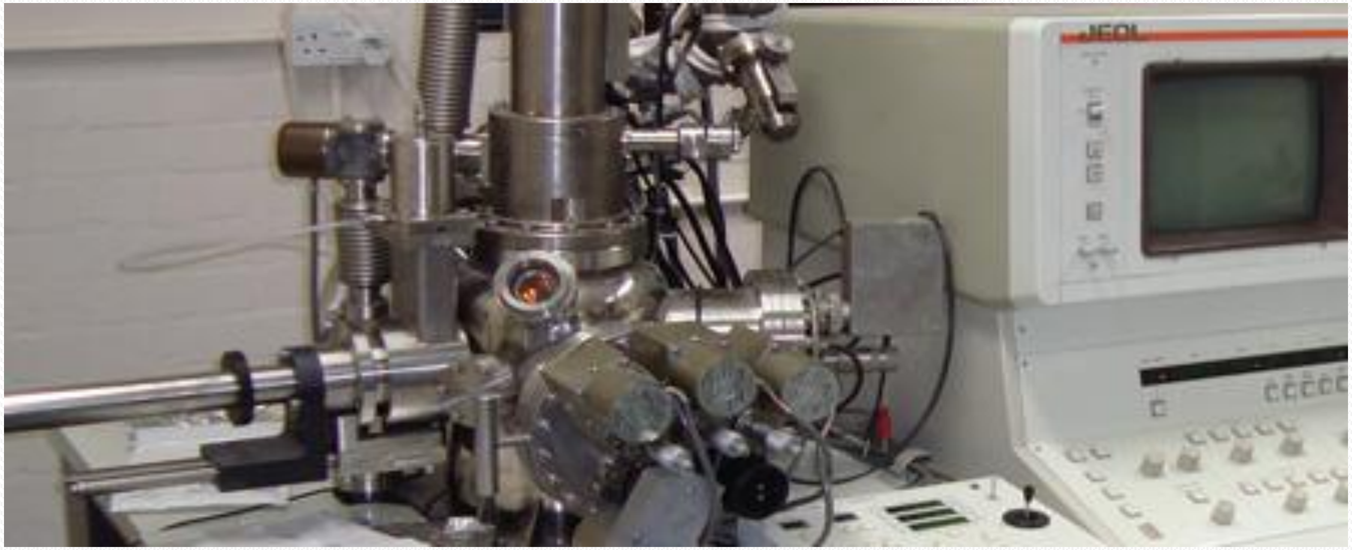
Auger Electron Spectroscopy



History

Auger Electron Spectroscopy (Auger spectroscopy or AES) was developed in the late 1960's, deriving its name from the effect first observed by Pierre Auger, a French Physicist, in the mid-1920's. It is a surface specific technique utilizing the emission of low energy electrons in the Auger process and is one of the most commonly employed surface analytical techniques for determining the composition of the surface layers of a sample.

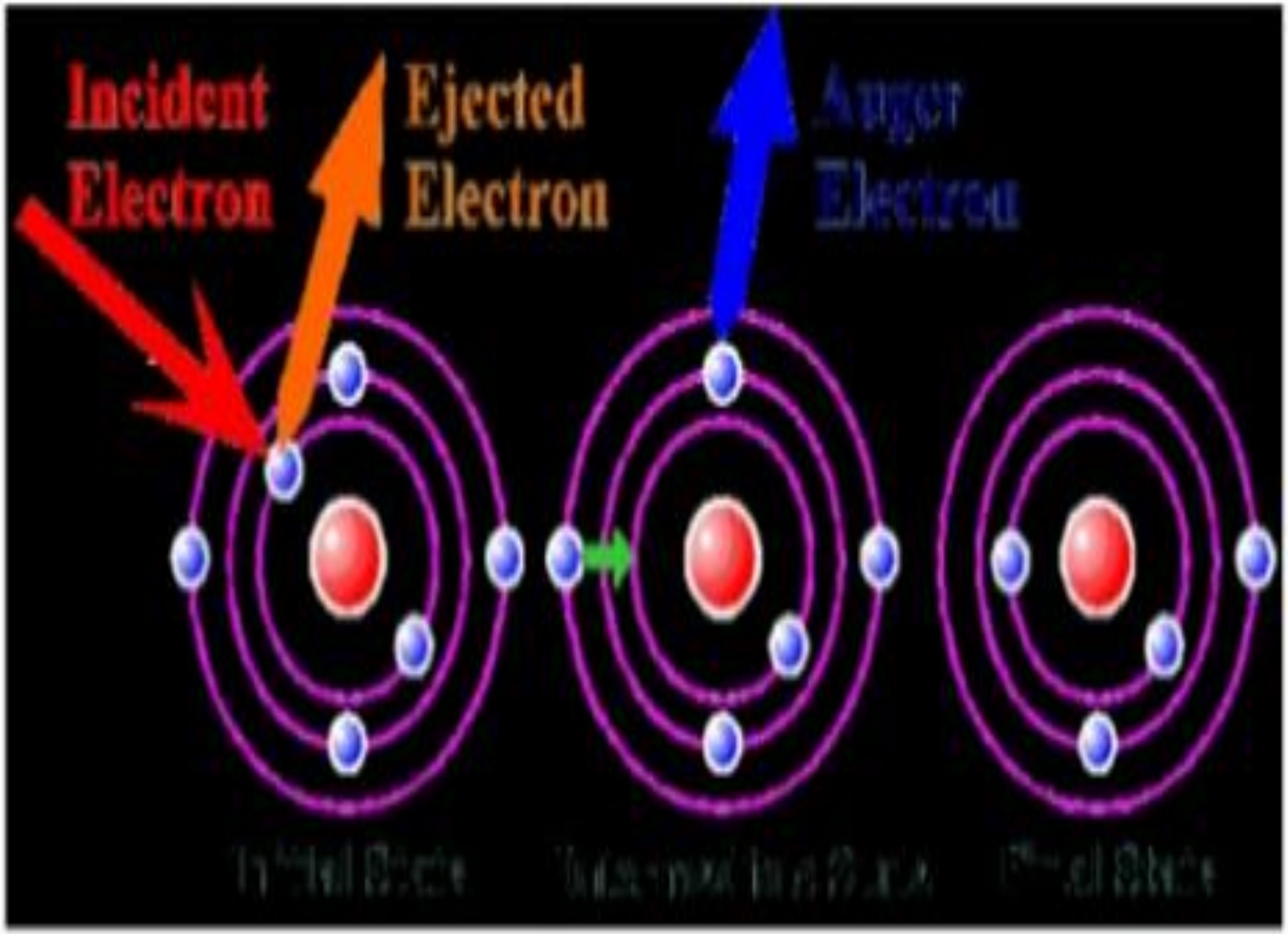
INTRODUCTION

Auger electron spectroscopy (AES) is a nondestructive core-level electron spectroscopy for semi-quantitative determination of the elemental composition of surfaces, thin films, and interfaces. The popularity of this ultrahigh vacuum technique may be attributed to high surface sensitivity (an analysis depth of less than 100 Å) and a relatively low detection limit (~0.1 atomic percent).

In addition to having an elemental coverage from lithium to uranium and beyond, AES has the ability to distinguish between two elements that are close to each other in the periodic table. In addition, AES has an atomic number-dependent sensitivity that varies at most by one order of magnitude.

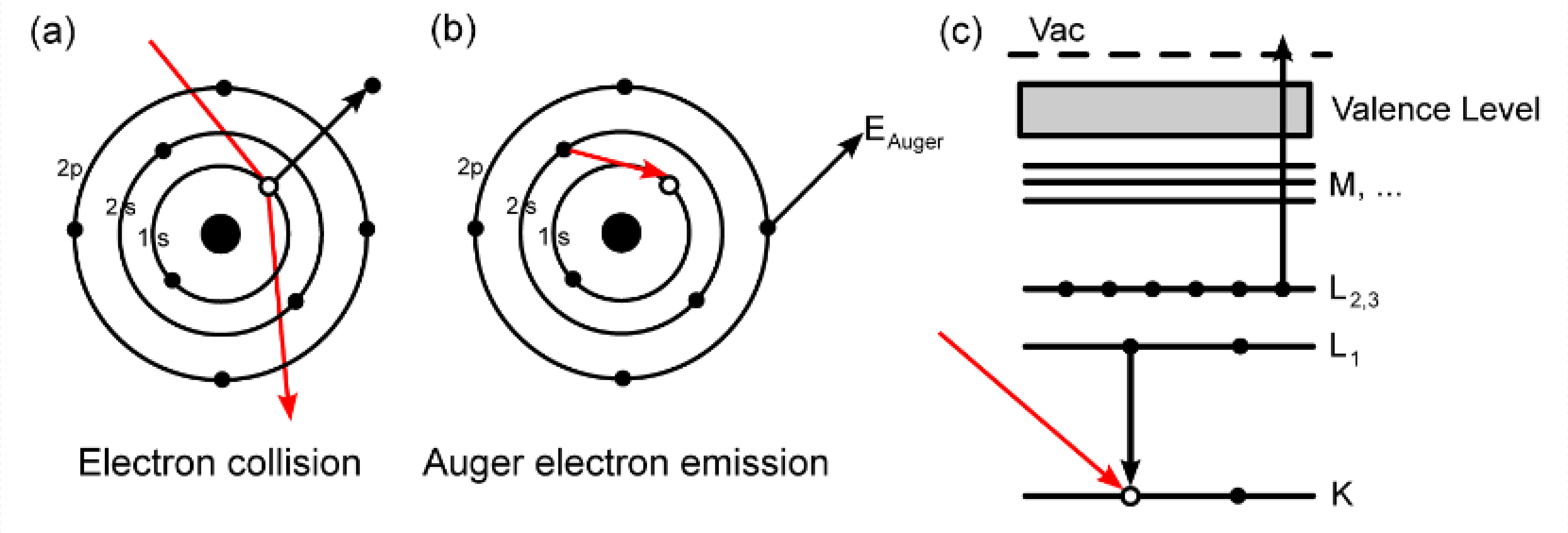
Principle of AES

- A fine focused electron beam bombards the sample and ejects an electron of the inner shell of the atom.
- This vacancy must be refilled by an electron from a higher energy level.
- When the higher energy electron fills the hole, the release of energy is transferred to an electron in an outer orbit electron.
- That electron has sufficient energy to overcome the binding energy and the work function to be ejected with a characteristic kinetic energy.
- The ejected electron is referred to as an Auger electron after Pierre Auger. • The Auger process require three electrons, thus we can not detect H and He but can detect all other elements from Li on up


Incident Electron
Ejected Electron
Auger Electron
Initial State
Final State

The Auger effect

The Auger effect describes the non-radiative emission of an electron after a core vacancy is filled. A schematic of the Auger process is shown in Figure



(a) An impinging high-energy electron collides with a core electron, leaving behind a vacancy. **(b)** The vacancy is filled by a higher-level electron. The energy released causes the emission of an Auger electron. **(c)** The energy of the Auger electron is defined by the difference between the initial transition and the original energy level of the Auger electron before emission.

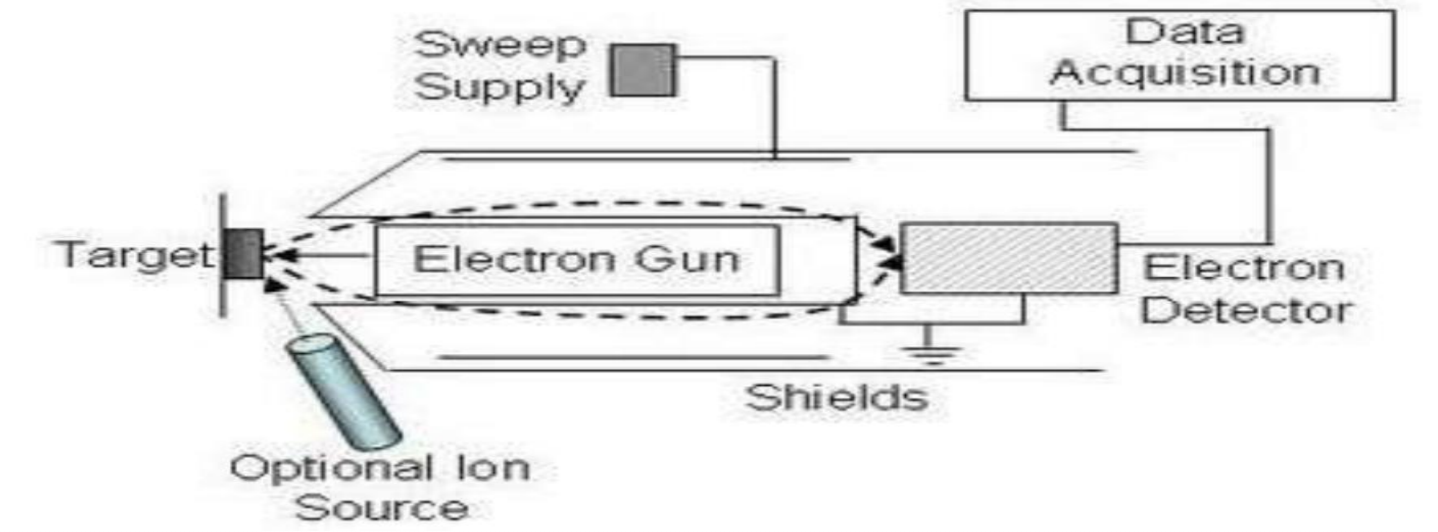
A high-energy electron (or photon) collides with an atom, causing the emission of a core electron (Figure a). The vacancy left behind is then filled by an outer-shell electron (Figure b). The energy released then stimulates the emission of an Auger electron, which can be detected and analysed. The kinetic energy of the Auger electron is the difference between the initial transition ($L_1 \rightarrow K$ in Figure c) and the Auger electron's ionisation energy ($L_{2,3}$). The Auger electron is defined by the spectroscopic notation of the energy levels involved in its emission ($KL_1L_{2,3}$ in Figure).

Instrumentation

The essential components of an AES spectrometer are

- UHV environment
- Electron gun
- Electron energy analyzer
- Electron detector
- Data recording, processing, and output system

- The sample is irradiated with electrons from an electron gun.
- The emitted secondary electrons are analyzed for energy by an electron spectrometer.
- The experiment is carried out in a UHV environment because the AES technique is surface sensitive due to the limited mean free path of electrons in the kinetic energy range of 20 to 2500 eV



UHV Environment

- UHV is the abbreviation of ultra high vacuum.
- UHV is required for the surface analysis for the following reasons.
  - To remove absorbed gases from the sample.
  - To eliminate absorption of contaminants on the sample.
  - To prevent arcing and high voltage breakdown.
  - To increase the mean free path for electrons, ions and photons.

Electron Gun

- The nature of the electron gun used for AES analysis mainly depends upon three factors:

--The speed of analysis (requires a high beam current).

--The desired spatial resolution.

--Beam-induced which changes to the sample surface.

- The lower current gives high spatial resolution whereas the higher current may be used to give speed and high sensitivity where spatial resolution is of little concern.
- In certain samples the high current used may induce surface damage to the specimen and should be avoided.
- The electron gun optical system has two critical components.

The electron source

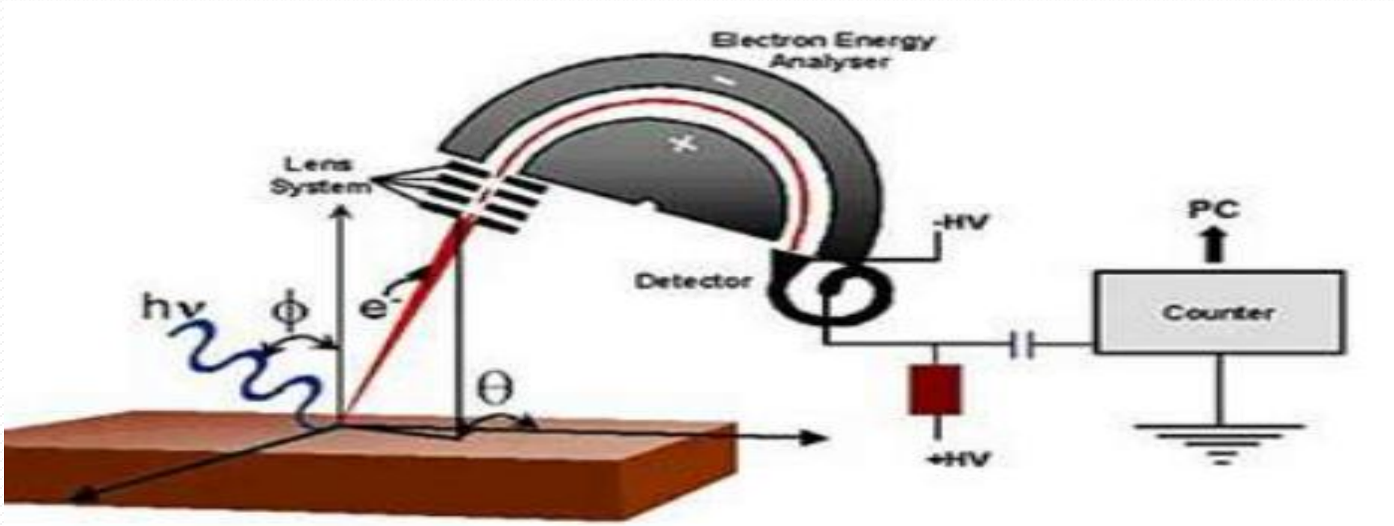
- In most cases the electron source is thermionic but for the highest spatial resolution the brighter field emission source may be used.
- The field emission sources have problems of cost and stability and are therefore limited in their use.

The focus forming lens

- The electron lenses used to focus the beam may be either magnetic or electrostatic.
- The magnetic lenses have low aberrations and therefore give the best performance.
- However, these lenses are complicated and expensive.
- The electrostatic lenses are easier to fit in a UHV system.

Electron Energy Analyzer

- The function of an electron energy analyzer is to disperse the secondary emitted electrons from the sample according to their energies.
- An analyzer may be either magnetic or electrostatic. Because electrons are influenced by stray magnetic fields (including the earth's magnetic field).
- It is essential to cancel these fields within the enclosed volume of the analyze.
- The stray magnetic field cancellation is accomplished by using metal shielding



Electron Detector

- Having passed through the analyzer, the secondary electrons of a particular energy are spatially separated from electrons of different energies.
- Various detectors are used to detect these electrons.

Single-Channel Detector (SCD)

- The detector used in conventional instrumentation is a channel electron multiplier.
- It is an electrostatic device that uses a continuous dynode surface which is a thin-film conductive layer on the inside of a tubular channel.
- It requires only two electrical connections to establish the conditions for electron multiplication.
- The output of this detector consists of a series of pulses that are fed into a pulse amplifier/ discriminator and then into a computer.
- The advantage of such a detector is that it can be exposed to air for a long time without damage.

- It counts electrons with a high efficiency.
- The only drawback is that a high count rate causes a saturation effect.

Multi-Channel Detector (MCD)

- A multiple detection system can be added at the output of the analyzer.
- The system may be in the form of a few multiple, parallel, equivalent detector chains or positionsensitive detectors spread across the whole of the analyzer output slit plane

Data Recording, Processing, and Output System

- The Auger electrons appear as peaks on a smooth background of secondary electrons.
- The background is usually sloping therefore, the Auger spectra are usually recorded in a differential form.
- In the differential mode it is easy to increase the system gain to reveal detailed structure not directly visible in the undifferentiated spectrum.
- At present, the data in commercial instruments are acquired digitally and can be presented in either analog or digital mode.

- A conventional Auger electron spectrometer uses a lock-in amplifier.
- The oscillator in this amplifier superimposes a sinusoidal modulation on the potential applied to the outer cylinder of the analyzer.
- The AC component of the signal is decoupled from the multiplier high voltage and detected in the lockin amplifier.
- The output is then fed to an x–y recorder
- The amplitude of the modulation is chosen to yield a compromise between sensitivity and resolution.
- A typical modern Auger electron spectrometer collects the data in the N(E) versus E integral mode.
- The data are then mathematically differentiated using computer software to yield Auger spectra.

Advantages

- Surface sensitive.
- Elemental and chemical composition analysis by comparison with standard samples of known composition.
- Detection of elements heavier than Li. Very good sensitivity for light elements.
- Depth profiling analysis: quantitative compositional information as a function of depth below the surface.
- Spatial distribution of the elements (SAM): Elemental or even chemical Auger maps analysis in lines, points and areas.