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Original Research

X-Ray Fluorescence (XRF): Interaction of X-Rays with a Substance, Multiple Transitions, Wavelength Dispersive, Fundamental Parameters Method and Multi-Point Analysis

Samar Basil Khudhur [1], Muslim Ahmed Abdulhasan [2], Mohammed Hasan Hadi [3], Zaid Noori Abbas [4], Kadhim Salam Jasim [5]

[1,2,3,5]Al-Israa University, Medical device technology engineering, Iraq
[4]Hilla University College, Medical device technology engineering, Iraq

Abstract

One method for analysing materials is X-ray fluorescence (XRF), which involves interacting X-rays with the substance in question to ascertain its constituent makeup. Powders, liquids, and solids can all be analysed using XRF, and the technique is often non-destructive. One reliable way to assess the chemical make-up of a material, both qualitatively and quantitatively, is by XRF spectroscopy. Two primary XRF techniques exist: energy dispersive XRF and wavelength dispersive XRF. Every approach has its own set of pros and cons. While the exact range of elements that can be detected by different instruments varies, EDXRF is usually capable of detecting elements from sodium (Na) to uranium (U) while WDXRF can detect elements down to beryllium (Be). The concentrations can be as high as 100% and as low as parts per million (ppm) and even lower. While individual elements and sample matrices determine detection limits, it is generally true that heavier elements will exhibit better limits. In analytical laboratories all over the globe, XRF is a popular quick characterization method for a wide range of materials and processes utilised in fields as varied as metallurgy, forensics, electronics, polymers, archaeology, geology, and mining. Minerals and trace elements found in human tissues serve as building blocks for big biological molecules or as catalysts in their catalytic reactions. Medicine and dental care also make use of a wide range of metallic and inorganic materials. For elemental analysis, it is common practice in the dentistry and medical industries to seek specimens that are either wet or have a poor heat resistance. Consequently, we need an elemental analysis approach that is both fast and non-destructive. X-ray fluorescence analysis (XRF) is a great way to get basic information about specimens without ruining them or making them more complicated to prepare

Keywords: X-Ray Fluorescence, Multiple Transitions, Wavelength Dispersive, Fundamental Parameters

Introduction

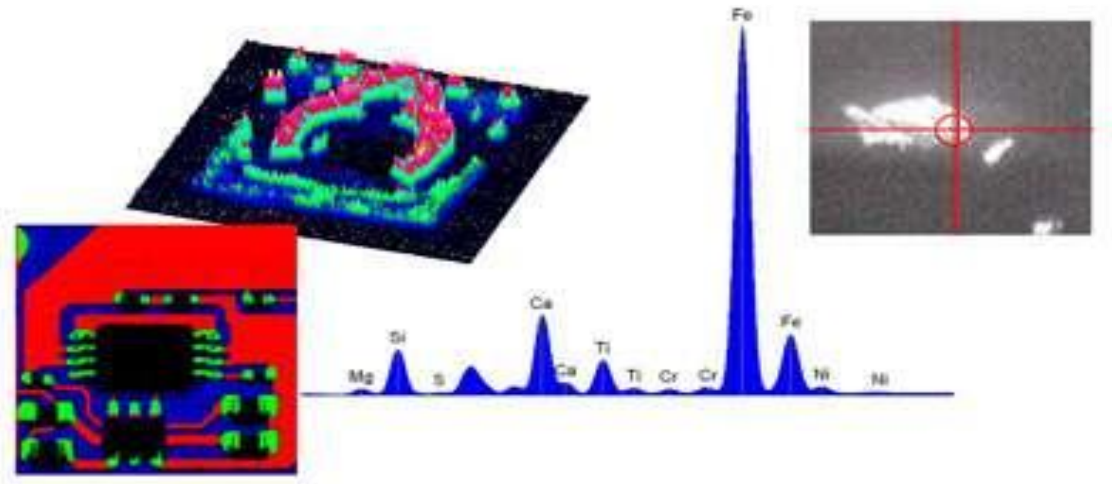
Minerals and trace elements have an important role in human tissues, either as catalysts or as building blocks of bigger biological compounds. Metabolic studies, for instance, could benefit from investigations on the distribution, concentration, and chemical condition of trace necessary elements. To add insult to injury, several foreign items can pierce the skin, airways, and stomach mucosa. Dietary and restorative materials, such as ions that have eroded or debris from metallic restorations, can come into contact with and expose the oral mucosa. Inhaled and trapped airborne debris also comes into touch with the respiratory mucosa. As these foreign particles can cause a variety of pathologies, it is crucial to analyse them in tissues in order to make a diagnosis. Biological, medicinal, and environmental samples are analysed for heavy elements using a variety of methodologies, and the results are presented in Table 1. The most common techniques for analysing trace elements are atomic absorption spectroscopy (AAS) and inductively coupled plasma atomic emission spectroscopy (ICP-AES, MS). Although these techniques necessitate a liquid specimen, their sensitivity is high (ppm—ppb). Consequently, it is necessary to dissolve solid specimens, such as biological and medicinal tissues, using methods such as acid treatment. Because the concentrations of the target elements are reduced during solubilization, it becomes increasingly difficult to detect trace elements. Furthermore, when trace metals are dissolved, all information regarding their distribution and chemical state is lost. Element analysis should also be done in a non-destructive way because biomedical specimens are scarce and limited in quantity. There are a number of standard methods for analysing elemental information, including energy-dispersed spectroscopy (EDS) and microanalysis with an electron probe microanalysis (EPMA). Through the use of distinctive X-rays generated by the studied region, these techniques offer microscopic imaging in addition to elemental information. Figure 1 demonstrates the process that produces distinctive X-rays. An atom's bonded electron is hit by a barrage of high-energy X-rays and electrons. Following its ejection, an electron from the outer shell descends into the empty inner shell, where it produces a distinctive X-ray with an energy level proportional to the energy gap between the two shells. The term "fluorescent X-ray" describes the radiation that is characteristic of X-rays produced by high-energy X-ray irradiation. Because electrons in different elements have different energy levels, the X-ray energies that they release are also distinct. The typical X-ray energy released by different elements are illustrated in Table 2 [1]. Element analysis using electron or X-ray irradiation can be accomplished with characteristic X-rays.

The term "X-ray fluorescence analysis" (XRF) refers to the process of analysing samples by use of X-rays that have certain properties and are produced as a result of high-energy X-ray photolysis. Here are a few ways in which XRF excels above EPMA and EDS. (1) Fluorescence and X-ray exposure The air is a good medium for X-ray detection since X-rays are easily transported through it. As a result, unlike electron microscopy, XRF analysis does not necessitate removing the specimen from the chamber. It is quite rare for specimens to be damaged by X-ray irradiation. (3) No specimens are needed. As a result, fixing, dehydrating, or electroconductive covering the specimen is unnecessary. (4) A portion of the X-rays that are irradiated can pass through the specimen, allowing for the simultaneous acquisition of an X-ray transmission image. For elemental analysis, it is common practice to seek specimens that are either wet or have a low heat resistance while doing dental and medical analyses. Furthermore, non-destructive analysis of rare pathology specimens is essential. For these kind of specimens, XRF is a great tool. Traditional XRF beams onto the specimen a broad, unfocused beam of radiation. As a result, the analysis necessitated a vast specimen surface. The development of a micro-focused X-ray source in recent years has made possible the study of micro-samples and the distribution of elements. Material transparency with a refractive index higher than 1 is what makes up visible light optics. On the other hand, X-rays necessitate specialised optics due to the fact that most materials have a refractive index close to 1. The XRF focusing optics commonly employ capillary focusing. The capillary's inner surface is shaped like a paraboloid of revolution, and the X-ray is directed to the focus by total reflection from this surface. Images of the elemental distribution can also be obtained by using XRF analysis during specimen scanning. The focus size determines the spatial resolution, which ranges from 10 to

100 metres. A scintillation detector placed behind the specimen can also measure the transmission X-ray intensity; thereafter, a high-resolution X-ray transmission picture can be produced simultaneously with the scanning of the specimen.

The use of synchrotron radiation in X-ray fluorescence imaging (SR-XRF)

The X-rays and other electromagnetic waves produced by synchrotron radiation (SR) are very intense. SR also produces visible, infrared, and ultraviolet light. Its intensity is many orders of magnitude greater than that of X-ray sources used in laboratories. Monochromatized X-rays can be used as incident X-rays in XRF with the help of SR X-rays. Continuous X-ray irradiation produces an XRF spectrum. Thus, the background obscured the specimens' weak characteristic X-rays, making routine XRF trace element analysis challenging. That is in contrast to the XRF spectrum of a monochromatized X-ray. The ability to concentrate SR X-rays into diameters ranging from millimetres to nanometers has recently made it possible to analyse trace element distributions on the cellular or intracellular levels. Copper builds up in tissues, causing neurological or mental symptoms as well as liver illness in Wilson disease. Therefore, it is important to estimate copper concentrations in tissues (liver) early on as early diagnosis and therapy dictate the subsequent convalescence. In order to diagnose Wilson disease, Matsuura et al. used SR-XRF. Visualising the distribution of copper in liver tissue allowed for the extraction of useful information on copper concentrations in the liver, which could be used for treatment planning purposes [20].



What is X-rays?

X-rays are a type of electromagnetic radiation with energies between those of gamma and ultraviolet (Figure 1). Typical wavelengths are between 0.01 and 10 nm, or 125 keV to 0.125 keV in energy terms.

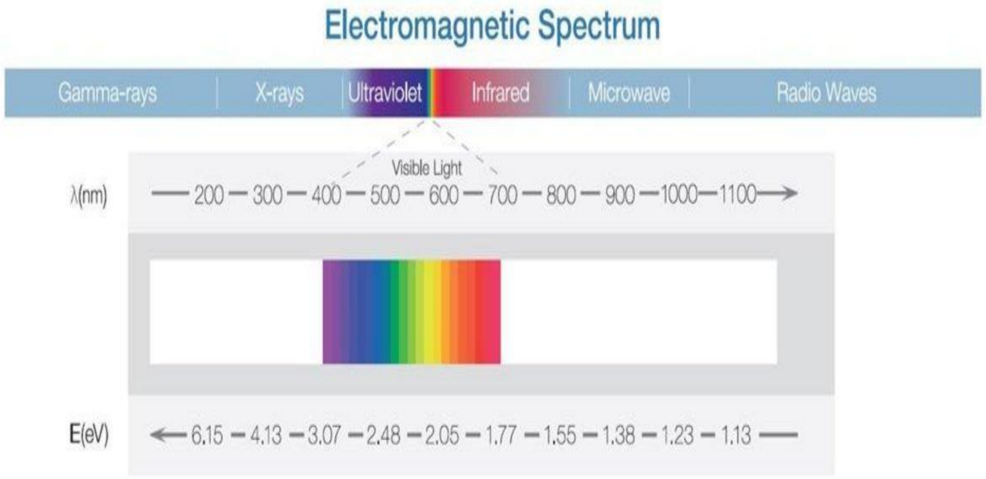


Figure 1. Electromagnetic Spectrum

X-Ray Interaction with a Material

Some of the X-rays irradiated to a material will go through it unabsorbed, while others will be absorbed. Figure 2 shows the numerous processes caused by the absorbed X-rays, which interact with the substance at the atomic level and release photons, electrons, and fluorescence X-rays, among others.

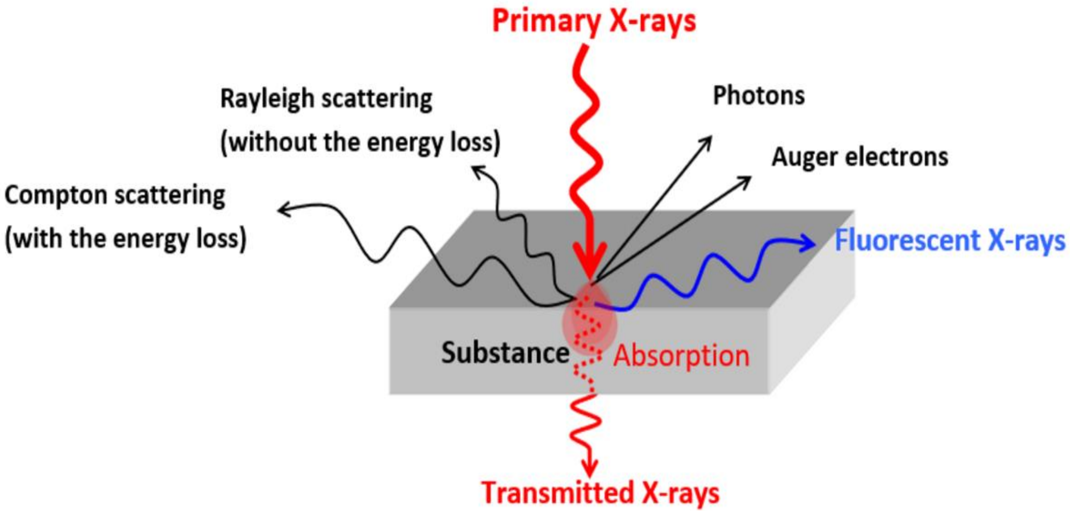


Figure 2. Interaction of X-rays with a substance

The Basic Process

medical imaging There is a straightforward three-step process that takes place at the atomic level that is known as fluorescence (XRF):

- One of the electrons in an atom's orbital around the nucleus is knocked out by primary X-rays.

The atom enters a highly energetic and unstable form as a result of the creation of an orbital hole. To get things back to normal, an electron in the outer, higher-energy orbit slips into the hole. Fluorescent X-rays are released as a result of the extra energy due to the lower energy position. The energy of the emitted fluorescent X-ray is directly related to the element being studied since it is a feature of the element atom in which the fluorescence process is occurring—the energy difference between the expelled and replacement electrons. Because of this crucial aspect, XRF is a very quick analytical instrument for elemental composition. The chemistry of a substance has little bearing on the energy of the X-rays released by a given element. A calcium peak, for instance, will have identical spectral positioning for CaCO3, CaO, and CaCl2.

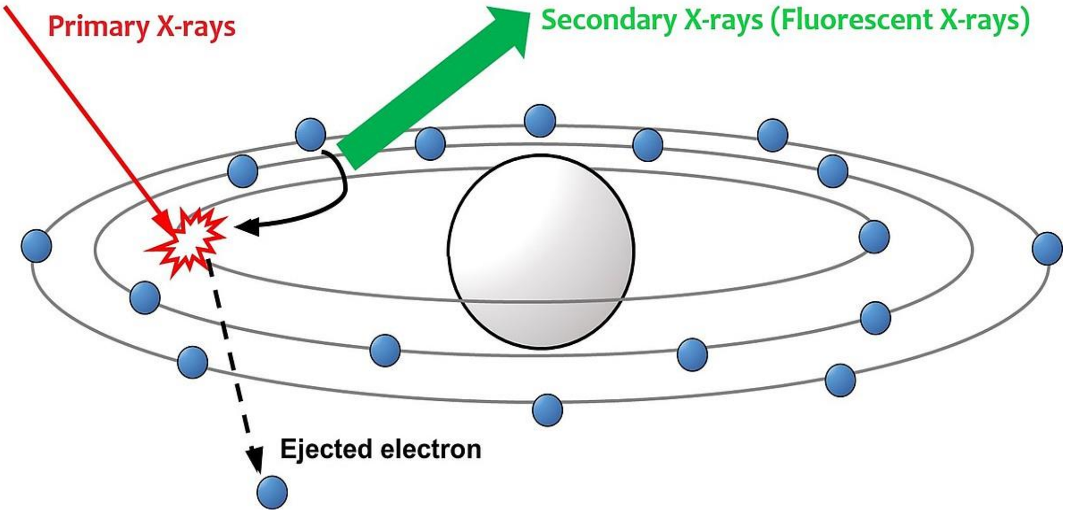


Figure 3. Principle of Fluorescent X-rays Emission

Different Shifts

Numerous fluorescence transitions are feasible due to the fact that the majority of atoms include multiple electron orbitals, such as the K, L, and M shells. For instance, when X-rays interact with an atom that possesses K, L, and M shells, it is possible for a K shell hole to be created, which is subsequently filled by an electron from either the L or M shells. These are known as K transitions in either scenario. On the other hand, a L transition could occur when an electron from the M shell enters the L shell through a hole that has already been produced. Therefore, it is feasible for a single element to have many XRF peaks, and it is common for all of these peaks to be seen in the spectrum, but at different strengths. For each given element, they create a unique fingerprint.

Max Power

The energy of X-rays determines how much of them a certain substance can absorb. Light with lower energy levels is generally more readily absorbed than light with higher energy levels. While it is necessary for the X-ray energy to surpass the binding energy of an electron in order to remove it from an orbital, an excessively high X-ray energy causes poor coupling between the X-ray and electron, leading to the expulsion of just a small number of electrons. The productivity of released electrons grows in relation to the X-ray energy, which decreases as it gets closer to the electron binding energy. The absorption decreases just below the binding energy because the energy is too high to emit electrons from the lower energy shells and not enough to emit electrons from that shell. Not all incident X-rays produce fluorescence, as mentioned above. In X-ray imaging, the fluorescence yield is defined as the ratio of incident X-rays to fluorescence X-rays. The following figure shows the relationship between the atomic number (Z) and the fluorescence yields of K and L. The attainable sensitivity for the light elements reflects the poor yield for these components, which is obvious.

Energy Dispersive X-Ray Fluorescence (EDXRF) is a method that uses a variety of X-rays generated by a material to determine their relative intensities. An XRF spectrum is created by quantifying and visualising the relative abundance of X-rays at each energy level. Energy dispersive (ED) detectors, like the HORIBA XerophyTM, work by trapping electrons and holes in a semiconductor material, most commonly silicon. The detector material absorbs an incident X-ray of energy EX, which causes the formation of one or more pairs of electrons and holes. This process requires a constant amount of energy, EEHP, for that specific material. The number of electron-hole pairs can be calculated by dividing the energy of the X-ray by the energy of the hydrogen atoms in a vacuum. After this happens, the detector removes the electrons, and the current that flows out is directly proportional to the X-ray energy, which is a function of the number of electron-hole pairs. Fast iteration of this analysis followed by sorting of data into energy channels.

Wide-Dimensional X-Ray Fluorescence (WDXRF)

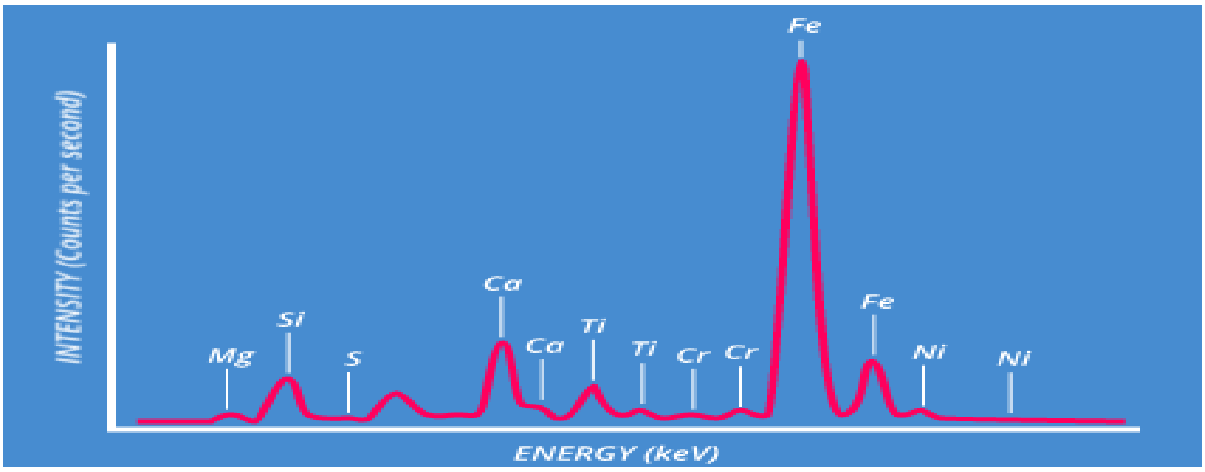
To physically separate the X-rays based on their wavelengths, a wavelength dispersive detecting device is used. The X-rays are focused on a crystal, which causes them to diffract in various directions based on their energy and wavelengths. By rotating the crystal, different wavelengths can be detected by a fixed-position detector on a sequential system. Each every point contributes to the XRF spectrum. Multiple crystal/detector units work together in a simultaneous system to allow for the simultaneous detection of many elements. In terms of energy (spectral) resolution, ED and WDXRF methods differ significantly. The operating resolutions of WDXRF systems can be anywhere from 5 eV to 20 eV, depending on their configuration, whereas the resolutions of EDXRF systems can range from 150 eV to 300 eV or even higher, depending on the detector type. Reduced spectrum overlaps are an advantage of WDXRF's better resolution, which allows for more precise characterization of complicated materials. Additionally, the detection limits and sensitivity are improved with high resolution since backgrounds are minimised. A WDXRF system's efficiency is significantly lower than that of a conventional XRF setup because of the extra optical components. In most cases, this is made up for using highly concentrated X-ray sources, which can greatly affect the price and usability. A relatively pricey device, WDXRF is impacted by the additional optical components that contribute to its overall cost.

Finally, spectral acquisition is where the differences end. Element detection over the majority of the periodic table is possible in a matter of seconds using an EDXRF device like the XGT series, which acquires the whole spectrum almost simultaneously. Spectrum acquisition with WDXRF is either exceedingly time-consuming and done point-by-point or has a very restricted number of simultaneous detectors and is expensive.

How XRF Works in Theory

In-Depth Evaluation

Rapid qualitative elemental analysis is a strong suit of XRF, and especially EDXRF. Spectra of high quality can usually be acquired in a matter of seconds or minutes, and the detection of elements ranging from sodium to uranium can usually be done concurrently. Since the peaks of each element in an XRF spectrum occur at a known, fixed location, band assignment is typically straightforward. However, overlapping bands can lead to confusion, however peak labelling software nowadays accounts for this. Rayleigh and Compton scattered characteristic lines from the X-ray generator, X-ray diffraction peaks, sum/escape peaks, and other artefact peaks may also be visible in the spectrum. To prevent misinterpretation of outcomes, knowledge of these is essential. While the exact lower limit varies with each instrument configuration, XRF is typically able to detect concentrations ranging from 100% down to sub-ppm.



Statistical Evaluation

XRF is a quantitative method; the height of an element's peak is proportional to the element's concentration in the sample. But be careful, because it only takes a couple of factors to interact for the results to be distorted. To illustrate the point, the presence of chlorine significantly weakens the expected intensity of the lead signal at a given concentration because chlorine atoms absorb fluorescent X-rays (Ka) from lead. There are two primary approaches to quantitative analysis, and most instrument software will have them both implemented.

Method for Fundamental Parameters (FPM)

To determine element concentrations from observed peak intensities, a suite of software algorithms is employed. These methods take into account theoretical X-ray beam intensity, detector solid angle, matrix effects (element-element interactions), band overlap, and spectral backgrounds.... For a wide range of matrices and experimental parameters (such as voltage, current, beam size, etc.), FPM offers a quick and reliable quantification approach.

Harmonisation using Reference Values

Calibration curves (XRF peak intensity vs concentration) are generated using calibration standards that have precisely known element concentrations. From the spectra that have been measured, concentrations can be determined by referring to these graphs. If you want the most precise results, this is the way to go. Calibration standards are only useful for samples that have very similar matrices, since matrix effects are not considered. For instance, when examining mineralogical materials, a calibration curve made with a collection of metal alloys is likely to produce erroneous results.

Depths of Penetration

It is well-known that X-rays can permeate materials to a certain extent. How deep into the sample does the spectrum emerge is a crucial question for XRF analysis. Given the complexity of the issue, it is not an easy question to answer. First, the primary X-ray beam's penetration depth into the material, and second, the escape depth from which fluorescent X-rays can be detected, are the two most important factors to think about. Both of these are proportional to the X-rays' energy; more powerful X-rays can penetrate deeper materials. It is reasonable to expect that X-rays will be able to pass through samples with a matrix ranging from a few micrometres to several millimetres in thickness. It is possible to detect fluorescent X-rays down to a few micrometres in many cases, but at most they will be observable from a few millimetres into the material.

Primary X-ray Penetration

There are two aspects to the main X-rays that are affected by the X-ray generator's voltage setting. To begin, the anode target material's signature X-rays have a constant energy. In order to expose the sample to both high- and low-energy X-rays, the generator voltage needs to be high enough to excite multiple lines, such as K and L. For most cases, the K lines will be the most prominent while thinking about penetration because of how intense they are. However, the anticipated penetration will be much diminished if the voltage is decreased to a point where the higher energy X-rays are no longer excited, leaving only low energy L lines as the distinctive X-rays.

As a second point, continuum X-rays, also known as bremsstrahlung, need to be thought about. These X-rays, as their name implies, have an energy spectrum that is continuous up to a maximum that is equal to the generator's accelerating voltage. At higher energy cutoffs, the continuum spectra are at their strongest; decreasing the voltage lowers the continuum's "average energy" and, by extension, penetration.

Evasion of X-Rays using Fluorescence

Once again, the energy of the fluorescent X-rays is closely related to the elements being detected, and how well they can pass through and out of the sample is another important consideration. Because of their low energy X-rays, the lighter elements (such as Na, Mg, Al, and Si) will be hard to detect even at extremely tiny depths within the sample. Because of their higher energy, X-rays from heavier elements (including Cu, Ag, and Au) can travel greater lengths within the sample. The sample's makeup is obviously a major consideration as well. A lower probability of X-rays escaping from deep inside the sample is associated with a higher concentration of heavier elements, which absorb heavily. In conclusion, given a sample matrix mostly made up of light elements (i.e., low absorption), heavy elements (i.e., energetic fluorescence X-rays) will be detected quite deep within. A sample matrix made up of heavy elements will only allow the detection of light elements (such as low energy fluorescence X-rays) at their surface (high absorption).

Comparison of Single-Point and Multi-Point Methods

In order to precisely place the sample beneath the X-ray beam, a high-precision motorised sample stage is a common component of micro-XRF instruments like the XGT systems. The operator is able to see the sample thanks to colour video cameras. The software on most instruments will allow for quick sample positioning by coordinating the movement of the sample with the images captured by the camera. You can manually align the sample to analyse features separately, or you can save a list of places to analyse in the software. The motorised stage will go to each position in turn, acquiring a spectrum at each, when all of them have been picked and the measurement conditions have been chosen.

This allows for the easy automated analysis of many visual aspects across the sample, or even the sequential analysis of numerous samples put out on the sample stage. So, the operator of the instrument can focus on other tasks while the tedious task of repeat measurements is taken care of automatically.

Crucial Parts of XRF

What is an Energy Dispersive X-ray Fluorescence Analyzer (EDXRF)? The following are the main parts of an EDXRF analyzer, and the picture below is a schematic of a simple benchtop model.

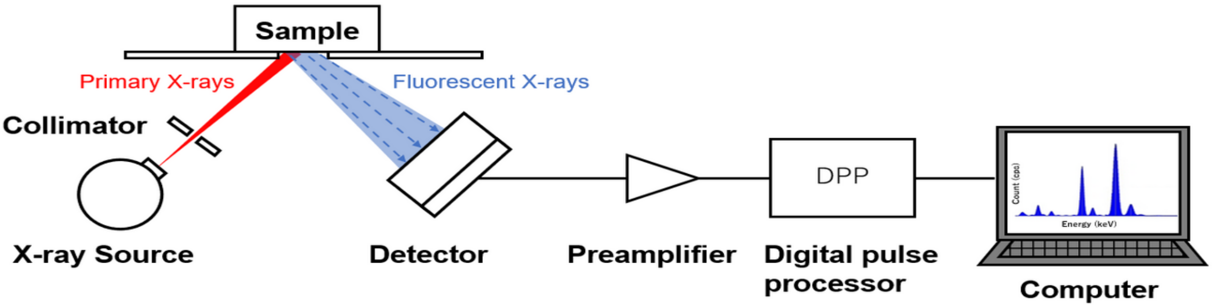


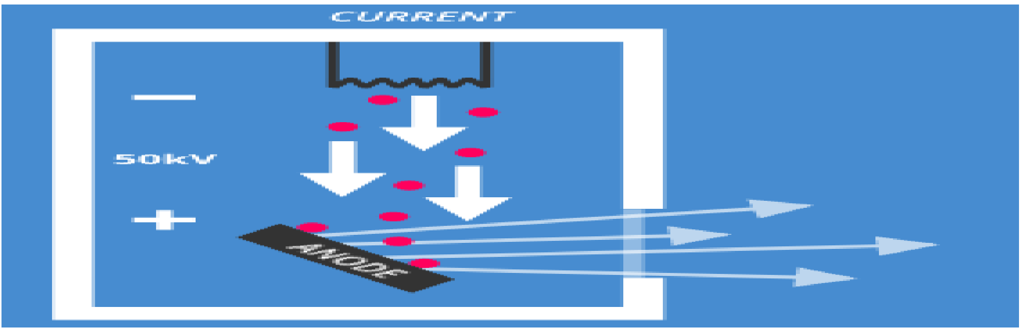
Figure. Schematic diagram of a basic benchtop EDXRF analyzer

- X-ray generator as X-ray source
- X-ray beam optics to control the spot size
- Sample stage
- Detector
- Preamplifier and Digital Pulse Processor to process fluorescent X-ray signals
- Computer

The Fundamentals of an X-Ray Generator

An in situ X-ray generator or, less often, a radioisotope material can supply the X-rays needed by all XRF spectrometers. In a standard X-ray generator, electrons are produced by running an electric current through a filament. Next, a high voltage, typically between 20 and 100 kilovolts, is used to accelerate these electrons towards an anode, or target. A wide X-ray continuum is produced because the electrons slow down as they contact the anode. Bremsstrahlung is the German word for this type of radiation. Furthermore, the anode material will exhibit characteristic X-ray fluorescence due to a fraction of the electrons. So, the X-rays emitted by a source will include both the diffuse and weak bremsstrahlung and the distinct and highly intense fluorescence lines of the substance of interest.

The X-rays are directed onto the sample through a thin beryllium window that is utilised to exit the generator.



X-ray Generator — Target, Current and Voltage

The target material, filament current and accelerating voltage all have significant effect on the final output of an X-ray generator.

Anode (target)

Generators with different target materials (e.g., Mo, Rh, W) are available, but they cannot be switched inside a single unit. The target material is a fixed component of the generator. An important component of the generator's output is created by the distinctive X-ray Luminescence of the intended substance. Increased output at a fixed voltage/current can be achieved by employing target materials with a higher atomic mass, as the fluorescence yield grows as atomic mass increases. Also, different materials will have varying fluorescence line energy, so using different target materials can make some elements in the sample more or less efficiently excited.

Current

How many electrons are blasted at the substance of interest is controlled by the filament current. Consequently, the X-ray output intensity for bremsstrahlung and characteristic radiation is directly affected by the current.

Voltage

Because the radiation's energy can't go beyond the voltage that's been applied, bremsstrahlung radiation shows a high energy cut off. Altering this voltage allows one to change the bremsstrahlung cut off as well as the overall continuum profile. The anode material's signature radiation can only be produced when the accelerating voltage (and, by extension, the energy of the impinging electrons) is higher than the material's absorption edge. Accordingly, the characteristic line(s) will vanish as soon as the voltage drops below the absorption edge.

Validation in Experiment

Despite the availability of generators made from a variety of materials, the user usually has little say over the target material utilised in the device. On the other hand, XRF experiments rely on the current and voltage in the tubes. Optimising the signal level at the detector is the primary goal of adjusting the current, which affects the intensity of X-rays emitted from the generator. The spectral profile of the generator's output is significantly impacted by the voltage. At low voltages (e.g., 15 kV or less), the typical fluorescence will be limited to the low energy L (and M) lines, and the bremsstrahlung will be centred at relatively low energies. The characteristic fluorescence will incorporate the high energy K lines of the target material and the bremsstrahlung will be more intense and centred at higher energies at high voltages (e.g., 40kV or above). When the energy of the incident X-ray beam is near the absorption edge of the element or elements in the sample, the XRF becomes very efficient. So, you can tweak the sample's fluorescence efficiency to a certain extent by changing the generator voltage. The amount of energy that an X-ray beam can carry has a significant impact on how deeply it can penetrate a substance. Penetration decreases as energy decreases. Changing the generator voltage allows one to manipulate the incident X-ray beam penetration and, by extension, the sampling depth.

Lasers for X-Rays

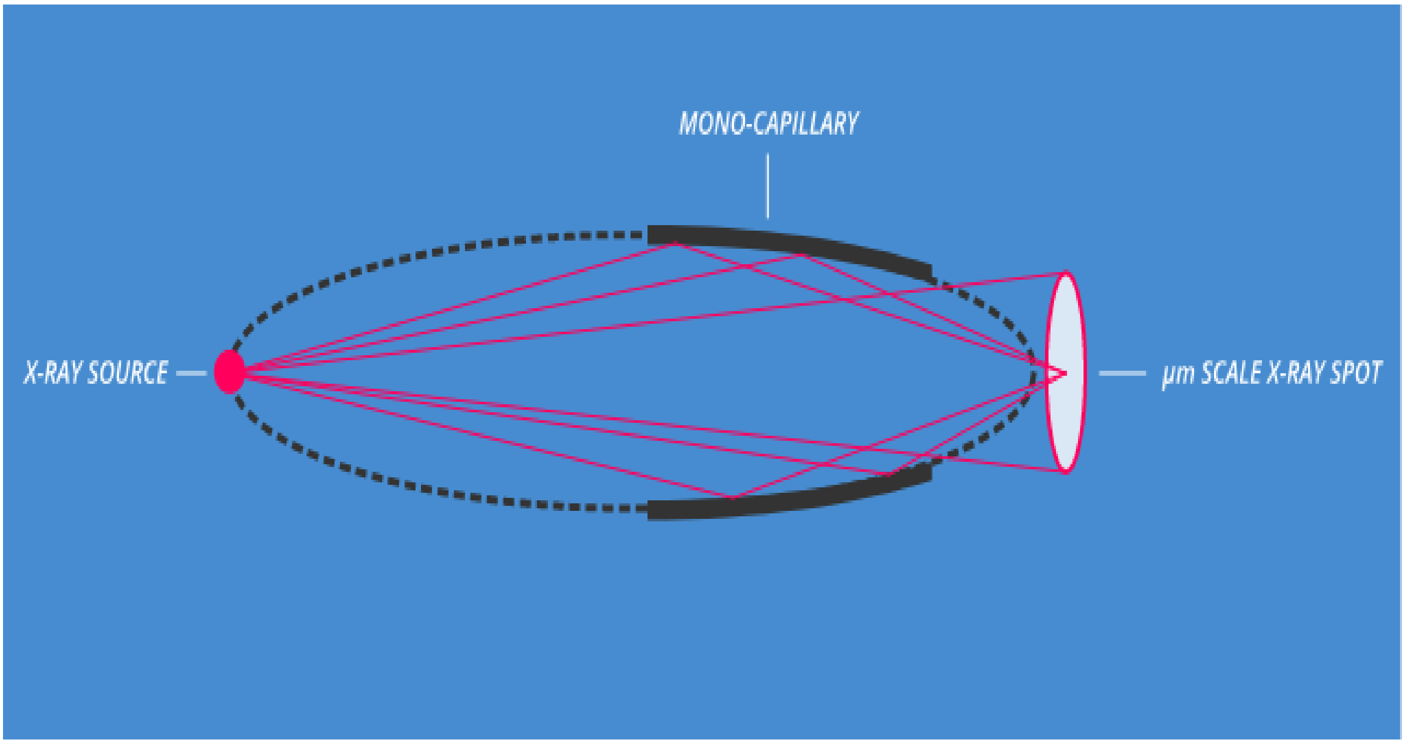
Muradin Kumakhov, a Russian scientist, put up the idea of using smooth solid surfaces to create, manipulate, and direct X-ray beams in 1984. This was done through the process of total external reflection. This resulted in the creation of several X-ray optics that can efficiently transport X-ray beams and shape them into parallel and focussed beams. An powerful and focused X-ray beam is required by a micro-XRF spectrometer. The two primary approaches will be covered in greater depth in the coming pages, although they are briefly reviewed below.

Collimators for light beams

A tiny hole, typically between a few millimetres and several hundred micrometres in diameter, is used to channel the X-rays produced by the generator. Even though collimators make it easy to create narrow X-ray beams, their intensity may decrease as the beam diameter gets smaller. The majority of the main X-rays are absorbed by the material surrounding the aperture when a relatively big X-ray beam is sent through a small aperture. X-rays can only enter the system through the aperture, producing a beam that is almost as wide as the aperture.

The percentage of X-rays that are blocked, however, grows substantially as the aperture is shrunk. Because of this issue, beams produced in this way with diameters less than 500 µm have a low intensity, while beams with diameters less than 100 µm are not usable. Today, synchrotron sources with very high beamline intensities do not experience intensity losses when using collimators for high spatial resolution analysis (beam diameters < 20 µm). Collimators are not utilised for ultra-high spatial resolutions on benchtop systems that use less intense X-ray sources.

Mono-Capillary Optics



The fact that X-rays are effectively reflected off of glass surfaces at low angles of incidence was found by Kumakhov. Total external reflection can be utilised to focus, collide, and guide X-ray photons through the production of precisely shaped glass optics.

Coupling between the X-ray source and the capillary is efficient because of the comparatively large solid angle between the two. Due to the fact that reflection is highly efficient, capillaries can be utilised to produce micro-beams of great intensity with diameters as tiny as 10 µm. This allows for extremely intense X-rays to be directed into the capillary. One example of a mono-capillary device that has been successfully used is the HORIBA X-ray guide tube (XGT). It is unusual in that it allows for a spatial resolution of 10 µm on a bench top. Beams produced by mono-capillary glass optics are perfectly suited for micro-XRF examination due to their intensity and nearly flawless collimation.

Multi-Plasma Photonics

Kumakhov also demonstrated the idea of poly-capillary optics, which is a combination of capillary optics. This type of optic is often called a Kumakhov lens since it produces intense beams that are also very focused. Containing dots with widths as small as 40 to 50 µm is certainly achieveable. It is not desirable to employ focused beams for spatially resolved XRF investigation. Although X-rays generate small spot sizes at the focus point, out-of-focus beams generate fluorescent X-rays from far broader analysis regions due to the X-rays' penetration into the material, which can range from several micrometres to several millimetres, depending on the specific sample. Furthermore, micro-XRF imaging of rough samples is challenging because of the concentrated beam's characteristic: small spot sizes are advantageous for in-focus areas, but parts exhibiting a height difference will become blurry as a result of significantly larger out-of-focus spot sizes.

Detectors for X-rays

Energy dispersive X-ray spectroscopy can be performed using a variety of detectors. We can classify them into three broad categories:

Permanent Magnet Semiconductor

The chips used in these are typically made of silicon or germanium. The X-rays hit a tiny beryllium window, which causes the semiconductor area of the detector to form electron-hole pairs. The energy of the entering X-ray determines the quantity of electron-hole pairs that are produced. There are more electron-hole pairs when the X-ray energy is higher. In this setup, a high voltage is used to attract the electrons to the detector's rear, where they are recorded as a negative pulse. A multi-channel analyzer (MCA) subsequently counts and sorts these pulses according to size, which is measured in X-ray energy. Typically, solid state detectors are chilled using liquid nitrogen to achieve an appropriate energy resolution, which is around 165 eV.

When it comes to semiconductors, cooling is often crucial for accurate dopant dispersion; conversely, warmth can severely harm the detector. But new high purity detectors (like HORIBA's XerophyTM) eliminate these worries and let you cycle the temperature of the detectors as needed; cooling is only needed when detecting.

Separators for Silicon Drift (SDD)

Similar to the conventional solid state detectors we covered earlier, silicon drift detectors rely on a silicon detecting element; however, their architecture differs slightly. To slowly bring the electrons (resulting from X-ray absorption) to the chip's centre, concentratic electrodes are positioned on the silicon's reverse surface. Just like before, an MCA counts the electrons as a negative pulse. Peltier cooling, usually down to -20 to -30 °C, is the only way to get very good energy resolutions (~ 150eV) with the SDD. Furthermore, numerous incident X-rays can be detected in a sequential fashion, as the anode-drifting durations of electrons produced by X-ray absorption in various parts of the detector would vary. Consequently, substantially greater count rates are tolerable. The sensitivity of SDDs to high intensity X-rays is lower than that of solid state detectors.

Semiconductor Network Diodes

An even smaller detector element is used by a pin diode detector, as its name implies. However, similar to the two types mentioned before, they are usually built on a silicon semiconductor material for detection. Semiconductor components are small enough to undergo peltier cooling, but their reduced thickness makes them less sensitive, especially when it comes to heavier elements.

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