XRF Technology in the Lab

XRF Technology for
Non-scientists

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1

What is XRF?

X-ray fluorescence (XRF): a non-destructive analytical technique used to determine the chemical composition of materials.

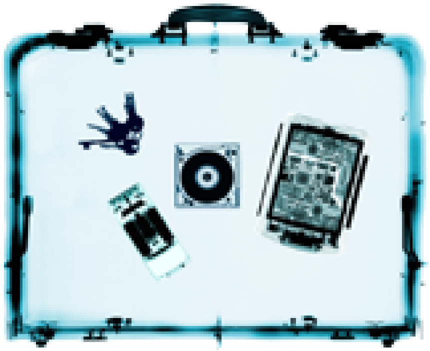
Overview

X-Ray Fluorescence (XRF)

XRF occurs when a fluorescent (or secondary) x-ray is emitted from a sample that is being excited by a primary x-ray source. Because this fluorescence is unique to the elemental composition of the sample, XRF is an excellent technology for qualitative and quantitative analysis of the material composition. XRF spectrometry has a broad range of applications in industry, which we will discuss later in this ebook.

X-rays

X-rays are simply light waves that we can't see. Other light waves that we can't see include ultraviolet (UV) light (which gives you a sun tan), infrared light (which warms you up), and radio waves. X-rays have a very short wavelength, which corresponds to a very high energy.



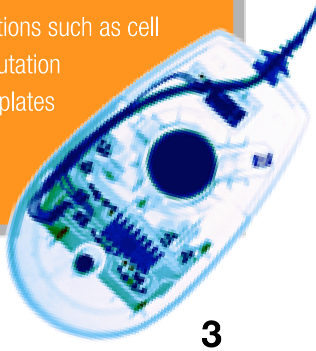
Properties of X-Rays

X-rays Are:

- Propagated in straight lines at speed of light
- Absorbed while passing through matter, depending on composition and density of the substance
- Emitted with energies characteristic of the elements present

They:

- Affect the electrical properties of liquids and solids
- Cause biological reactions such as cell damage or genetic mutation
- Darken photographic plates
- Ionize gases



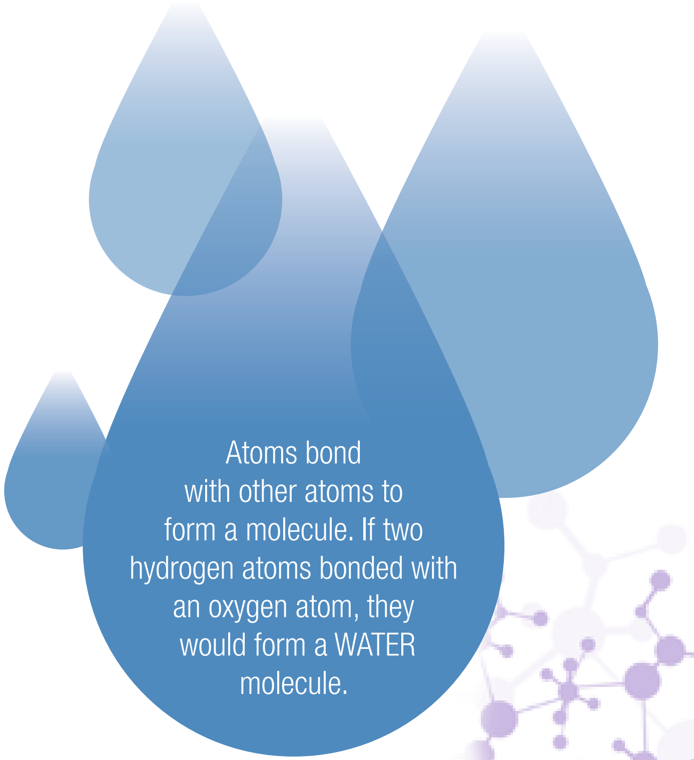
How XRF Works

Fingerprints

Each of the elements present in a sample produces a unique set of characteristic x-rays that is a “fingerprint” for that specific element.

It All Starts With the Atom

Atoms are the extremely small particles of which we, and everything around us, are made. There are 92 naturally occurring elements and scientists have made more, bringing the total to 114 confirmed and at least 4 more claimed. Atoms are the smallest unit of an element that chemically behaves the same way the element does.



Atoms bond with other atoms to form a molecule. If two hydrogen atoms bonded with an oxygen atom, they would form a WATER molecule.

How XRF Works

Anatomy of the Atom*

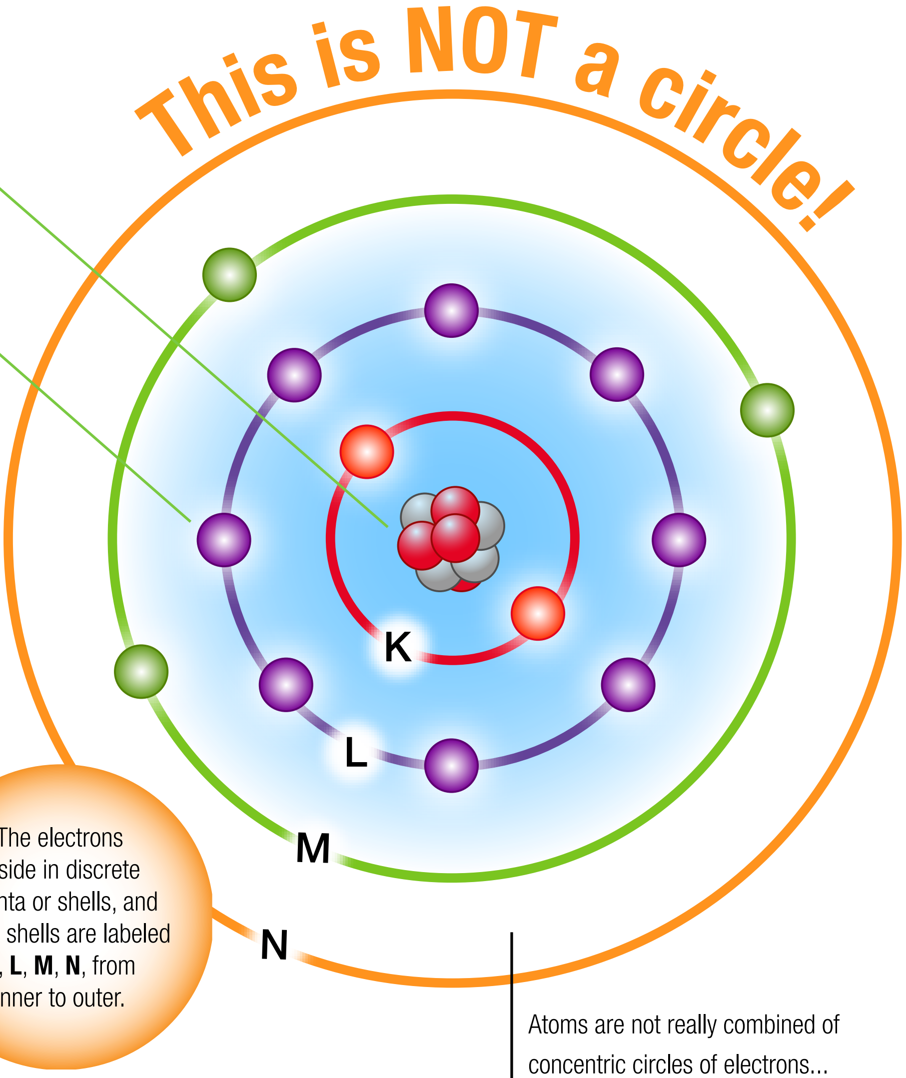
In the center of the atom is the nucleus, made up of **protons** and **neutrons**. Each proton carries a positive electrical charge, but neutrons carry no electrical charge, so the nucleus of an atom is positively charged because of its protons.

Electrons are particles that orbit the nucleus at a high speed and carry a negative charge, which balances the positive electrical charge of the protons in the nucleus. Since the total negative charge of electrons is equal to the positive charge of the nucleus, an atom is neutral.

The negative electrons are attracted to the positive protons, so the electrons stay around the nucleus in discrete shells.

When two chemicals react with each other, the reaction takes place between individual atoms at the atomic level. The outermost or covalent electrons are involved in this bonding.

The processes that cause materials to be radioactive occur at the atomic level, generally within the nucleus.



The electrons reside in discrete quanta or shells, and these shells are labeled **K**, **L**, **M**, **N**, from inner to outer.

Atoms are not really combined of concentric circles of electrons... we just draw them that way to understand how the electrons orbit around the nucleus.

*this section site reference: http://www.epa.gov/radiation/understand/atom.html

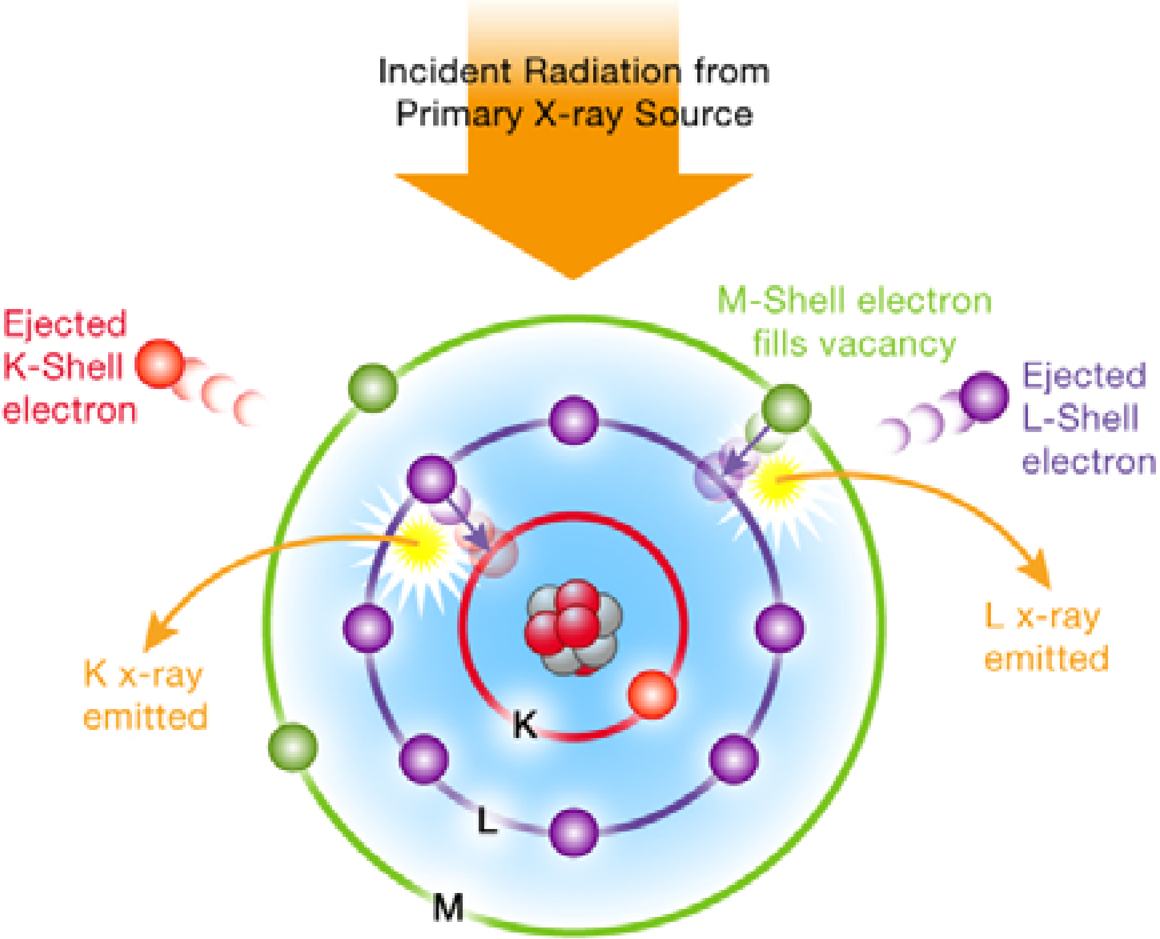
The X-Ray Fluorescence Process

1. A solid or a liquid sample is irradiated with high energy x-rays from a controlled x-ray tube.

2. When an atom in the sample is struck with an x-ray of sufficient energy (greater than the atom's K or L shell binding energy), an electron from one of the atom's inner orbital shells is dislodged.

3. The atom regains stability, filling the vacancy left in the inner orbital shell with an electron from one of the atom's higher energy orbital shells.

4. The electron drops to the lower energy state by releasing a fluorescent x-ray. The energy of this x-ray is equal to the specific difference in energy between two quantum states of the electron. The measurement of this energy is the basis of XRF analysis.



The Periodic Table

Number of protons = Atomic Number (different for each element).

Number of electrons typically = number of protons (so that the atom is neutral).

Number of neutrons is variable and is what allows some atoms to have isotopes.

Electrons in shells closest to the nucleus are most strongly bound to the atom. Binding energy increases with atomic number. The higher the number, the higher the weight.

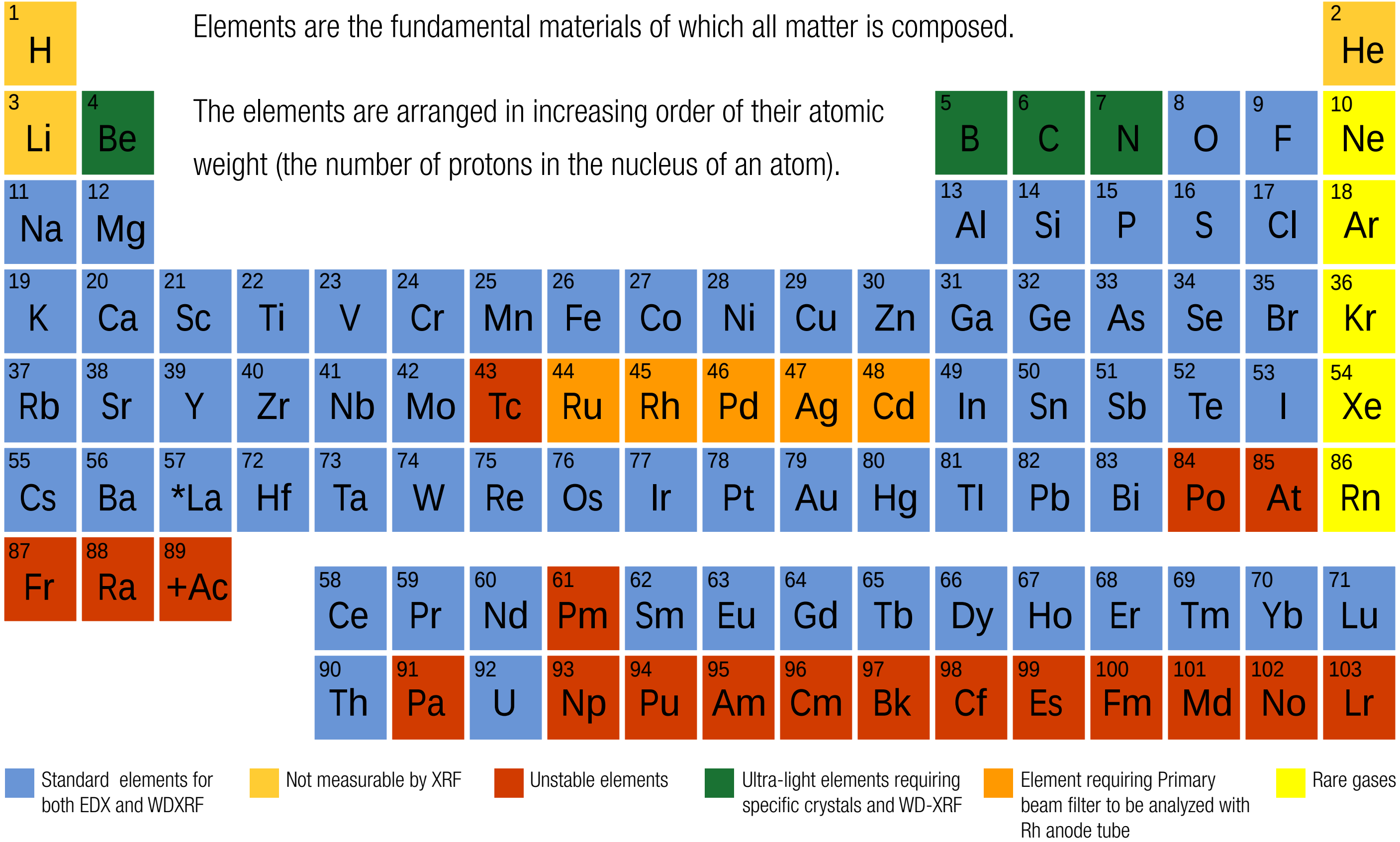
An isotope of an element has the same number of protons but a different number of neutrons.

What is an Element?

An element is a chemically pure substance composed of atoms.

Elements are the fundamental materials of which all matter is composed.

The elements are arranged in increasing order of their atomic weight (the number of protons in the nucleus of an atom).



1 H 🟡																	2 He 🟡
3 Li 🟡	4 Be 🟩											5 B 🟩	6 C 🟩	7 N 🟩	8 O 🟦	9 F 🟦	10 Ne 🟨
11 Na 🟦	12 Mg 🟦											13 Al 🟦	14 Si 🟦	15 P 🟦	16 S 🟦	17 Cl 🟦	18 Ar 🟨
19 K 🟦	20 Ca 🟦	21 Sc 🟦	22 Ti 🟦	23 V 🟦	24 Cr 🟦	25 Mn 🟦	26 Fe 🟦	27 Co 🟦	28 Ni 🟦	29 Cu 🟦	30 Zn 🟦	31 Ga 🟦	32 Ge 🟦	33 As 🟦	34 Se 🟦	35 Br 🟦	36 Kr 🟨
37 Rb 🟦	38 Sr 🟦	39 Y 🟦	40 Zr 🟦	41 Nb 🟦	42 Mo 🟦	43 Tc 🟥	44 Ru 🟧	45 Rh 🟧	46 Pd 🟧	47 Ag 🟧	48 Cd 🟧	49 In 🟦	50 Sn 🟦	51 Sb 🟦	52 Te 🟦	53 I 🟦	54 Xe 🟨
55 Cs 🟦	56 Ba 🟦	57 *La 🟦	72 Hf 🟦	73 Ta 🟦	74 W 🟦	75 Re 🟦	76 Os 🟦	77 Ir 🟦	78 Pt 🟦	79 Au 🟦	80 Hg 🟦	81 Tl 🟦	82 Pb 🟦	83 Bi 🟦	84 Po 🟥	85 At 🟥	86 Rn 🟨
87 Fr 🟥	88 Ra 🟥	89 +Ac 🟥															
				58 Ce 🟦	59 Pr 🟦	60 Nd 🟦	61 Pm 🟥	62 Sm 🟦	63 Eu 🟦	64 Gd 🟦	65 Tb 🟦	66 Dy 🟦	67 Ho 🟦	68 Er 🟦	69 Tm 🟦	70 Yb 🟦	71 Lu 🟦
				90 Th 🟦	91 Pa 🟥	92 U 🟦	93 Np 🟥	94 Pu 🟥	95 Am 🟥	96 Cm 🟥	97 Bk 🟥	98 Cf 🟥	99 Es 🟥	100 Fm 🟥	101 Md 🟥	102 No 🟥	103 Lr 🟥

🟦 Standard elements for both EDX and WDXRF

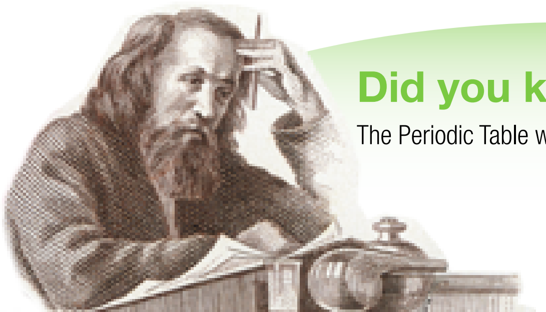
🟡 Not measurable by XRF

🟥 Unstable elements

🟩 Ultra-light elements requiring specific crystals and WD-XRF

🟧 Element requiring Primary beam filter to be analyzed with Rh anode tube

🟨 Rare gases



Did you know?

The Periodic Table was created in 1869 by Dmitry I. Mendeleev.

List of Periodic Table Elements

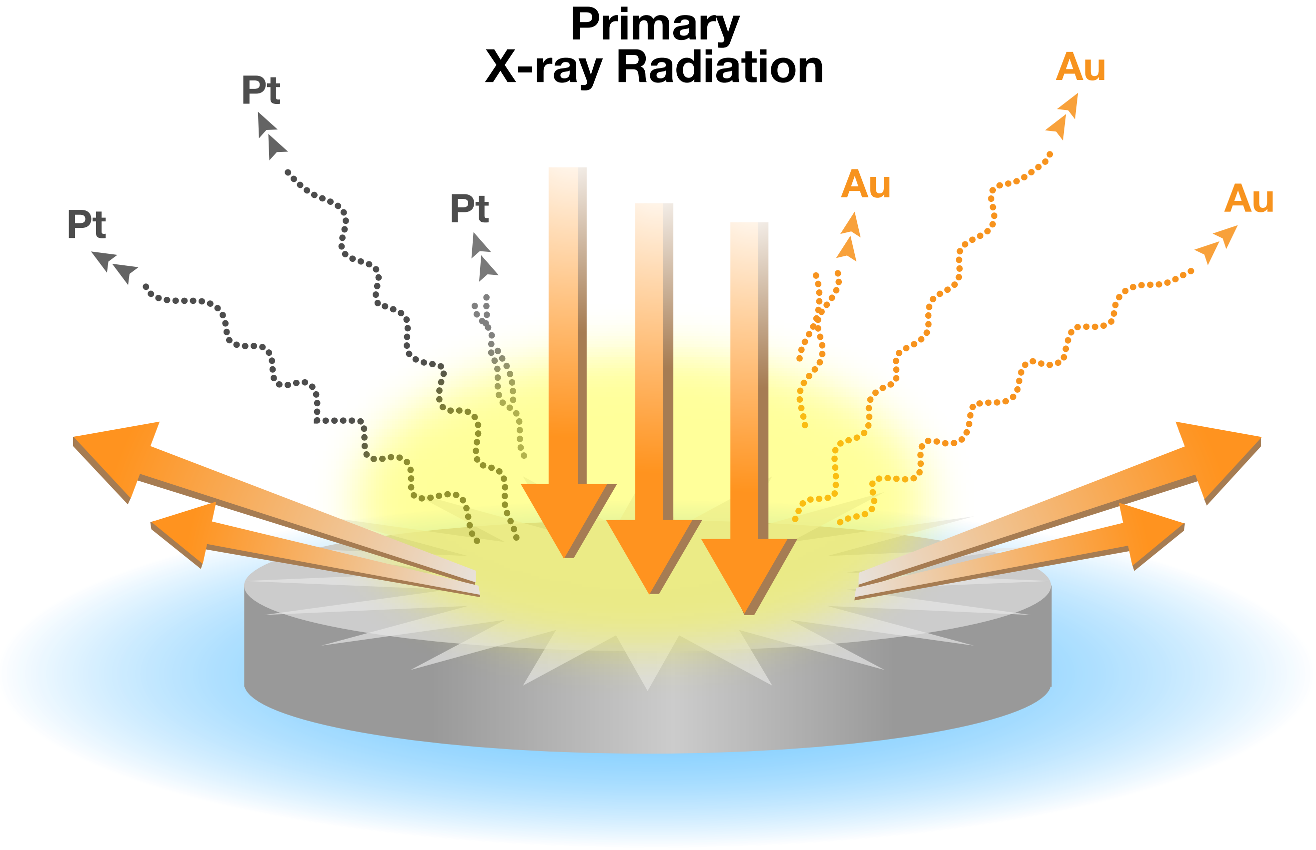
1	Hydrogen	H
2	Helium	He
3	Lithium	Li
4	Beryllium	Be
5	Boron	B
6	Carbon	C
7	Nitrogen	N
8	Oxygen	O
9	Fluorine	F
10	Neon	Ne
11	Sodium	Na
12	Magnesium	Mg
13	Aluminum	Al
14	Silicon	Si
15	Phosphorus	P
16	Sulfur	S
17	Chlorine	Cl
18	Argon	Ar
19	Potassium	K
20	Calcium	Ca
21	Scandium	Sc
22	Titanium	Ti
23	Vanadium	V
24	Chromium	Cr
25	Manganese	Mn
26	Iron	Fe
27	Cobalt	Co
28	Nickel	Ni
29	Copper	Cu
30	Zinc	Zn
31	Gallium	Ga
32	Germanium	Ge
33	Arsenic	As
34	Selenium	Se
35	Bromine	Br
36	Krypton	Kr
37	Rubidium	Rb
38	Strontium	Sr
39	Yttrium	Y
40	Zirconium	Zr
41	Niobium	Nb
42	Molybdenum	Mo
43	Technetium	Tc
44	Ruthenium	Ru
45	Rhodium	Rh
46	Palladium	Pd
47	Silver	Ag
48	Cadmium	Cd
49	Indium	In
50	Tin	Sn
51	Antimony	Sb
52	Tellurium	Te
53	Iodine	I
54	Xenon	Xe
55	Cesium	Cs
56	Barium	Ba
57	Lanthanum	La
58	Cerium	Ce
59	Praseodymium	Pr
60	Neodymium	Nd
61	Promethium	Pm
62	Samarium	Sm
63	Europium	Eu
64	Gadolinium	Gd
65	Terbium	Tb
66	Dysprosium	Dy
67	Holmium	Ho
68	Erbium	Er
69	Thulium	Tm
70	Ytterbium	Yb
71	Lutetium	Lu
72	Hafnium	Hf
73	Tantalum	Ta
74	Tungsten	W
75	Rhenium	Re
76	Osmium	Os
77	Iridium	Ir
78	Platinum	Pt
79	Gold	Au
80	Mercury	Hg
81	Thallium	Tl
82	Lead	Pb
83	Bismuth	Bi
84	Polonium	Po
85	Astatine	At
86	Radon	Rn
87	Francium	Fr
88	Radium	Ra
89	Actinium	Ac
90	Thorium	Th
91	Protactinium	Pa
92	Uranium	U
93	Neptunium	Np
94	Plutonium	Pu
95	Americium	Am
96	Curium	Cm
97	Berkelium	Bk
98	Californium	Cf
99	Einsteinium	Es
100	Fermium	Fm
101	Mendelevium	Md
102	Nobelium	No
103	Lawrencium	Lr
104	Rutherfordium	Rf
105	Dubnium	Db
106	Seaborgium	Sg
107	Bohrium	Bh
108	Hassium	Hs
109	Meitnerium	Mt
110	Darmstadtium	Ds
111	Roentgenium	Rg
112	Copernicium	Cn
113	Ununtrium	113
114	Flerovium	Fl
115	Ununpentium	115
116	Livermorium	Lv

Interpretation of XRF Spectra

Spectral Peaks

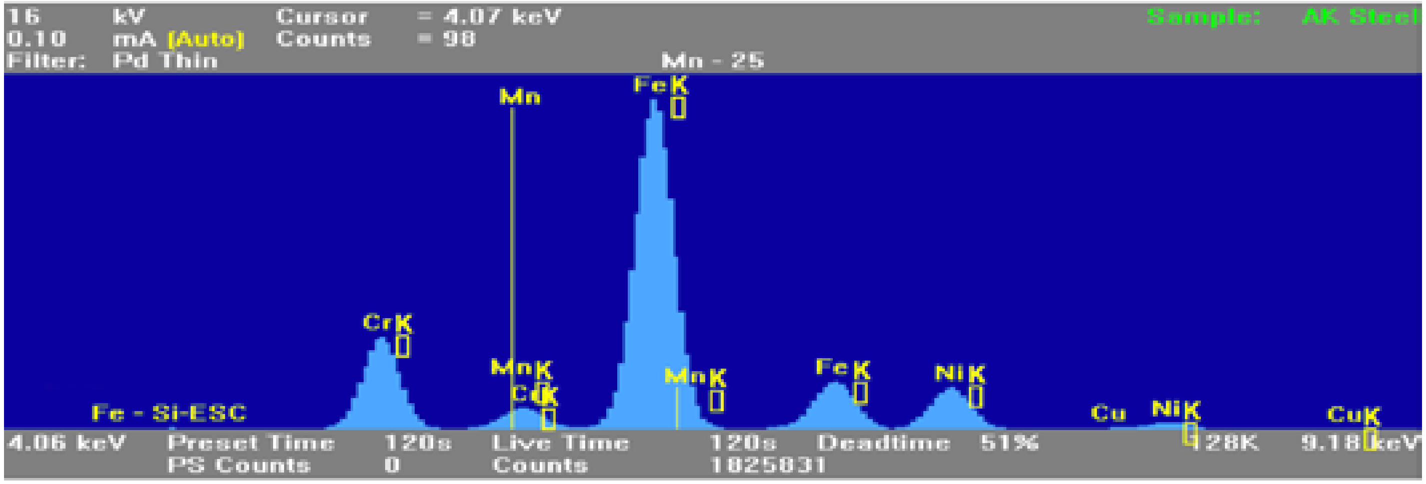
As we learned in the previous pages, each of the elements present in a sample produces a set of characteristic fluorescent x-rays that is unique for that specific element, which is why XRF spectroscopy is especially useful for elemental analysis. This elemental "fingerprint" is best illustrated by examining the x-ray energy spectrum and its "scattering peaks."

Most atoms have several electron orbitals (K shell, L shell, M shell, for example). When x-ray energy causes electrons to transfer in and out of these shell levels, XRF peaks with varying intensities are created and will be present in the spectrum. The peak energy identifies the element, and the peak height / intensity is indicative of its concentration.

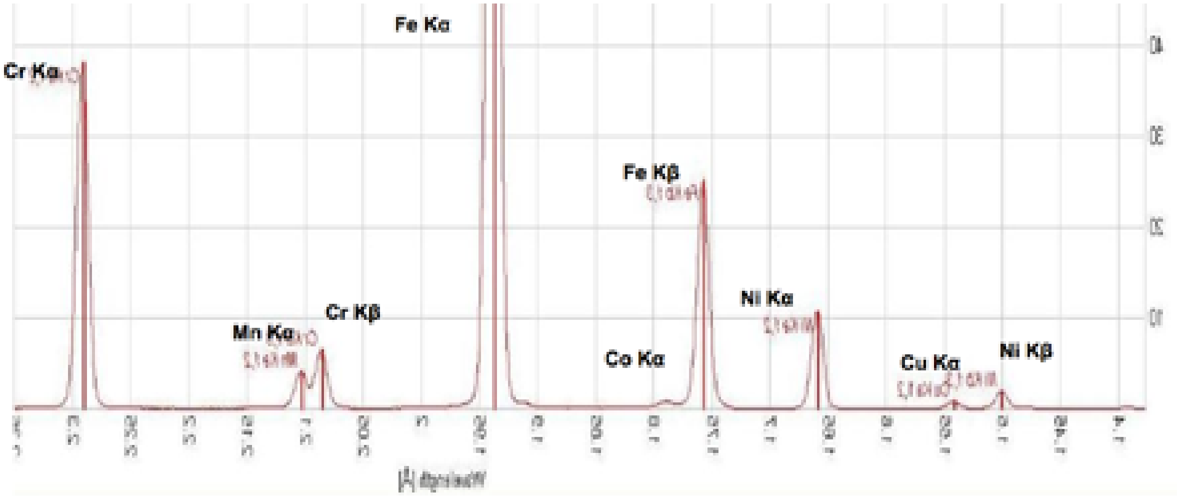


Examples of an XRF Spectra

Energy Dispersive XRF (EDXRF)



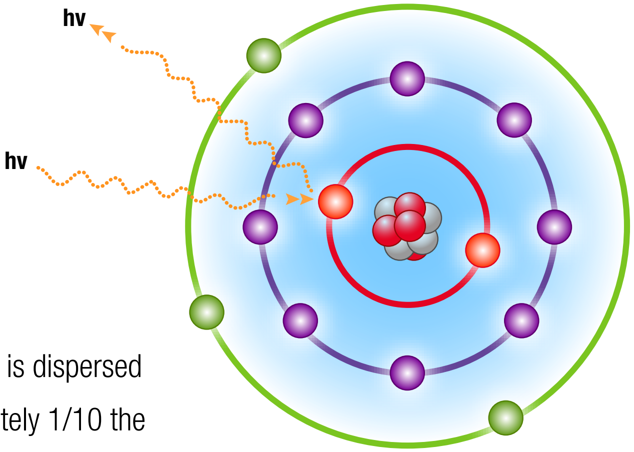
Wavelength Dispersive XRF (WDXRF)



Rayleigh/Compton Scatter Peaks

Overview

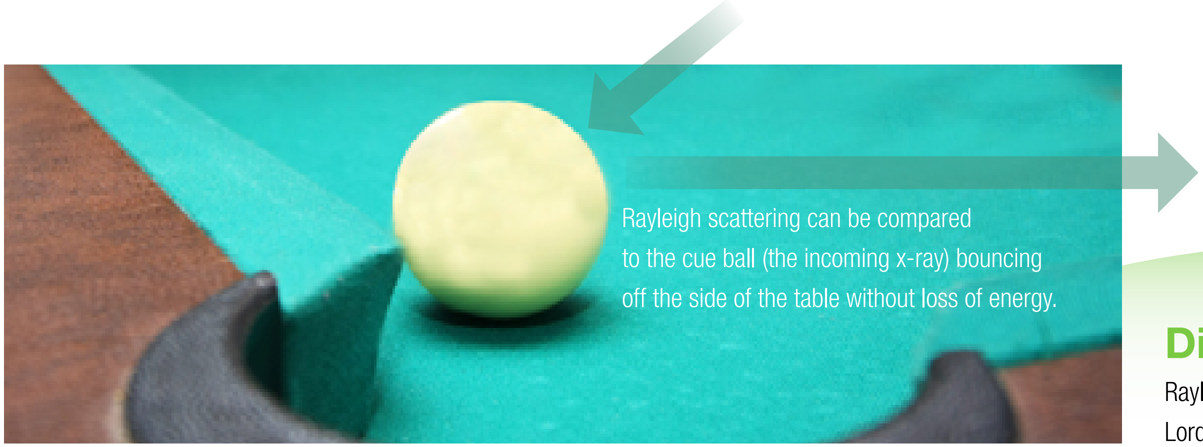
Scattering occurs when incoming x-rays do not produce fluorescence, but rather "collide" with the atoms of the sample which results in a change in the direction of motion of a particle.



Rayleigh Scattering

In Rayleigh scattering, electromagnetic radiation is dispersed by particles having a radius less than approximately 1/10 the wavelength of the radiation.

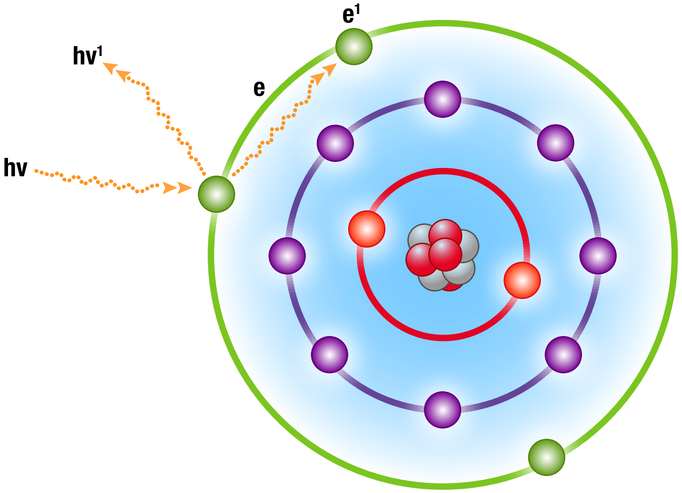
During the Rayleigh scattering process, photons are scattered by tightly bound electrons in which the atom is neither ionized nor excited. The incident photons are scattered with (essentially) an unchanged energy. Rayleigh scattering occurs mostly at low energies and for high atomic weight.



Rayleigh scattering can be compared to the cue ball (the incoming x-ray) bouncing off the side of the table without loss of energy.

Compton Scattering

In Compton scattering, the x-ray strikes an electron of the sample. Since some energy is transferred to the electron in the collision, the x-ray leaves the collision with less energy. That's why we see the Compton peak at an energy lower than the source excitation energy.



Did you know?

Rayleigh scattering is named after the British physicist Lord Rayleigh, who discovered the process.

Limitations

Overview

Light element analysis with XRF can be challenging depending on what type of system you're using because the fluorescent x-rays from lighter elements (Z<18) are less energetic and are greatly attenuated as the x-rays pass through air. Wavelength Dispersive XRF (WDXRF) instruments tend to be more successful with light element analysis than Energy Dispersive XRF (EDXRF) instruments. The differences between WDXRF and EDXRF will be explained further in chapter 2.

Spectral Effects

Some elements have lines that overlap other elements. Fortunately the software will strip out and correct most of these overlaps (as long as the interfering element is in the model being used), but limits of detection may be worse when two overlapping elements are present. WDXRF produces fewer spectral overlaps because of its higher resolution.

Matrix Effects

The matrix is any other element present in or on the sample other than the one element being considered. Enhancement and absorption effects are typically taken care of in the software if you are using a fundamental parameters based calibration with all the necessary elements present.

Enhancement Effects

Some fluorescent x-rays have more energy than the binding energy of other elements present in the sample, and so their energy will excite those other elements. These elements will give a greater signal return to the detector, i.e. "enhancing" the reading.

Absorption Effects

The fluorescent x-ray does not reach the detector as it is scattered or absorbed by other elements present in the sample, so the signal is weaker.

Sample Effects

The surface of the material being analyzed is not representative of the entire sample (particle size, inhomogeneity, surface contamination, etc.). XRF is a surface analysis technique, so inhomogeneity or contamination will skew the results.

Calibration

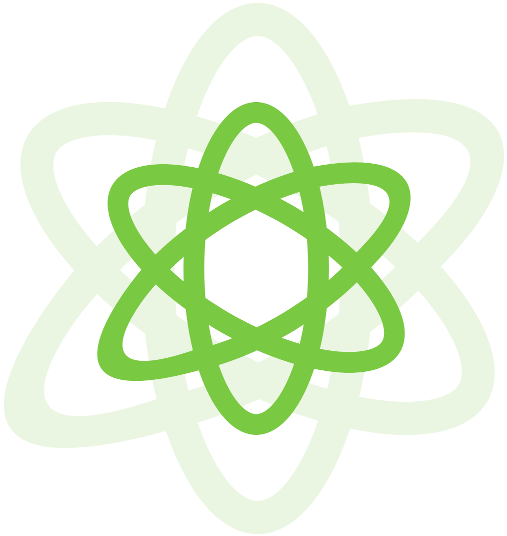
Common calibration routines include the following:

Empirical Calibration

In empirical calibration, the user must first analyze known samples to obtain the count intensity, which is then plotted using off-line software to generate the calibration curve. This curve data is then put back onto the analyzer which can then be run to give immediate results. Empirical testing modes are only suited for measuring samples for which chemical compositions will fall within the narrow calibration range, and interferences (spectral and matrix) must be taken into consideration within the calibration. This method is the most accurate and widely used in process control where similar, well known reference samples are available.

Fundamental Parameters

For measuring samples of unknown chemical composition in which concentrations of light and heavy elements may vary from parts per million (ppm) to high percent levels, Fundamental Parameters (FP) analysis is used to simultaneously compensate for a wide variety of geometric effects (including small and odd-shaped samples), plus x-ray absorption and enhancement effects as well as spectral overlaps. FP is the preferred analysis tool when no reference samples are available.



2

XRF Analyzers in the Lab: Technology

Energy Dispersive XRF = **EDXRF**
Wavelength Dispersive XRF = **WDXRF**

Overview

Lab-based XRF analysis can be used in tandem with handheld XRF analysis to provide confirmatory data, but its analytical range and applications are wider.

Handheld XRF analyzers are designed to provide instant elemental analysis in situations where immediate feedback is needed to determine the next course of action.

Laboratory-based XRF systems provide qualitative and quantitative analysis for process and quality control. WDXRF is the standard test method for analytical laboratories serving applications as diverse as cement manufacturing, metallurgy, mining, geology and geochemistry, petroleum, polymers, glass and ceramics, semiconductors, paints and chemicals, forensics investigations, and environmental applications.

Lab-based XRF can evaluate all kinds of materials and sample types including conductive or non-conductive solids, liquids, loose powders, pressed pellets, fusion beads, pastes, granules and coatings.

Lab-based XRF Systems

Overview

The two primary types of lab-based XRF systems are EDXRF and WDXRF. Each has a different detection system.

EDXRF

EDXRF instruments may be either handheld for use in the field or benchtop for use in a lab. EDXRF is a convenient technology to screen all kinds of materials for quick identification and quantification of elements with little or no sample preparation. Low cost of ownership and rapid elemental analysis of regular or irregular samples make EDXRF an attractive front-end analysis tool.

WDXRF

WDXRF technology is well established for high sensitivity down to low atomic number elements, high repeatability and element selectivity in order to achieve the performance needed for routine industrial applications. WDXRF is also exploited for its wide dynamic range and extremely good reliability for laboratory applications.

EDXRF

How It Works

EDXRF is designed to analyze groups of elements simultaneously. This type of XRF instrumentation separates the characteristic x-rays of different elements into a complete fluorescence energy spectrum which is then processed for qualitative or quantitative analysis. Filters positioned between sample and detector are used to improve signal, background reduction, and focus on certain regions of the spectra.

Direct Excitation vs. Indirect Excitation

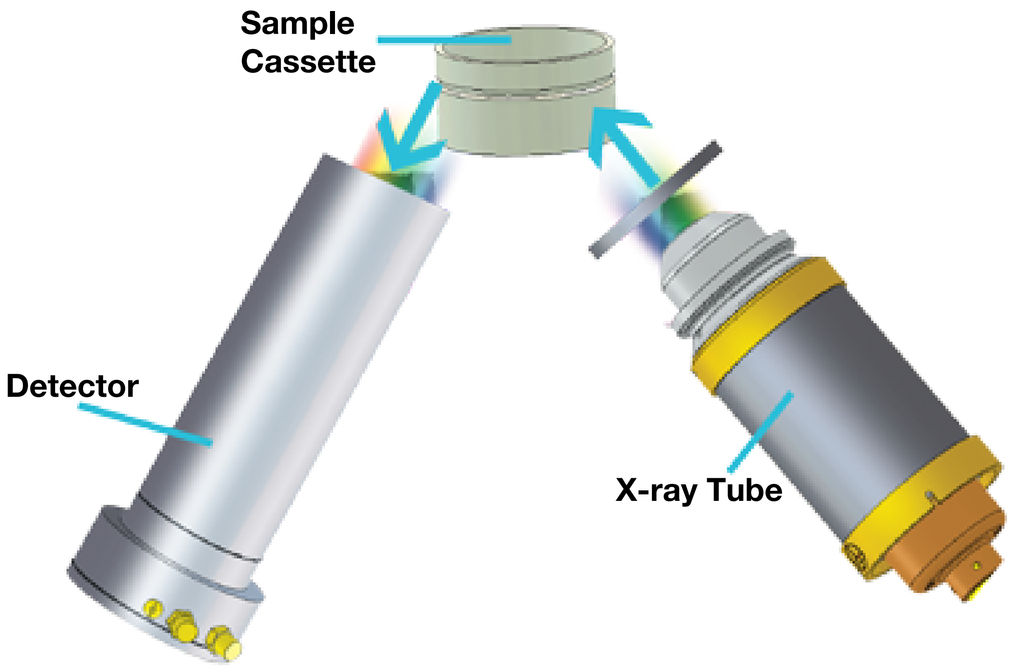
Overview

EDXRF instruments can have one of two types of excitation geometry; direct excitation, or 2D optics, and indirect excitation, also called 3D optics. The purpose of these geometries is to remove the background below the characteristic element lines in the spectrum and to increase the peak-to-background ratio (peak-to-noise). Both types rely on an energy dispersive detector and an x-ray tube; the difference is in the optic path.

EDXRF

Direct Excitation Geometry (2D optics)

In direct excitation geometry, the detector, sample and x-ray tube are positioned in the same plane. Primary x-rays from the tube are filtered according to which elements are being detected. The filtered primary radiation excites the sample elements and the resulting secondary radiation is detected by the detector.



2D Optics

Indirect Excitation (3D optics)

Indirect excitation features a 3D geometry with the x-ray tube, secondary target and sample in one plane, and the detector in a perpendicular plane.

Instruments with 3D optics direct the primary x-rays first to a secondary target in the sample-target-tube plane, and then to the sample outside the plane. If reflections happen at exactly 90°, the primary radiation coming from the tube, which produces the background in the spectrum, is completely eliminated. However, irradiating the secondary target produces almost monochromatic radiation which is used to excite the sample elements.

For EDXRF instruments with a tube power up to 50 Watts, the analytical performance of 2D and 3D are very similar.

EDXRF

Detectors

The resolution and elemental range achieved by EDXRF analyzers depends on the type of detector used.

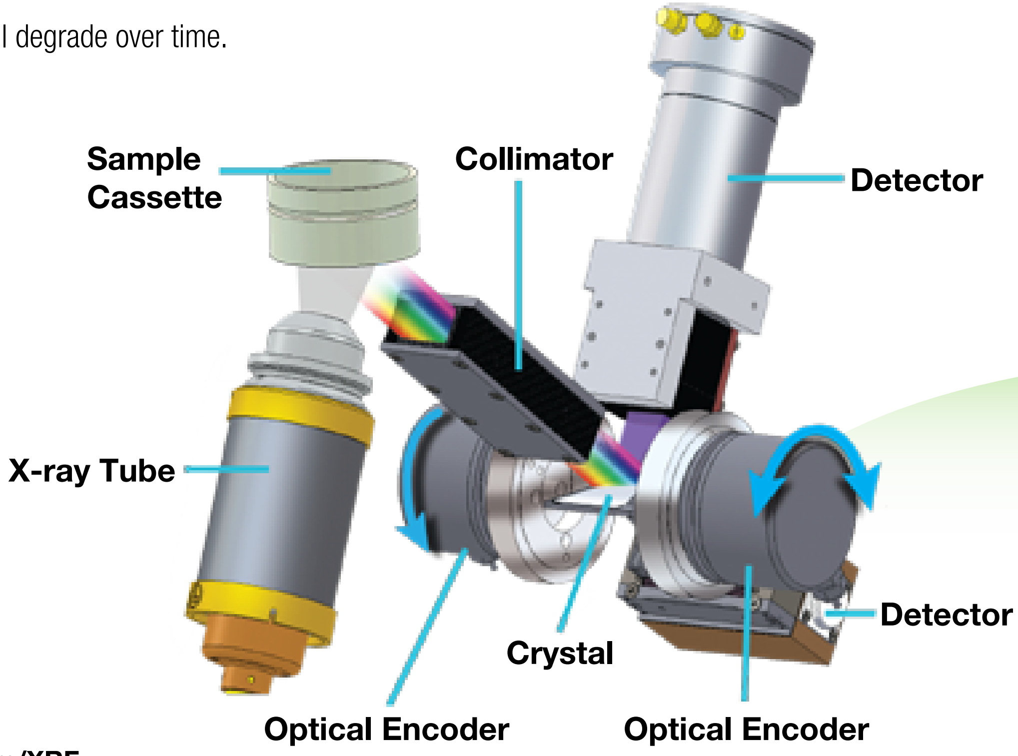
Si(Li) Solid State Semiconductor	PIN Diode	Silicon Drift Detectors (SDDs)
• Highest stopping power (efficiency) • Resolution as good as silicon drift detectors, but lower count rate • Silicon or germanium chip detector material • Liquid nitrogen or Peltier cooled (requires -90°C)	• High detection efficiency but lower resolution • Silicon semiconductor detector material • Peltier cooled (requires -20°C) • No longer used in new instruments	• Most popular thanks to better resolution, higher count rates, and faster results than Si(Li) detectors • Peltier cooled (requires -20°C) • Silicon chip detector material • Lower efficiency, especially for heavy elements

WDXRF

How It Works

WDXRF uses crystals to disperse the fluorescence spectrum into individual wavelengths of each element, providing high resolution and low background spectra for accurate determination of elemental concentrations.

The types of crystals used in WDXRF include minerals, metallic, organic and synthetic multi-layers. Synthetic thin film multilayer crystals are increasing in popularity because they offer higher sensitivity and resolution for enhanced light element analysis. Some traditional crystals are sensitive to instrument temperature changes and x-ray exposure and will degrade over time.



WDXRF systems are based on Bragg's law, which states that crystals will reflect x-rays of specific wavelengths and incident angles when the wavelengths of the scattered x-rays interfere constructively. While the sample position is fixed, the angles of the crystal and detector can be changed in compliance with Bragg's law so that a particular wavelength can be measured. Only x-rays that satisfy Bragg's law are reflected.

Collimators further improve resolution by providing different angular divergences to restrict unwanted secondary x-rays from reaching the detector. Larger collimators can be used when high intensity is favored over resolution.

Did you know?

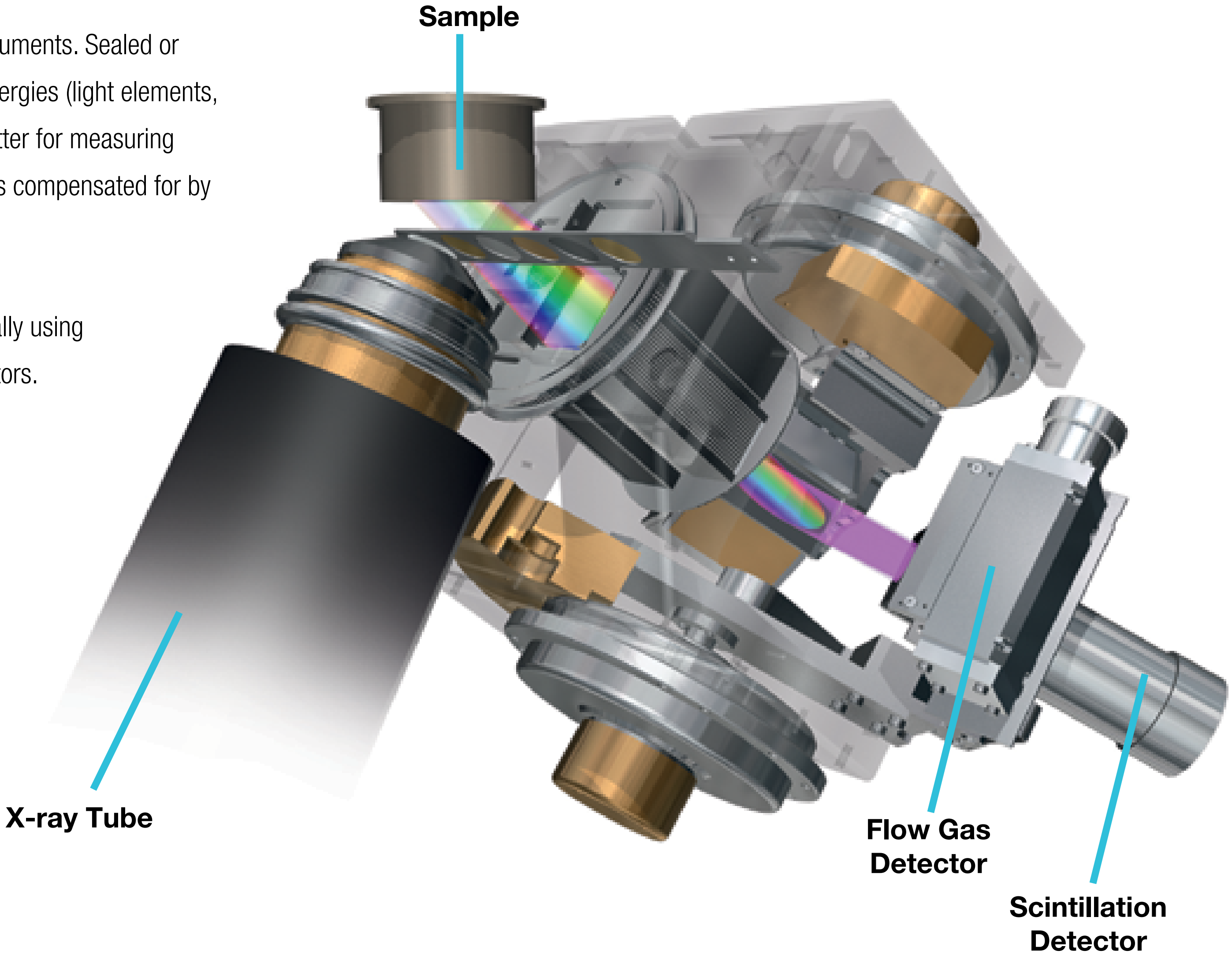
In 1912, William Lawrence Bragg and William Henry Bragg won a Nobel Prize in Physics for their discovery.

WDXRF

Detectors

Two types of detectors can be used in WDXRF instruments. Sealed or flow gas detectors are best for measuring lower energies (light elements, below iron [Fe]), while scintillation detectors are better for measuring higher energies. Both have poor resolution, which is compensated for by the crystals.

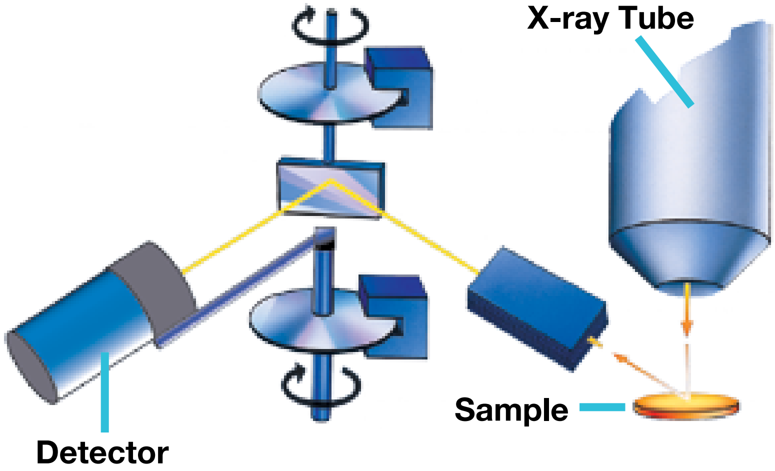
WDXRF analysis can be performed either sequentially using goniometers or simultaneously using monochromators.



WDXRF

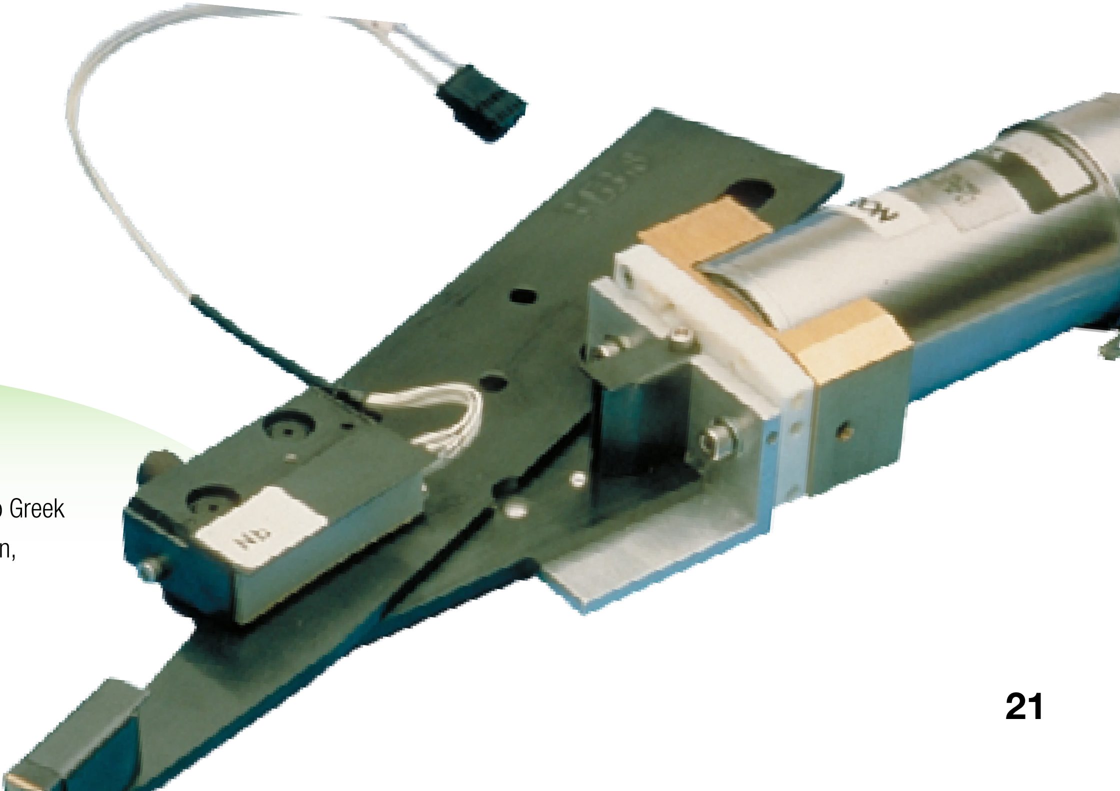
Goniometers

Detectors can be mounted on a goniometer and moved through a range of angles to measure the intensities of different wavelengths in sequential fashion. This system offers flexibility and optimum performance across the periodic table. However, the sequential nature of WDXRF instruments and the need to readjust the geometry between measurements make them operate slowly.



Monochromators

When monochromators are used, the crystal and detector combination is in a fixed geometry. Each monochromator measures a single element but they all work simultaneously. This set-up offers speed and precision for a given set of elements.



Did you know?

The term goniometry is derived from two Greek words, gonia, meaning angle, and metron, meaning measure.

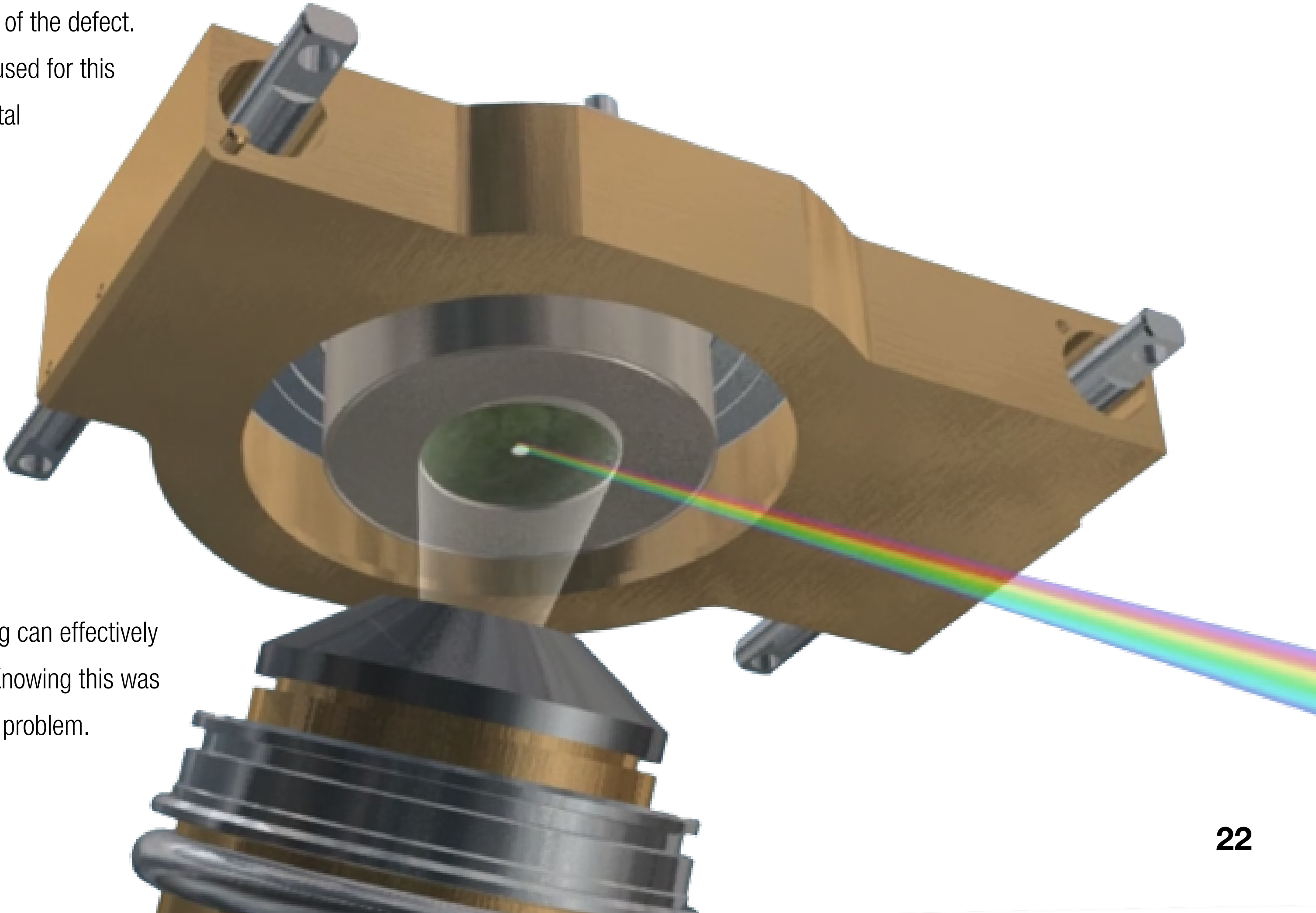
WDXRF

Small Spot Analysis

Some instruments feature small masks that restrict the analyzed area on the sample. Combined with appropriate sample movement, this allows the measurement of an individual spot of the sample.

When samples present a defect, the ability to analyze a small area in isolation can help determine the source of the defect. XRF instruments with a spotting capability are used for this purpose in various industries like glass and metal production.

Only an instrument equipped with spotting can effectively measure a small defect as shown here. Knowing this was Copper helped pinpoint the source of the problem.



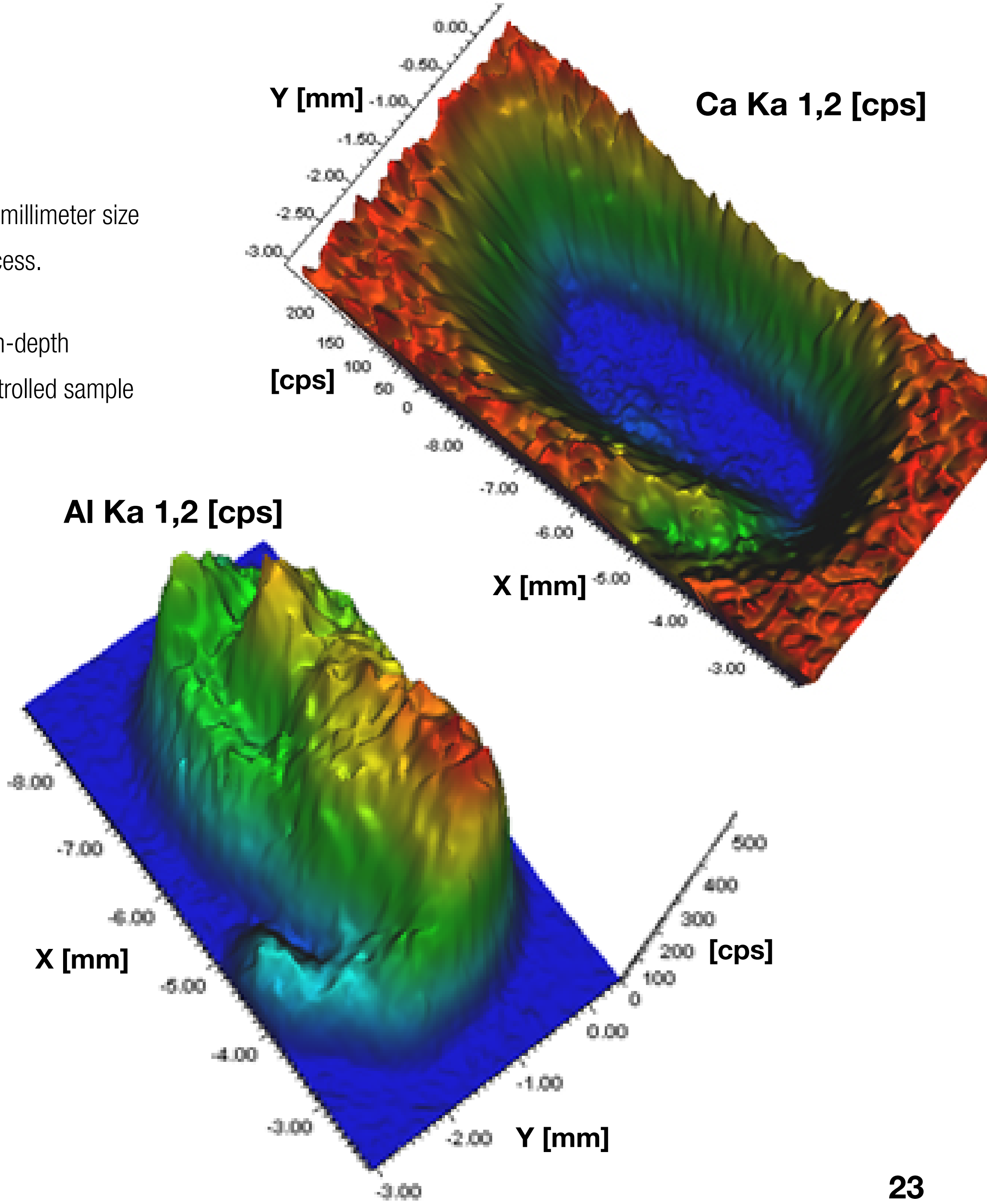
WDXRF

Elemental Mapping

XRF Mapping is a great tool to measure the homogeneity of a sample in a sub-millimeter size range. This can help validate sample preparation or indicate problems in a process.

Geologist's use XRF elemental mapping to select or screen samples for more in-depth analysis with a scanning electron microscope (SEM), which requires highly controlled sample preparation and provides information in the sub-micrometer size range.

Elemental mapping of a rock gives understanding to its genesis.



EDXRF vs. WDXRF

	EDXRF	WDXRF
Elemental Range:	From Sodium (Na) to Uranium (U), very accurate and sensitive for heavy metal analysis.	From Beryllium (Be) to Uranium, preferred method for light elements and rare earths.
Pros and Cons:	• Poor energy resolution: ~150 eV • More efficient, less costly. • Fewer optical components. • Acquires an entire spectrum of elements within seconds. • No moving parts, more compact, energy-efficient and has lower operating costs.	• Better energy resolution: ~15-150 eV • Less efficient, more costly. • More optical components, benefits from a higher power x-ray tube. • Wide range of instruments to suit various performance needs. • Moving parts under vacuum, larger footprint.
Samples:	Accommodates almost any sample size.	Accommodates powder or liquid samples in standardized holders and placed in a sample loading system.

General Use Guidelines

Radiation

When operating any type of instrumentation that emits x-rays, reasonable effort should be made to maintain exposures to radiation as far below dose limits as is practical. This is known as the ALARA (As Low as Reasonably Achievable) principle. For any given source of radiation, three factors will help minimize your radiation exposure: Time, Distance, Shielding.

Time

Distance

Shielding

Did you know?

All modern lab XRF instruments are very safe. You would receive more radiation dose travelling in an airplane than by working next to a modern XRF lab instrument.

Sample Preparation

XRF analysis is significantly improved by proper sample preparation. This is especially true for strongly altered and mineralized samples.

A sample must represent all of the material being analyzed; non-homogenous samples contain different concentrations of elements at different points across the sample, so the analysis may not indicate what is really in the material of interest.

Sample preparation creates a homogeneous sample, which is extremely important because sample composition and sampling techniques can greatly impact results. Powdered samples are fine-grained and contain more consistent particle sizes. A fused bead is even more representative of the sampling media and will produce consistent and repeatable assay data.

There is a trade-off between the time and effort spent in sample preparation versus the accuracy of the analytical result. Sometimes it's better to do limited sample preparation in order to get rough results very quickly. Other applications require higher accuracy and hence careful sample preparation.

Analysis

XRF instruments are calibrated with a set of reference standards for a list of selected elements. Once the reference list is stored, analysis of incoming samples is straightforward. Just prepare the new sample in the same way as the reference ones were prepared and run the analysis. Instruments are automated and display results on a screen which can then be exported and sent to remote locations.

Whenever possible, a quantitative calibration will provide more accurate and faster results than a standard-less analysis. However, obtaining enough known standards to create a calibration isn't always possible. Standard-less analysis techniques provide quantitative data when reference material can't be procured, for example, waste processing, or unstable materials.

The strength of standard-less analysis is that it can directly analyze all elements in any type of sample in about 15 minutes and provide fairly accurate results, down to ppm levels. This is a great tool when someone comes in the lab with some exotic material and asks "could you analyze this, please?"

Did you know?

Automated XRF systems are available that combine sample preparation and analysis in one integrated system.

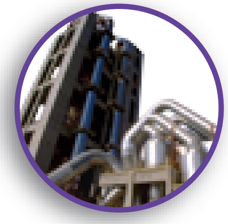
3

XRF Analyzers in the Lab: Applications

Lab XRF analyzers have many applications for elemental analysis. Here are a few industries putting XRF technology to work in daily operations.

Metals and Alloys Manufacturing

Geology, Mining and Minerals



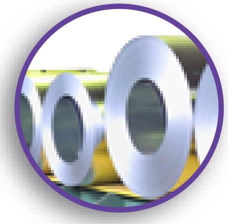
Cement Manufacturing

Petroleum Industry

Precious Metals and Gemstones

Polymers and Plastics

Glass and Ceramics, Refractories



Semiconductor, Thin Films, Coatings

Environment, RoHS and WEEE screening

Paints and Chemicals

Forensics

Food

Metals and Alloys Manufacturing

XRF instrumentation is used to verify the quality and composition of metals used in fabrication to ensure final product integrity. This analysis prevents incorrect or out-of-specification metal alloys caused by material mix-ups, incorrect weld chemistry and dilution, or even counterfeit materials from entering the manufacturing process.

Special alloys are made by adding expensive elements to steel. XRF is the only technique that can measure high concentrations of the alloying element directly in the solid metal. This allows large cost savings by preventing overuse of the expensive alloying agents.

Slag, a by-product of the metallurgical smelting process, can contain environmentally hazardous materials and must be analyzed for elemental composition before reuse. Quick and reproducible analyses of all the oxides in the slag are needed to control slag quality as well as alloy quality during the smelting process. WDXRF is an excellent technology to accomplish this analysis.

Geology, Mining and Minerals

WDXRF instruments are employed in geology laboratories to evaluate materials and products with wide elemental coverage, wide concentration ranges and varied samples matrices.

Some examples include the analysis of samples at various stages during mineral processing for quality control, and optimization of the recovery rate.

XRF also has important applications in detecting penalty and waste elements in iron ore that dilute the overall grade of the ore, change the physical properties of iron and, impede the proper operation of the smelting facility.

Cement Manufacturing

XRF is used to perform elemental analysis on cement-making raw materials to ensure the concentrations for the major oxides are correct. If the raw materials are inappropriate, or if they are blended improperly, buildings and roads made from the concrete will have poor strength and durability.

Oxide	CaO	SiO2	Al2O3	Fe2O3	MgO	Na2O	K2O	SO3
Concentration	67.4	22.1	5.32	1.88	1.69	0.12	0.66	0.49

Typical clinker analysis result

Petroleum Industry

The demand for analysis of sulfur in fuels and oils is increasing as environmental regulations worldwide continue to tighten. Current fuel sulfur standards in some countries are already as low as 10 ppm, and other countries are likely to follow suit. WDXRF instrumentation can achieve these low levels of quantification with excellent precision. WDXRF is commonly used to validate the formulation of oil additives and to control for wear metals in the running process.

Precious Metals and Gemstones

EDXRF is a nondestructive tool to test the purity and composition of all precious metals. It can provide the exact karat weight and percentage of all elements within an item.

EDXRF is also used to determine the authenticity of colored gemstones and their geographical origin. Identification and quantification of characteristic combination of trace elements at different concentrations may allow tracking of a gemstone down to its location of origin. Similarly the presence of certain trace elements also helps to distinguish between a valuable naturally formed gemstone and a worthless synthetic crystal.

Polymers and Plastics

XRF is the best method for the analysis of trace elements in polymers. Additives such as plasticisers, lubricants, stabilizing agents, neutralizers, antioxidants, pigments, as well as catalytic agents, are used to make polymers. XRF is an important process control tool to evaluate the presence of these agents in the finished product. Elements, including Al, P, Cl, Ti and Fe are typically analyzed between 5 and 100 ppm.

Glass and Ceramics, Refractories

Most glass is composed of silica, carbonate and sulfate, lime, and other types of oxides like alumina or magnesia. WDXRF analysis can be used to confirm that each ingredient is present in the correct percentage to impart specific physical properties to the glass.

Semiconductor, Thin Films, Coatings

XRF can be used to simultaneously measure all the layers in magnetic media for in-line process control and quality assurance. It also has applications in measuring metal coatings and analyzing layers in glass.

Environment, RoHS and WEEE Screening

High-resolution EDXRF instruments with large sample changers are ideal for analysis of toxic metals in the air resulting from leaks or spills of petroleum or other toxic products. EDXRF can be used to evaluate components in waste and sludge for recycling and reuse.

Restriction of Hazardous Substances = **RoHS**
Waste Electrical and Electronic Equipment = **WEEE**

Paints and Chemicals

Elemental analysis using WDXRF instrumentation validates the integrity, conformity and homogeneity of paints and coatings to be certain they can be applied successfully, as well as to test ink and toner quality.

Forensics

EDXRF is an important tool for the crime lab.
Forensic evidence such as gunshot residue on fabrics can be identified with elemental analysis. EDXRF is also routinely used to analyze glass chips, metals, and unknown materials.

Food

Food and chemical products contain major and trace elements and contaminants which can be detected with XRF. One important application is monitoring nutritional additives to powdered milk. Milk powder can be measured directly to confirm minerals are present in the appropriate quantities for quality control and compliance to local regulations.

About the Author

Raphael Yerly

Raphael Yerly works as a Senior Product Specialist at Thermo Fisher Scientific within the Marketing department of Thermo Scientific Laboratory Analyzers, based in Ecublens, Switzerland. He was born and educated in Switzerland but worked in Germany and the USA before graduating.

Raphael has been working with both X-Ray Fluorescence and X-Ray Diffraction equipment in a variety of application fields, including cement production, ore beneficiation and food quality control. He has traveled around the world to develop analytical methods that improve production processes and have a positive impact on the ecological footprint of the industry.

Raphael's motto in life is to make sure we use our limited resource in the best possible way.

Debbie Schatzlein, author of XRF in the Field: XRF Technology for the Non-scientist, contributed to sections of Chapter 1.

Company Intro

About Thermo Fisher Scientific

Thermo Fisher Scientific is the world leader in serving science. Our mission is to enable our customers to make the world healthier, cleaner and safer. With revenues of $17 billion, we have approximately 50,000 employees and serve customers within pharmaceutical and biotech companies, hospitals and clinical diagnostic labs, universities, research institutions and government agencies, as well as in environmental and process control industries. We create value for our key stakeholders through four premier brands, Thermo Scientific, Life Technologies, Fisher Scientific, and Unity Lab Services, which offer a unique combination of innovative technologies, convenient purchasing options and a single solution for laboratory operations management. Our products and services help our customers solve complex analytical challenges, improve patient diagnostics and increase laboratory productivity.

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