Introduction to PIXE

PIXE-PAN Summer Science Program
Notre Dame
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Particle

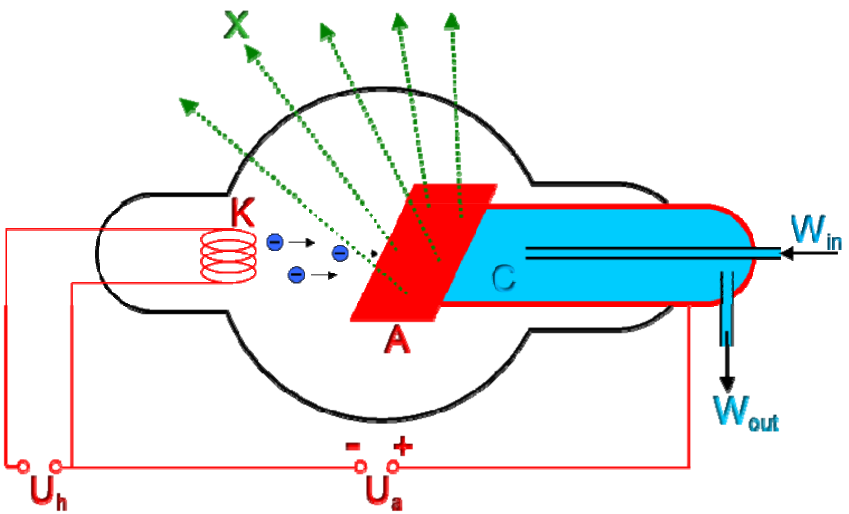
Induced

X-Ray

Emission

X-rays

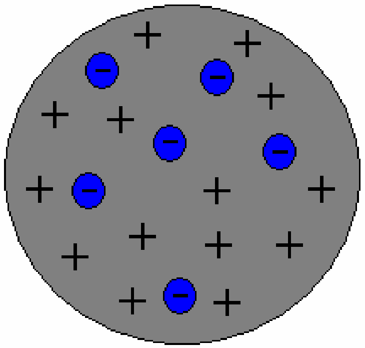
- "Discovered" in 1895 by Wilhelm Conrad Röntgen (Roentgen)
- He coined the phrase X-rays (X for unknown)
- Won the 1st Nobel prize in Physics, 1901, for this work.



- Part of the electromagnetic spectrum, wavelengths in the range of 10 to 0.01 nm.

Model of the Atom

- Thompson (1904)– “Plum Pudding”, electrons (discovered by Thompson in 1897) imbedded in a large sphere of positive charge, much like the plums in a pudding.



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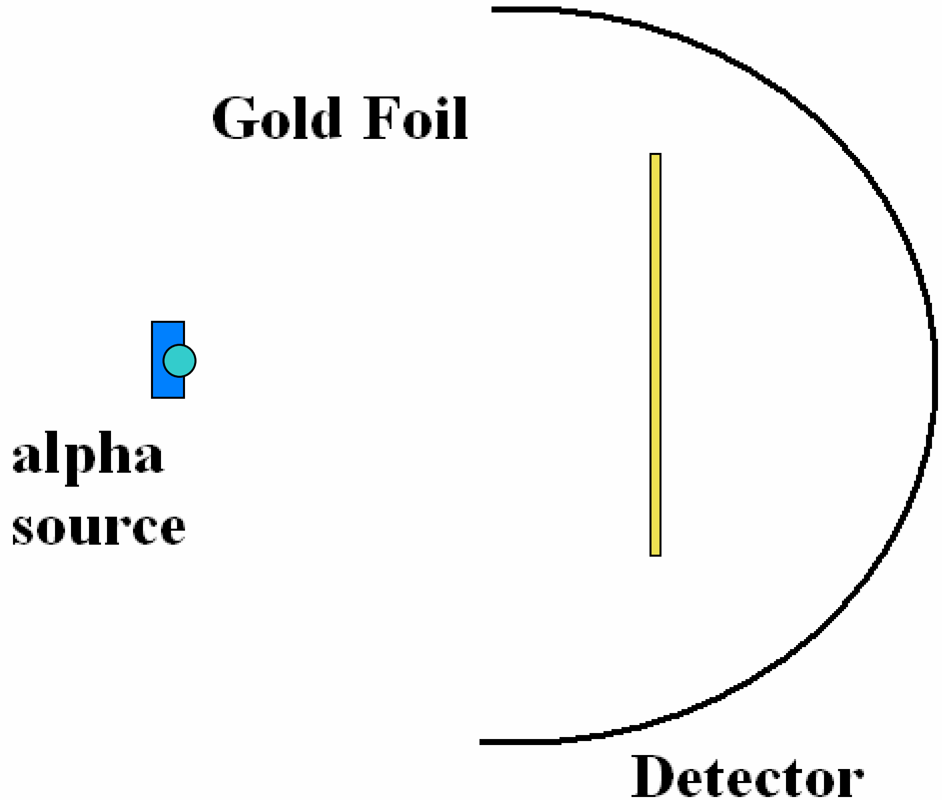
Rutherford Backscattering

- Geiger and Marsden (undergraduate) 1908 experiments with alpha particles striking a gold foil

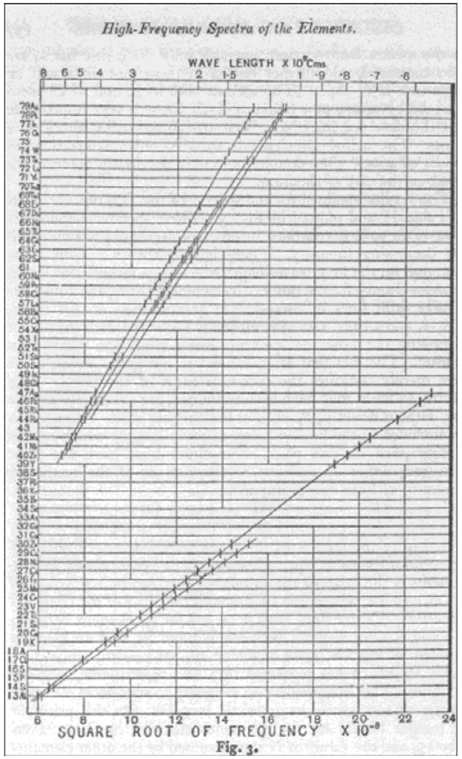


Rutherford Backscattering

- Rutherford (1911) – To explain backscattered alpha particles, theorized that the atom must have a small, heavy positively charged nucleus at its center, with very small, very light electrons in orbits about the nucleus.

Moseley's Law

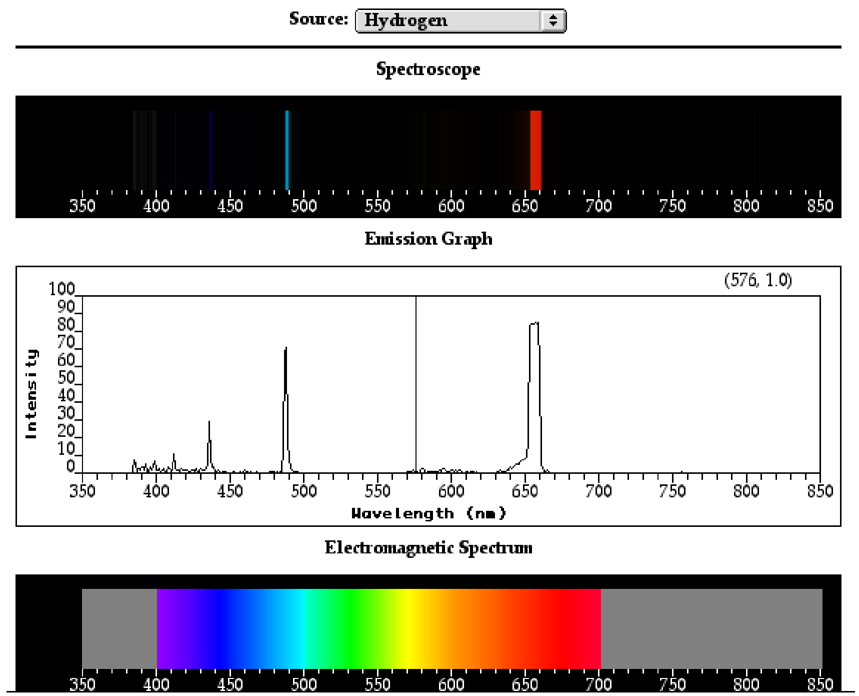
- Henry Moseley (1913) – studied X-rays given off by a variety of materials
- Discovered the relationship between atomic number and the frequency of the X-rays given off



THE HIGH FREQUENCY SPECTRA OF THE ELEMENTS
By H. G. J. Moseley, M. A., *Phil. Mag.* (1913), p. 1024

Hydrogen Spectrum

- It was known (1880s) that hydrogen gave off certain, particular colors of light when excited.
- Why only certain colors?
- Balmer (1885), Rydberg (1888) – empirical relationship

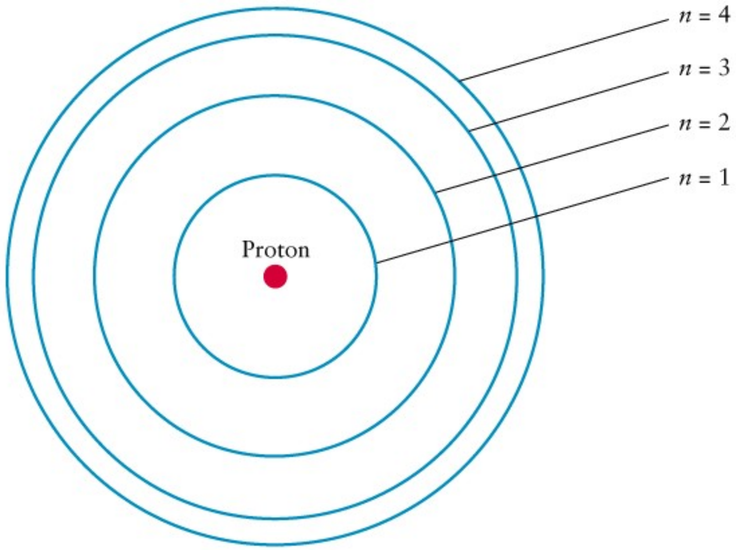


$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \quad n = 3, 4, 5\cdots$$

http://www.cfa.harvard.edu/seuforum/galSpeed/

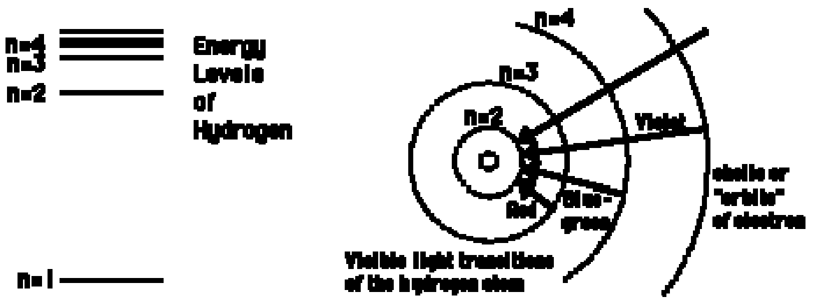
Bohr Model

- Neils Bohr (1913) – proposed a planetary model (electrons in circular orbits), but only certain orbits were allowed (quantized).
- Orbits labeled by principle quantum number n.



Bohr Model

- Explains the observed spectrum of hydrogen (as well as other features)
- When hydrogen is excited, electrons "jump up" to higher energy orbits

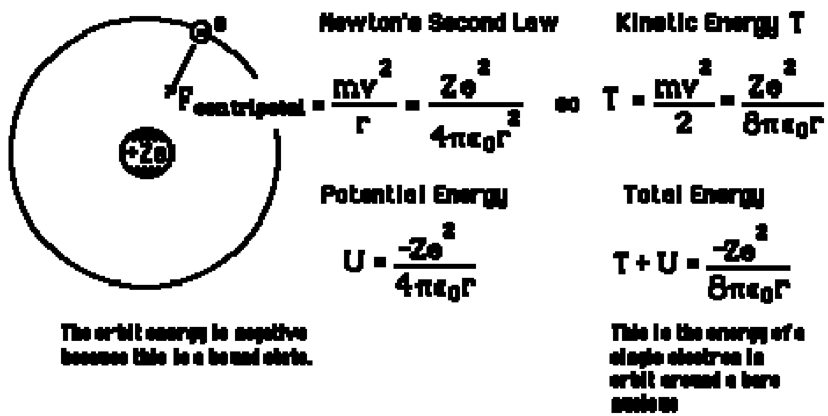


from HyperPhysics, copyright 2005, C. R. Nave, Georgia State University

- When the electrons "fall back" to lower energy orbits, energy is given off as photons (light).

Classical Orbital Energy

- The energy of the electron in a classical orbit can be calculated from the Coulomb force being the agent of the centripetal force holding the electron in orbit.



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Quantized Angular Momentum

- Quantization of angular momentum (orbits with standing wave patterns) leads to only certain orbits allowed, with the energy of orbit depending upon the atomic number Z (the number of protons in the nucleus), and n, the principle quantum number.
- NOT an entirely accurate description, but a good model for understanding basic concepts.

$$E_n = -\frac{Z^2 m e^4}{8 n^2 h^2 \varepsilon_0^2} = -13.6 \frac{Z^2}{n^2} (\mathrm{eV})$$

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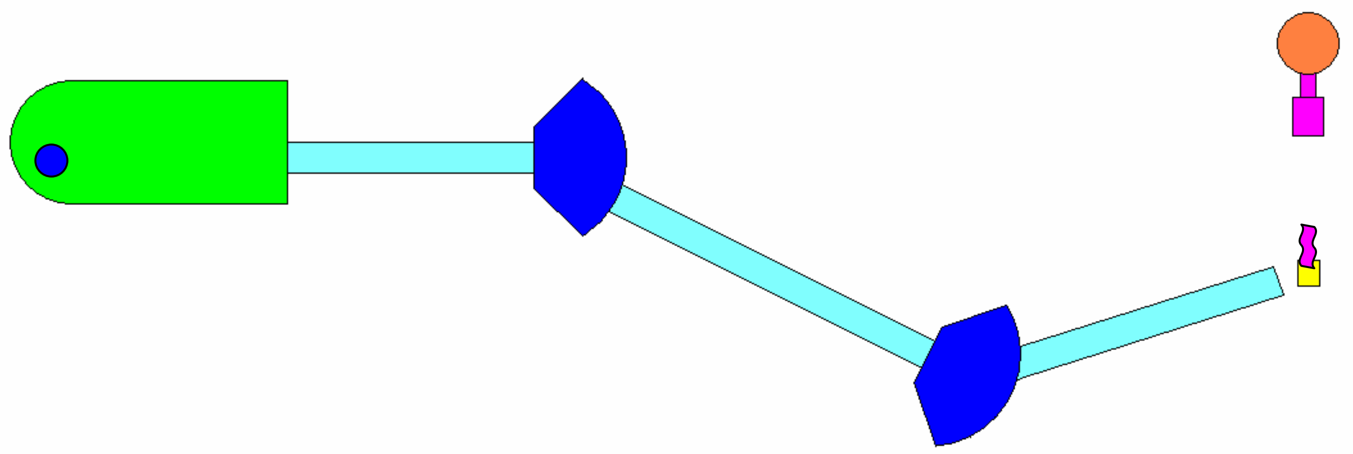
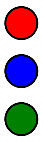
Experimental Layout

- Protons are accelerated by the KN Van de Graaff particle accelerator, momentum analyzed to select the correct energy, then directed to target. X-rays are emitted by atoms in the target during collisions with the protons, and detected with a Si(Li) detector.

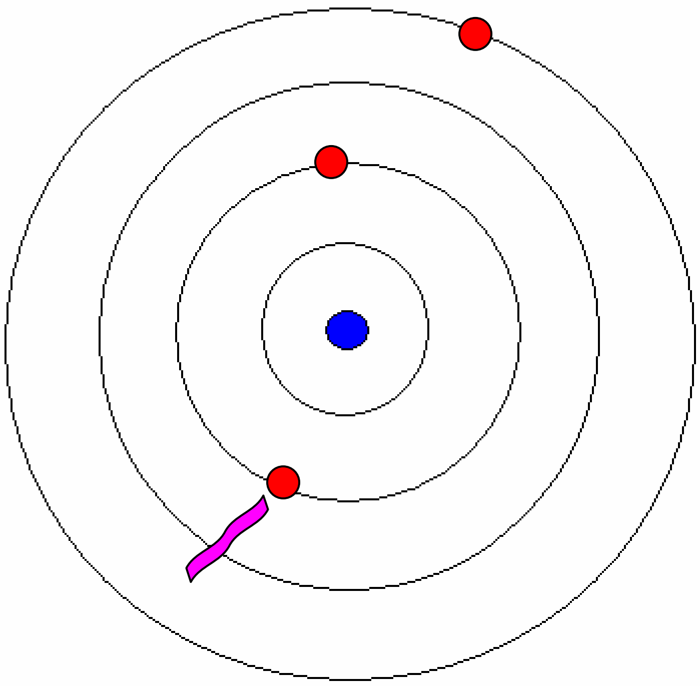


Electron in orbit around the nucleus,

In quantized energy level.



Protons from the accelerator impinge upon the target.



The atom spontaneously de-excites, releasing the excess energy in the form of an X-ray.

Interaction with the passing proton excites the electron into a higher energy orbit.

Material Analysis

- Imagine a target we wish to analyze, which is comprised of unknown material.
- If we can measure the energies of the X-rays given off by our targets when we strike them with protons, we should be able to determine the atomic number Z of the target material, as well as the energy levels involved.

$$E_n = -\frac{Z^2 m e^4}{8 n^2 h^2 \varepsilon_0^2} = -13.6 \frac{Z^2}{n^2} (\mathrm{eV})$$

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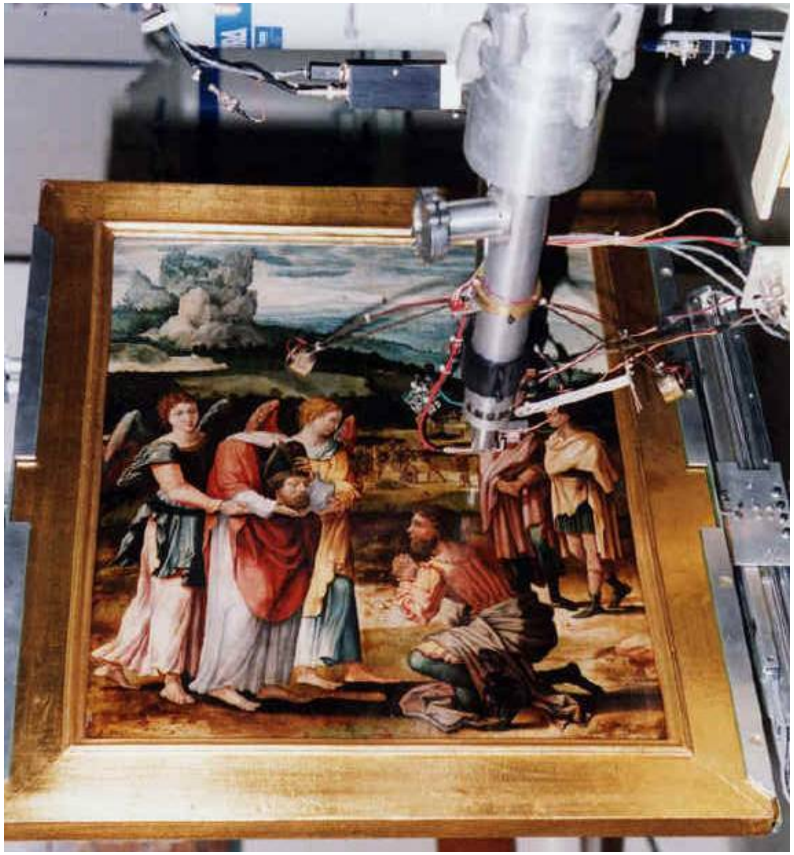
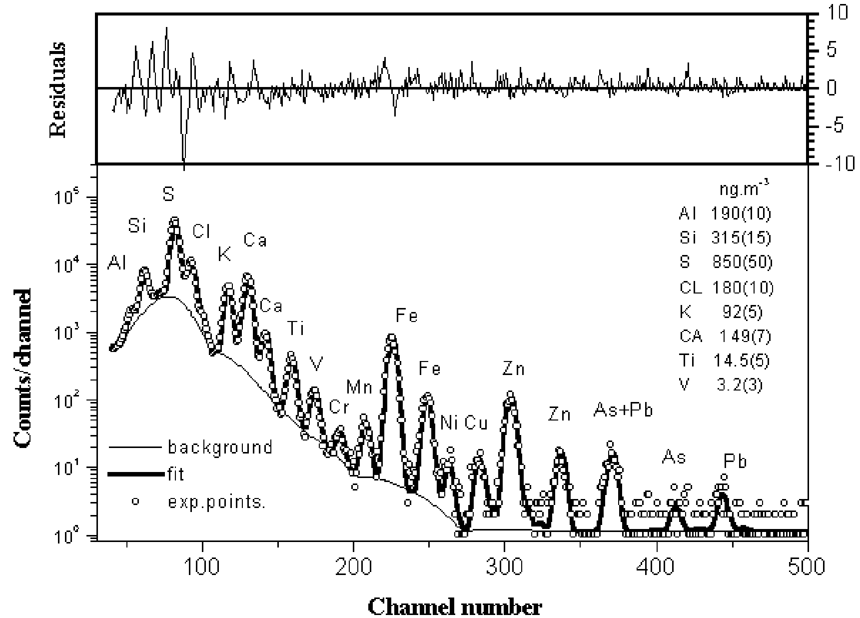
Artwork Analysis

- An example of this type of analysis is the use of PIXE to examine artwork. Provenance can often be established by examining the pigments used in the paints. Forgeries can easily be distinguished by the modern components in the pigments.



Trace Element Analysis

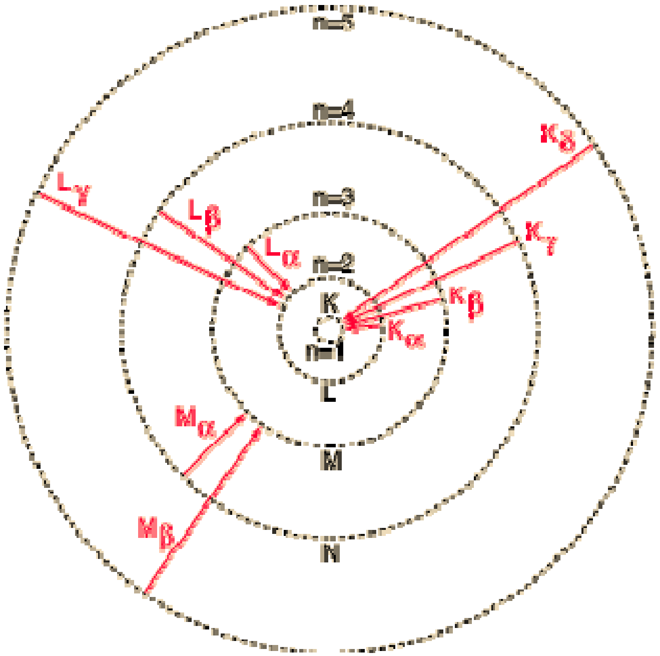
- Here is a PIXE measurement of aerosols collected on filter paper, showing airborne trace elements.



http://omega.ujf.cas.cz/CFANR/pixe.html

Some Nomenclature

- The orbits (or shells) are most often referred to by a letter rather than the principle quantum number (n=1 is the K shell, n=2 is the L shell, etc.)
- Transitions are labeled K_{α}, K_{β}, etc. as shown.



X-ray Energies

- A database is maintained at the National Institute of Standards and Technology (NIST) which contains all known theoretical and experimental values for X-rays from all the elements.
- http://physics.nist.gov/PhysRefData/XrayTrans/index.html