Trace Element Analysis of Geological, Biological & Environmental Materials By Neutron Activation Analysis: An Exposure

ILA PILLALAMARRI

Earth Atmospheric & Planetary Sciences
Neutron Activation Analysis Laboratory
Massachusetts Institute of Technology
Cambridge, MA 02139

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Session 2

- **Review of some concepts from Session 1**
- **Gamma Detection – Instrumentation Concepts**
- **Neutron Activation Analysis – Applications: Trace Element Analysis of Geological, Biological, Environmental and Industrial Materials**
- **Presentation and report assignment (one per student): Epithermal, Delayed Neutron, Prompt Gamma Neutron Activation Analysis Essay (Report)**

Gamma Spectrometer

- An irradiated material is radioactive emitting radiations – α, β, γ, ………
- For Neutron Activation Analysis – usually gamma radiation is selected.
- **Gamma spectrometer** is the detection system that measures gamma ray intensity.

Gamma Spectrometer

Gamma spectrometer system for measuring the gamma-ray activity of an irradiated material consists, typically, of

1)Detector

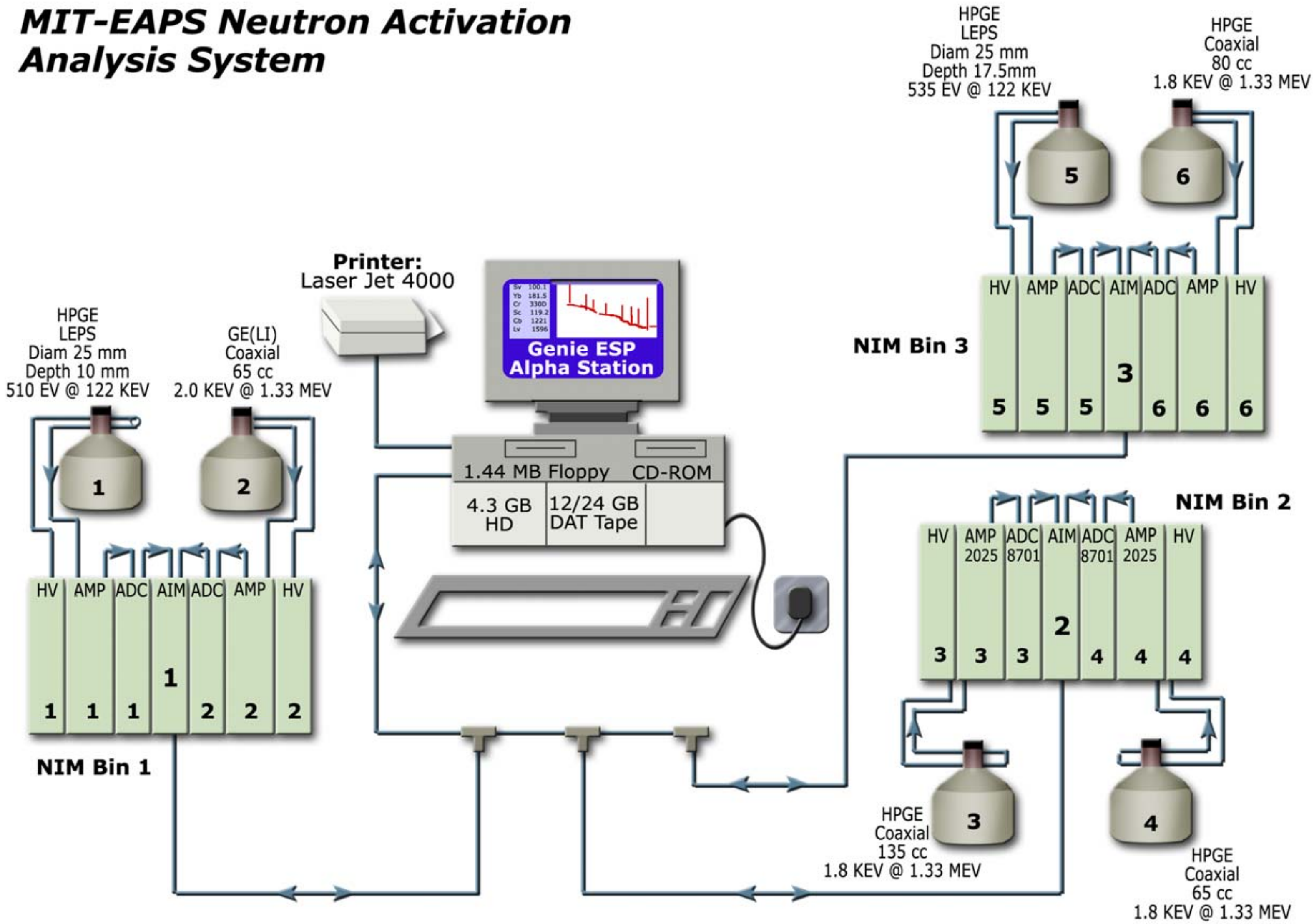
2)Amplifier

3)Multi Channel Analyzer

4)Computer & peripherals

This is shown pictorially: (Figure 1)

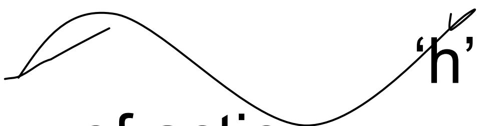
MIT-EAPS Neutron Activation Analysis System



Gamma Detector

- Gamma rays are photons – meaning …

Max Planck introduced the concept of particles and waves in 1901.



'h' is Planck's constant describing the quantum of action.

The frequency of oscillation of this wave is ν . $h\nu$ is packet of quantum energy of the electromagnetic radiation, and is termed photon. Photons have no mass. Gamma-rays are photons. They have no mass.

Gamma detector…

The energy of nuclear radiation is converted into an electrical signal by a device - the nuclear radiation detector.

The three major categories of gamma detectors used in Neutron Activation Analysis are:

1)Scintillators : NaITl), CsF, ZnS(Ag)

2)Semiconductors : Si, Ge, CdTe, GaAs

3)Gas Filled : He, Air, H_2, N_2

Gamma detector…

- The nuclear radiations emanating from the irradiated material will cause ionization in the detector medium by means of charged particle products of their interactions.

- The scintillators and the semiconductors have energy discrimination capacity better than the gas filled detectors.

Gamma detectors…

Scintillation detector consists of a phosphor, photocathode photo- multiplier tube and a charge collector. The kinetic energy of the gamma radiation causes ionization, the phosphor converts the ionization into light pulses. The light photons, when they strike the photocathode, emit Photoelectrons. The photomultiplier tube accelerates and multiplies the photoelectrons. This negative charge collected as an electrical signal is proportional to the incident radiation energy.

Schematic diagram of NaI(TI) scintillation detector optically coupled to a photomultiplier was shown in Chapter IV : Instrumentation in neutron activation analysis by P. Jagam and G. K. Muecke p 77, Figure 4.2,Mineralogical Association of Canada Short Course in Neutron Activation Analysis in the Geosciences, Halifax May 1980, Ed: G. K. Muecke

Gamma detectors…

Semiconductor detector crystals are good insulators without any free charge carriers at absolute zero temperatures.

Schematic diagram of the configuration of a planar and coaxial Ge(Li) detector crystal was shown in Chapter IV : Instrumentation in neutron activation analysis by P. Jagam and G. K. Muecke p 77, Figure 4.3,Mineralogical Association of Canada, Short Course in Neutron Activation Analysis in the Geosciences, Halifax, May 1980, Ed: G. K. Muecke

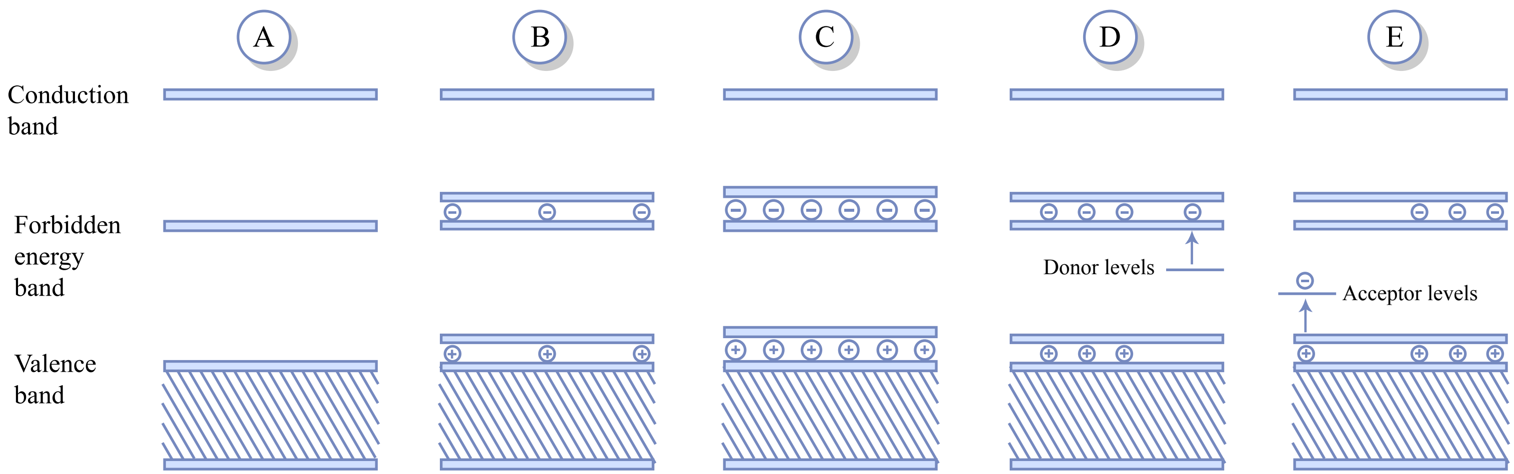
The nuclear radiations incident on the crystal initiate ionizations by creation of electrons (negative charge) and holes (positive charge). An electric field is created by applying high voltage to the electrodes mounted on opposite sides of the detector crystal. The charge carriers get attracted to the electrodes of opposite polarity because of the electric field. The charge collected at the electrodes is proportional to the energy lost by the incident radiation.

Chapter IV : Instrumentation in neutron activation analysis by P. Jagam and G. K. Muecke p 77, Figure 4.3
Mineralogical Association of Canada
Short Course in Neutron Activation Analysis in the Geosciences, Halifax May 1980,
Ed: G. K. Muecke

Gamma detectors…

Neutron Activation Analysis

Properties of semiconductor materials



KEY:- Shading indicates valence band fully occupied by electrons. Arrows indicate direction of ionization of electrons to or from impurity atoms.

Schematic behaviour of a semiconductor crystal

A: Perfect (intrinsic) semi-conductor at 0 K, the valence band is fully occupied by electrons, and the conduction band is empty, in this state the semiconductor cannot conduct.

B: Semiconductor at 77 K; vast reduction in thermal ionization to conduction band.

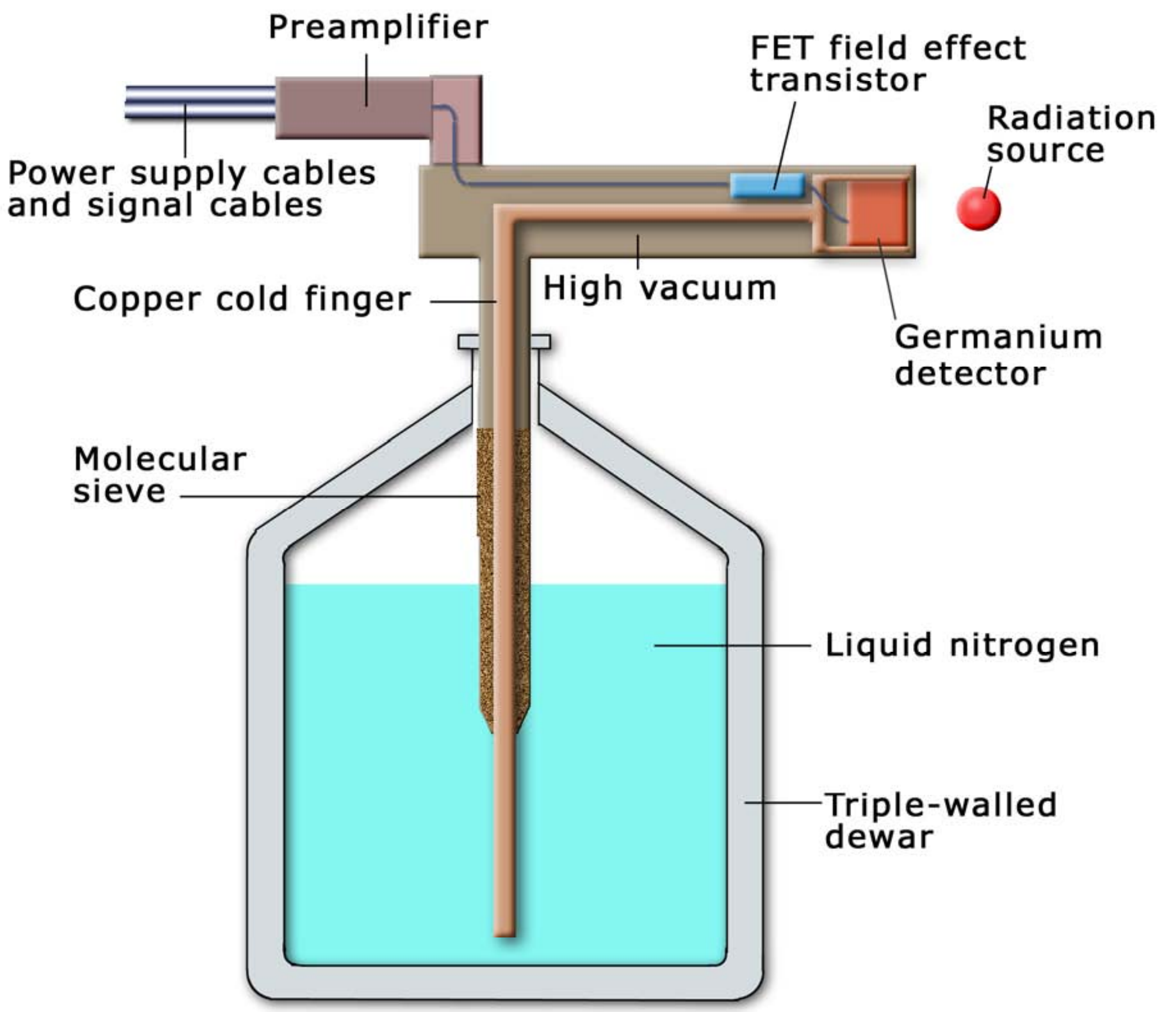
C: Semiconductor at room temperature; significant thermal excitation of electrons from valence to conduction band; in this state the semiconductor will conduct.

D: Effect of 'donor' atom impurities in *n*-type semiconductor material.

E: Effect of 'acceptor' atom impurities in *p*-type semiconductor material.

Reference: A Handbook of Silicate Rock Analysis by P. J. Potts, Blackie Chapman and Hall New York page 406 Figure 12.7

Gamma Spectrometer



Germanium Detector Configuration

Gamma Spectrometer…

An excellent diagram, showing **a cutout view of Ge detector** and cryostat assembly , providing all the details of detector assembly, the cooling rod, was given in Chapter 2.1.5: Detector mounting, Figure 2.4, A drawing of a Ge detector assembly (by courtesy of EG&G ORTEC) page 84; Figure 2.5 **Photograph of a disassembled Ge detector** (by courtesy of Canberra Industries), page 85; Figure 2.6 **Photograph of a Ge detector assembly, showing the preamplifier components** (by courtesy of Canberra Industries), page 95 were given in the below reference.

Reference: Gamma- and x-ray spectrometry with semiconductor detectors by K. Debertin and R. G. Helmer, North Holland Elsevier, New York, 1988.

Reference: Chapter 2.1.5 Detector mounting, Figure 2.4, page 84, Gamma- and x-ray spectrometry with semiconductor detectors by K. Debertin and R. G. Helmer, North-Holland Elsevier Science New York, 1988

Interaction of gamma radiation with matter

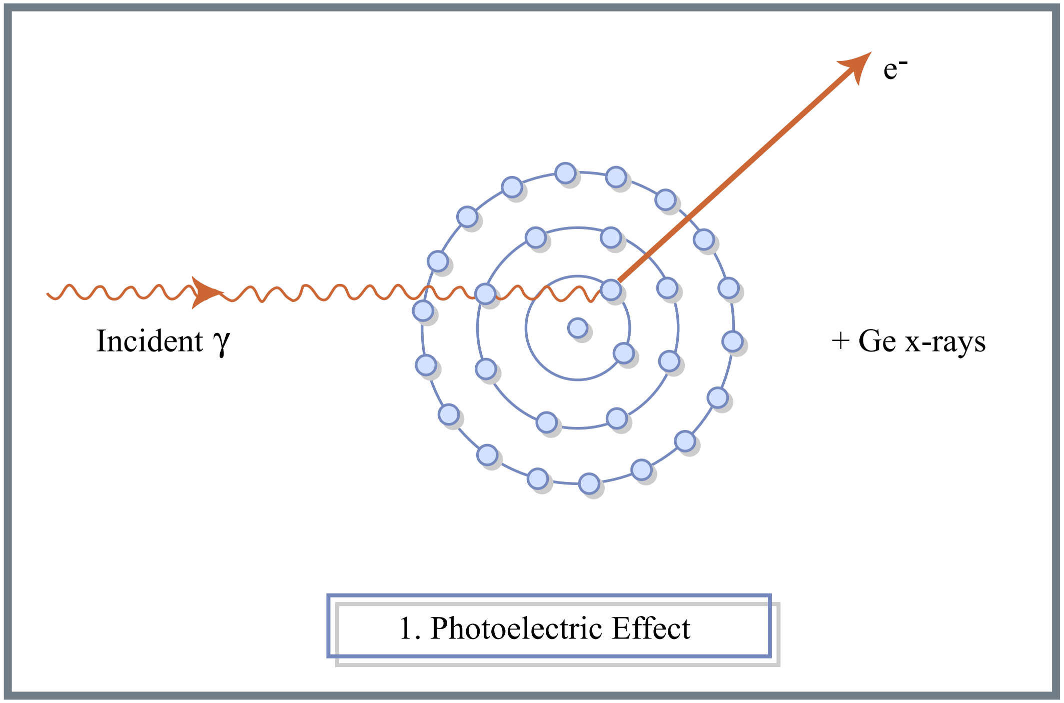
Gamma radiation interacts with matter causing ionization in matter by three principal processes:

1)Photoelectric effect
2)Compton scattering
3)Pair production

Reference: Chapter 12.6 Interaction of gamma-radiation with Ge detectors, A Handbook of Silicate Rock Analysis by P. J. Potts, Blackie Chapman and Hall New York

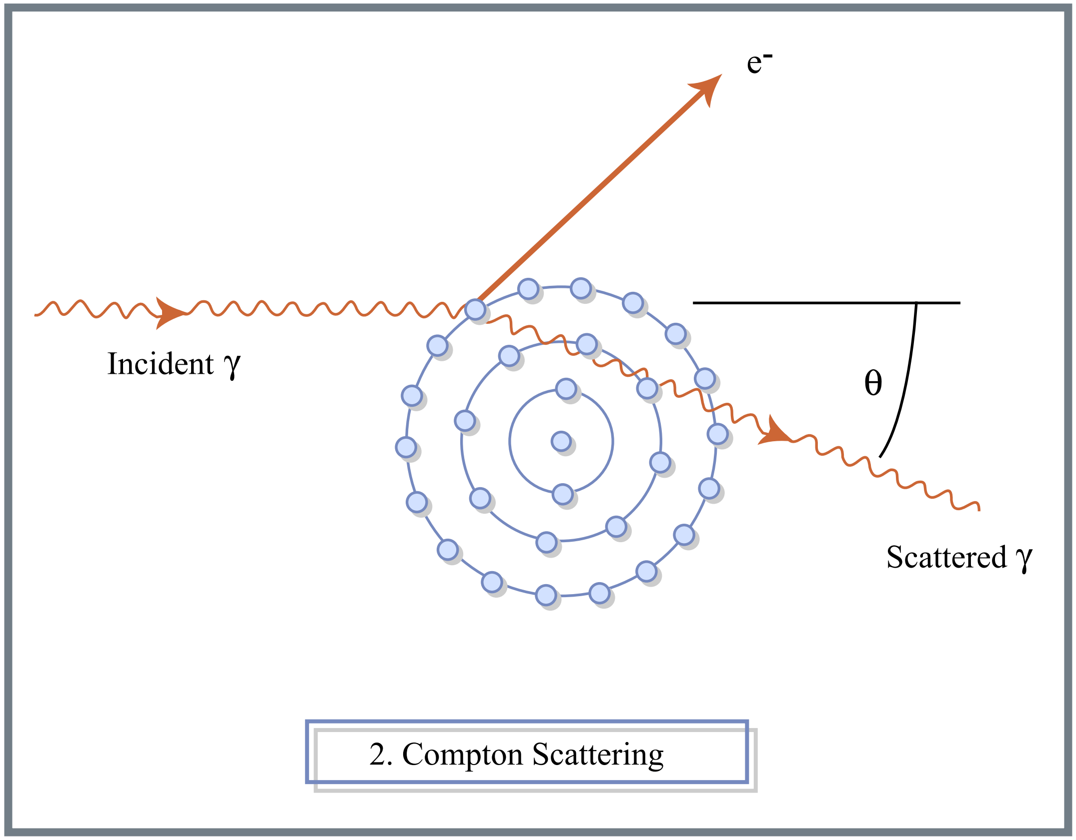
Interaction of gamma radiation with matter

- **Photoelectric effect** is the interaction between the incident gamma-ray and orbital electron of the atom of the detector crystal. The energy of the gamma-ray is completely transferred to the electron. The electron overcomes the ionization potential by utilizing part of the transferred energy, the remainder becomes the kinetic energy of the electron. Photoelectric interaction predominantly takes place with orbital shells close to the nucleus (K-shell). The vacancy created by the ionized electron gets filled by an electron falling from the next higher shell simultaneously emitting the characteristic K X rays of Ge. Thus characteristic X rays of the detector material are emitted when photoelectric interaction takes place.



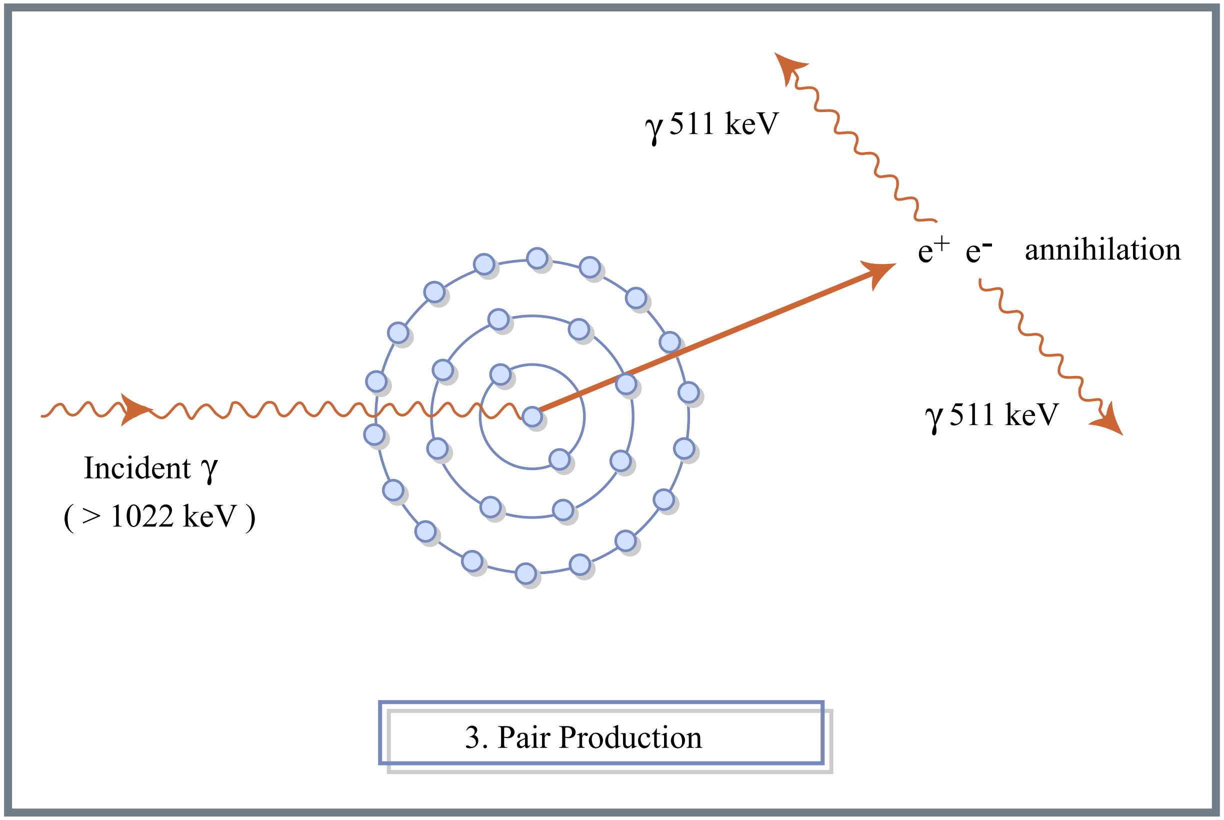
Interaction of gamma radiation with matter…

Compton scattering is the interaction between the incident gamma ray and an outer orbital electron in which only part of the gamma energy is transferred to the electron and the the remainder is reirradiated as a lower energy gamma ray (scattered inelastically) preserving the total energy and momentum. In a head-on collison maximum transfer of energy occurs following which the secondary gamma ray is emitted at 180 to the first. The secondary gamma photon can itself interact by further compton or photoelectric interactions. However, there is a probability that this gamma will itself escape from the detector. Compton scattering in the detector is the main cause of the high background contnuum below the energies of the principal gamma photo peaks recorded on Ge detectors.



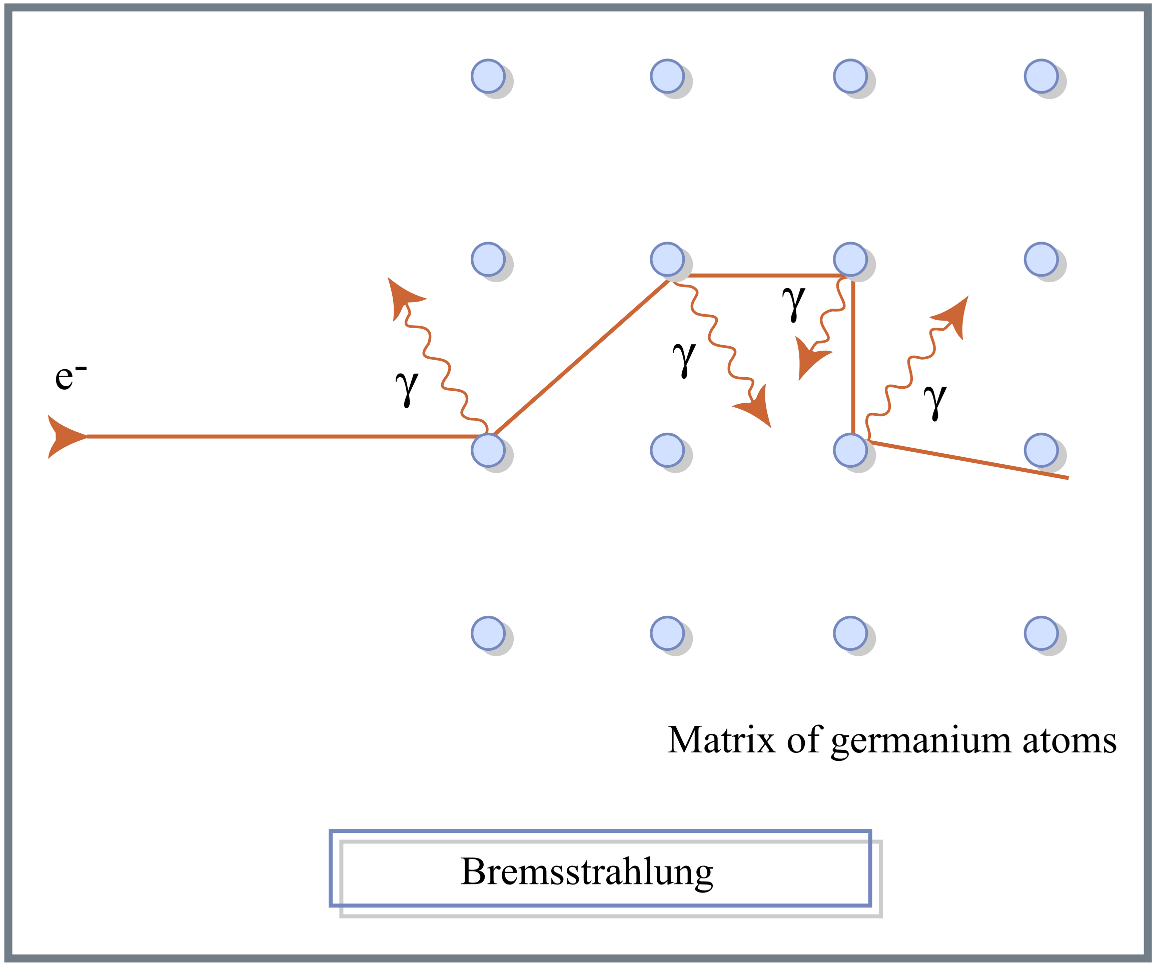
Interaction of gamma radiation with matter…

Pair production interaction becomes significant when incident gamma ray energies exceed 1.022 MeV. The interaction of the incident gamma-ray in the strong electromagnetic field surrounding the nucleus results in complete transmutation of gamma photon energy into an electron – positron pair. The particles, which are very short lived, lose their kinetic energy very quickly, by further collison with the atoms of the detector and then spontaneously annihilate to generate two 511 keV gamma –rays emitted at 180 degrees to one another.



Interaction of gamma radiation with matter…

- **Bremsstrahlung continuum** radiation is also created in the detector by the deceleration of energetic electrons within the electrostatic fields surrounding the nucleus. Bremsstrahlung radiation can randomly contribute to the continuum spectrum.



Reference: Chapter 12.3.6 Bremsstrahlung, page 405,
A Handbook of Silicate Rock Analysis by P. J. Potts,
Blackie Chapman and Hall New York

Interaction of gamma radiation with matter…

The predominant interaction of incident gamma-rays of energies in the range 100 – 4000 keV is Compton scattering, Below this energy, the photoelectric effect is significant. Pair production Interaction becomes predominant above 5000 keV.

The graphical representation was shown in the reference:
Chapter 12.6: Interactions of gamma-rays with Ge detector,
Figure 12.16, page 412, in A Handbook of Silicate Rock Analysis by P. J. Potts, Blackie Chapman and Hall New York 1987.

Gamma-ray Spectra

Gamma-ray spectra catalogs are available in book format, CD-ROM format and on the web. Some references are:

1)An excellent book with figures of gamma-ray spectra of isotopes of almost all elements.
Kernforschungsanlage Julich GmbH, Betriebsabteilung Dekontamination,
Katalog von Ge(Li)-y-Spektren Band 2 von G. Zaddach, July 14, Neuauflage Okt. 1979
ISSN 0366-0885.

2)CD-ROM :
Gamma-ray Spectrum Catalogue Ge(Li) & Si(Li) Gamma-ray Spectra,
R. G. Helmer, R. J. Gehrke, J. R. Davidson,
Idaho National Engineering and Environmental Laboratory, 1999.
id.inel.gov/**gamma**/data1.html

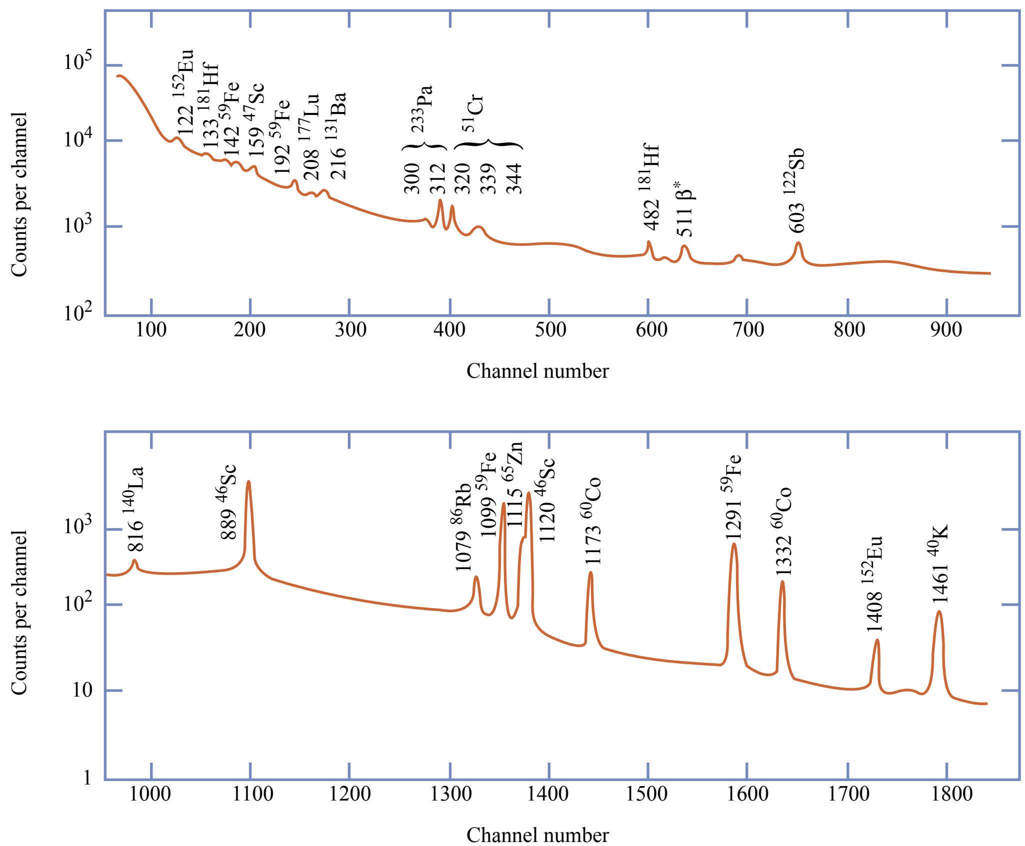
3)On-Line
http://id.inel.gov/**gamma**/data1.html

Reference:
Kernforschungsanlage Julich GmbH, Betriebsabteilung Dekontamination,
Katalog von Ge(Li)-y-Spektren Band 2 von G. Zaddach, July 914, Neuauflage Okt. 1979 ISSN 0366-0885, page 219

Gamma Spectrum - Multielement

A multi-element gamma-ray spectrum of a food material is shown below:
Reference:
Multielement analysis of food spices by instrumental neutron activation analysis,
P. Ila and P. Jagam,
Journal of Radioanalytical and Nuclear Chemistry, 57 (1980) 205-210.

Typical Gamma-ray Spectrum of Irradiated Cayenne after a Delay of 10 d



After P. ILA, P. JAGAM: Multielement Analysis of Food Spices

References

1. Radiation detection and measurements
G. F. Knoll,
John Wiley & Sons New York 1979
2. Gamma and X-ray spectrometry with semiconductor detectors
K. Debertin and R. G. Helmer,
North Holland New York 1988
3. Chapter IV : Instrumentation in neutron activation analysis,
P. Jagam and G. K. Muecke, pages 73-108,
Mineralogical Association of Canada
Short Course in Neutron Activation Analysis in the Geosciences,
Halifax May 1980, Ed: G. K. Muecke

References …

4. Chapter 12:Neutron Activation Analysis,
pages 399-439 in Handbook of silicate rock analysis,
P. J. Potts,
Blackie Chapman and Hall New York 1987.
5. Multielement analysis of food spices by instrumental neutron activation analysis,
P. Ila and P. Jagam,
Journal of Radioanalytical and Nuclear Chemistry,
57 (1980) 205-210.

Session Break