In-situ materials characterization for planetary exploration

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Outline

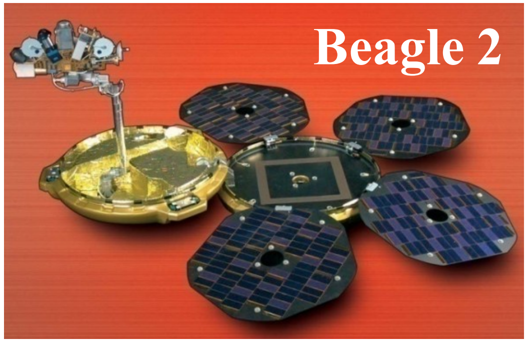
- *Motivation*
- *Instruments on lander*
  - *Working principle*
  - *Recent development*
    - XRD/XRF (CheMin)
    - Portable XRD/XRF (Terra)
- *Instruments on orbiter*
  - *Working principle*
  - *Recent development*
    - Portable FT-IR

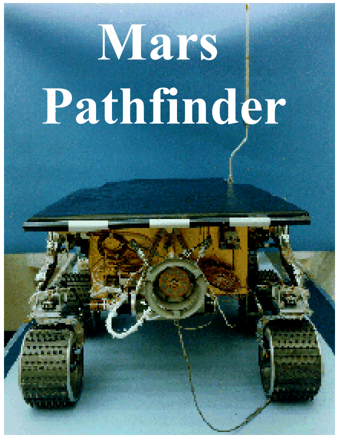
Motivation

- *In situ analyses of surface rocks and soils*
  - Investigate the structure and composition at the site by *analysis tools integrated into tele-operated robot*
- *Benefits:*
  - Survey before planning human to a site of interest
  - Acquire information for decisions in real time at the site with remote control

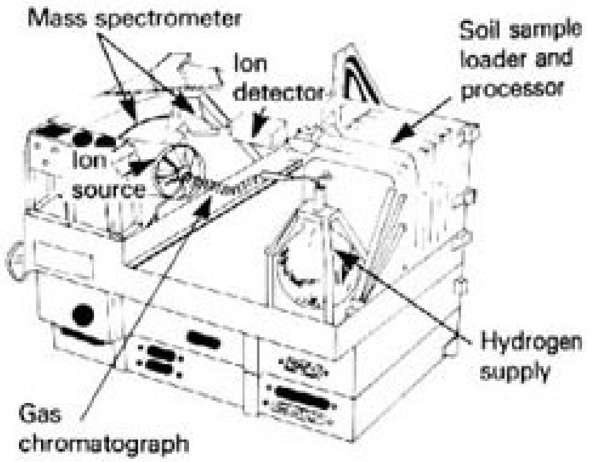
Instruments deployed by space agency

- Lander
  - Gas Chromatography Mass Spectrometry
  - X-Ray Fluorescence Spectrometry
  - Alpha Proton X-Ray Spectrometry
  - X-Ray Diffraction Spectrometry





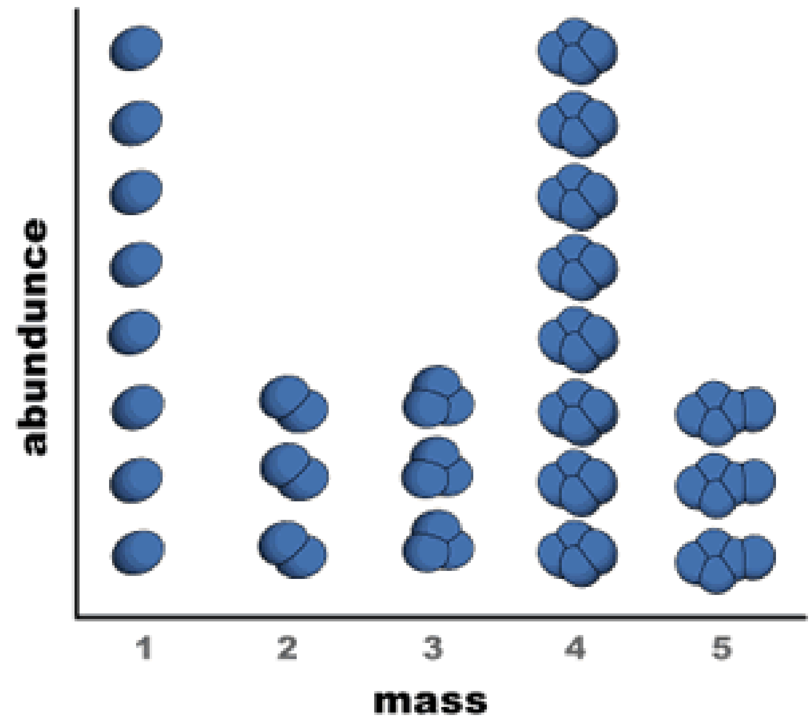
Gas Chromatography Mass Spectrometry



- Identify organic molecule or atmosphere composition (NASA Viking 1 - 1976)
- GCMS setup
  - Gas chromatography (GC) separates chemical mixture into pure chemicals
  - Mass spectrometer (MS) identifies and quantifies the chemicals
  - Data from mass spectrometer is sent to a computer to plot mass spectrum

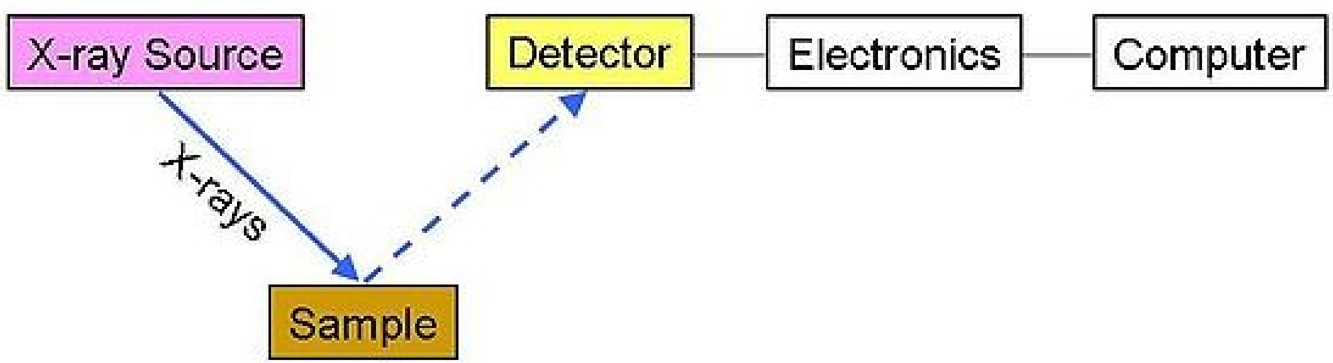
Principle of GCMS

- Decomposition of the pure molecules in MS, data is plot as mass spectrum
  - This observed spectrum is compared with published patterns of known decomposition that is stored in a fragmentation library to identify the organic molecule



X-Ray Fluorescence Spectrometry

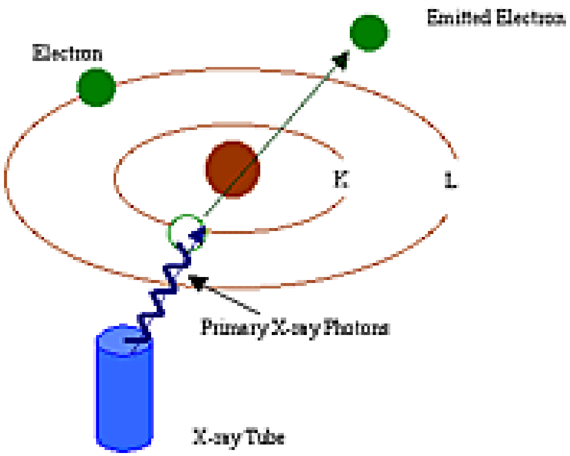
- Identify and determined concentration of elements: (NASA Viking 1 - 1976)
  - solid,powdered and liquid samples
- XRF setup

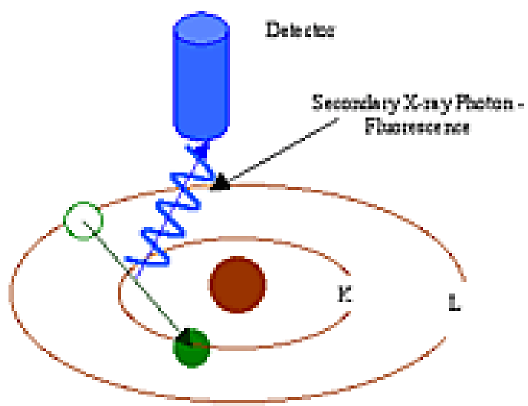


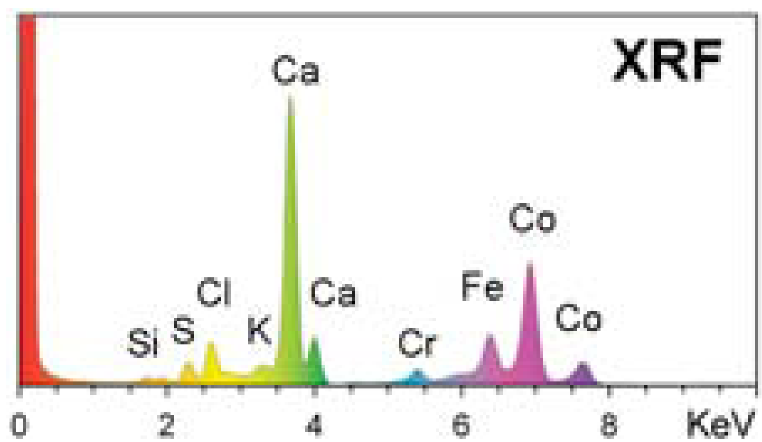
Principle of XRF

- Measures characteristics X-rays of fluorescent emission produced by a irradiated sample

$$\lambda = h \cdot c / E$$



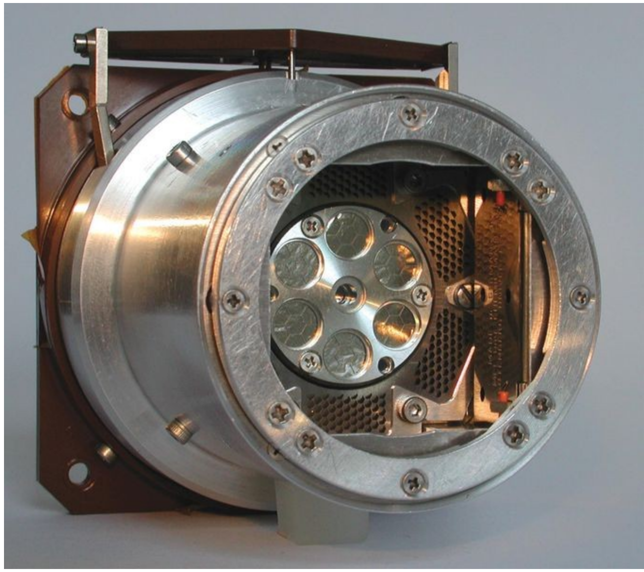




Alpha Proton X-Ray Spectrometry

- Analyses the chemical element composition of a sample (NASA Mars Pathfinder- 1996)
- APXS set up
  - Alpha particles sources irradiated on sample
  - Detector:
    - Scattered alpha particles
    - Emitted protons
    - Fluorescent X-rays

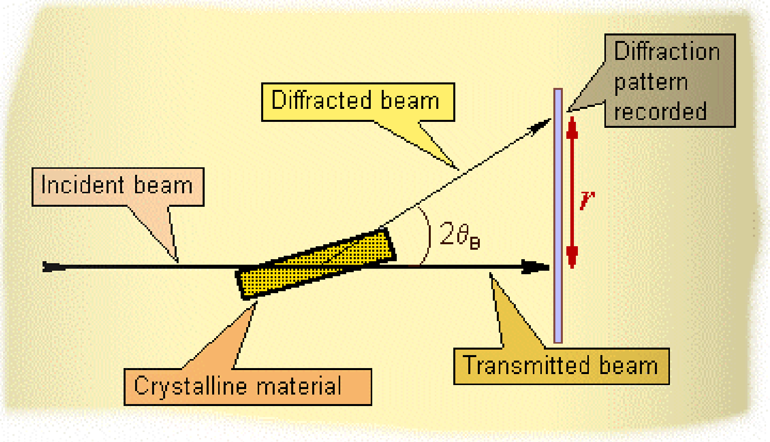
Principle of APXS



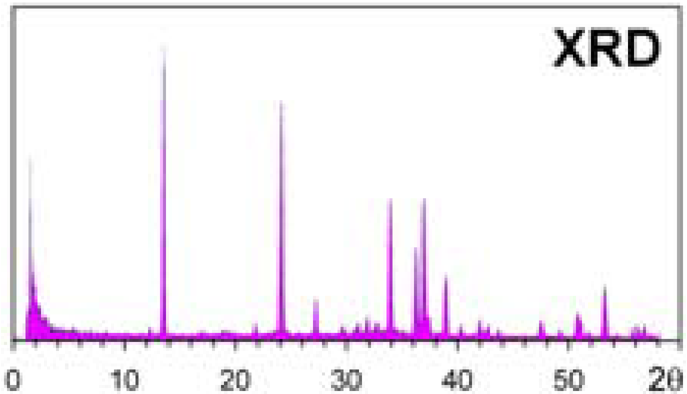
- Principle:
  - Based on interactions of alpha particles with matter:
    - Collision of alpha particles with nuclei
      - Elastic scattering of alpha particles by nuclei
      - Alpha particles absorbed by nuclei produce proton of certain energy by alpha-proton nuclear reactions
    - Collision of alpha particles with electrons of the atoms
      - Excitation of the atomic structure of atoms leading to the emission of characteristic X-rays

X-Ray Diffraction Spectrometry

- XRD the most comprehensive tool to identify crystal structure (ESA Beagle 2 - 2003)
  - Examine reflection of X-rays from a material at various angles.
    - X-rays were passed through slits to produce narrow beam, which fell on a material at centre of the spectrometer
    - Reflected (Diffracted) beam was measured in an charge coupled device (CCD)

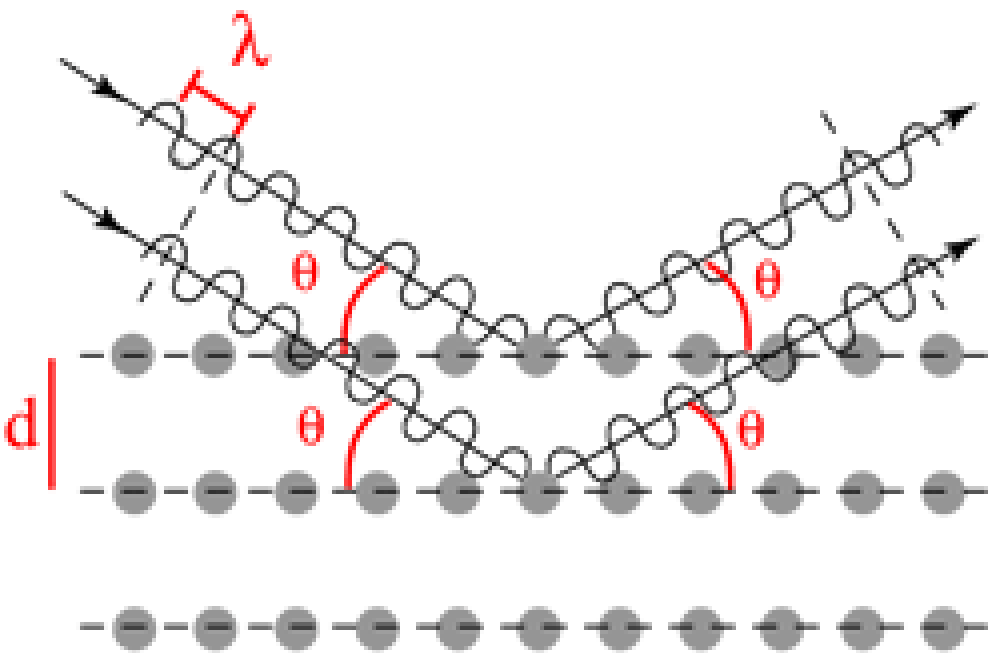


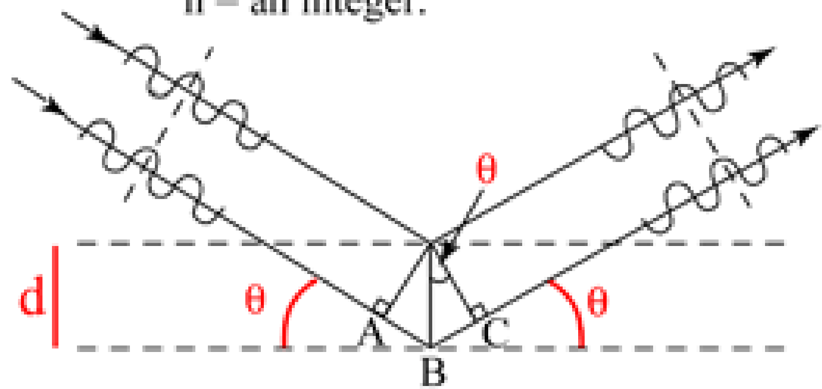
Principle of XRD



Bragg's law: $n \lambda = 2 d \sin \theta$

where
λ = wavelength of the X-ray,
d = interplanar spacing of the crystal,
θ = angle between the lattice plane and the X-rays,
n = an integer.





$\sin \theta = \frac{BC}{d}$ or $d \sin \theta = BC$

If $2d \sin \theta = (AB + BC) = n \lambda$, then constructive interference

Recent Development

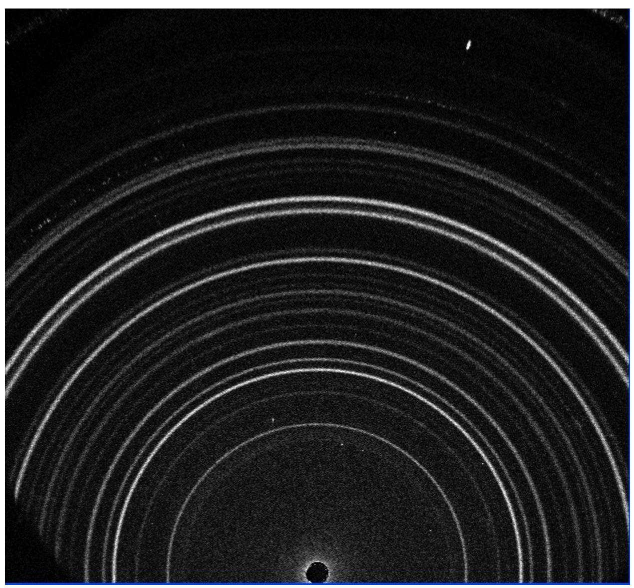
- To characterize a material completely, need to identify the composition and structure of a material
  - GCMS, XRF and APXS can determine the composition of the element
  - XRD can determine the structure of the material
- Integration of XRD and XRF
  - XRD/XRF (CheMin)
  - Portable XRD/XRF (Terra)

XRD/XRF (CheMin)

- CheMin developed (NASA Mars Science Laboratory rover to be launched in 2011)
  - Capable of getting the composition and the structure of the sample

XRD/XRF (CheMin)

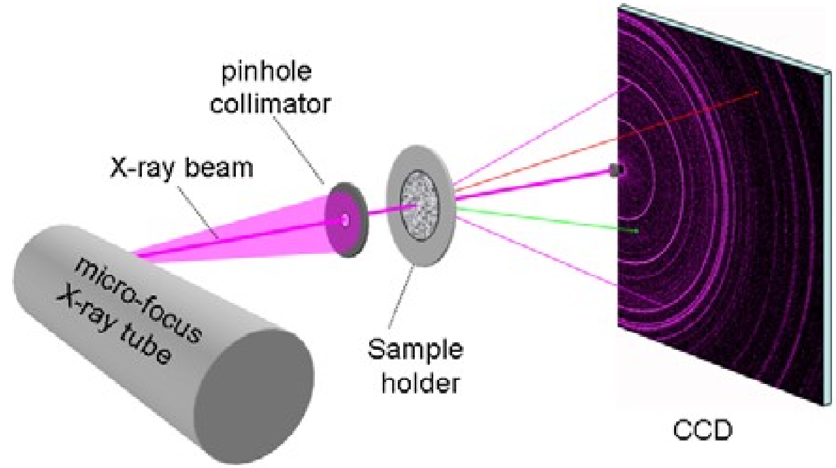
- Enabler for CheMin integration
  - Same source (X-ray)
  - An electronic area array detector
    - Charge coupled device(CCD) sensitive to X-ray
      - Records fluorescent X-rays (characteristics X-rays)
      - Records diffracted X-rays that are scattered from sample



Bright rings correspond to diffraction bands; fluoresced pixels have no spatial correlation.

XRD/XRF (CheMin)

- Architecture
  - X-ray generated by microfocus X-ray tube
  - Combined with pinhole collimator
  - Material loaded in sample holder
  - CCD detector collects the X-ray signal of sample in term of energy and position
  - CCD is cooled to -100°C to limit dark current
  - Weighs 30 kg



XRD/XRF (CheMin)

- Parties involves:
  - *inXitu (USA)*
  - *NASA Ames Research Center (USA)*
  - *Los Alamos National Laboratory (USA)*
  - Detector Advanced Development, Jet Propulsion Laboratory (USA)
  - *Indiana Univ. (USA)*

Portable XRD/XRF (Terra)

- Terra developed based on CheMin technology to provide a field deployable instrument
  - Temperature or humidity sensitive minerals can experience phase transitions during transport to the laboratory.
  - Capability to analyze these materials *in-situ allows determination* of native mineralogical compositions

Portable XRD/XRF (Terra)

- Architecture developed based on CheMin
  - Redesigned around a smaller CCD to save cost, mass and power.
    - CCD is cooled to -45°C using a Peltier cooler.
    - Collimation with miniature slits in place of pinhole to maximize throughput.
    - System includes an embedded computer to control the instrument, acquire and process data in real time, and offer a graphical user interface through a wireless link.
    - Li-ion batteries ~4 hrs of autonomous operation.
    - Complete instrument weights less than 15 kg

Portable XRD/XRF (Terra)

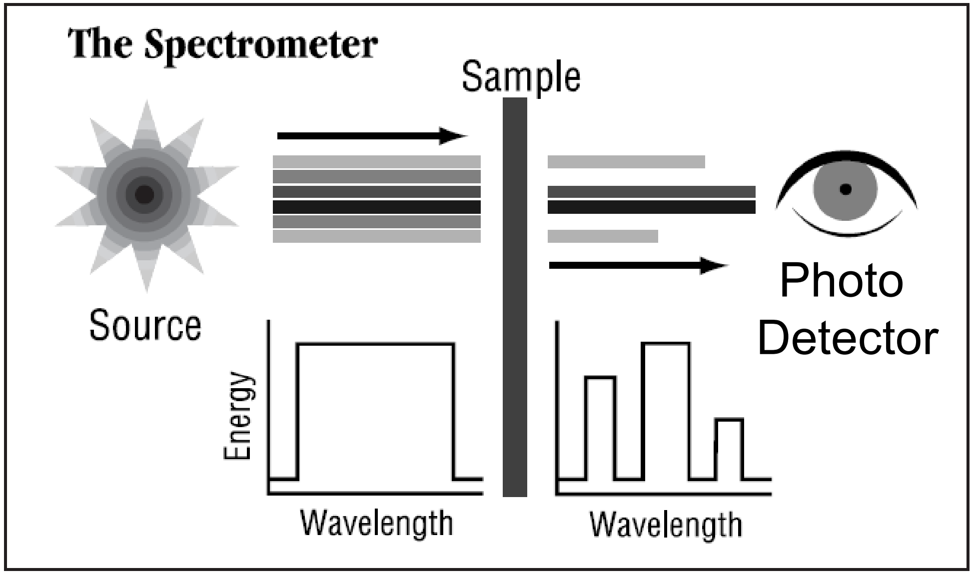
- Parties involves:
  - InXitu (USA)
  - Chesapeake Energy Corporation (USA)
  - NASA Ames Research Center (USA)
  - Earth & Env. Sciences, Los Alamos National Laboratory (USA)
  - NASA Johnson Space Center (USA)
  - TECSEN, Univ. Paul Cézanne (France)
  - Dept. of Geological Sciences, Indiana Univ. (USA)
  - Dept. of Geosciences, Univ. of Oslo (Norway)
  - Earth and Planetary Exploration Services, Univ. of Oslo (Norway)
  - Dept. of Geological Sciences and Geological Engineering, Queen’s Univ. (Canada)

Instruments deployed by space agency

- Orbiter
  - Infrared Spectrometry

Infrared Spectrometry

- SPICAM-IR Atmospheric Spectrometer (ESA Mars Express Orbiter)
  - Determining composition of atmosphere from wavelengths absorbed by constituent gases
- SPICAM-IR setup



Record amount of energy absorbed when the frequency of the infrared light is varied to form infrared spectrum

Principle of IR

- Infrared spectrum represents sample's fingerprint
  - Absorption peaks correspond to frequencies of vibrations between bonds of atoms
  - Different material has unique combination of atoms, no two compounds produce same infrared spectrum.
  - Range of this photo detector (1.0-1.7 μm)
    - Carbon dioxide (absorption at 1.43 μm and 1.57-1.6 μm bands)
    - Water vapor (absorption at 1.38 μm)

Recent Development

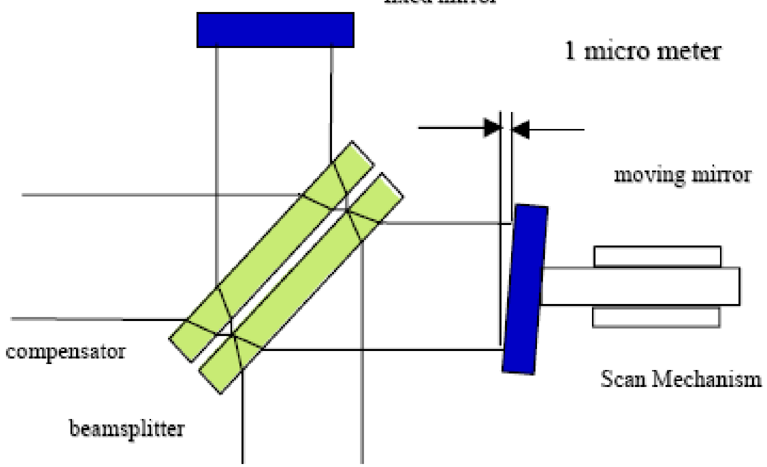
- Portable FT-IR
  - Advantages of Portable FT-IR
  - Disadvantages of Michelson interferometer
    - Solution with Rotary scanning interferometer

Advantages of Portable FT-IR

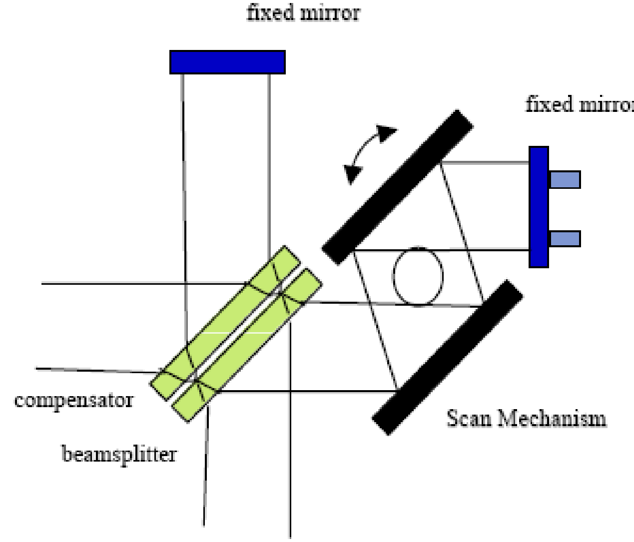
- Provide a rapid on-site spectroscopic information to identify the composition of sample
  - Faster measurement technique for collecting infrared spectra
    - IR light is guided through an interferometer (Michelson) and pass through the sample, the measured signal is interferogram
    - Performing a mathematical Fourier transform on this signal results in a spectrum
  - Portable instrument allows an analyst to take the lab to the field

Disadvantages of Michelson interferometer

Michelson interferometer



Rotary scanning interferometer



- Mirror alignment sensitive to vibration, shock, temperature, and component fatigue
  - Tilt of 1 micrometer will change interferogram by >10%
- Maintaining constant alignment is a routine and costly process

- Mirrors are fixed
- Stable performance
- Repeatable rotary scan mechanism

Portable FT-IR

- Specifications of portable FT-IR
  - Resolution:
    - From 4 cm^{-1} for routine analysis up to 0.5 cm^{-1} for high resolution work such as gas and multi-component analysis
    - Higher energy near-IR (0.8-2.5 μm), wave number ~14000-4000 cm^{-1}
  - Dimensions: 49x39x19 cm
  - Power consumption: 40 W
  - Input voltage:12 V
  - Weight: 18 kg

Portable FT-IR

- Parties involves:
  - Tallinn Tech. Univ. (Estonia)
  - Monash Univ. (Sydney)
  - Interspectrum (Estonia)
  - Thermo Scientific (USA)
  - ABB (Germany)
  - A2 Technologies (USA)
  - Bruker AXS (Germany)

assignment

- **Name:**
  - **2 types of wave that has heat effect**
  - **3 types of radiation that has reaction with a photographic film**
  - **2 types of radiation that has ionisation and kill living cell**

assignment

- **Determine the 4 characteristics that all the radiation share with the 4 hints given:**
  - **Speed of all the radiation?**
  - **What do all the radiation carry from place to place?**
  - **Could all the radiations travel from the Sun to Venus? Is there a need for a medium to enable travelling?**
  - **Is all the radiation longitudinal or transverse type of wave?**

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