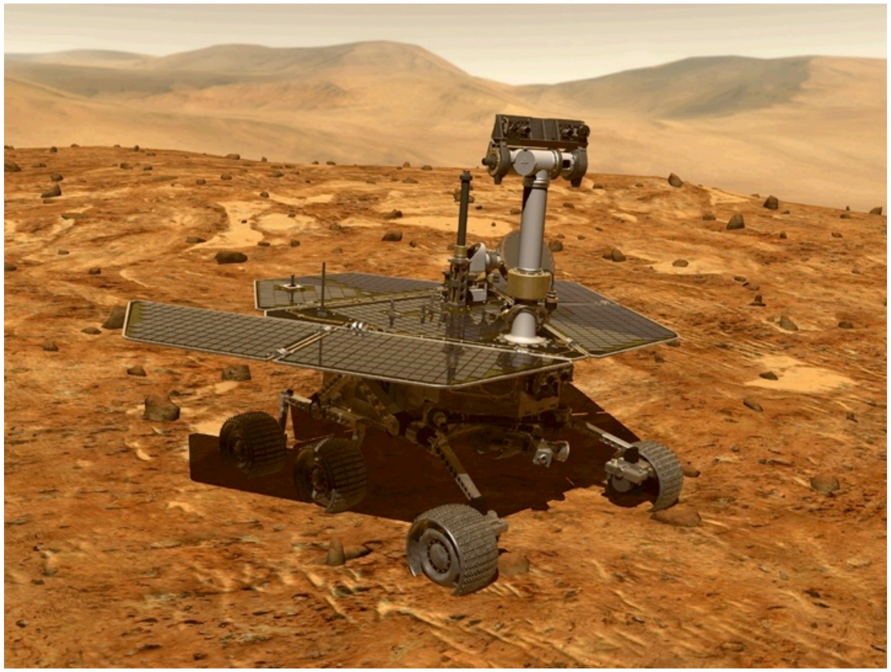
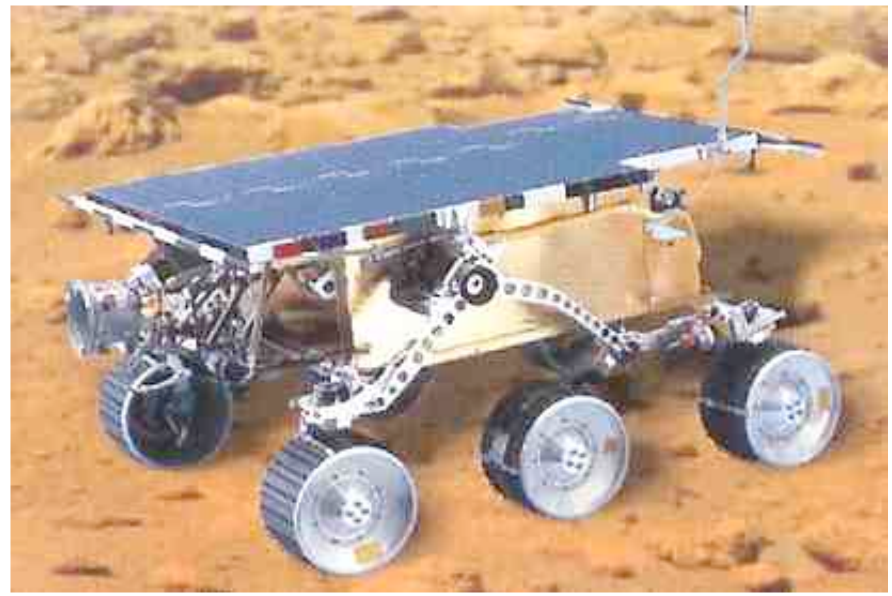
Spectroscopy on Mars!



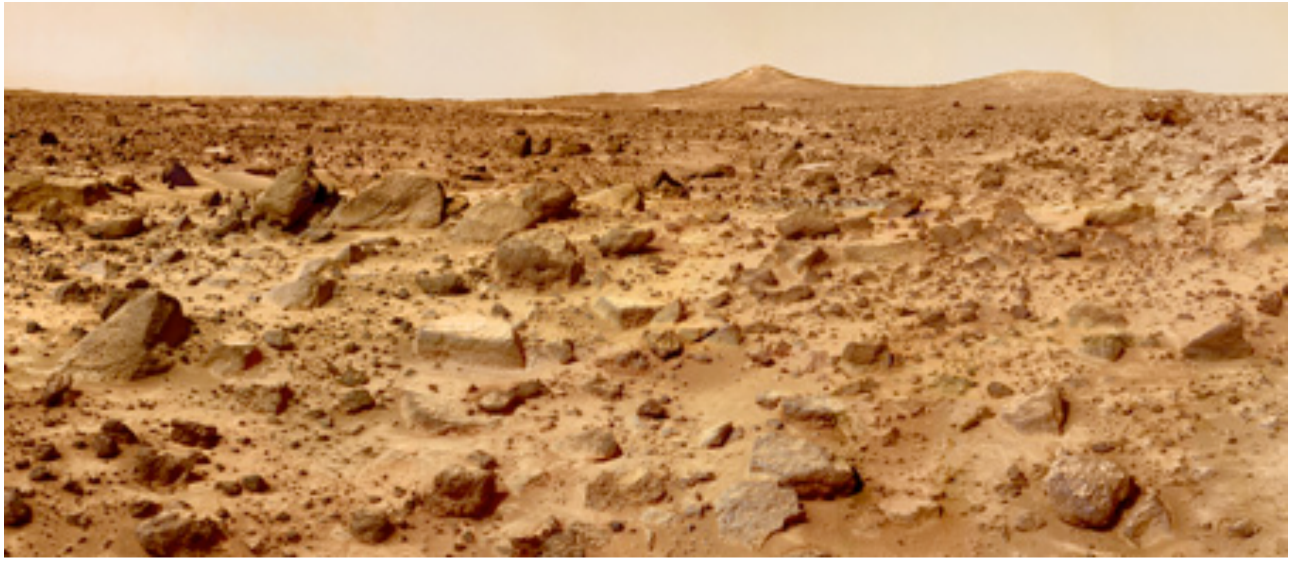
Spirit and Opportunity

Pathfinder



Real World Friday H2A

The Mars Pathfinder: Geological Elemental Analysis



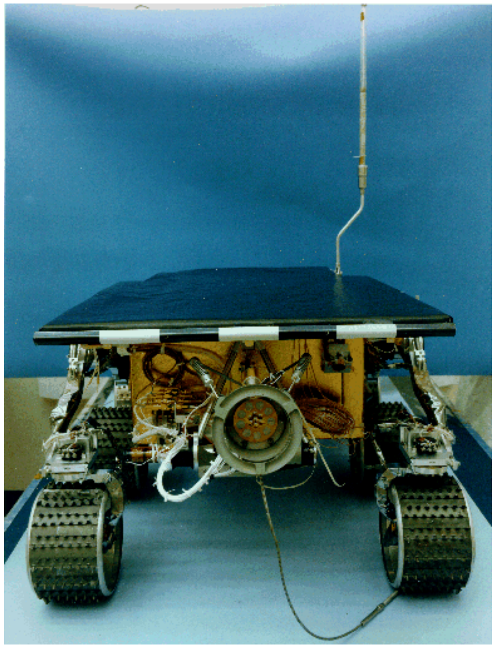
On December 4th, 1996, the Mars Pathfinder was launched from earth to begin its long journey towards the planet Mars. The Pathfinder landed on Mars on July 4th, 1997, and operated until September 27, 1997.

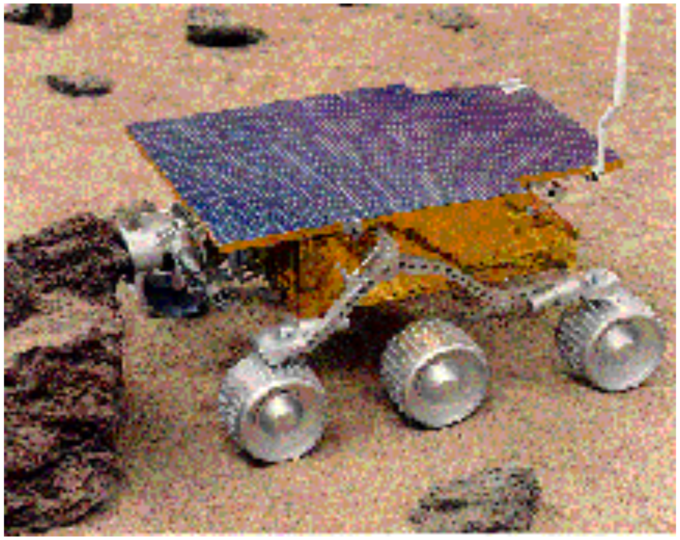
During the time spent on the planet, the rover was able to utilize its analysis tools to gather data on the composition of Mars. The Mars Pathfinder included three major instruments: a Stereoscopic Imager with Spectral Filters, an Atmospheric Structure Instrument/ Meteorology combination and an Alpha Proton X-Ray Spectrometer.

Two new Mars Rovers, Spirit and Opportunity, landed on Mars on January 4, 2004 and January 25, 2004 respectively. They also have APXS instruments.

Alpha Proton X-Ray Spectrometer

The main geological analysis was performed with the Alpha Proton X-Ray Spectrometer. This instrument uses a combination of multiple interactions of alpha particles with the specimen to determine its composition. More specifically, the instrument emits alpha particles, and measures the returning alpha particles, protons, and x-ray photons from the specimen. This allows for the identification of most elements, with the main exception being hydrogen. The alpha and proton spectrometer portions are provided by the Max Planck Institute, Department of Chemistry, Mainz Germany. The x-ray spectrometer portion is provided by the University Of Chicago.



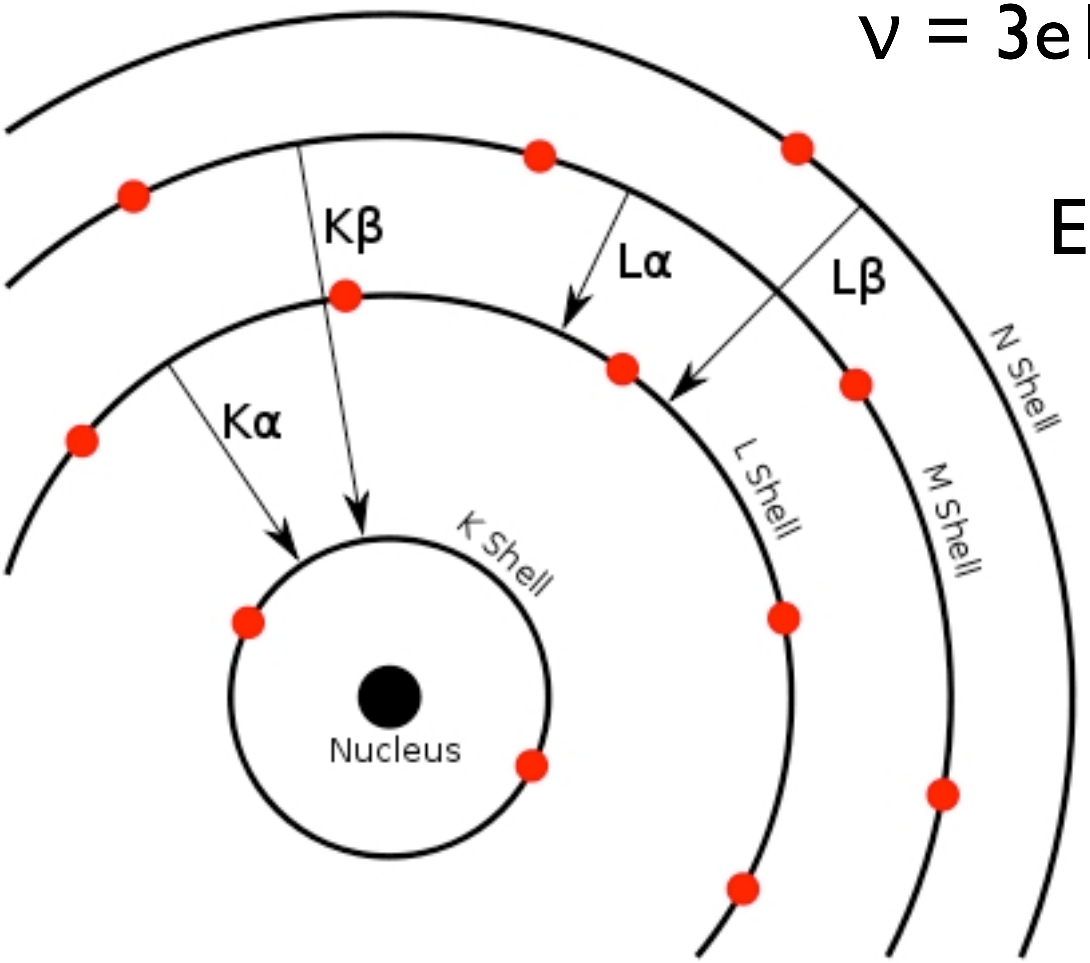


X-Rays are photons:

λ = 10 nm to 10 pm

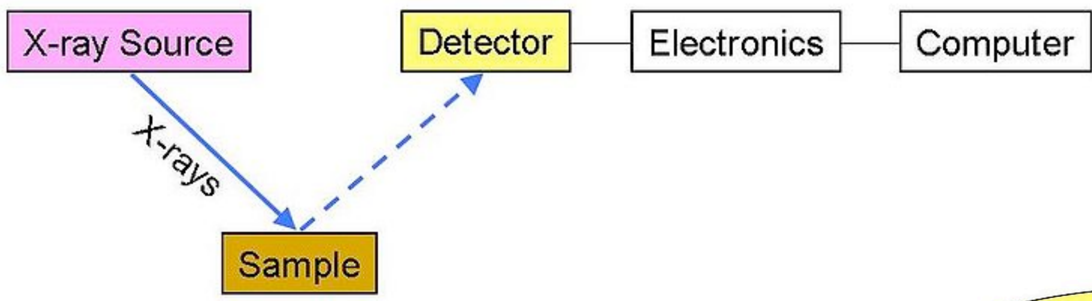
ν = 3e16 to 3e19 Hz.

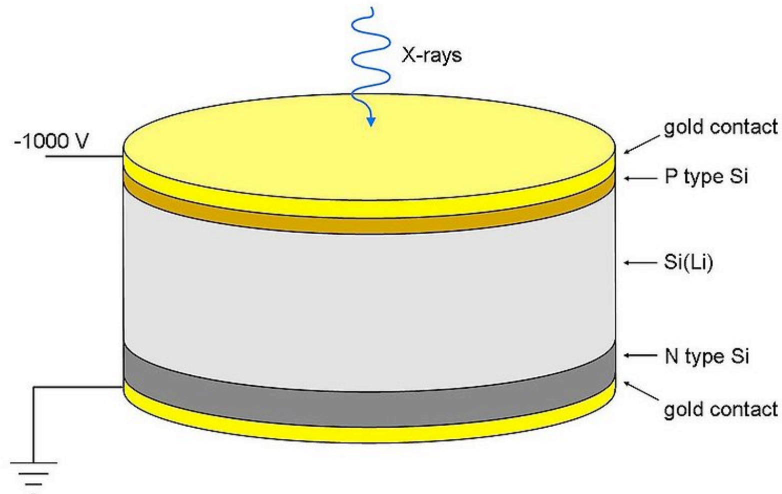
E = 124 ev to 124 keV



X-Rays are created by ejection of a 1s electron followed by filling from a higher shell.

X-Ray Fluorescence Spectroscopy (XRF)

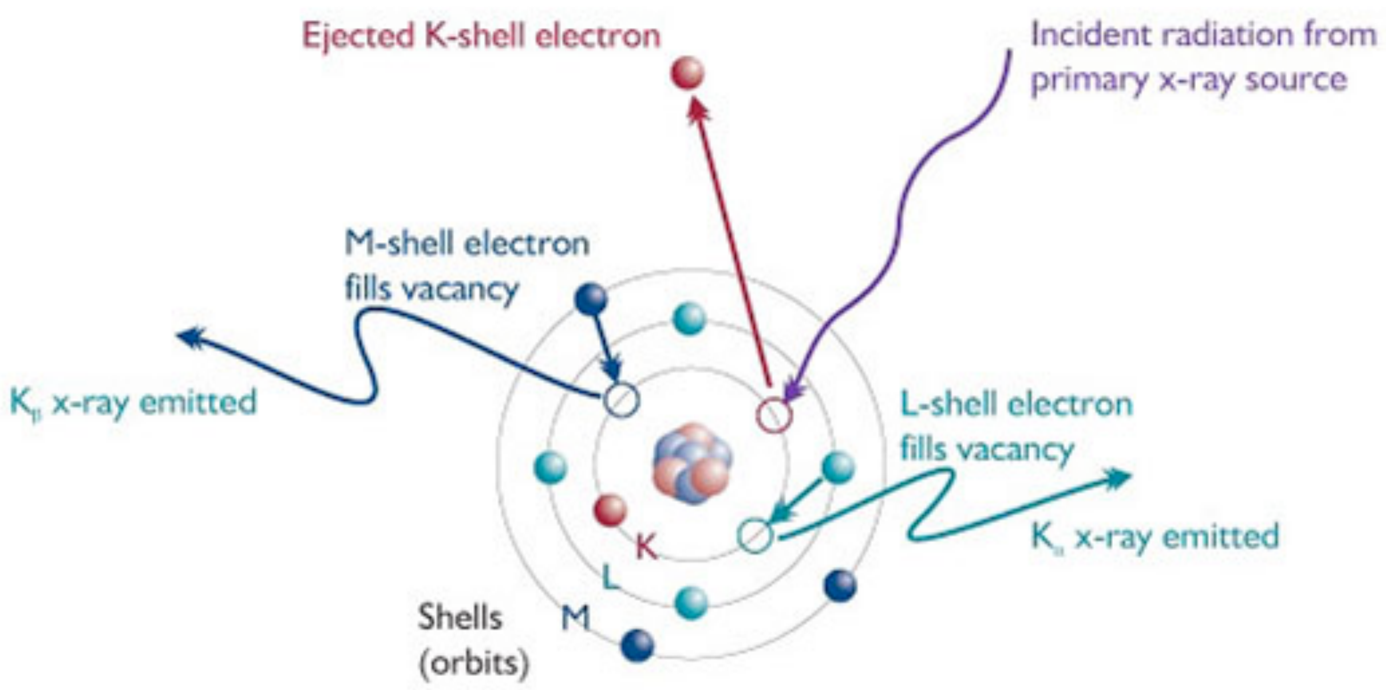




Si(Li) photodiode

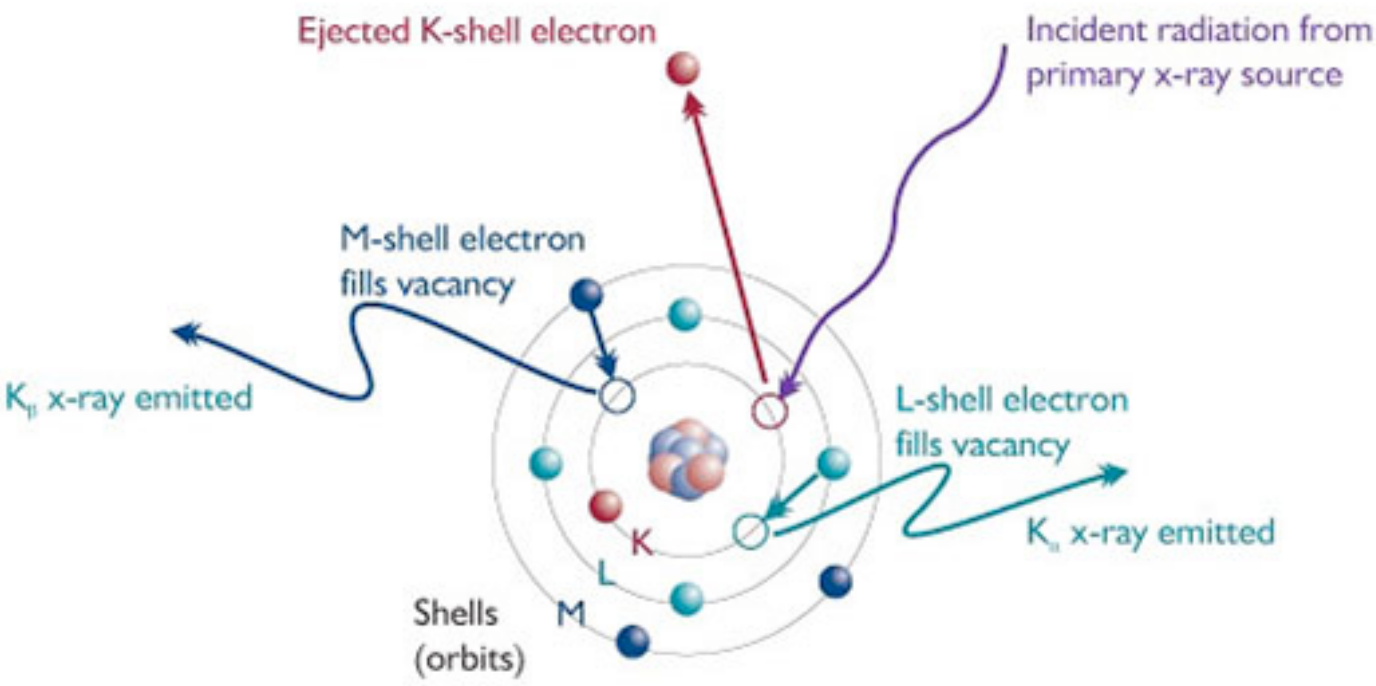
XRF is an atomic spectroscopy that uses a x-ray source and a semiconductor Si(Li) photodiode detector.

X-Ray Fluorescence Spectroscopy (XRF)



Step 1: a high energy x-ray photon is absorbed by a atom, ejecting (ionizing) an electron from the 1s (K-shell) or 2s (L-shell).

X-Ray Fluorescence Spectroscopy (XRF)



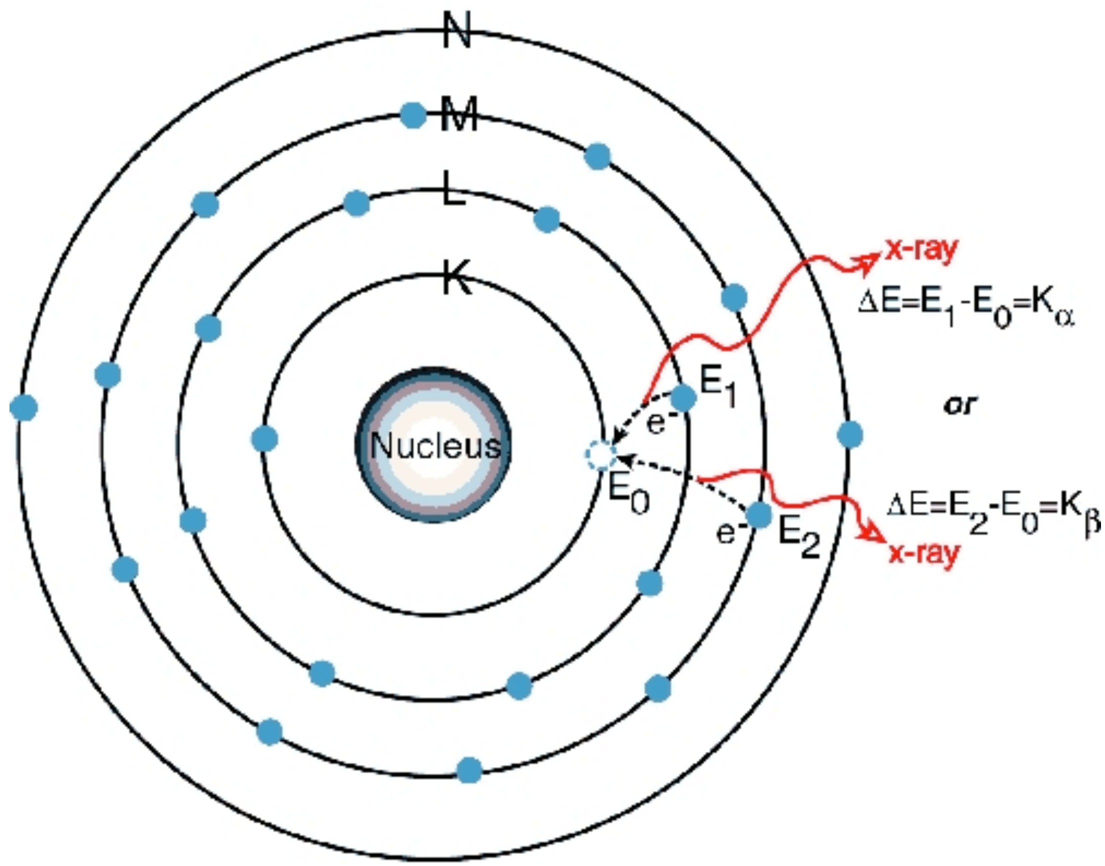
Step 2: an electron from a higher energy orbital (n=2 or 3 typically) fills the vacancy and emits an x-ray photon of characteristic energy.

X-Ray Fluorescence Spectroscopy (XRF)

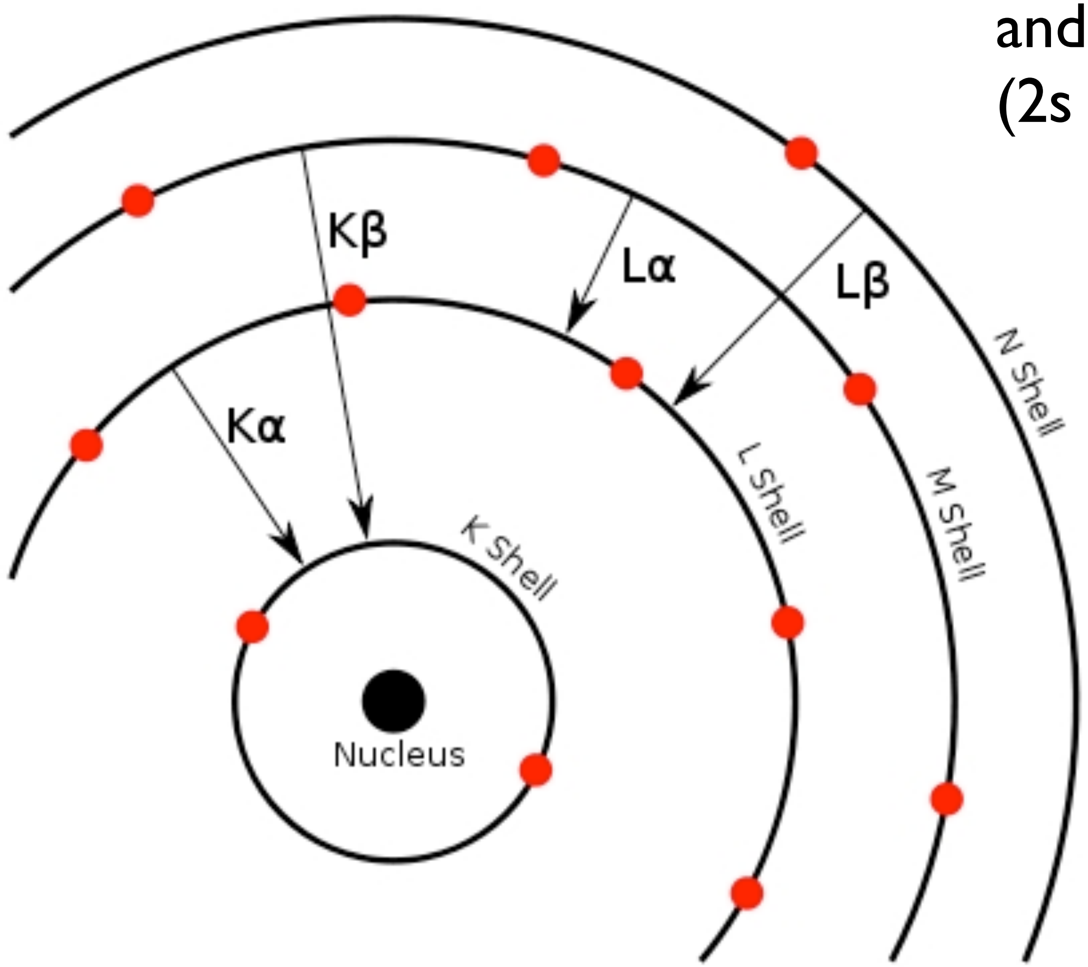
The energy of the x-ray photon is, of course, determined by the energy difference between the two orbitals.

$$\Delta E(K_\alpha) = E(n=2) - E(n=1)$$

$$\Delta E(K_\beta) = E(n=3) - E(n=1)$$



X-Ray Fluorescence Spectroscopy (XRF)

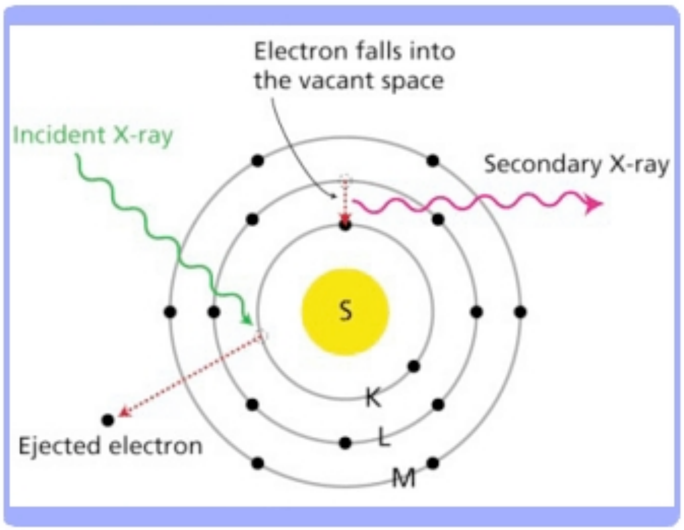


The transitions are labelled K if the final state is n=1 (1s), and L if the final state is n=2 (2s or 2p).

The transitions are sub-labelled α β γ... based on the initial state of the electron that is filling the hole.

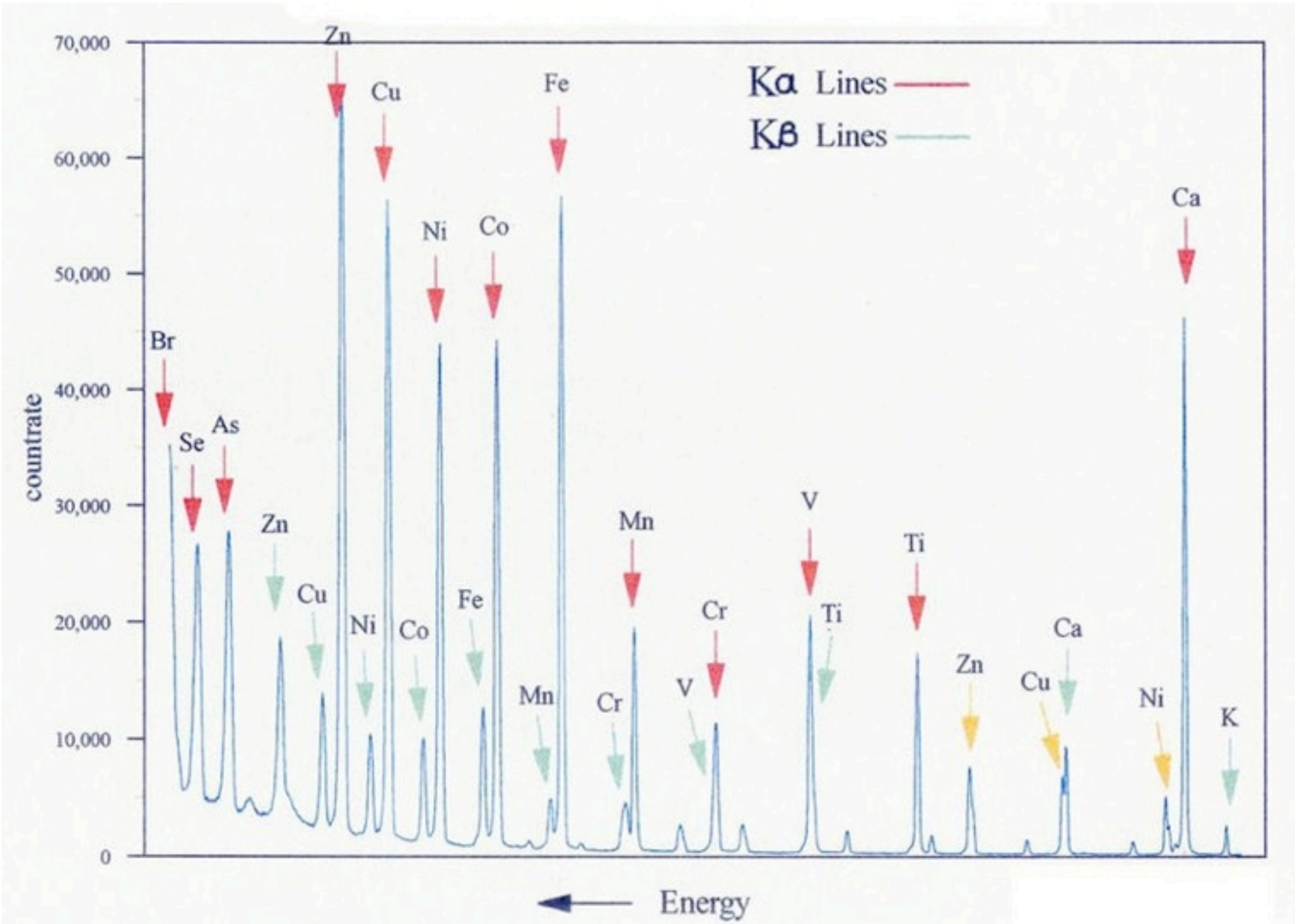
X-Ray Fluorescence Spectroscopy (XRF)

The good news is that every element emits x-ray photons at a slightly different wavelength.

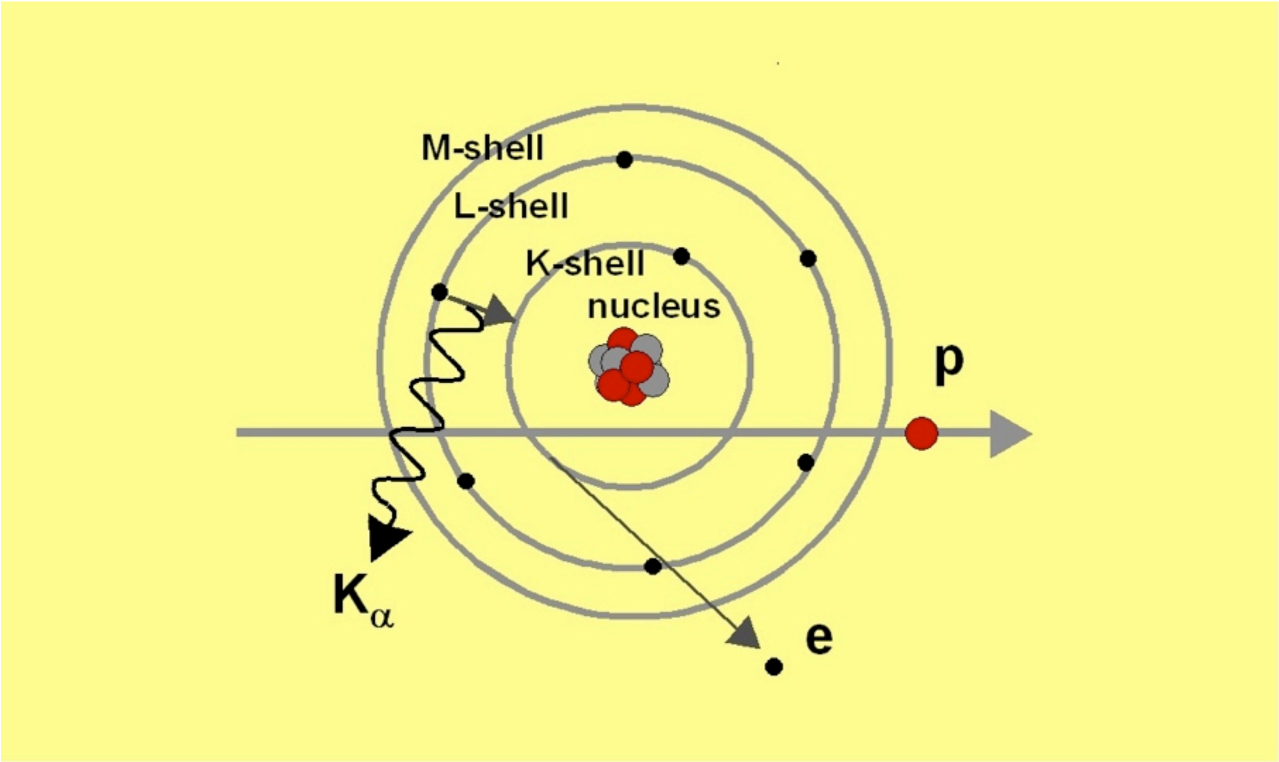


element	line	wavelength (nm)	element	line	wavelength (nm)
Li	Kα	22.8	Ni	$K\alpha_1$	0.1658
Be	Kα	11.4	Cu	$K\alpha_1$	0.1541
B	Kα	6.76	Zn	$K\alpha_1$	0.1435
C	Kα	4.47	Ga	$K\alpha_1$	0.1340
N	Kα	3.16	Ge	$K\alpha_1$	0.1254
O	Kα	2.362	As	$K\alpha_1$	0.1176
F	$K\alpha_{1,2}$	1.832	Se	$K\alpha_1$	0.1105
Ne	$K\alpha_{1,2}$	1.461	Br	$K\alpha_1$	0.1040
Na	$K\alpha_{1,2}$	1.191	Kr	$K\alpha_1$	0.09801
Mg	$K\alpha_{1,2}$	0.989	Rb	$K\alpha_1$	0.09256
Al	$K\alpha_{1,2}$	0.834	Sr	$K\alpha_1$	0.08753
Si	$K\alpha_{1,2}$	0.7126	Y	$K\alpha_1$	0.08288
P	$K\alpha_{1,2}$	0.6158	Zr	$K\alpha_1$	0.07859

X-Ray Fluorescence Spectroscopy (XRF)



Particle-Induced X-Ray Emission (PIXE)

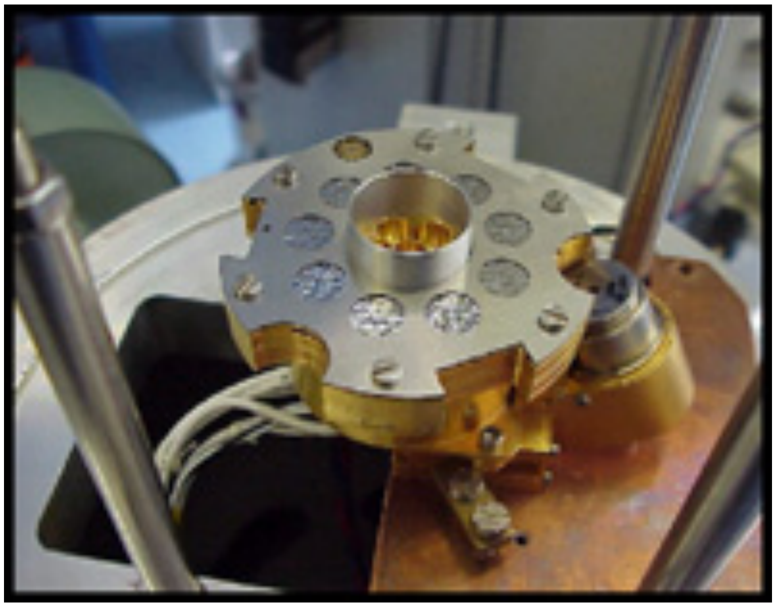


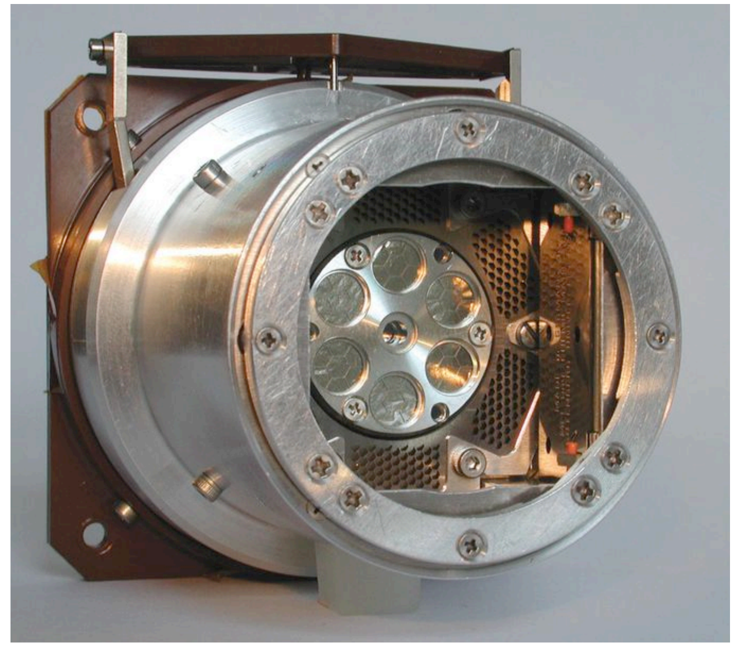
PIXE is the same as XRF, but uses an alpha particle to eject the K shell or L shell electron.

Particle-Induced X-Ray Emission (PIXE)

Most particle sources are too big for the Rover!

The Alpha Particle Source

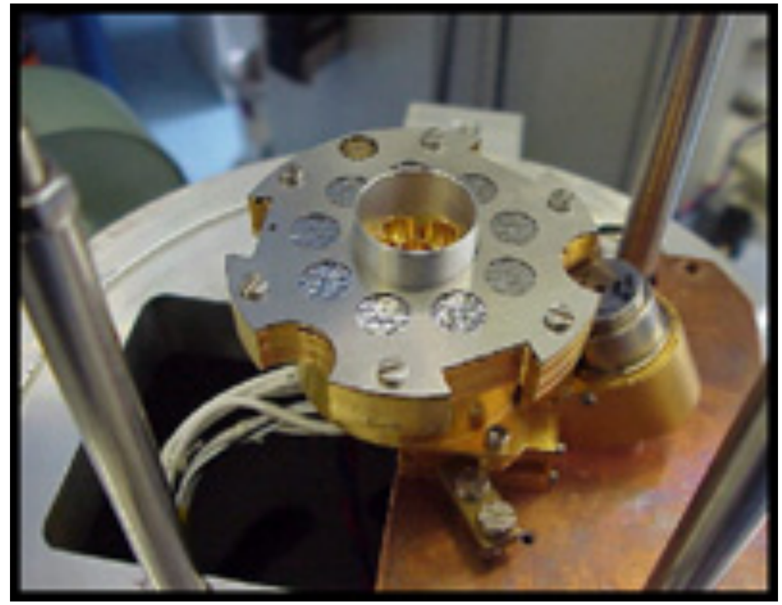


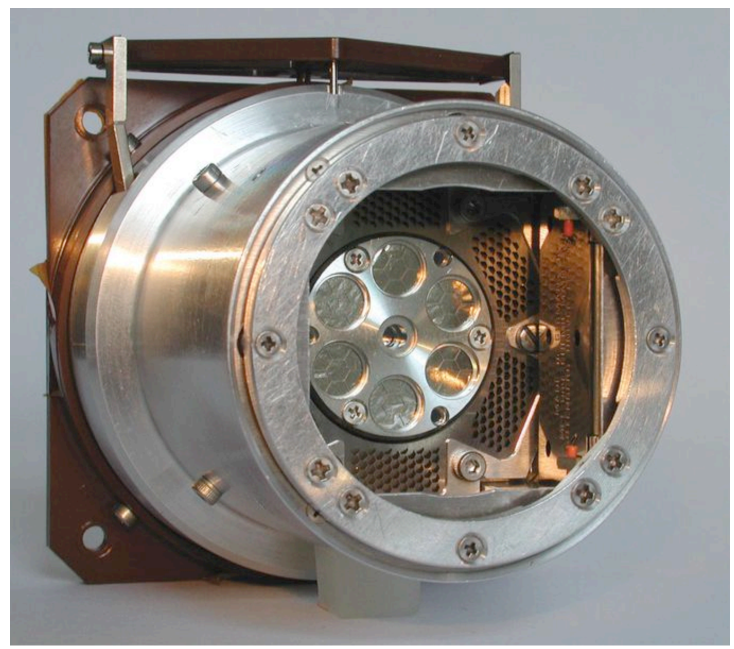


Nine radioactive Curium sources supply
the alpha particles for all three spectroscopies!

The Alpha Particle Source

^{244}Cm Alpha Radioactive Source. The APXS needs for its operation in alpha, proton and X-ray modes a beam of alpha particles with high intensity and low energy spread. The intensity of the beam determines the total measurement time needed to obtain data with the necessary statistical accuracy; its energy spread directly determines the resolving capability of the alpha mode. For space applications, such a beam is most conveniently obtained from a radioactive source. ^{244}Cm with a half-life of 18.1 years was chosen as suitable for applications on Mars. It produces 5.80 MeV photons.





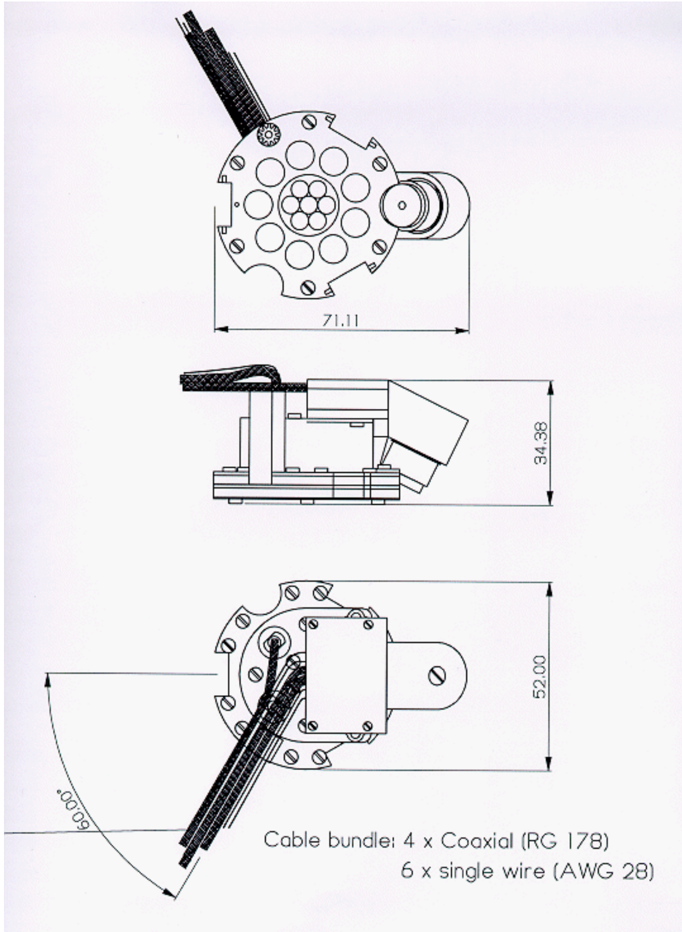
APXS Detection Principles

The APXS geological measurements are based on three interactions of alpha particles from a radioisotope source with matter:

a) Rutherford Backscattering,

b) Proton Emission, and

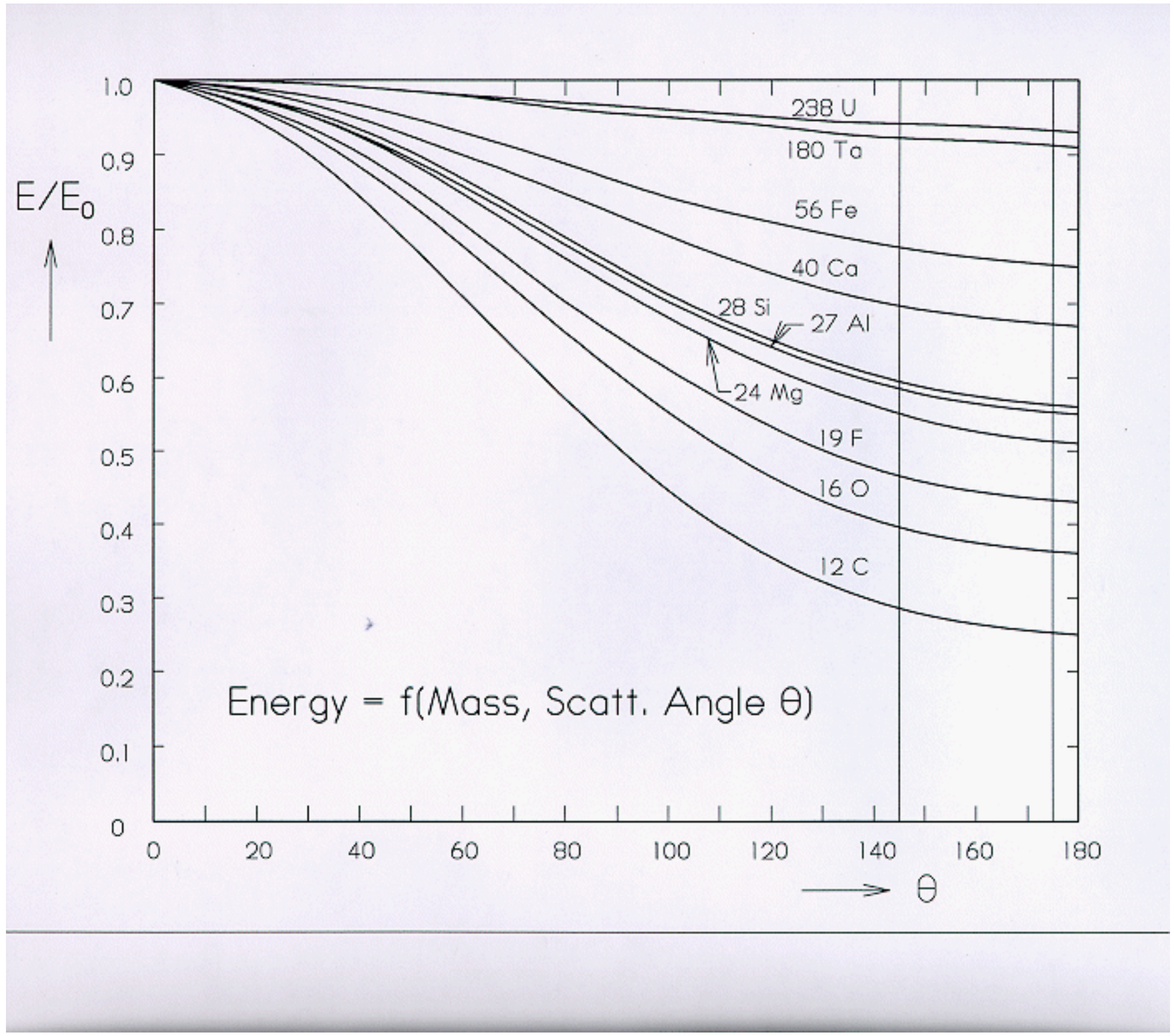
c) X-Ray Fluorescence.



In terms of sensitivity and selectivity, data are partly redundant and partly complementary: Alpha backscattering is superior for light elements (C, O), while proton emission is mainly sensitive to Na, Mg, Al, Si, S, and X-ray fluorescence is more sensitive to heavier elements (Na to Fe and beyond). A combination of all three measurements enables determination of all elements (with the exception of H) present at concentration levels above typically a fraction of one percent.

Rutherford Backscattering

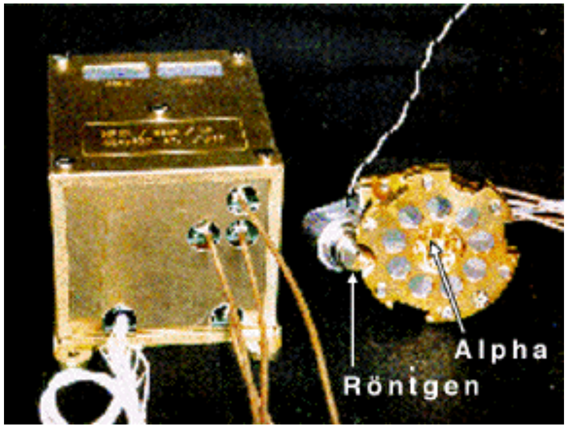
Rutherford backscattering involves collisions between alpha particles and atoms of a sample material. These collisions are generally modeled as elastic, and result in both a change in energy and direction. The energy changes are a function of the element used to scatter the particles, how far the alpha particles penetrate the sample before scattering and the angle of scatter.



Alpha Particle-Induced Proton Emission

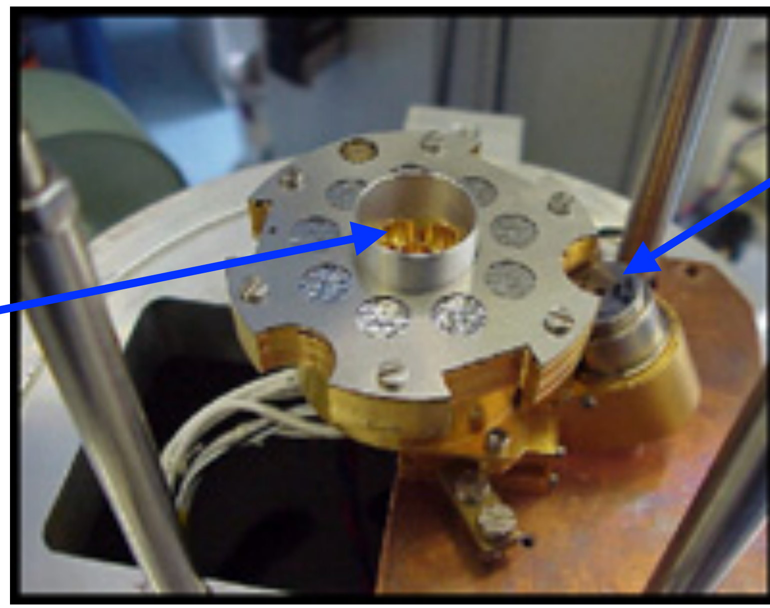
Another process important for geological analysis is the nuclear (a,p) reaction: Alpha particles merge with the target nucleus, followed by the emission of a proton and a gamma ray. This process is characterized by the Q-value, i.e. the difference in binding energy of the alpha-particle and the target nucleus on the one side and of the proton and the product nucleus on the other side. This process is energetically possible when the kinetic energy of the incoming alpha-particle E exceeds the binding energy Q; the excess energy is transferred to the kinetic energy of the proton Ep and the energy of an associated gamma transition Eg. This process is of particular interest for detecting the light rock-forming elements Na, Mg, Al and Si.

$$E - Q = Ep + Eg$$



APXS Detectors

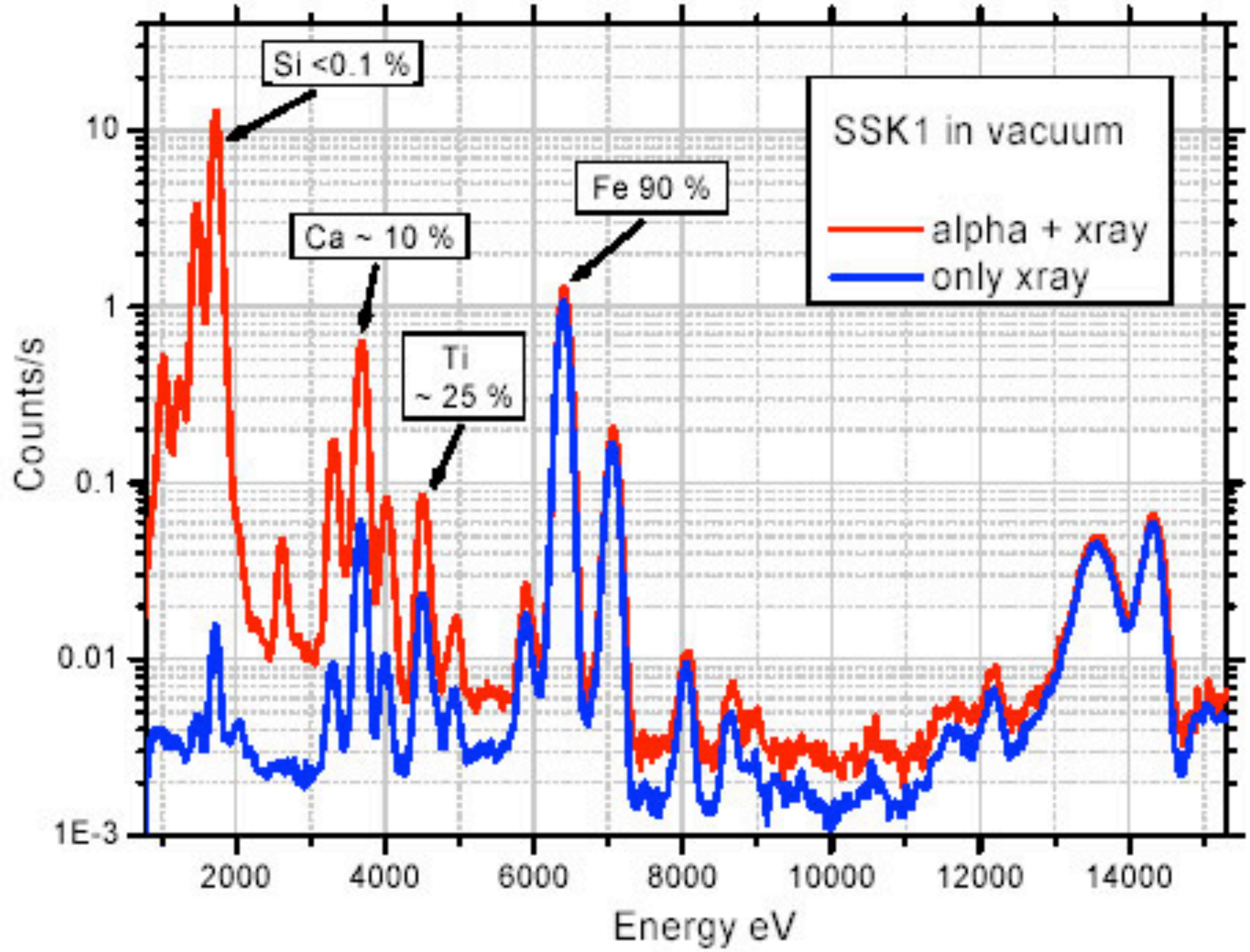
The APXS sensor head contains three detectors for the measurement of the three components: A telescope of two Si-detectors for the measurement of alpha-particles and protons and a Si-PIN X-ray detector with its preamplifier.



Alpha-Proton Detector System

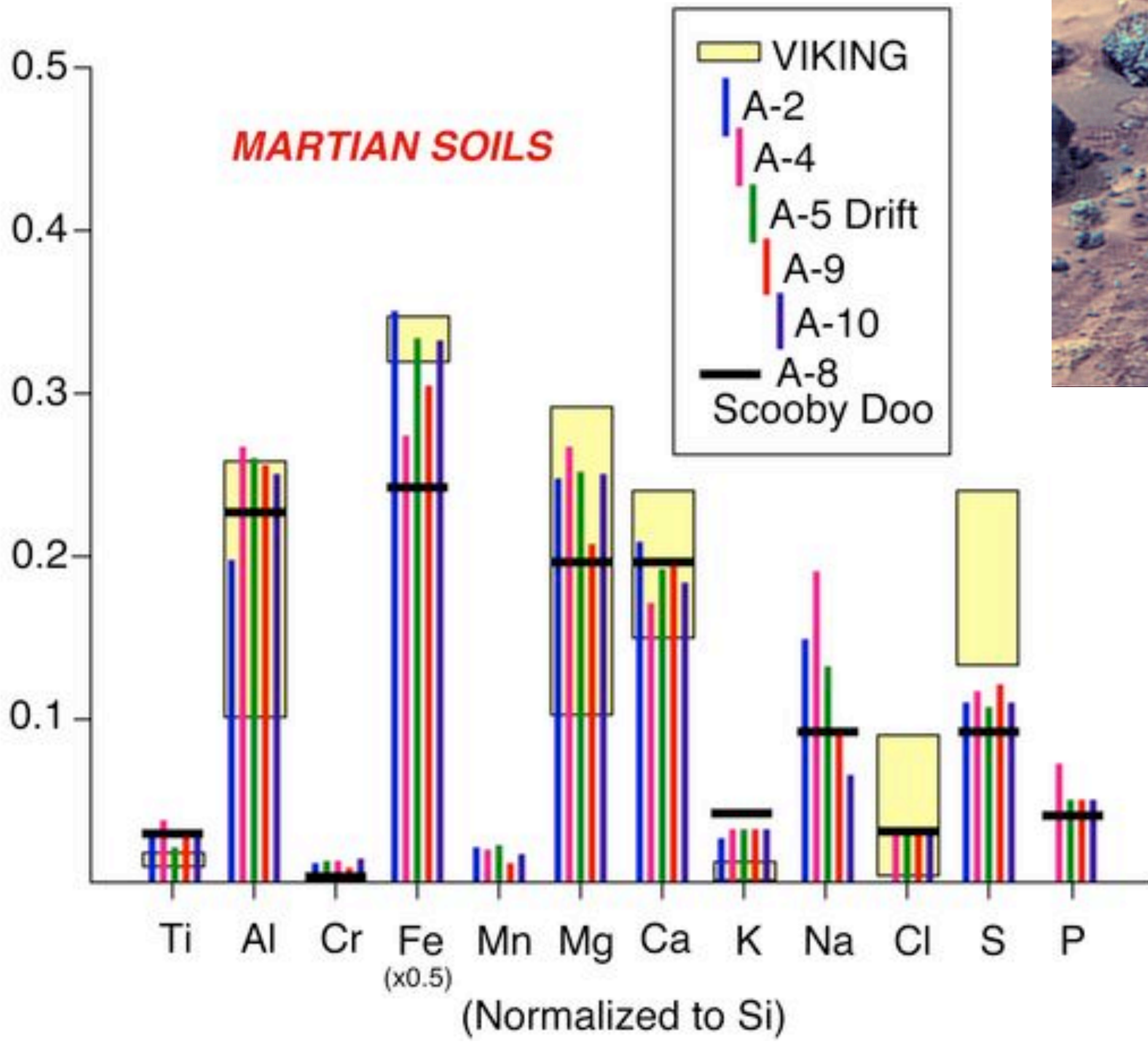
The maximum energy in the backscatter spectrum of ^{244}Cm is the emission energy at 5.80 MeV. A Si detector is the first detector used in this instrument. It is 35 micrometers thick and has the ability to stop all alpha particles with energy of less than 6.5 MeV. However, it does allow protons with energy greater than 1.6 MeV to pass through to a second detector. This detector is also silicon, but of a greater thickness than the first detector -- thick enough to completely stop protons of energies up to 6 MeV. The two separate detectors allow for separate proton and alpha spectrum to be recorded.

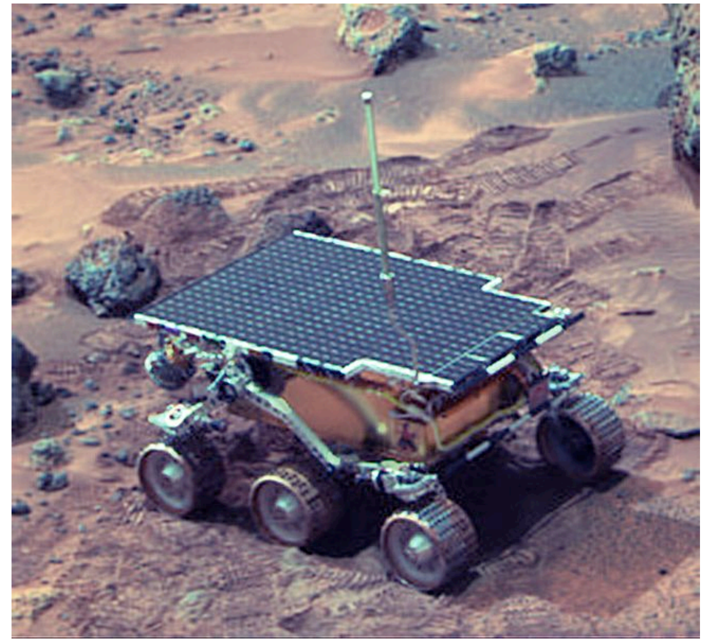
Some APXS data



RBS plus XRF covers the entire spectrum.

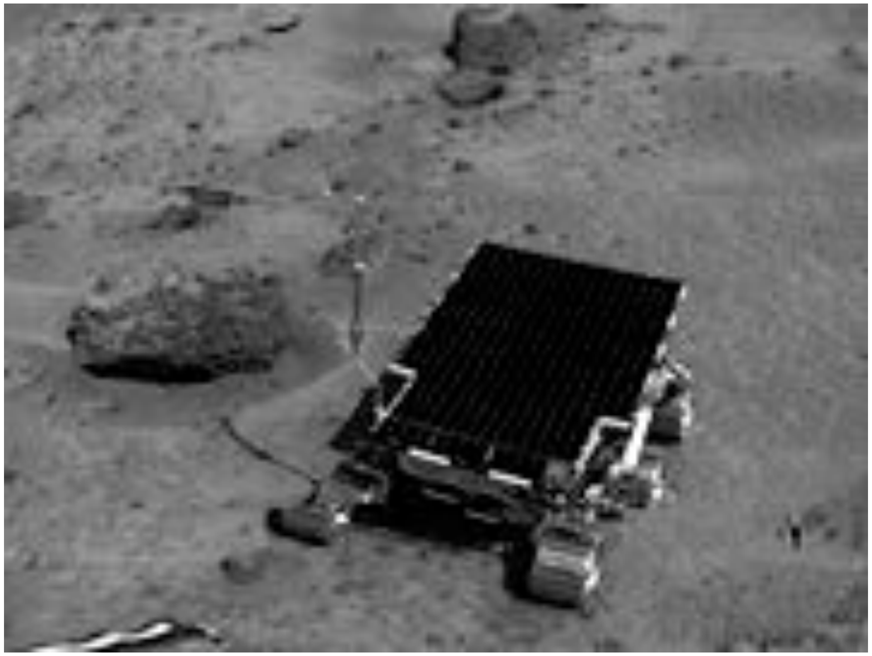
Some APXS data





Some APXS data

Element	A-2, Soil Weight %	A-4, Soil Weight %	A-5, Soil Weight %	A-3, Rock Weight %	A-7, Rock Weight %
Carbon [C]	0	0	0	0	0
Oxygen [O]	42.5	43.9	43.2	45	44.6
Sodium [Na]	3.2	3.8	2.6	3.1	1.9
Magnesium [Mg]	5.3	5.5	5.2	1.9	3.8
Aluminum [Al]	4.2	5.5	5.4	6.6	6
Silicon [Si]	21.6	20.2	20.5	25.7	23.8
Phosphorus [P]	0	1.5	1	0.9	0.9
Sulphur [S]	1.7	2.5	2.2	0.9	1.7
Chlorine [Cl]	0	0.6	0.6	0.5	0.6
Potassium [K]	0.5	0.6	0.6	1.2	0.9
Calcium [Ca]	4.5	3.4	3.8	3.3	4.2
Titanium [Ti]	0.6	0.7	0.4	0.4	0.5
Chromium [Cr]	0.2	0.3	0.3	0.1	0
Manganese [Mn]	0.4	0.4	0.5	0.7	0.4
Iron [Fe]	15.2	11.2	13.6	9.9	10.7
Nickel [Ni]	0	0	0.1	0	0
Sum	100	100	100	100	100



They're still up there.
Spirit stopped on March 22, 2010.
Opportunity is still roving around.

You can follow them online:

http://marsrover.nasa.gov/home/index.html