Non-destructive Elemental Analysis of Extraterrestrial Materials by Muonic X-ray

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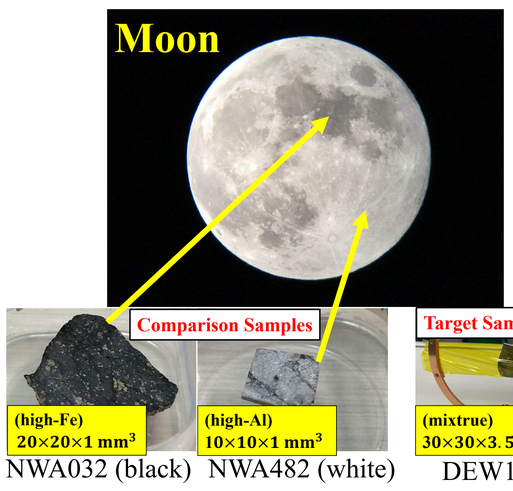
Abstract:

Non-destructive elemental analysis using negative muon beam can determine elemental composition of the bulk samples precisely without causing damage. We conducted a muon irradiation experiment at J-PARC for lunar meteorites. Six germanium semiconductor detectors arranged around the analysis chamber were used for muonic X-ray measurement, and a Monte-Carlo simulation was applied for estimation of the detection efficiency of each detector. In the result, we successfully investigated the elemental component of the meteorite sample.

Lunar meteorites



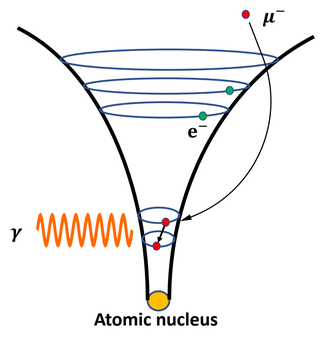
- The evolution of the Earth-Moon system can be investigated by analyzing lunar meteorites, which provides important information for near Earth space.
- This study present the elemental analysis for **DEW12007**, which is a lunar meteorite containing rare agglutinates.
- NWA032 (black) & NWA482 (white) were prepared for comparison.

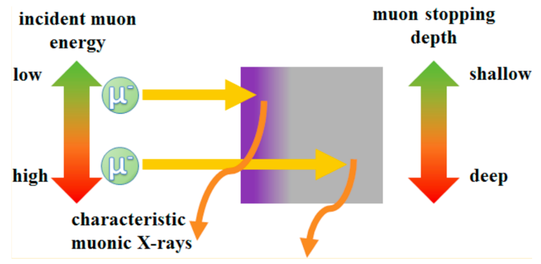
Purpose of this work:

The elemental composition was investigated for the DEW12007 surface [1]. We report the "**depth-profiling**" elemental composition using muon beam.

Muonic X-rays

Elemental analysis via muonic X-ray measurement has been developed in recent years.



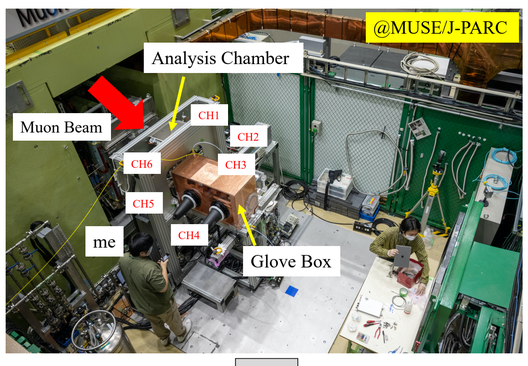


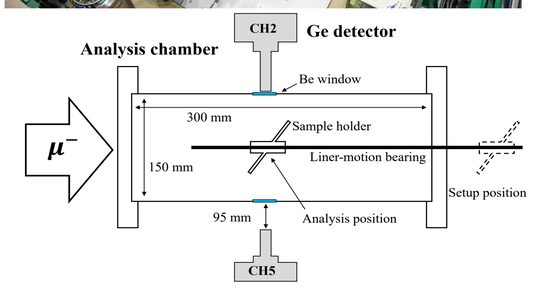
Principle

1. Muon captured by an atomic system.
2. Muonic X-rays are emitted by muon transitions between the orbits.
3. Muonic X-ray can pass through a material without being absorbed due to its high energy.
4. Muon stopping depth can be controlled by adjusting its momentum [2].

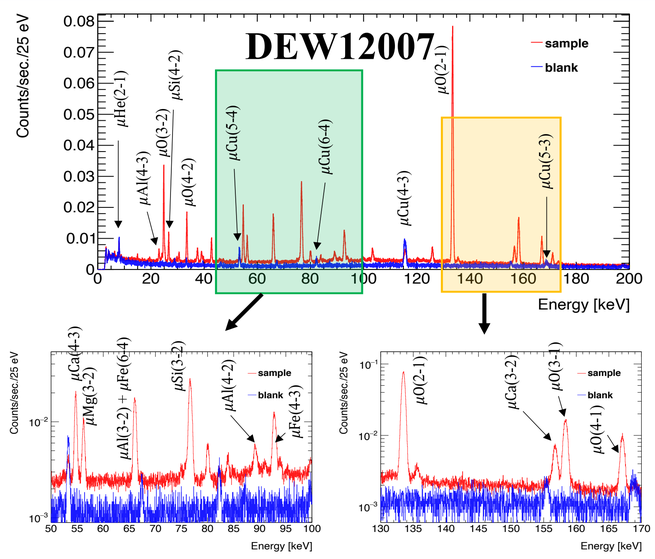
Experiment at J-PARC

- The muon experiment was performed at the MUSE/J-PARC.
- Six HP-Ge detectors (CH1-CH6) were installed around the chamber.
- Muon irradiation time is ~ 12 hours per sample.
- Muon momentum: 27 & 35 MeV/c

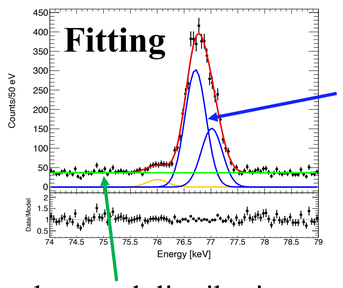




Energy spectrum



Intensity (I_{fit}) of each muonic X-rays was obtained based on the fitting method.



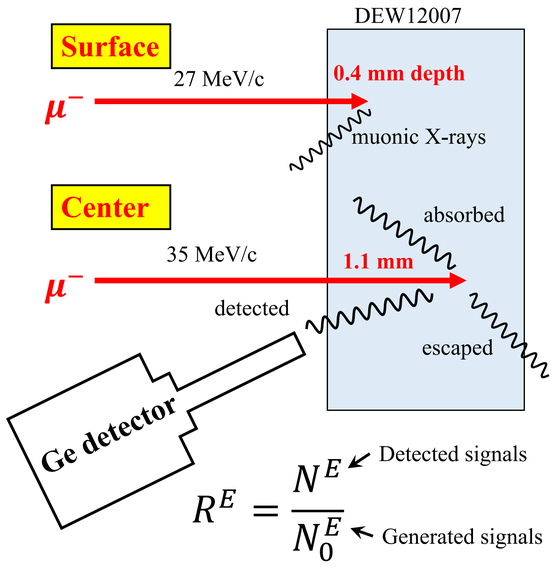
Energy distribution of μSi(3-2) measured from standard sample.

background distribution measured from blank.

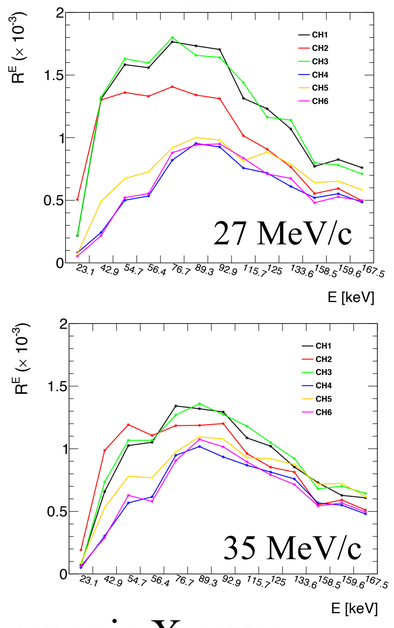
Geant4 Simulation

Because the detector efficiency (R^E) is affected by stop position of the muons, different solid angles of the detector, and self-absorption effect of the sample, we applied Monte-Carlo simulation using Geant4 toolkit [3] to estimate the each detection efficiency of the detectors.

Simulation Scheme



R^E



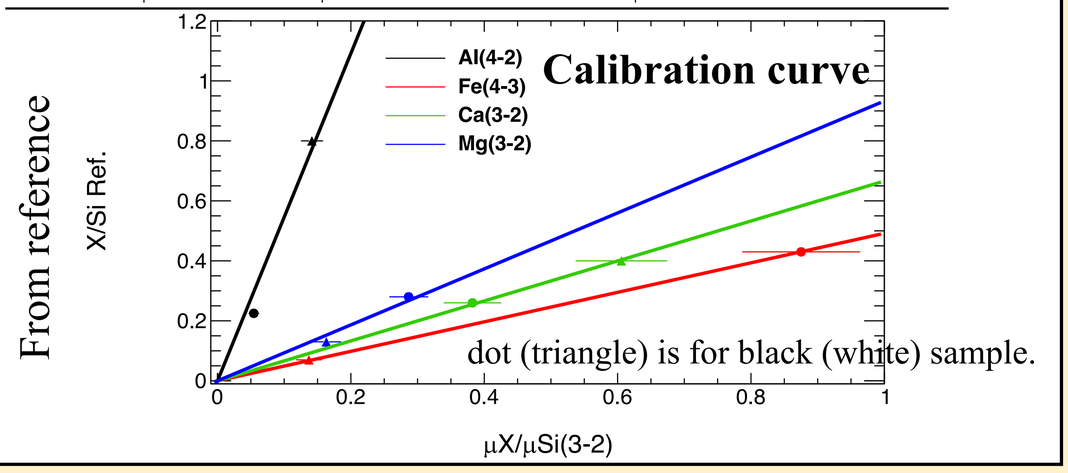
Total intensity of emitted muonic X-rays:

$$I_{emit} = I_{fit}/R^E$$

Calibration Curve

The I_{emit} (counts/sec.) results of comparison samples (black & white) were used to make calibration curve.

		White		Black	
μX-rays	Energy [keV]	$I_{fit}(10^{-3})$	I_{emit}	$I_{fit}(10^{-3})$	I_{emit}
μSi(3-2)	76.7	299.6±21.4	188.8±16.4	611.6±35.2	401.0±28.2
μMg(3-2)	56.3	48.2±4.8	30.8±3.1	163.3±10.5	114.9±8.3
μAl(4-2)	89.1	41.1±2.8	26.7±2.0	32.1±3.0	21.8±2.7
μFe(4-3)	92.7	38.3±3.3	25.9±2.8	505.3±26.3	351.0±25.3
μCa(3-2)	157.0	87.1±6.6	114.3±8.2	110.7±6.1	153.3±13.4



Results & Discussion

The elemental composition of DEW12007 can be defined from the intensity of muonic X-rays using the curves.

	DEW12007 (Ratio)	
X/μSi(3-2)	Surface	Center
μMg(3-2)	0.30±0.04	0.30±0.04
μAl(4-2)	0.09±0.01	0.09±0.01
μFe(4-3)	0.40±0.04	0.40±0.04
μCa(3-2)	0.43±0.04	0.42±0.03

Calibration curve

	This work (Surface)	This work (Center)	Previous (Surface)
Mg/Si	0.28 ± 0.04	0.28 ± 0.03	0.26
Al/Si	0.48 ± 0.06	0.50 ± 0.05	0.46
Fe/Si	0.20 ± 0.02	0.20 ± 0.02	0.20
Ca/Si	0.29 ± 0.03	0.28 ± 0.02	0.30

- ✓ We successfully determined the depth-profiling elemental abundance of DEW12007 with muonic X-ray measurement.
- ✓ Our results of both "surface" and "center" research for DEW12007 are consistent with the previous study (surface analysis) very well.
- ✓ The DEW12007 is a mixture of 73% basalt (NWA 032 type) and 27% anorthosite (NWA 482 type) in terms of Al, Fe, Ca, and Mg contents.

Reference:

[1]. A. Collareta, Meteorit Planet Sci. **51**, 2 (2016)

[2]. K. Ninomiya et al., Anal. Chem. **87**, 9 (2015)

[3]. N. Metropolis et al., J Am. Stat. Assoc. **44**, 335 (1949)

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Poster Session