Measurement of a neutralization efficiency of francium with Y , Zr and Gd for the electron EDM search

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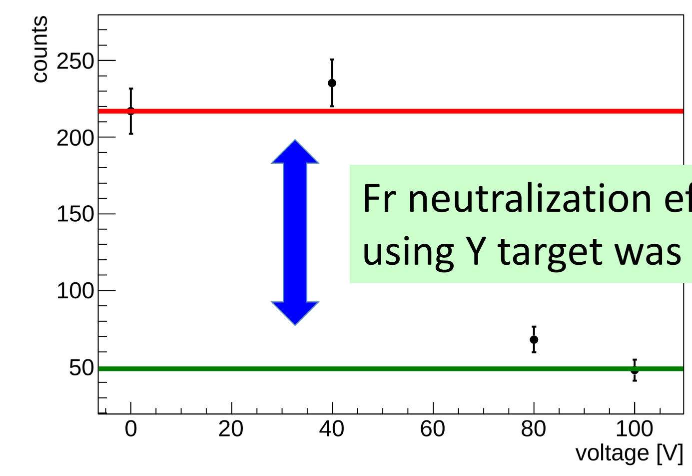
The final goal of our group is to measure a permanent electric dipole moment (EDM) of electron. If EDM is exist, it means time-reversal symmetry is violated. To measure the electron EDM, we use Fr (Francium) atoms because they have two big advantages. First, Fr has a large enhancement factor of a electron EDM rather than other alkali elements. Second, Fr are alkali atoms, thus trapped in Magneto-Optical Trap (MOT) because of their simple energy states.

Only neutral atoms can be trapped in MOT. For this reason, Fr ions which transported by our beam line must be converted to neutral atoms.

Once we tried to measure the Fr neutralization efficiency using yttrium target. The result was only 23% emitted atoms were neutralized, but that experiment contained some uncertainties such as Fr beam flux, ion removal system and yttrium deterioration. For this reason, we studied the Fr neutralization efficiency of the yttrium target using new detection system. In addition, we tried to find better neutralization target.



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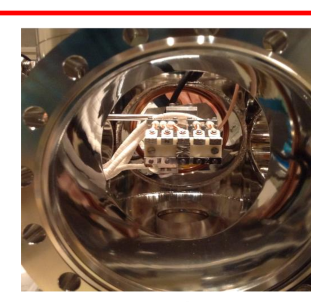
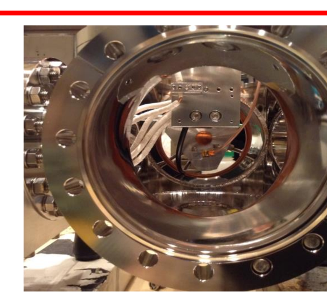
Fr and Rb ion transportation and detection system

Neutralizer

We can use 5 different target materials



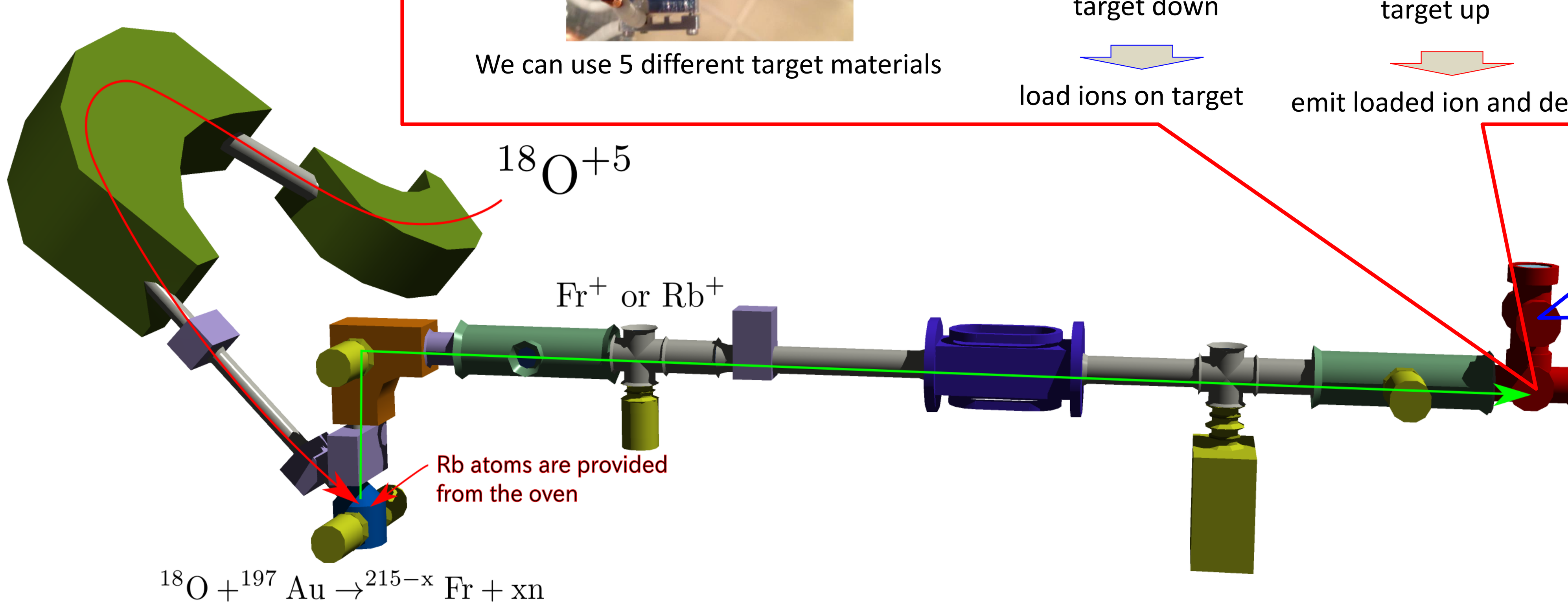
target down



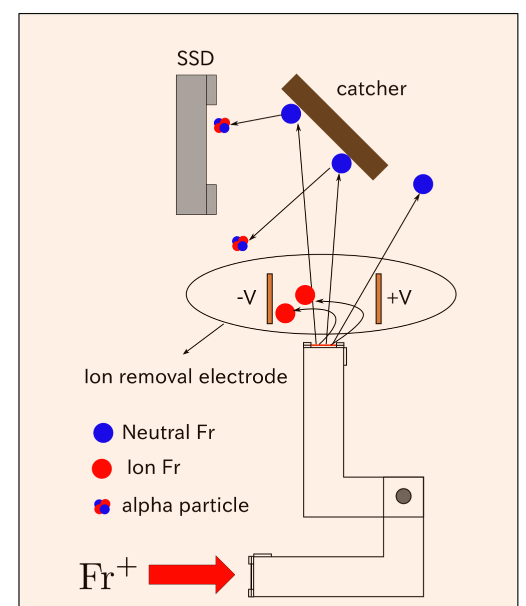
target up

load ions on target

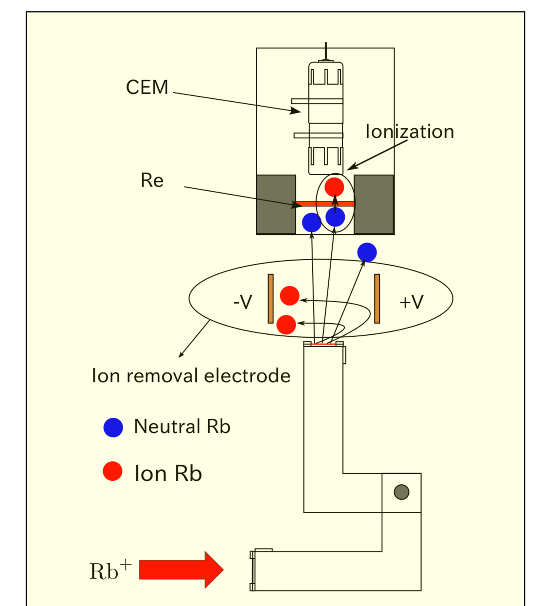
emit loaded ion and detection



Detector



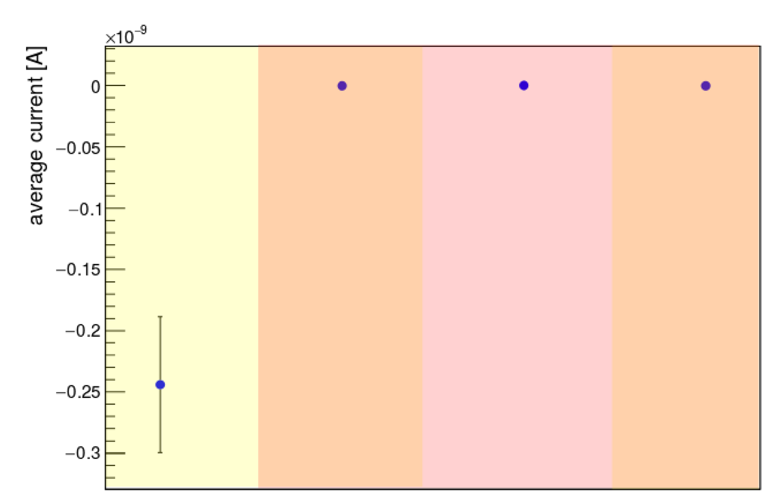
Fr detection system



Rb detection system

Test of the ion removal electrode

We tested the ion removal electrode really remove emitted ions from the neutralization target. In this time, Rb atom was used.The target material was Zr. The applied voltage was ± 10V. The value of the vertical axis is the average current of CEM counts during measurement time.



All ions emitted from target were removed by the electrode.

Experiment

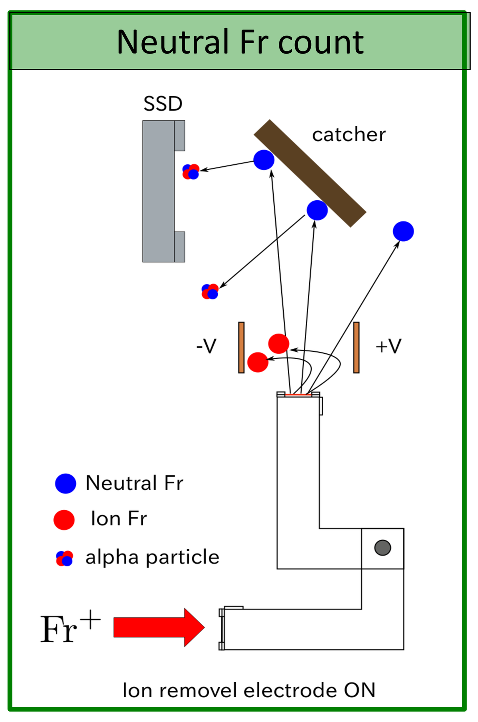
The definition of the neutralization efficiency (ε) is following.

$$\varepsilon = \frac{\sigma_{neutral}}{\sigma_{neutral+ion}}$$

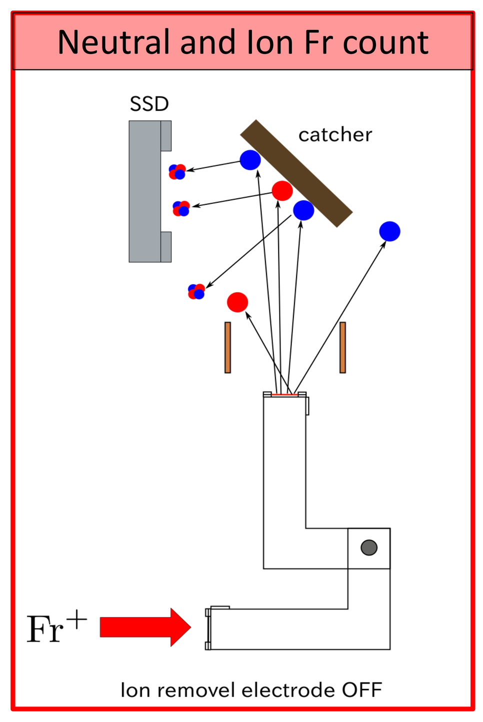
$$\sigma_{neutral} = \frac{\text{Neutral Fr count}}{\text{Accumulated Fr atoms on the target}}$$

$$\sigma_{neutral+ion} = \frac{\text{Neutral and Ion Fr count}}{\text{Accumulated Fr atoms on the target}}$$

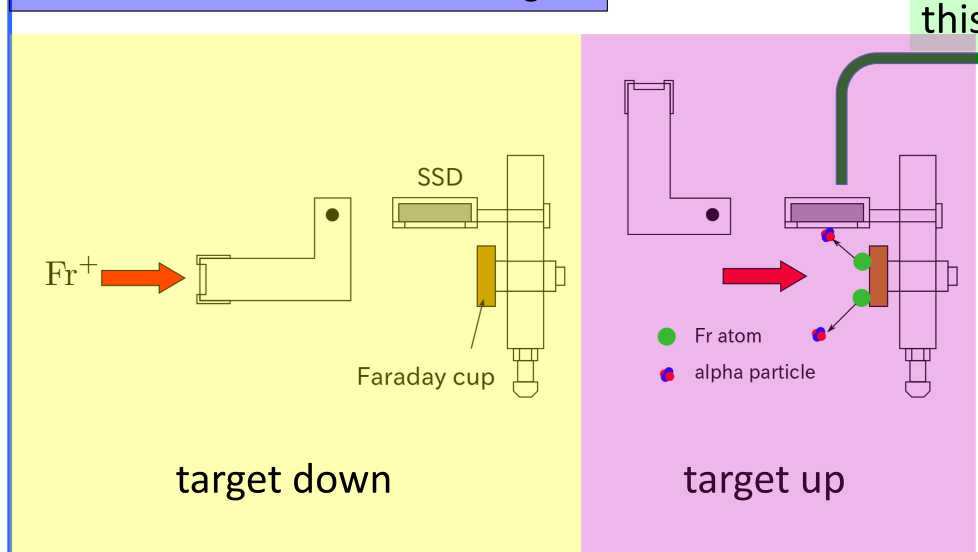
Neutral Fr count



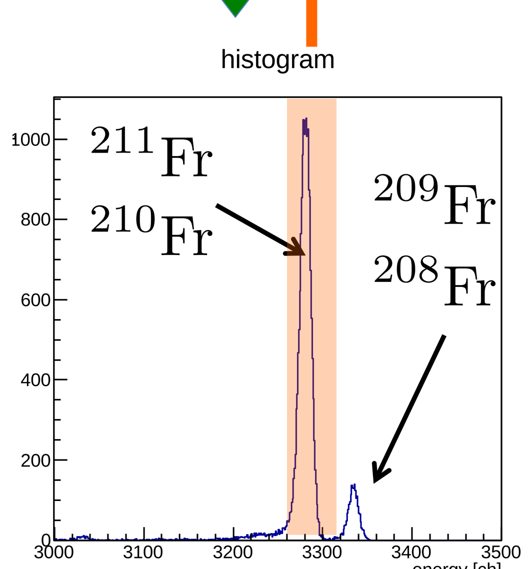
Neutral and Ion Fr count

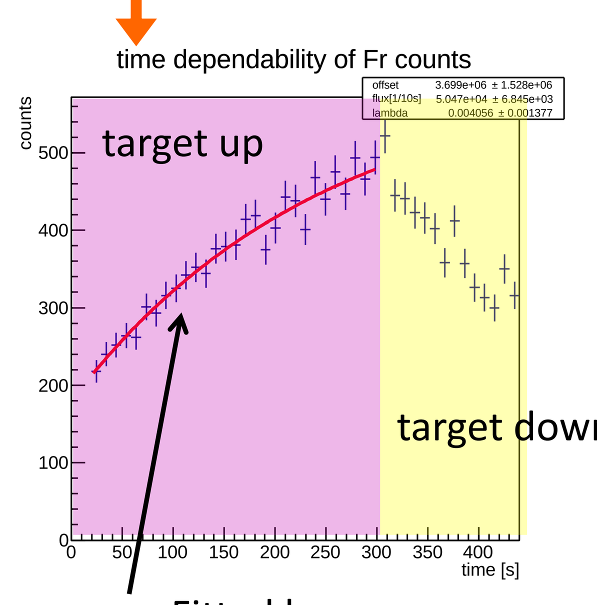


Accumulated Fr atoms on the target



counts of this SSD





The number of accumulated Fr atoms was calculated

$$\frac{f}{\lambda}(1 - e^{-\lambda t})$$

f : flux of the Fr ion beam

λ : decay constant

(^{210}Fr : 5.24 × 10^{-3}[1/s] , ^{211}Fr : 5.38 × 10^{-3}[1/s])

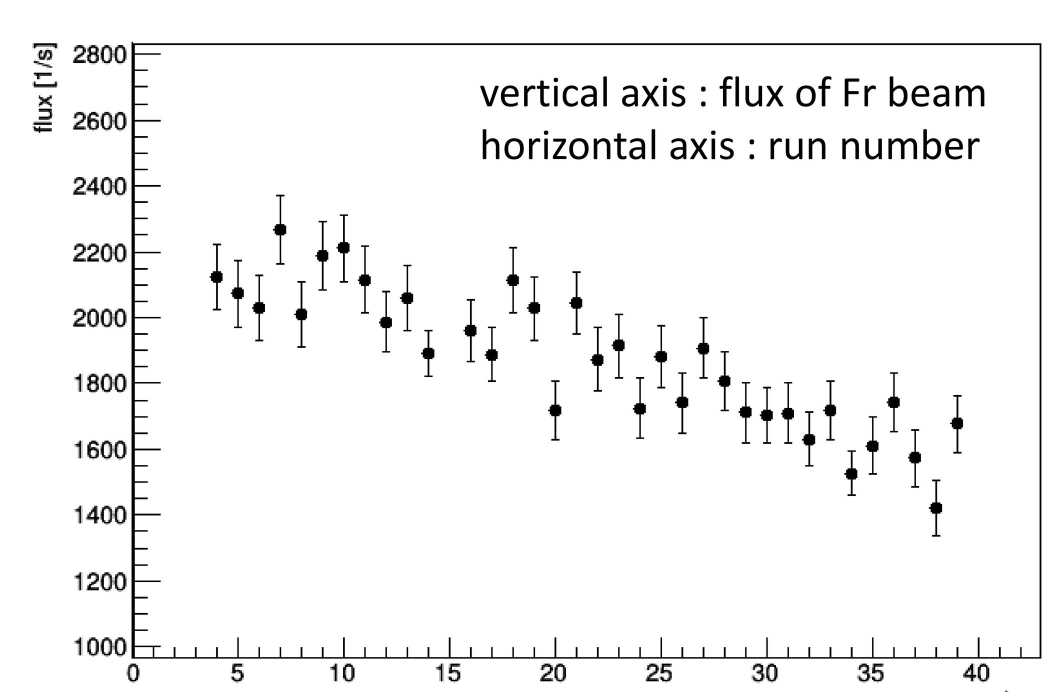
use this flux

This curve was Fitted by

$$\eta[f(1 - e^{-\lambda t}) + \lambda N_0]$$

η : detection efficiency (faraday cup -> SSD) -> 1.2 × 10^{-2}

Main origin of the error of the neutralization efficiency

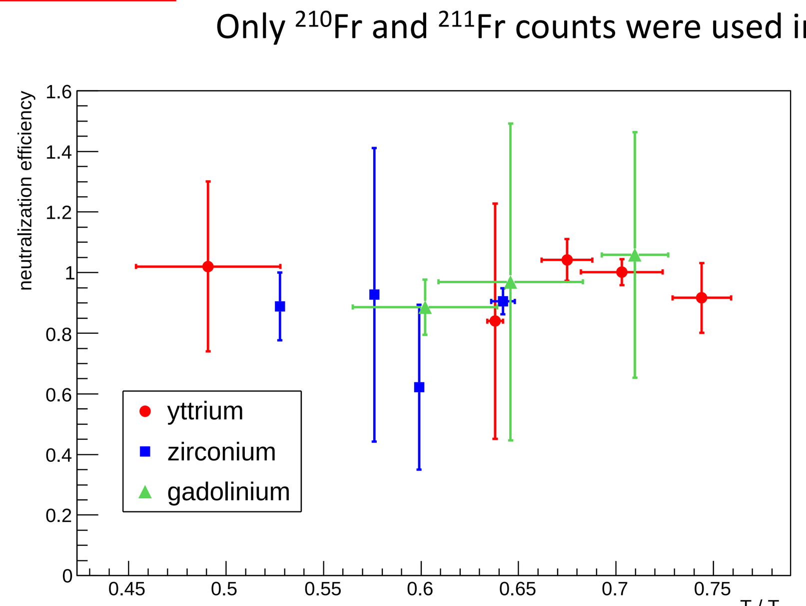


The fluctuation of the Fr beam flux was large.

This fluctuation caused the big neutralization error.

Result

Fr ions were accumulated 200 seconds on the neutralization target.
The target was heated for 300 seconds.
Only ^{210}Fr and ^{211}Fr counts were used in following results.

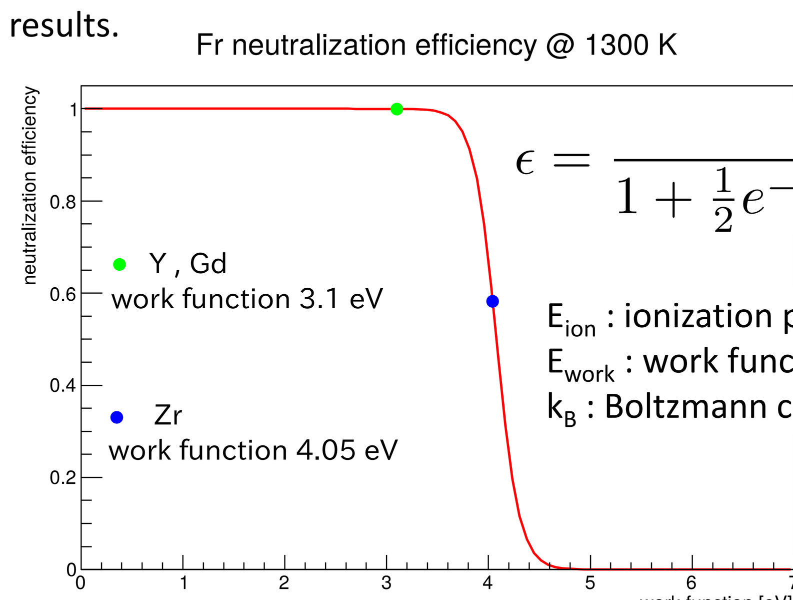


T_M : melting point

(Y : 1799 K , Gd : 1585 K , Zr : 2128 K)

T : temperature of the target

Fr neutralization efficiency @ 1300 K



$$\epsilon = \frac{1}{1 + \frac{1}{2}e^{-(E_{ion} - E_{work})/k_B T}}$$

E_{ion} : ionization potential of Fr (4.0 eV)

E_{work} : work function of the target material

k_B : Boltzmann constant

The neutralization efficiency calculated by Saha-Langmuir equation at 1300 K.
This result is theoretical calculation.

Conclusion and future plan

- The neutralization efficiency of the yttrium and gadolinium seems 100% and zirconium seems a little smaller than 100%.
- We study more about the neutralization efficiency using Rb atoms.