# Electron Screening Effects on α-decay

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**Abstract.** An open problem in Nuclear Astrophysics concerns the understanding of electron-screening effects on nuclear reaction rates at stellar energies. In this framework, we have proposed to investigate the influence of the electron cloud on α-decay by measuring Q-values and α-decay half-lives of fully stripped, H-like and He-like ions. These kinds of measurements have been feasible just recently for highly-charged radioactive nuclides by fragmentation of $^{238}U$ at relativistic energies at the FRS-ESR facility at GSI. In this way it is possible to produce, efficiently separate and store highly-charged α-emitters. Candidates for the proposed investigation were carefully selected and will be studied by using the Schottky Mass Spectroscopy technique.
In order to establish a solid reference data set, lifetimes and $Q_\alpha$-value measurements of the corresponding neutrals have been performed directly at the FRS, by implanting the separated ions into an active Silicon stopper.

**Keywords:** Electron Screening, Alpha-Decay, Lifetimes
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## ELECTRON SCREENING EFFECTS IN CHARGED-PARTICLE REACTIONS AT ASTROPHYSICAL ENERGIES

One important subject in nuclear astrophysics concerns the interpretation of electron screening effects observed in low-energy nuclear reactions with light nuclei [1]. As pointed out by several authors [1,2], screening corrections deeply affect the reaction rates at low relative energies. Screening in the laboratory largely differs from plasma screening in stars, forcing a double step procedure in extracting astrophysical reaction rates. Therefore it is essential to clarify at least the screening effects on the measured cross sections.

The screening enhancement factor in charged-particle reactions at the astrophysical energies is usually written as $f(E)=\frac{\sigma_s(E)}{\sigma_b(E)}=\exp\left(\frac{\pi\eta U_e}{E}\right)$ [2], where $\sigma_s(E)$ and $\sigma_b(E)$ are the screened and bare cross sections of an arbitrary charged-particle reaction respectively, $\eta$ is the Sommerfeld parameter and $U_e$ the so called electron screening energy. In order to extract information on $U_e$, $\sigma_s(E)$ and $\sigma_b(E)$ must be determined. Large experimental sources of uncertainty for $\sigma_s(E)$ are due to the small reaction cross sections involved, the missing knowledge of stopping powers and the high accuracy needed in the knowledge of the relative energy between the interacting ions[3]. Concerning $\sigma_b(E)$, so far it can be evaluated by extrapolation or, at the best, by using R-matrix fit.

In this uncertain scenario comes out the discrepancy between experimental $U_e^{exp}$ and theoretical $U_e^{th}$ values so far deduced. In particular, the $U_e^{\exp}$ values mostly exceed the maximum admitted theoretical ones and in some cases also by a factor two [2,4].

## ELECTRON SCREENING EFFECTS IN α-DECAY

Since extracting information on $U_e$ by studying nuclear reactions at very low energy is quite ambiguous, we suggest a completely different experimental method by simplifying, as much as possible, the system affected by the electron screening. It is well known that $Q_\alpha$−values and nuclear α-decay lifetimes should be different for bare nuclei with respect neutral atoms. $Q_\alpha$−values are simply related to the electron screening energy by the formula:

$$Q_\alpha(bare)\text{-}\ Q_\alpha(screened)=U_e(adiabatic) \qquad (1)$$

In case of alpha-emitters with Z=70-90 $U_e$(adiabatic)=30-40 keV. Thus the measurement of $Q_\alpha(bare)$ and $Q_\alpha(screened)$ allows direct determination of Electron Screening energy $U_e$. Furthermore we recently theoretically investigated the effects of electron screening on half-lives of alpha-emitters [5]. It turns out that relative changes in half-lives due to Electron Screening $\Delta T_{1/2}/T_{1/2}$ are expected to be in the order of few per mil.

## EXPERIMENTAL METHOD

The FRS-ESR facility at GSI(Darmstadt, Germany) offers a unique opportunity to perform precise half-lives and Q-value measurements for highly charged radioactive ions [6,7,8]. Time-resolved Schottky Mass Spectrometry (SMS) [8] is ideally suited for measuring decay half-lives and Q-values of radioactive ions in the $T_{1/2}$ range from about a few seconds to a few ten of minutes. In our case highly charged alpha decaying species can be produced by fragmentation of relativistic $^{238}$U ions, selected by the FRS and injected in the ESR for in-flight half-life and $Q_\alpha$-value measurements. The $^{213}$Fr nucleus has been put forward as a good candidate for such an investigation. Shown in table 1 the main decay properties of such nuclide, also reported expected screening energy and decay constant relative changes.

**TABLE 1.** $^{213}$Fr alpha decay properties, expected screening energy and $\Delta\lambda/\lambda$ relative changes.

| | $T_{1/2}$ | $\alpha$-branch(%) | $Q_\alpha$(MeV) | $U^{ad}$(keV) | $\Delta\lambda/\lambda$ % |
|---|---|---|---|---|---|
| **$^{213}$Fr** | 34.6 s (*3*) | 99.45 | 6.905 | 38.0 | 0.5 |

Half-life measurement of bare $^{213}$Fr can be performed by using the SMS technique in regime of many particle or single particle decay [9]. For implementing single particle decay and bare $Q_\alpha$-value measurements, parent ($^{213}Fr^{87+}$) and daughter ($^{209}At^{85+}$) nuclei must circulate in the ESR at the same time, in order to record simultaneously Schottky frequencies for both species.

## PRELIMINARY $T_{1/2}$ AND $Q_\alpha$ MEASUREMENT OF NEUTRALS $^{214}$Ra AND $^{213}$Fr

As a first step, in order to establish a solid reference data set, we performed precise half-life and $Q_\alpha$ measurements for $^{214}$Ra and $^{213}$Fr neutral atoms by using the RISING silicon implantation-decay set-up [10], installed at the FRS-S4 focal plane. It consisted of 6 DSSSD 1 mm thick with 16x16 strips. Fig 1 shows the implantation pattern of $^{213}$Fr in the first layer of the stack. The secondary alpha-emitters have been produced by using projectile fragmentation of $^{238}$U at 1 GeV·A on a Be target and then separated in the FRS by applying the well known Bρ-ΔE-Bρ method [6].

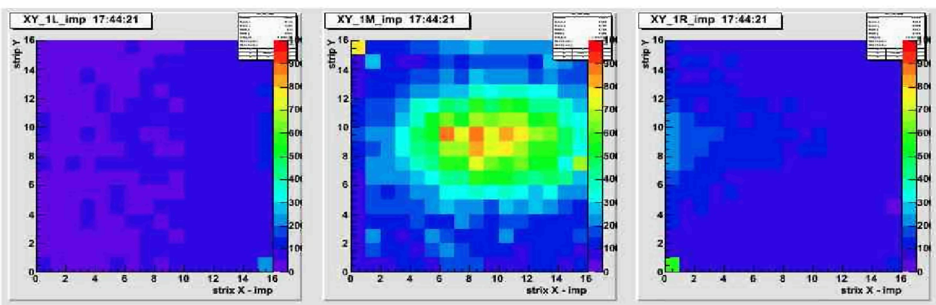


**FIGURE 1.** Implantation pattern on DSSSD for $^{213}$Fr settings during 4 second spill time.

Owing to the high selectivity of the FRS, a clear identification of the implanted ions is shown in Fig. 2 in case of $^{214}$Ra: characteristic $Q_\alpha$-values peaks detected during 12 s interspill time are clearly resolved with very low background. A decay curve shown in the upper left panel of Fig. 1 has been obtained after gating on the $^{214}$Ra decay peak. A preliminary half-life of $T_{1/2}$=(2.485±0.025)s has been deduced. This measurement is in agreement with the accepted value [11] and is more precise than any previous measurements, confirming the validity of the technique used. The presence of systematic errors will be estimated by performing correlation analysis between the identified implanted ion and α-decay and furthermore by extending the analysis to all the other implanted α-emitters.

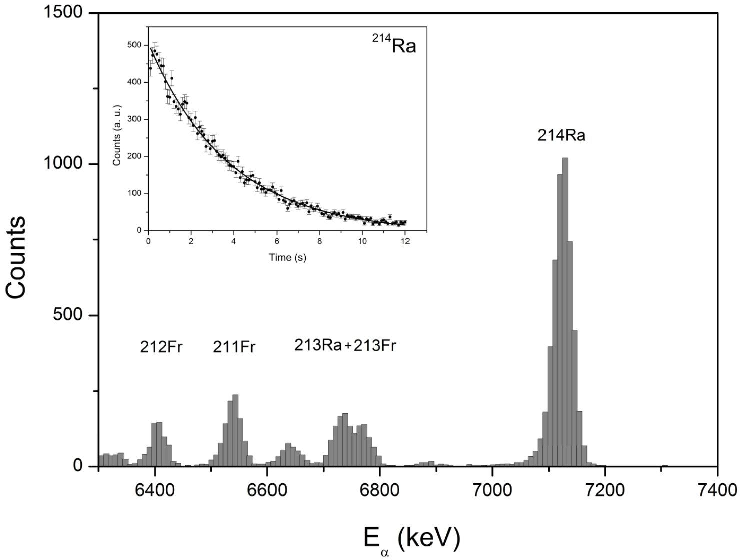


**FIGURE 2.** $Q_\alpha$-value spectrum; upper left panel: $^{214}$Ra decay curve.

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