Charge Exchange Reactions in Conjunction with the Oslo Method

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Introduction

- There are many types of reactions in Nuclear Physics.
- Charge-Exchange reactions are important for studying the isovector spin-isospin response of nuclei.
- There are important applications in nuclear astrophysics as well as nutrino physics.
- Ability to test theoretical models used for β-decay and electron-capture in astrophysical environments model independently.
- Used to create EC-rate library which used in astrophysical models.

Fig.1 FRIB-NSCL charge exchange group[1]

[1]https://groups.nscl.msu.edu/charge_exchange/index.html

Charge-Exchange Reactions

- CE reactions are characterized by the exchange of a proton and a neutron between the target nucleus and the projectile nucleus.[2]
- Yielding a change in Isospin $\Delta T = 1$.
- CE reactions is mediated by the strong nuclear force.
- CE reactions are often used to extract Gamow-Teller strengths ($\Delta s = 1$, $\Delta L = 0$ & $\Delta T = 1$).

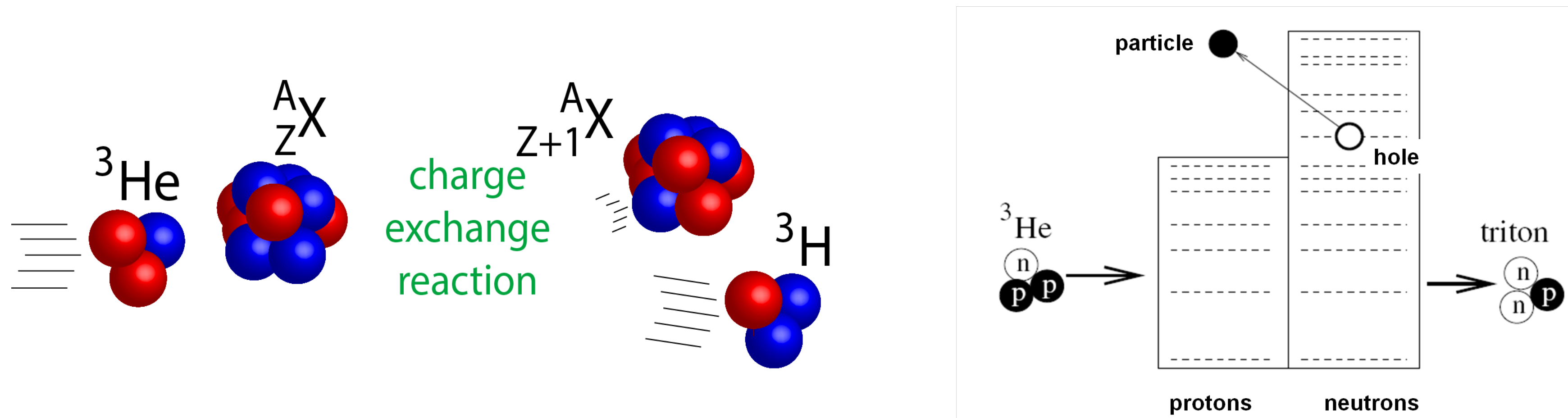
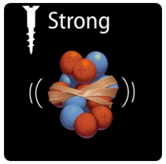


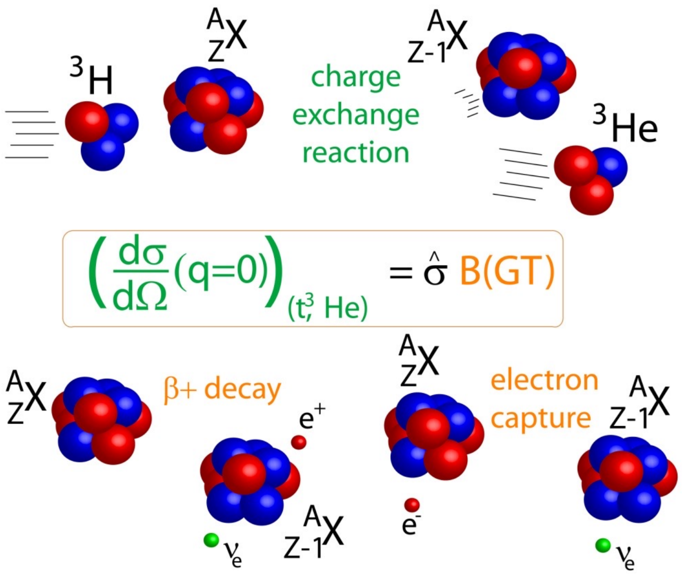
Fig.2 (^{3}He, t) charge-exchange reaction[3]

[3]https://groups.nscl.msu.edu/charge_exchange/index.html

Extraction of B(GT) using CE reactions [4]



$$\left(\frac{d\sigma}{d\Omega}\right)_{q=0} = \hat{\sigma} B(GT)$$



$$\frac{K}{ft} = \left(\frac{g_A}{g_v}\right)^2 B(GT)$$

- Perform experiments ~ 100 MeV/nucleon or above where reaction mechanism is simple
- B(GT) can be extracted from the proportionality relationship with differential cross section at zero momentum transfer (q=0) (at 0-degree scattering angles).
- It can be done by using the unit cross section $\hat{\sigma}$

[4]R.C.T.Titus Ph.D Dissertation, Michigan Sate University (2019)

Why CE Reactions important?

- However, such a probe also provides information about reactions mediated by the weak weak nuclear force

  → ***β*-decay & electron-capture**

  - Because, both reactions populate the same initial and final states and are associated with the same σ,τ operators

- In ***β***-decay experiments, states can be only measured from,

0 MeV of Ex. Energy → Q-value of the reactions

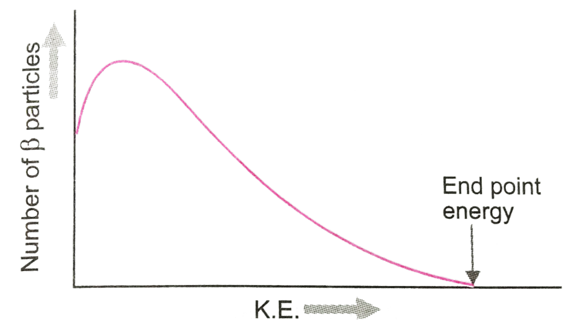


Fig.3 Distribution of K.E. of beta-decay [5]

- Thus, states with higher excitation energy cannot be observed
- CE reactions are not limited by the reaction Q-value and provide GT strengths up to high excitation energies [4]

[4]R.C.T.Titus Ph.D Dissertation, Michigan Sate University (2019)
[5]http://hyperphysics.phy-astr.gsu.edu/hbase/Nuclear/beta.html

My Project

Tentative Title: Development of Charge Exchange Oslo Method [6]

- It is supposed to measure the $^{92}Zr(^{3}He, t+\gamma)$ reactions at 420 MeV in forward kinematics to develop CE-Oslo method.
- And extract reaction rates for the nucleosynthesis of Cosmochronometer ^{92}Nb.
- This high precision study yield a solid foundation for study CE-Oslo method in future (p, n+γ) experiments in inverse kinematics with rare isotopes and make it possible to extract,

1. Nuclear level densities (NLDs)
2. γ-ray strength functions (γSFs)
3. β-decay strengths
4. (β-delayed) neutron decay probabilities on neutron-rich unstable nuclei

in a single experiment.

[6] Zegers, Research Proposal, RCNP, Osaka University (2020)

CE-Oslo Method [6]

- The so called "Oslo method" for extracting first-generation γ-rays and, subsequently, NLDs and γSFs, was established decades ago.[7]
- More recently, the technique has been successfully supplied to extract NLDs & γSFs from γ-ray spectra obtained after β-decay, so called "β-Oslo method" such that,[8]
    1. Unfolding γ-ray spectra at each excitation energy using detector response function
    2. Extraction of first-gen (primary) γ-ray distribution for given excitation energy
    3. Extraction of NLDs & γSFs using primary γ-ray distribution
    4. Normalization of NLDs & γSFs
- CE-Oslo method is a combination of the "original" Oslo method as well as more recent β-Oslo method.[6]
- By using a combination of the fine-structure analysis and auto-correlation function analysis, CE-Oslo method can be verified.[6]

[6]R.Zegers, Research Proposal, RCNP, Osaka University (2020)
[7]M.Guttormsen, Nucl. Instrum. Methods Phys. Res., Sect. A 255, 518 (1987))
[8]A. Spyrou et al., Phys. Rev. Lett. 113, 232502 (2014)

Experiment [6]

- 1st experiment is planned at RCNP, Osaka in Japan.
- Perform high-precision pilot study in forward kinematics with the (^{3}He, t+γ) using the Grand Raiden Spectrometer in coincidence with the Scintillation Gamma-Ray Detector (SGD) array at RCNP.

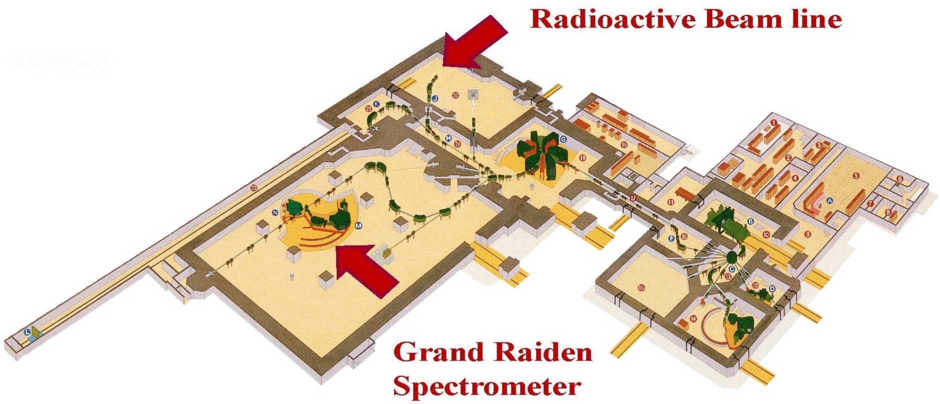


Fig.5 RCNP experiment in Japan[9]

[6]R.Zegers, Research Proposal, RCNP, Osaka University (2020)
[9]https://www.rcnp.osaka-u.ac.jp/en/local/album/

Thank You!

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