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CROSS SECTIONS FOR SINGLE AND DOUBLE ELECTRON CAPTURE FROM He^{++} ON HYDROGEN, NEON AND ARGON

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Cross sections σ_{21} and σ_{20} from doubly charged helium ions have been measured in H_2, Ne and Ar. The measurements were performed in the velocity range $1.6–4.4 \times 10^7$ cm/s. $^3He^{++}$ was used as a projectile as $^4He^{++}$ could not be separated from background H_2^+ by magnetic deflection in our apparatus. Isotope effects are known to be negligible in this velocity range.

Results obtained for the double electron-capture process at low energies indicate near resonant ($\Delta E \simeq 0$) types of collisions, which show that in the case of processes $He^{++} + X \rightarrow He + X^{++}$, where X is Ne or Ar, the recoiling doubly-charged ions are produced in highly-excited states. Structure is observed in the cross sections versus velocity curves for collisions with Ne targets.

1. Introduction

Though charge-changing collisions of protons on different targets have been investigated in great detail[1]), many features of this type of collisions are not well understood. Collisions involving He^{++}, next in simplicity to H^+, are important to study since they introduce for single electron capture the effect of Coulomb repulsion between the scattered particles and, for double electron capture, a two-electron neutral system. These types of collisions of He^{++} beams have been studied on only a few target gases. We report measurements of cross sections for single and double electron capture by He^{++} ions on H_2, Ne and Ar, in the ^3He energy range 55–400 keV. Our results are compared with published data for H_2 and Ar.

2. Apparatus and experimental results

The experimental apparatus is shown in fig. 1. Helium ions are produced in the radio-frequency ion source of the Bariloche Cockroft–Walton accelerator (Kevatron). A beam of $^3He^{++}$ was used as $^4He^{++}$ could not be resolved from background H_2^+ with our sorting magnet. Isotope effects are known to be negligible in our energy range[2,3]) and therefore our results can be compared to those taken with $^4He^{++}$ projectiles, at equal velocities.

The momentum-analyzed beam passes through a 10.3 cm long, differentially-pumped, gas-target cell which has entrance and exit channels of 1.2 mm and 2.3 mm in diameter respectively. This geometry

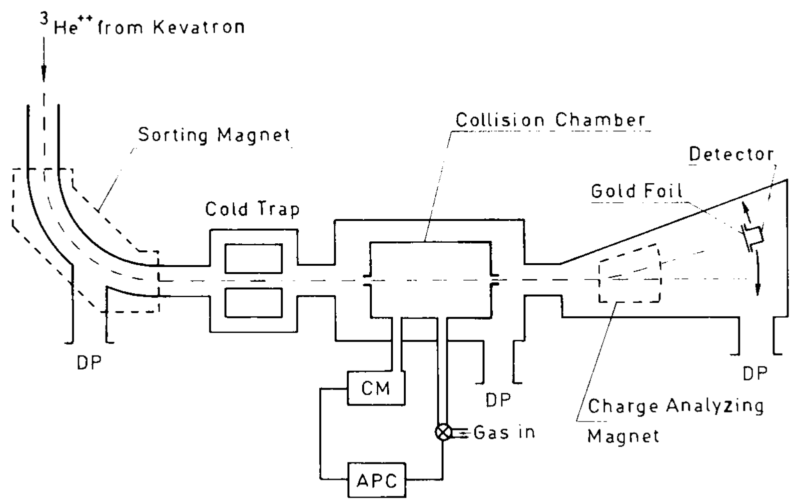

Fig. 1. The experimental apparatus. DP: LN_2-trapped diffusion pumps; CM: capacitance manometer; APC: automatic pressure-controller.

TABLE 1

States of recoil targets and energy defects ΔE(eV).

Final He state	H_2 State	ΔE	Ne State	ΔE	Ar State	ΔE
He (1^1S)	$H^+ + H^+$	+22.30	Ne^{++} $(2p^4\ ^1S)$	+9.05	$Ar^{++}(**)$	~0
He (2^1S)	$H^+ + H^+$	+ 1.69	Ne^{++} $(2p^4\ ^1D)$	−7.46	Ar^{++} $(3s3p^5\ ^1P_0)$	−2.86
He (2^3S)	–	–	Ne^{++} $(2p^4\ ^3P)$	−3.46	Ar^{++} $(3s3p^5\ ^3P_0)$	+1.50
He^+ (1^2S)	$H_2^+(**)$	≈ 0	Ne^+ $(3p'\ ^2F)$	−1.18	Ar^{++} $(3s3p^5\ ^3P_2)$ + e	−3.09
He^+ (2^2S)	H_2^+ $(X^1\Sigma)$	− 1.83	Ne^+ $(3p^5\ ^2P)$	−5.80	Ar^+ $(3p^5\ ^3P)$	−2.16

allows essentially all of the scattered beam to reach the detection chamber[4]).

High-purity gas is admitted to the target cell through a valve commanded by an automatic pressure-controller fed by the output signal of the capacitance manometer used to measure the gas pressure. After traversing the target cell, the beam is analyzed in charge by a magnetic field and each charge component collected on a charge-independent movable detector[2]). A vibrating-reed electrometer registers the collected current and feeds the signal to the Y axis of an X–Y plotter, while the X signal source is a biased potentiometer mechanically coupled to the motor used to drive the detector. Background gas pressure outside the collision chamber was kept below 3×10^{-6} torr.

The charge fractions were measured six times at each energy and at constant pressure. The cell pressure was then varied from 1.5×10^{-4} to about 8×10^{-4} torr in six or seven steps. This range of pressures was checked to correspond to single-collision conditions. The cross sections were determined from the initial

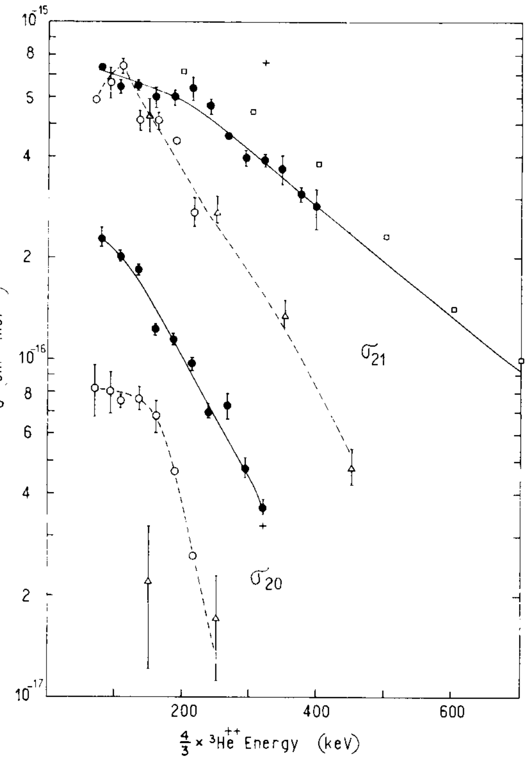

Fig. 2. Single and double electron capture cross sections for He^{++} on H_2 and Ar. H_2: ○ – these results; △ – Allison[8]). Ar: ● – these results; + – Nikolaev et al.[9]); □ – Pivovar et al.[10]). The lines are drawn to guide the eye and have no other meaning.

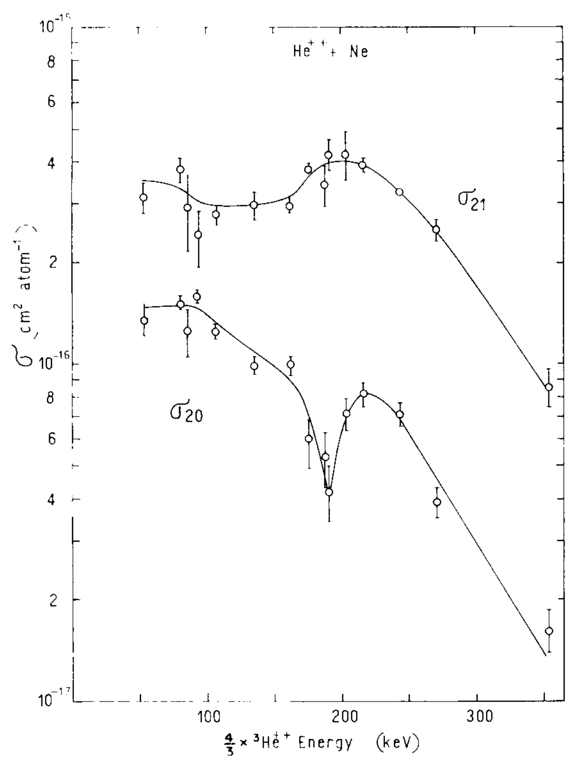

Fig. 3. Single and double electron capture cross sections for He^{++} on Ne. The lines are drawn to guide the eye and have no other meaning.

slopes of the curves which gave the dependence of the He and He^+ fractions on target thickness. The method of analysis is described elsewhere[5]). Results are plotted in figs. 2 and 3 with their statistical uncertainties. Systematic errors have been estimated to be less than 15%. The energy scale is accurate to within 2%. A check of the overall performance of the apparatus was made by measuring equilibrium fractions and electron capture cross sections for He^{++} on He gas. The results agreed within experimental errors with those by Meckbach and Nemirovsky[2]) and by Berkner et al.[6]) respectively.

3. Conclusions

The high values of the electron capture cross sections at low energies can be correlated to the existence of outgoing channels yielding very small energy defects. The reactions obeying spin conservation and giving ground and metastable states of He and He^+ are presented in table 1, where the energies are taken from Moore's compilation[9]), Franck-Condon transitions are assumed in the case of H_2 and (**) indicates a highly excited state.

Results suggest that single and double electron capture involving He^{++} projectiles should be an efficient way of producing metastable He and He^+ for use in atomic collision experiments.

The feature in the cross sections versus energy curves at ≈ 190 keV for Ne was measured three different days and averaged. It is possible due to contributions from different shells of the target atom. As the minimum in σ_{20} is correlated with the maximum in σ_{21}, the structure could also result from interference effects in the outgoing channels or to a sharp peak at this energy of ths cross section for electron capture to autoionizing levels of He which would decay in flight and be counted as He^+ ions.

It is hoped that our results will stimulate theoretical work, not yet available, on these processes.

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