EXCITED STATES AND EMISSION CROSS SECTIONS IN COLLISION OF Ne^{4+} WITH He*

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I. INTRODUCTION

The collision of ion beams with atomic or molecular target has attracted many physists, for it provides rich information, which, as shown by experiments, includes ion signals, electron signals, photon signals and cluster signals, etc. As for soft X-ray lasers, the information of photons and highly charged ions is spectacular.

In 1982, the excited projectiles in the collision of Ne^{z+} ($z=1, 2, 3, 4$) with He, Ne, and Ar were studied by Bloemen et al. [1], and the impact energy ranges of Ne^{4+} ions are from 60 to 800 keV. In 1984, Nikulin et al. [2] studied the 60 — 100 keV Ne^{4+} – Ne collision with ECR ion source.

Recently, we conducted the experimental studies of single electron capture and double-electron capture into excited states in the collision between Ne^{4+} and He, using the ECR ion source-CAPRICE and LHT-30 VUV monochromator made in France. The energy of Ne^{4+} ranges from 48 to 64 keV, the ion beam current is about 45 — 60 μA, and the wavelength range of the monochromator is from 10 to 80 nm.

II. EXPERIMENTAL RESULTS

For details of the experimental setup please refer to Ref. [3]. Fig. 1 shows the emission spectra of NeIV, NeIII and HeII in the collision between Ne^{4+} and He at 52 keV incident ion impact energy. The NeIV, NeIII and HeII lines observed are listed in Tables 1 and 2.

The emission lines show that there are two channels of excitation in the energy range of 48 — 64 keV.

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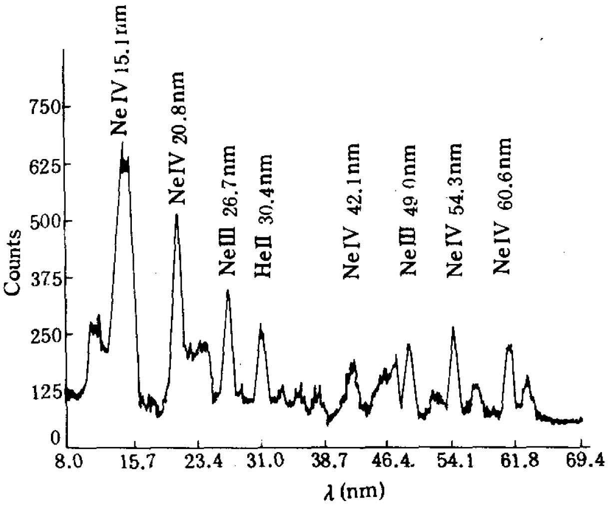

Fig. 1. The spectra of NeIV and HeII lines in collision between Ne^{4+} and He at 52 keV energy.

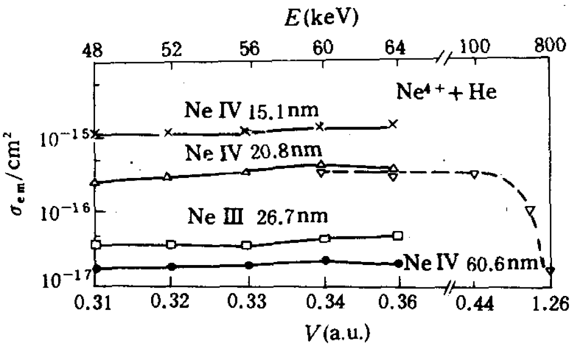

Fig. 2. Emission cross sections for Ne^{4+} + He as a function of the velocity of projectile. The dashed line denotes the results of Bloemen, and the solid lines denote our results.

Table 1

Doublet and Quartet Lines of NeIV

Doublet		Quartet	
Transition	λ (nm)	Transition	λ (nm)
$2p^2 4d\ ^2D \rightarrow 2p^3\ ^2D^0$	15.1	$2p^2 3s\ ^4P \rightarrow 2p^3\ ^4S^0$	20.8
$2s2p^4\ ^2S \rightarrow 2p^3\ ^2P^0$	42.1	$2s2p^4\ ^4P \rightarrow 2p^3\ ^4S^0$	54.3
$2p^5\ ^2P^0 \rightarrow 2s2p^4\ ^2P^0$	60.6		

Table 2

Triplet NeIII and Doublet HeII Lines

NeIII Triplet		HeII Doublet	
Transition	λ (nm)	Transition	λ (nm)
$2p^3 3s\ ^3P^0 \rightarrow 2p^4\ ^3P$	26.7	$2p\ ^2P^0 \rightarrow 1s\ ^2S$	30.4
$2p^3 3s\ ^3S^0 \rightarrow 2p^4\ ^3P$	31.3		
$2s2p^5\ ^3P^0 \rightarrow 2p^4\ ^3P$	49.0		

(i) Single electron capture into excited states:

$$Ne^{4+} + He \rightarrow Ne^{3+*}(n, l) + He^{+*}(n, l)$$
$$\rightarrow Ne^{3+} + He^{+} + h\nu\,(NeIV) + h\nu\,(HeII).$$

(ii) Double-electron capture into excited states:

$$Ne^{4+} + He \rightarrow Ne^{2+*}(n, l) + He^{2+}$$
$$\rightarrow Ne^{2+} + He^{2+} + h\nu\,(NeIII).$$

According to the definition[4], the emission cross sections of NeIV, NeIII and HeII lines have been measured absolutely, and are listed in Table 3.

Fig. 2 shows the emission cross section σ_{em} for Ne^{4+} + He as a function of collision velocity.

Table 3

Emission Cross Sections of NeIV, NeIII and HeII Lines (Unit in 10^{-16} cm^2)

E (keV)	NeIV Doublet λ (nm)			Ne IV Quartet λ (nm)		Ne III Triplet λ (nm)		He II Doublet λ (nm)
	15.1	42.1	60.6	20.8	54.3	26.7	49.0	30.4
48	10.37	0.17	0.16	2.83	0.10	0.39	0.11	0.19
52	11.37	0.14	0.15	3.17	0.11	0.39	0.12	0.20
56	9.95	0.15	0.15	3.34	0.12	0.47	0.10	0.21
60	12.22	0.26	0.20	4.76	0.13	0.51	0.14	0.29
64	12.57	0.20	0.16	3.63	0.14	0.55	0.16	0.25

Error estimation: The photon signal counts are about 10^3—10^4, and the statistical error is <3%. The errors of measurements of optics, charge quantity, and gas target density are ±3% respectively. The uncertainty of quantum efficiency of optical detection system is about ±10%. The total error of emission cross sections is about ±22%..

III. Discussion

1. Electron capture is an important process in collisions between multi-charged ions and atoms. Our experiments suggest that there are two processes: single electron capture and double-electron capture. Generally, the cross-sections of the former are greater than those of the latter.

2. Fig. 3 shows the potential energy curves of the exothermic exit channels (Ne^{3+*} — He) across the potential energy curve of the entrance channel (Ne^{4+} — He) and the corresponding crossing radius R_c is given in Fig. 3. According to the potential curve-crossing model, only those reactions, which are moderately exothermic and have intermediate values of R_c ($3 < R_c < 10$ a.u.)[1], lead to large cross sections.

Table 4 gives ΔE values of potential energy defect : $\Delta E > 0$ is exothermic reaction, and $\Delta E < 0$ is endothermic reaction. From Fig. 3 and Table 4, for the NeIV quartet line $2p^2 3s\ ^4P \rightarrow 2p^3\ ^4S^0$, $\lambda = 20.8$ nm, $\Delta E = 12.98$ eV, $3 < R_c < 10$ a.u. Therefore, the emission cross sections of this line are larger than other lines, while for the NeIV doublet line $2s2p^4\ ^2S \rightarrow 2p^3\ ^2P^0$, $\lambda = 42.1$ nm and for NeIV quartet line $2s2p^4\ ^4P \rightarrow 2p^3\ ^4S^0$, $\lambda = 54.3$ nm, R_c is intermediate values, but ΔE is very large, being 35.34 eV and 49.66 eV respectively.

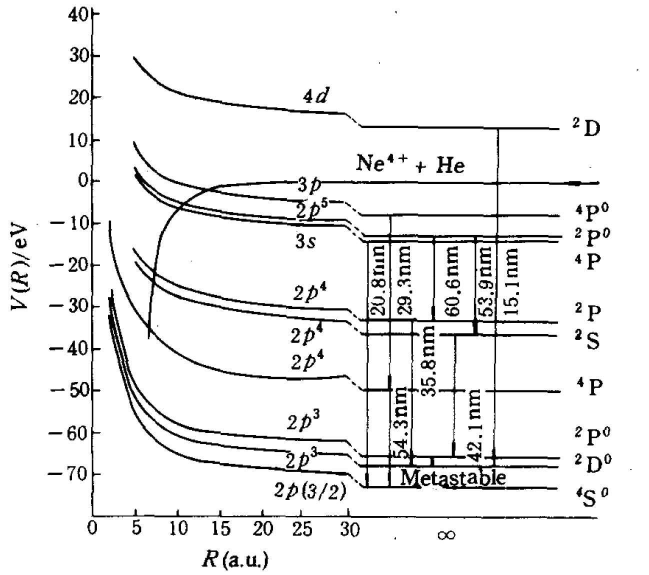

Fig. 3. The diabatic potential diagram for Ne^{4+} + He collision.

Therefore, the emission cross sections of both lines are not large. In addition, for NeIV doublet line $2p^5\ ^2P^0 \rightarrow 2s2p^4\ ^2P$, $\lambda = 60.6$ nm, $\Delta E = 12.37$ eV, R_c is intermediate value, but it is only the transition from $2p^5\ ^2P^0$ to $2s2p^4\ ^2P$ state, not the transition to ground state, so the emission cross sections are not large either.

Table 4

ΔE Values of NeIV Lines Observed

λ (nm)	15.1	20.8	42.1	54.3	60.6
ΔE(keV)	−14.16	12.98	35.34	49.66	12.37

3. The emission cross sections of NeIV quartet line $2p^2\ 3s^4\ P \rightarrow 2p^3\ ^4S^0$ ($\lambda = 20.8$ nm) in Fig. 2 show that our experimental results agree well with Bloemen's results.

Fig. 2 indicates that the velocities of emission cross sections have weak dependence relation in the range of velocity of incident ion Ne^{4+} from 0.31 to 0.36 a.u. It means that the curves are smooth in energy range of 48 — 64 keV.

4. NeIV double line $2p^2\ 4d\ ^2D \rightarrow 2p^3\ ^2D^0$ ($\lambda = 15.1$ nm) has large cross sections which is an endothermic reaction, the potential energy defect $\Delta E = -14.16$ eV. In the case of endothermic processes transitions can only occur via a non-crossing type of coupling, which has been treated by Demkov[5], Olson[6] and Dinterman[7].

References

[1] Bloemen, E. W. P. et al., *J. Phys. B: At. Mol. Phys.*, **15**(1982), 1391.
[2] Nikulin, V. K. et al., *J. Phys. B: At. Mol. Phys.*, **17**(1984), L721.
[3] Pan Guangyan et al., *Acta Physica Sinica*, **41**(1992), 228.
[4] Dijkkamp, D. et al., *J. Phys. B: At. Mol. Phys.*, **18**(1985), 737.
[5] Demkov, Yu N., *Sov. Phys. JETP*, **18**(1964), 138.
[6] Olson, R. E., *Phys. Rev.*, **A6**(1972), 1822.
[7] Dinterman, T. R. & Delos, J. B., *Phys. Rev.*, **A 15**(1977), 463.