Journal of Physics B: Atomic and Molecular Physics

A new He^- resonance in the excitation of the $(2s2p)^3P$ autoionising state by electrons

J. Phys. B: At. Mol. Phys. 18 (1985) L171-L174. Printed in Great Britain

LETTER TO THE EDITOR

A new He^- resonance in the excitation of the $(2s2p)^3P$ autoionising state by electrons

P J M van der Burgt, J van Eck and H G M Heideman

Fysisch Laboratorium, Rijksuniversiteit Utrecht, Princetonplein 5, 3584 CC Utrecht, The Netherlands

Received 19 November 1984

Abstract. Four He^- resonances with all three electrons in the $n=2$ shell are accessible by electron impact from the He ground state but only two resonances have been identified unambiguously in electron-helium scattering experiments. Experimental evidence for the presence of a He^- resonance at 59.90 eV in the excitation cross section of the $He^{**}(2s2p)^3P$ autoionising state is presented and discussed.

During the last ten years much attention has been paid to the 57-61 eV energy region in electron-helium scattering experiments. Four autoionising states are known in this region, which decay to the ground state of the helium ion by ejecting an electron. The well known post-collision interaction (PCI) causes the scattered and the ejected electron to exchange energy and orbital angular momentum. The energy exchange may even be large enough for the scattered electron to be captured into a singly-excited state of the helium atom. This indirect excitation process gives rise to structures in the excitation functions of singly-excited helium states. Identification of these structures is hindered by He^- resonances, which decay either directly or indirectly via the autoionising states (PCI) to the singly-excited states. Although near 60 eV four He^- resonances with all three electrons in the $n=2$ shell are accessible (Fano and Cooper 1965) only two of these resonances have been identified experimentally. The $He^-(2s^22p)^2P$ resonance at 57.22 eV lies below all autoionising states and therefore only affects the excitation cross sections of singly-excited helium states, whereas the $He^-(2s2p^2)^2D$ resonance at 58.30 eV also decays strongly to the lowest two autoionising states. It is the purpose of this Letter to present experimental evidence for a new resonance occurring in the excitation of the $He^{**}(2s2p)^3P$ state.

The electron spectrometer used for the present work is of a conventional type, first described by Kuyatt and Simpson (1967). After passing a hemispherical energy selector the incident electron beam is directed into the interaction chamber containing the helium gas. The ejected electrons are detected after passing a second hemispherical energy selector. The energy selectors are operated at a resolution of 90 and 65 meV, respectively. Ejected-electron spectra of the $He^{**}(2s2p)^3P$ autoionising state may be measured by detecting the yield of ejected electrons as a function of the incident electron energy at a fixed ejected-electron energy. In the absence of post-collision interaction ejected electrons from the $He^{**}(2s2p)^3P$ state have an energy of 33.71 eV, but the electrons may acquire a higher energy during the post-collision interaction. So when measuring ejected-electron spectra, we may choose the fixed ejected electron energy in a small range of, say, 0.5 eV upward from 33.71 eV.

0022-3700/85/060171+04\$02.25

Analysis of structures in the measured ejected-electron spectra is complicated by the fact that the ejected electrons interfere with electrons from the direct ionisation of helium. When measuring spectra at a fixed incident energy this interference gives rise to the familiar PCI line profiles (Hicks *et al* 1974, Baxter *et al* 1979). When measuring spectra at fixed ejected energies (in the mode described above) slow oscillations are observed, which extend over several eV on the incident energy scale (Baxter *et al* 1979, van der Burgt *et al* 1985). Without knowledge of this interference effect these oscillations might easily be mistaken for broad resonances, as indeed was done by previous investigators. We are able to distinguish between resonance structures and PCI structures by comparing spectra measured at several values of the fixed ejected-electron energy. The oscillations due to PCI have minima and maxima whose positions on the incident energy scale change rapidly with the ejected-electron energy, whereas a structure due to a negative-ion resonance will show up at the same incident energy in all spectra.

Spectra of ejected electrons of the He**(2s2p)^{3}P state are presented in figure 1, curves A–C. The global curved appearance of these spectra is not the result of variations in the transmission current of the electron spectrometer but is entirely due to (PCI) interference of ejected electrons with electrons from the direct ionisation. Superimposed on this structure a narrower structure is clearly visible at 59.9 eV. These spectra may be compared with those of Baxter *et al* (1979): also their spectra show a small structure near $E_i = 59.9$ eV (see curves A and C in their figure 3). This structure is apparently overlooked by them as they do not mention it. We have measured two other ejected-electron spectra at $E_{ej} = 33.35$ and 33.00 eV, not shown in figure 1. At $E_{ej} = 33.35$ eV ejected electrons from the He**(2s^2)^{1}S state are observed, whereas at $E_{ej} = 33.00$ eV only electrons from the direct ionisation of helium can be detected. In both spectra structure around $E_i = 59.9$ eV is lacking, so the structure in the figure 1, curves A–C is associated with the excitation of the He**(2s2p)^{3}P state only.

As to the interpretation of the structure in the spectra A, B and C of figure 1 we can first of all note that it certainly cannot be the result of a post-collision interaction. Other possibilities are: (i) a Wigner cusp due to the He**(2s^2)^{1}D threshold at 59.9 eV or (ii) a negative-ion resonance. The first possibility seems to be excluded by the relatively large width ($\simeq 0.4$ eV) of the measured structure. The cusps measured by Cvejanović *et al* (1974) and Andrick *et al* (1972) have widths much less than 0.1 eV. Some experimental evidence for a resonance near 59.9 eV was given by Heideman (1980) and Morgenstern *et al* (1977). Heideman (1980) has found that the strength of PCI structures in the excitation functions of singly-excited helium states, caused by the He**(2p^2)^{1}D state, suggests that the cross section for excitation of this autoionising state is enhanced by a resonance. A similar suggestion was made by Morgenstern *et al* (1977) based on fits of a semiclassical model for PCI to the He**(2p^2)^{1}D PCI structures in singly-excited helium states. From the spectrum A in figure 1 we have determined the position and the width of the resonance to be $E_i = 59.90 \pm 0.05$ eV and $\Gamma = 0.4 \pm 0.1$ eV.

Spectrum D in figure 1 shows scattered electrons which have excited the He*(1s2s)^{3}S singly-excited state. This spectrum was measured in a different mode of operation of the electron spectrometer in which the incident energy E_i and the energy of the detected electrons E_c were varied at the same time, keeping the energy loss $E_l = E_i - E_c$ at a constant value of 19.82 eV. In this spectrum also a structure is observed at $E_i = 59.9$ eV (first reported by Roy *et al* 1978). Although we cannot exclude the possibility that the structure seen in spectrum D of figure 1 is due to PCI via the He** (2p^2)^{1}D

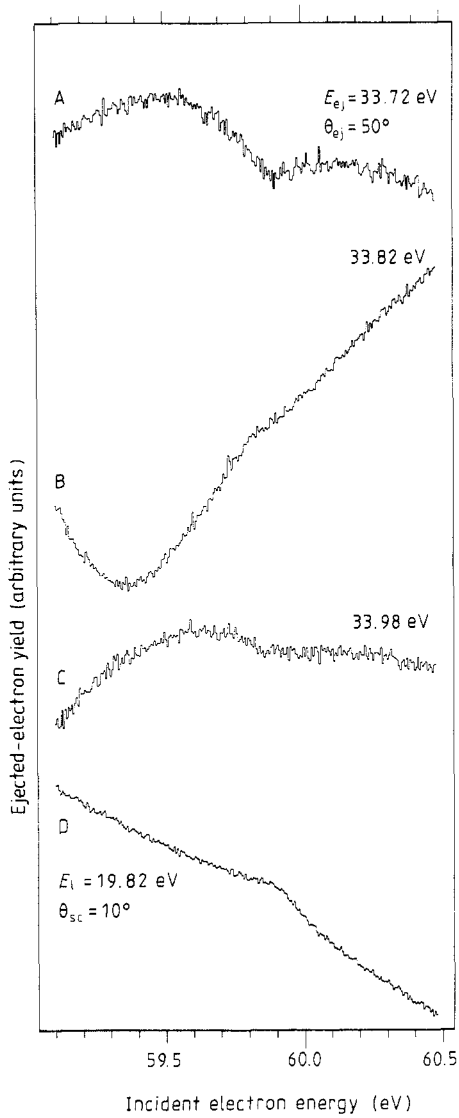

Figure 1. A, B, C, ejected-electron spectra of the He**(2s2p)^{3}P autoionising state measured with fixed ejected-electron energy at $\theta_{ej} = 50°$. D, scattered electron spectrum of the 2^3S singly-excited helium state measured at $\theta_{sc} = 10°$. No sloping background was subtracted from these spectra.

autoionising state, the PCI energy exchange required for PCI excitation of the 2^3S state seems too large (4.77 eV). We therefore assume that it is also caused by the resonance seen in the spectra A, B and C.

Two He^- resonances have been predicted theoretically (Nesbet 1976) in the energy region around 60 eV: the $He^-(2s2p^2)^2S$ state at 59.5 eV and the $He^-(2p^3)^2P$ state at 60.6 eV. By close-coupling calculations, Ormonde *et al* (1974) have predicted that the $He^-(2s2p^2)^2S$ state mainly decays to the He**(2s2p)^{3}P autoionising state and the He*(1s2s)^{3}S singly-excited state. Based on this result we could tentatively identify the

59.9 eV structure as the $He^-(2s2p^2)^2S$ resonance. The width of this resonance as calculated by Ormonde *et al* (1974) (0.3 eV) agrees well with the width we observe but the position of the resonance (59.4 eV) deviates significantly from our measured position. So no definite identification is possible as experimental evidence for the position of the fourth resonance is still lacking. An experimental way of determining the orbital angular momentum of the resonance would be the measurement of the angular distribution of the resonant scattered electron (resulting from excitation of the $He^{**}(2s2p)^3P$ state). However, such a measurement is hampered by interference between the resonant scattered electron and the slow electron from the direct ionisation of helium (see van der Burgt *et al* 1985).

The present measurements clearly show that great care has to be exercised in interpreting the structures around 60 eV in the excitation functions of the singly-excited helium states. Both negative-ion resonances in this region may affect the excitation cross sections either directly or indirectly via PCI. Summarising we conclude that the 59.9 eV structure we observe in the excitation of the $He^{**}(2s2p)^3P$ state is due to a negative-ion resonance with probable configuration $He^-(2s2p^2)^2S$. A similar structure in the excitation functions of the $n = 2$ singly-excited helium states is probably due to the same resonance. Measurements on PCI structures in the excitation of $n \geq 3$ states provide evidence that the threshold excitation of the $He^{**}(2p^2)^1D$ autoionising state is strongly enhanced by this resonance.

This work was performed as part of the research programme of the 'Stichting voor Fundamenteel Onderzoek der Materie' (FOM) with financial support from the 'Nederlandse Organisatie voor Zuiver-Wetenschappelijk Onderzoek' (ZWO).

References

Andrick D, Eyb M and Hofmann M J 1972 *J. Phys. B: At. Mol. Phys.* **5** L15-7
Baxter J A, Comer J, Hicks P J and McConkey J W 1979 *J. Phys. B: At. Mol. Phys.* **12** 2031-41
van der Burgt P J M, van Eck J and Heideman H G M 1985 *J. Phys. B: At. Mol. Phys.* **18** 999-1009
Cvejanović S, Comer J and Read F H 1974 *J. Phys. B: At. Mol. Phys.* **7** 468-77
Fano U and Cooper J W 1965 *Phys. Rev.* A **138** 400-2
Heideman H G M 1980 *Coherence and Correlation in Atomic Collisions* ed H Kleinpoppen and J F Williams (New York: Plenum) pp 493-508
Hicks P J, Cvejanović S, Comer J, Read F H and Sharp J M 1974 *Vacuum* **24** 573-80
Kuyatt C E and Simpson J A 1967 *Rev. Sci. Instrum.* **38** 103-11
Morgenstern R, Niehaus A and Thielmann U 1977 *J. Phys. B: At. Mol. Phys.* **10** 1039-58
Nesbet R U 1976 *Phys. Rev.* A **14** 1326-32
Ormonde S, Kets F B and Heideman H G M 1974 *Phys. Lett.* **50A** 147-8
Roy D, Delâge A and Carette J-D 1978 *J. Phys. B: At. Mol. Phys.* **11** 4059-66