# Autoionizing Rydberg Series ($np'$, $nf'$) of Ne Investigated by Stepwise Excitations with Lasers and Synchrotron Radiation

**Y.-Y. Lee (李英裕)[1], W.-C. Pan (潘婉君)[2], T.-Y. Dung (董讚儀)[1], T.-P. Huang (黃自平)[1], J.-Y. Yu (喻霽陽)[1], Y.-F. Song (宋艷芳)[1], I-C. Chen (陳益佳)[2], S.-Y. Tu (塗時雨)[3], A. H. Kung (孔慶昌)[3], and L. C. Lee[4]**

**[1]National Synchrotron Radiation Research Center, Hsinchu, Taiwan**
**[2]Department of Chemistry, National Tsing Hua University, Hsinchu, Taiwan**
**[3]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei, Taiwan**
**Department of Photonics, National Chiao Tung University, Hsinchu, Taiwan**
**[4]Department of Electrical and Computer Engineering,**
**San Diego State University, San Diego, USA**

Ne atoms are first excited by synchrotron radiation to the intermediate states, $2p^5{}_{1/2}$ ($3d'$ $[3/2]_1$, $5d'$ $[3/2]_1$, and $6s'$ $[1/2]_1$), and then excited by lasers to the even-parity autoionizing Rydberg series, $2p^5{}_{1/2}$ ($np'$ ($[1/2]_{0,1}$, $[3/2]_{1,2}$) and $nf'$ $[5/2]_2$). For the $6s'$ intermediate state, all the four $np'$($[1/2]_{0,1}$ and $[3/2]_{1,2}$) series are observed. When the polarization vectors of two light beams rotate from parallel to orthogonal, the intensity of the $[1/2]_0$ state decreases, but the intensities of other three states remain about the same. The spectra of the $np'$ series are assigned in according to their linewidths. The quantum defects for the $np'$ $[1/2]_0$ ($n$ = 14–50) and $np'$ $[3/2]_2$ ($n$ = 14– 78) series are 0.768±0.019 and 0.838±0.021, respectively, which agree very well with theoretical prediction. The peak energies for the $np'$ ($[3/2]_1$ and $[1/2]_1$) series are so close to those of $np'$ $[3/2]_2$ that their quantum defects are about the same. The spectral lineshapes of the $np'$ $[1/2]_0$ ($n$ = 14–24) series are analyzed with Beutler-Fano profile to determine the reduced-autoionization linewidths that vary larger than expected from theory, indicating that the interaction between the Rydberg electron and core electrons varies greatly with excitation energy. The $nf'$ $[5/2]_2$ series is observed via both the $3d'$ and $5d'$ intermediate states. For the $3d'$ intermediate state, the $np'$ $[1/2]_0$ series is also observed when the polarization vectors of two light beams are in parallel, although its intensity is very weak (~ three orders of magnitude smaller than that of $nf'$ $[5/2]_2$). The $np'$ $[1/2]_0$ series disappears when the polarization vectors of two light beams rotate to orthogonal.

The lineshapes of the $nf'$ $[5/2]_2$ series produced via the $3d'$ intermediate state are asymmetric. The average quantum defect of the $nf'$ $[5/2]_2$ series is 0.001(0.040) for $n$ = 13 to 84. Our results show that the spectra of autoionizing Rydberg series strongly depend on intermediate states.

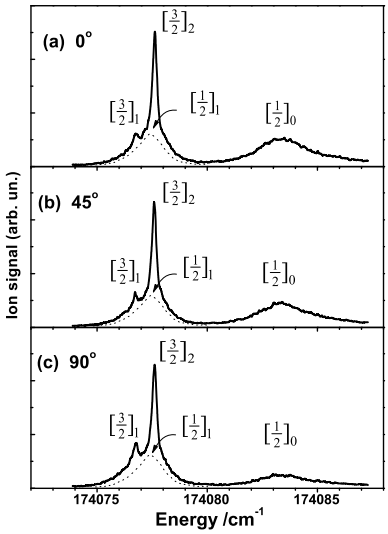


**Fig. 1:** Two-photon ionization spectra of the $2p^5{}_{1/2}$ $14p'$ state produced via the intermediate state, $2p^5{}_{1/2}$ $6s'$ $[1/2]_1$. The abscissa denotes a wavenumber sum of the TS laser and the intermediate state. The positions of the $2p^5{}_{1/2}$ $14p'$ ($[l/2]_{0,1}$ and $[3/2]_{1,2}$) components are indicated. The angles between the polarization vectors of two light beams are: (a) 0° (in parallel), (b) 45°, and (c) 90° (in perpendicular). The dotted line is an eye-guide sketch for the $[1/2]_1$ state.

**TABLE I. Peak positions, $E_p$, and quantum defects, QD, for the np' $[3/2]_2$ series.**

| n | $E_p$ (cm$^{-1}$) | q | Γ (cm$^{-1}$) | $\Gamma_r$ (cm$^{-1}$) | QD | n | $E_p$ (cm$^{-1}$) | QD | n | $E_p$ (cm$^{-1}$) | QD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | 174083.6 | 4.05 | 2.19 | 5065 | 0.767 | 27 | 174550.7 | 0.775 | 40 | 174639.0 | 0.736 |
| 15 | 174168.5 | 3.13 | 2.07 | 5983 | 0.767 | 28 | 174562.2 | 0.776 | 41 | 174642.5 | 0.755 |
| 16 | 174237.4 | 5.22 | 1.87 | 6623 | 0.766 | 29 | 174572.4 | 0.781 | 42 | 174645.6 | 0.790 |
| 17 | 174293.8 | 3.35 | 1.60 | 6847 | 0.767 | 30 | 174581.6 | 0.786 | 43 | 174648.6 | 0.804 |
| 18 | 174341.2 | 2.61 | 1.15 | 5913 | 0.756 | 31 | 174590.0 | 0.788 | 44 | 174651.5 | 0.766 |
| 19 | 174380.1 | 3.21 | 0.96 | 5806 | 0.767 | 32 | 174597.7 | 0.777 | 45 | 174654.2 | 0.748 |
| 20 | 174413.7 | 1.93 | 0.74 | 5261 | 0.761 | 33 | 174604.7 | 0.746 | 46 | 174656.6 | 0.753 |
| 21 | 174441.8 | 4.35 | 0.79 | 6544 | 0.779 | 34 | 174610.8 | 0.776 | 47 | 174658.9 | 0.778 |
| 22 | 174467.5 | 4.39 | 0.75 | 7202 | 0.739 | 35 | 174616.4 | 0.802 | 48 | 174661.0 | 0.764 |
| 23 | 174487.9 | 8.66 | 0.69 | 7521 | 0.783 | 36 | 174621.9 | 0.757 | 49 | 174663.1 | 0.732 |
| 24 | 174507.2 | 4.44 | 0.58 | 7267 | 0.751 | 37 | 174626.8 | 0.742 | 50 | 174664.9 | 0.820 |
| 25 | 174523.3 | | | | 0.768 | 38 | 174631.0 | 0.775 | | | |
| 26 | 174537.7 | | | | 0.777 | 39 | 174635.2 | 0.757 | | *average* | 0.768(0.019) |