# Energy Transfer Processes in Neon-Hydrogen Mixtures Excited by Electron Beams ◇

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It was observed that particle beam excitation of dense neon-hydrogen mixtures leads to very intense emission of hydrogen Lyman-$\alpha$ radiation (121.6 nm) [1]. Lyman-$\alpha$ radiation is of interest for various applications such as photolithography [2] and photoionization [3] due to its short wavelength. The 121.6 nm radiation is still in the transmission range of $MgF_2$ and LiF optics so that lenses and optical windows can be used. Lyman-$\alpha$ vacuum ultraviolet sources using neon-hydrogen mixtures have considerable advantages with respect to other sources, such as deuterium or helium-hydrogen discharge lamps, since they combine high efficiency (up to 10% [1]) with a nearly monochromatic emission spectrum. The high efficiency of Lyman-$\alpha$ emission from neon-hydrogen mixtures was attributed either to a near- resonance energy transfer from $Ne_2^*$ excimers to hydrogen molecules [1], or to the energy transfer from the four lowest excited states of neon atoms to hydrogen [4]. The aim of this study was to clarify the energy transfer processes which lead to Lyman-$\alpha$ emission.

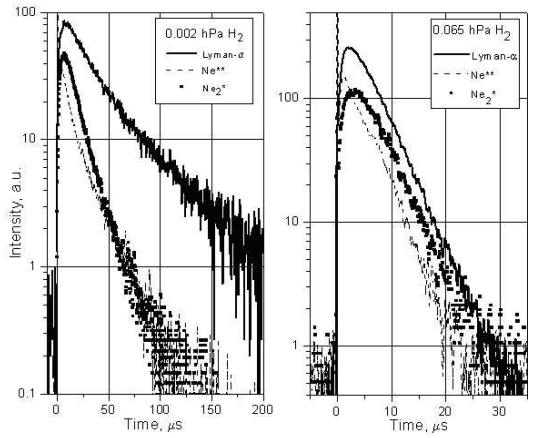


Fig. 1: Time spectra of Lyman-$\alpha$, Ne** and $Ne_2^*$ emission at 1 bar of Ne for two hydrogen partial pressures.

Combining experimental techniques of time resolved spectroscopy using pulsed electron beam excitation [5] and XUV (extreme ultraviolet) spectroscopy [6], we were able to study the time dependence of light emission from neon-hydrogen mixtures following short pulse (5 ns) low energy (12 keV) electron beam excitation. All significant emissions which can be observed from neon-hydrogen mixtures were considered and studied experimentally: the red lines of atomic neon (3p $\rightarrow$ 3s transitions), the Lyman-$\alpha$ line (121.6 nm) and the neon excimer emission (second continuum emission at ~83 nm). Examples of time spectra for these three emissions are given in Fig.1. It has been shown that at low hydrogen partial pressures Lyman-$\alpha$ emission shows a decay considerably slower than the decay of atomic Ne lines and $Ne_2^*$ molecules, while at high hydrogen partial pressures all emissions show the same decay time.

Lyman-$\alpha$ emission intensity was systematically measured for a broad range of Ne - $H_2$ gas compositions. The dependence of the intensity of Lyman-$\alpha$ emission on the partial pressures of neon is shown in Fig.2 for four different partial pressures of hydrogen. The data also show that the emission intensity changes only by about factor of 2.5 for 1 bar neon over the whole hydrogen partial pressure range from 0.002 to 3 hPa shown in Fig. 2. Our experimental data and an analysis of literature data available for elementary processes allowed us to construct a complete system of gas-kinetic reactions [7].

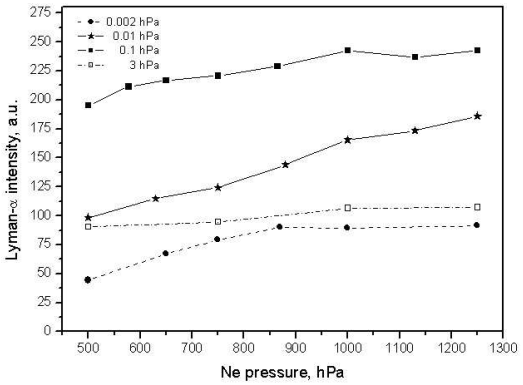


Fig. 2: Intensity of Lyman-a emission as a function of neon and hydrogen partial pressures.

It was found that three energy channels contribute to Lyman-$\alpha$ emission. Two channels involve direct energy transfer from the lowest excited states of atomic neon and $Ne_2^*$ excimer molecules to $H_2$ molecules producing H atoms in the n=2 state. The third channel, which gives a substantial contribution only at very low hydrogen partial pressures, implies dissociative recombination of $H_3^+$ ions. All experimental results are explained using the suggested system of reactions. The results also allowed us to specify the gas conditions for which each particular channel contributes substantially to Lyman-$\alpha$ emission.

Analyzing the time resolved data, the rate constant of the reaction $Ne_2^+ + H_2$ ($k_i = (4.2 \pm 1.4) \times 10^{-11} cm^3 s^{-1}$ and a lower limit of the rate constant for the reaction $Ne_2^* + H_2$ ($k_e > 1.0 \times 10^{-10} cm^3 s^{-1}$) were obtained. It is also shown that the rate constant, obtained earlier [1] from decay curves of Lyman-$\alpha$ light which had been attributed to the direct energy transfer from $Ne_2^*$ to $H_2$ refers instead to the charge transfer reaction from $Ne_2^+$ ions.

## References

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