FORMATION OF LONG-LIVED GAS SPECIES IN HYDROGEN THYRATRONS

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ABSTRACT

Direct evidence is presented for the formation of $c^3\Pi_u$ metastable molecules in hydrogen thyratrons. The presence of these species had not previously been realized. Because these states have lifetimes of 100 μsec and 1 msec, and energies greater than 11eV, their behavior may affect thyratron recovery rates.

INTRODUCTION

This paper reports recent studies of electrically excited hydrogen at low pressures bearing on the physics of the operation of hydrogen thyratrons. These include 1) spectroscopic measurement and analysis of visible emission from thyratrons and 2) observation of the formation of metastable electronic molecular states in hydrogen thyratrons. These results suggest the following: 1) The temporal behavior of specific electronic states in the switch can be studied making it possible to determine the role of these states in the operation of the device. This point is significant because previous experimental work in this area is inadequate. 2) Further study should make it possible to determine precisely the role of long-lived electronic states in thyratron *recovery*.

EXPERIMENTAL

Spectra from glass-enclosed thyratrons were obtained using a scanning monochromator with resolution of approximately .3A, and additional time resolved spectra were observed with a temporal resolution of approximately 40 nsec. In a typical experiment a diffuse emission from a 5C22 was observed through holes in the grid structure. Detailed spatial resolution was limited by the tube geometry. Current in the tube was varied from less than one to over 300 amps (peak) by discharging capacitors directly into the tube at voltages of the order of 10 kV. The glow from the heater interfered with spectra taken continuously only below 4500A, and was not observed at all in the time-resolved spectra. This emission can be easily eliminated by terminating the photomultiplier output impedance with several kΩ or less.

With this apparatus it is also possible to make estimates of electron densities and electric field strengths as a function of current. This can be done by measuring the line width of the atomic Balmer emission as a function of current and determining the corresponding field and/or electron density from Stark broadening.[1,2]

SPECTROSCOPY

Typical emission spectra taken from a 5C22 hydrogen thyratron are shown in Figure 1. Two features (not shown) are the only atomic features; except for a broadband emission from the heater the other features are molecular emission from excited H_2. Identifications were made using the Dieke H_2 tables.[3,4]

The dominant feature of the molecular emission is a cluster of lines due to transitions into $c^3\Pi_u$. The states are seen in the potential energy diagram in Figure 1. The $c^3\Pi_u$ state is metastable (lifetimes are given in Table I). Relaxation of $c^3\Pi_u$ state is complex. Briefly, vibrational and rotational states within $^3\pi$ can predissociate via $b^3\Sigma$ if they have positive symmetry with respect to a reflection through the molecule axis. This process is fast (10 nsec) and quickly accounts for 1/2 of the $^3\pi$ molecules. For the remainder this transition is very strongly selection ruled disallowed. These molecules (except v=0) relax through a dipole allowed infrared transition to a^3 , a non-metastable state, with lifetimes of approximately 100 msec. The c^3 v=0 state is lower in energy than all a^3 states, and decays by quadrupole or magnetic dipole emission in 10^{-3} sec.

The 2s state of the hydrogen atom is also long-lived (Table I). Its formation is indicated by a strong Balmer emission.

DISCUSSION

The presence of long-lived species in a low pressure gas-phase switch following electrical excitation deserves serious consideration because these species may provide an intrinsic limitation to switch recovery rates. Research into switches has not recognized that such metastables exist in hydrogen, partly because these states have only recently begun to be understood in detail,[5-12] but primarily because the hydrogen thyratron has a relatively rapid recovery rate, and the fundamental limitations to recovery are not well understood in detail.[9] In particular, the physical processes occurring during the recovery phase that are a function of collisions between species in excited electronic states have not been investigated, and the

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14. ABSTRACT
Direct evidence is presented for the formation of c3rru metastable molecules in hydrogen thyratrons. The presence of these species had not previously been realized. Because these states have lifetimes of 100 psec and 1 msec, and energies greater than lleV, their behavior may affect Â·thyratron recovery rates.

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relative roles of ambipolar diffusion and metastable collision processes deserve study.

A list of metastable collision processes is given in Table II. In a gas at 300 millitorr collision rates between molecules will be of the order 3 $\times 10^6$ sec^{-1}, e.g. approximately 3 per microsecond. Thus suggests that collision processes involving long lived species deserve consideration. Collisions with walls should play a role in quenching of metastables; however this process has not been characterized. Of the processes listed in Table II Penning ionization should be efficient. Thus for example assuming an initial concentration of metastables of 10^{10} cm^{-3} and a typical gas kinetic rate of 10^{-10} obtains for a rate of electron and ion generation, r,

$$r \simeq 10^{(10)}\ sec^{-1}\ cm^{-3}$$

This number is only an estimate and cannot be used to characterize an actual device; in particular it is difficult to make an accurate estimate of initial concentrations, and to account accurately for collisions with walls. However, it should serve to demonstrate the importance of the problem.

It should be possible to study the temporal behavior of these states using laser induced fluorescence. For example, using tunable dye laser at approximately 5800Å one may excite molecules in various vibrational states of $c^3\pi$ to $^3\Delta$ or others, and then observe emission either back to $c^3\pi$ or to $a^3\Sigma$. By varying the delay between the current pulse and the dye laser excitation it will be possible to measure the temporal decay of $^3\pi$ *in situ*. In addition, it should be possible to obtain good spatial resolution by modifying the grid structure, although in lieu of this it is possible to make observations in specially constructed optical cells. It may even be possible to correlate current densities with those in actual devices, using Stark broadening and current measurements as diagnostics.

CONCLUSIONS

These results demonstrate that long-lived species are being formed in hydrogen thyratrons, and suggest that some further understanding of the subsequent behavior of these species would be useful, and is probably important.

REFERENCES

1. S.K. Dhali, P.F. Williams, R.J. Crumley, and M.A. Gundersen, "Electron Densities in Laser-triggered Hydrogen Sparks," IEEE Trans Plasma Sci PS-8, 164 (1980).
2. G. Bekefei, C. Deutsch and B. Yaakobi. "Spectroscopic Diagnostics of Laser Plasmas," in Principles of Laser Plasmas, G. Bekefei, Ed., 549-669, Wiley (1976).
3. H.M. Crosswhite, ed., The Hydrogen Molecule Wavelength Tables of G.H. Dieke, J. Wiley (1968).
4. K-P Huber and G. Herzberg, Constants of Diatomic Molecules, Van Nostrand (1979).
5. C.E. Johnson, "Lifetime of the $c^3\pi_u$ Metastable State of H_2, D_2 and HD," Phys. Rev. A., 5, 1026 (1972).
6. B. Meierjohann and M. Vogler, "Vibrationally resolved predissociation of the $c^3\pi_u$ and $e^3\pi_u^+$ states of H_2 by time of light spectroscopy," Phys. Rev. A., 17, 47 (1978).
7. M. Vogler and B. Meierjohann, "Predissociation of the $c^3\pi_u$ state of H_2", Phys. Rev. Lett., 38, 57 (1977).
8. W. Lichten, "Metastable hydrogen molecules," Phys. Rev., 120, 848 (1960).
9. S. Levy, private communication.
10. T.E. Sharp, "Potential energy curves for molecular hydrogen and its ions," Atom. Data, 2, 119 (1971).
11. G. Herzberg, "A new predissociation of the H_2 molecule," Sci. Lt., 16, 14 (1967).
12. R.P. Freis and J.R. Hiskes, "Radiative lifetimes for the $2p^3\pi_u$ state of the hydrogen molecule," Phys. Rev. A., 2, 573 (1970).

TABLE I

Metastable Species in Hydrogen

	State	Radiative Lifetime (sec)	Energy (eV)
H_2	$c^3\pi_u(v>0)$	10^{-4}	10.8
H_2	$c^3\pi_u(v=0)$	10^{-3}	10.75
H_2	$X^1\Sigma_g(V>0)$	very long	.5
H	$2^2S_{1/2}$	.14	10.2

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TABLE II

Collisional Processes involving Hydrogen Metastables

$H_2 + e$	$\rightarrow H_2^* + e$	Hornbeck-Molnar
$H + H_2^*$	$\rightarrow H_2 + e$	
$H^*(2^2S) + H_2$	$\rightarrow H_3^+ + e$	Associative Ionization
$H_2^* + H_2$	$\rightarrow H_3^* + H + e$	Rearrangement Ionization
$H^* + H^*$	$\rightarrow H + H^+ + e$	Penning Ionization
	$\rightarrow H_2^+ + e$	
$H_2^* + H_2^*$	$\rightarrow 2H + H_2^+ + e$	
	$\rightarrow H_2 + H_2^+ + e$	
	$\rightarrow H + H^+ + H_2 + e$	
	$\rightarrow H + H_3^+ + e$	
$H_2^* + H^*$	$\rightarrow 2H + H^+ + e$	
	$\rightarrow H_2 + H^+ + e$	
	$\rightarrow H + H_2^+ + e$	

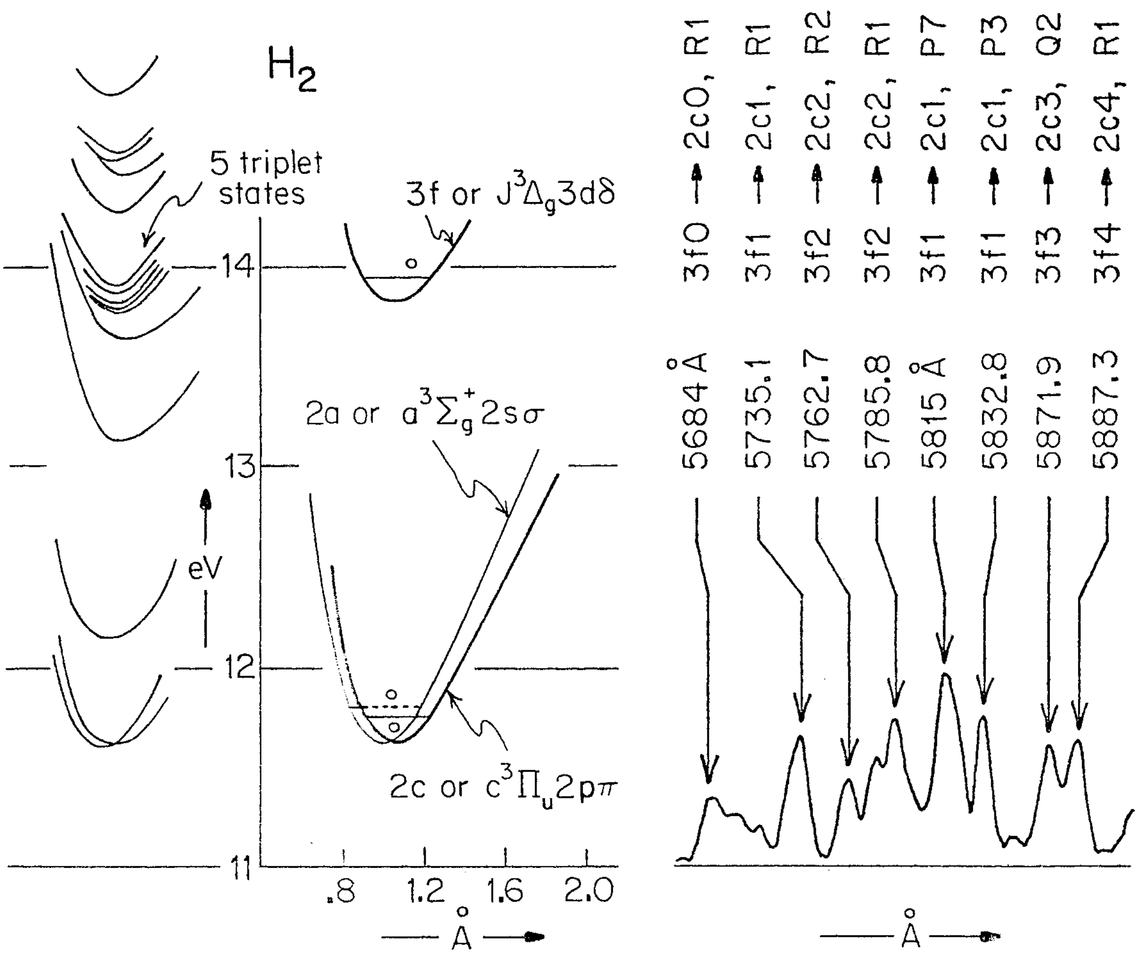

FIGURE 1. (a) Left hand side of diagram shows potential energy curves in region of interest; simplified right hand side shows curves relating to metastable formation.

(b) Spectra obtained from 5C22 showing metastable formation.