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Observation of Nonobligatory Potential Structure in a Collision of the Second Kind*

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Low-energy structure in the total He 2^3S–Ne $4s'[\frac{1}{2}]_1^0$, $4s'[\frac{1}{2}]_0^0$ transfer cross section has been extracted from temperature-dependent pulsed-afterglow measurements. The results confirm the existence of a nonobligatory potential barrier in an exothermic atom-atom transfer collision.

Jones, Niles, and Robertson[1] have suggested that the exponential variation of the He 2^3S–Ne $4s'[\frac{1}{2}]_1^0$ transfer rate with temperature may be caused by a long-range nonobligatory[2] potential barrier. The present measurements provide the first determination of thermal-energy structure in an exothermic atom-atom transfer collision and confirm the existence of the proposed barrier.

A previous study[3] of the He 2^1S–Ne $5s'[\frac{1}{2}]_1^0$ endothermic reaction rate has shown that it is possible to isolate the low-energy structure of the reaction cross section from pulsed static afterglow-emission measurements. The studies revealed the existence of a sharp threshold for excitation transfer with an activation energy corresponding to the difference between initial and final states. In the present situation transfer proceeds exothermically, i.e., from a higher to a lower excited state. Since the excess potential energy can be continuously absorbed as kinetic energy of motion, no activation threshold should be required. Alternatively, if a repulsive barrier exists between excited helium and neutral neon states, an exothermic transfer collision will also require a minimum activation energy.

A convenient method for monitoring thermal energy transfer rates involves the use of pulsed static afterglow-emission measurements.[3,4] In the afterglow of a He-Ne positive column discharge at low neutral densities and low electron densities, the He 2^3S metastable-level relaxation time ordinarily exceeds the natural lifetime of all radiatively emitting levels. The relatively long-lived metastable-state atoms eventually become the principal source of excitation for the near-resonant Ne $4s'[\frac{1}{2}]_1^0$, $4s'[\frac{1}{2}]_0^0$ states (the Ne $2s_2$, $2s_3$ states in Paschen notation). Since the relaxation rate of these neon levels is rapid with respect to that of the metastable level, the emission from these states provides an extremely sensitive measure of the He 2^3S population. The decay rate of the 2^3S population contains a component which is linearly proportional to neon partial pressure. This component provides an absolute value for the He-Ne transfer rate. If the transfer rate is evaluated as a function of temperature, thermal energy structure in the total transfer cross section may be defined through iterative solutions of the transfer rate integral.[3] Although the structure obtained in this way is not unique, the representation grows increasingly more realistic as the range of energy variation is extended. In this way, progressively more refined approximations to the actual transfer cross section may be extracted.

If recombination effects involving Ne^+, Ne_2^+, and $HeNe^+$ are important or if effects due to relatively slow inelastic transfer between the Ne $2s_2$ and $2s_3$ states become significant, the after-

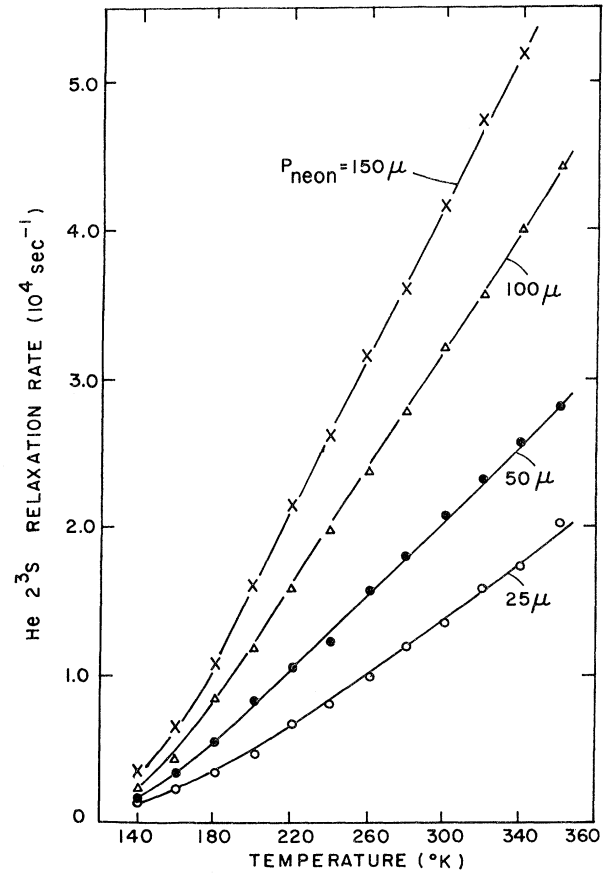

FIG. 1. Temperature dependence of the He 2^3S relaxation rate at various neon partial pressures. The helium partial pressure was maintained at 1.44 Torr.

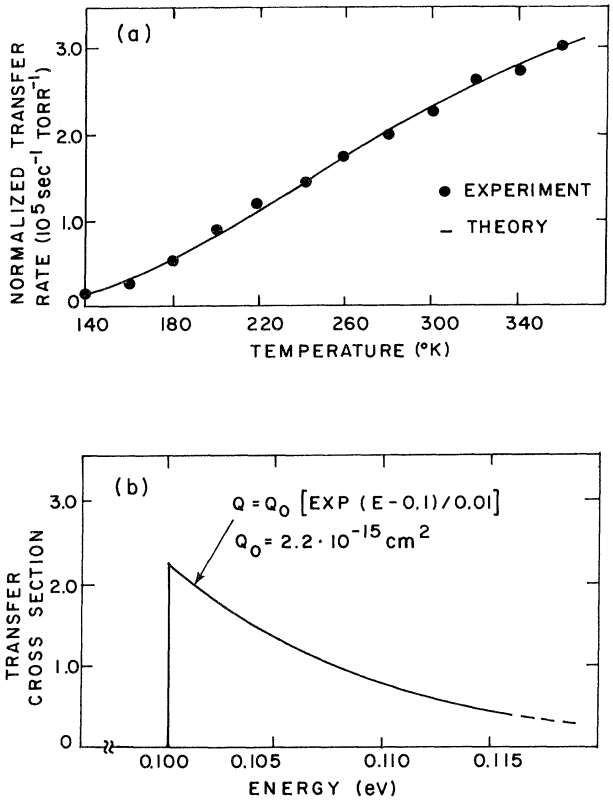

FIG. 2. (a) Temperature dependence of the He-Ne transfer rate normalized to a neon partial pressure of 1 Torr. The solid line is the calculated transfer rate. (b) Iteratively extracted total cross section for He 2^3S–Ne $2s_2$, $2s_3$ transfer.

glow-emission data may deviate from a true proportionality to the 2^3S population. Moreover, any cascading induced by He 2^1S–Ne $3s_2$ transfer may also alter the accuracy of the emission measurements. Finally, He^+ and He_2^+ recombination, as well as 2^1S-2^3S collisional transfer, will decrease the apparent 2^3S relaxation rate and introduce errors in the He-Ne transfer measurements. Values for these processes have been determined elsewhere[3-11]; consequently, discharge and data acquisition conditions may be appropriately selected to essentially eliminate unwanted effects. At thermal energies the proposed potential barrier retards He 2^3S–Ne $2s_2$, $2s_3$ transfer. Reduced transfer rates tend to quickly increase measurement errors involving sequential molecular/atomic ion recombination processes. In this situation, recombination errors may be minimized if ambipolar diffusion is selected as the dominant ion-loss mechanism and if the 2^3S relaxation times are kept relatively rapid with respect to sequential ion formation or recombination times.

An improved version of the apparatus described previously[3] was used in these experiments. The cleanliness of the test discharge was increased through the addition of local bakeout facilities, and the data-acquisition rate was enhanced through the use of a 100-channel analog waveform-averaging device. All He 2^3S relaxation rates were determined photoelectrically from the emission of the Ne $2s_2$–$2p_{10}$ transition at 8865 Å. The overall detection system possessed a maximum resolution of 1 μsec/channel. Typical experimental results are presented in Fig. 1. At each temperature, the slope of the 2^3S decay rate with neon partial pressure provides a value for the He-Ne transfer rate. These rates are presented in Fig. 2(a). At 300°K the measurements define a velocity-averaged cross section of 5.2×10^{-17} cm^2. The absolute value of this cross section is somewhat higher than that obtained by other

methods.[7,12] Also shown in Fig. 2(a) is a solid line corresponding to the best fit of an exponential cross section to the data. The derived function has the form

$$Q = Q_0 \exp[(E - E_1)/E_0], \quad E > E_1,$$
$$Q = 0, \quad E < E_1, \tag{1}$$

where E_1, E_0, and Q_0 are constants. Equation (1) is plotted in Fig. 2(b), where a definite threshold corresponding to $E_1 = 0.1$ eV is indicated. A variety of other less accurate representations involving polynomials or combinations of polynomials with exponentials all suggest a sharp threshold in the vicinity of 0.1 eV.

The existence of a threshold for excitation transfer in an exothermic atom-atom reaction indicates the presence of a distinct repulsive barrier. The barrier appears to be nonobligatory[1,2] only in the sense that it is not essential for a smooth transition from the equilibrium He 2^3S potential curve to the final Ne $4s'[\frac{1}{2}]_1^0$, $4s'[\frac{1}{2}]_0^0$ potential curves. Since there is no known long-range resonance force acting between He 2^3S atoms and ground-state neon atoms, tentative indications are that the potential barrier is caused by intermediate- and short-range valence forces. More extensive studies concerning the physical origin of the repulsive forces are currently in progress.

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Observation of a K X-Ray Band Emitted by the Transient C-C System Formed at keV Energies*

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The yield and high-energy limit (from 1.1 to 1.5 keV) of a K x-ray band emitted by the transient C-C collision system are reported for 19- to 240-keV carbon ions incident on graphite. This K x-ray band is interpreted as characteristic of the C-C system when the nuclear separation approaches the united-atom limit. A small yield of a similar band produced by other light ions in graphite has been observed; this can be accounted for in part by integrating the C-C yield over the appropriate energy distribution of recoil carbon atoms.

In this Letter, we report the observation of x rays that are produced in collisions of carbon ions with solid carbon. The x rays have a maximum energy comparable to K x rays in a united-atom limit. With increasing carbon ion energy, a large increase was observed in both the yield of x rays and the maximum energy of the x-ray band when the distance of closest approach in these collisions was less than the united-atom K-shell radius. In addition, a small yield of x rays was observed when graphite was bombarded with helium and lithium ions at 100 keV. An integration of the yield from symmetric C-C collisions over the energy distribution of recoil carbon atoms fully accounts for the observed yield with these light ions. However, with 100-keV boron ions incident upon graphite only 10% of the yield can be attributed to recoil events.