EXPERIMENTAL INVESTIGATION OF THE CHEMISTRY
OF EXCITED STATES OF RARE GASES

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SUMMARY

During the third quarter Mr. Harold Brashears and Dr. Hiroyuki Horiguchi worked on this contract. A new student, Mr. Y. C. Yu, also has worked for one month. Mr. Yu has been learning techniques and his efforts will not be described. Mr. Brashears' photo-sensitized studies of $\text{Xe}(^3\text{P}_1)$ and $\text{Kr}(^3\text{P}_1)$ reactions with halogen donors have been very productive and this work comprises most of the data in the report. Dr. Horiguchi continued to work on the laser excitation methods for generating selected states of the rare gas atoms lying above the $np, n+1s$ set of levels. Both of these projects are summarized in the following pages.

The principal investigator completed three manuscripts, see attached listing of publications, and also had extensive correspondence with Drs. (former associates) Tamagke and Kolts regarding writing of additional manuscripts describing state-to-state reaction dynamics of the $\text{Xe}(^3\text{P}_2)$ atom reactions with bromine and iodine donors. The principal investigator visited France for two weeks giving invited lectures at the Congress of the French Physical Society and several Universities. This trip, which was financed entirely by the French government, provided a valuable opportunity for visiting several French laboratories studying excited state chemistry/physics of rare gas systems. The visit probably will lead to some collaborative work with Dr. Sadgehi at Grenoble University and the observation of results and techniques used in France will influence the studies suggested in next year's contract.

Cumulative Listing of Published Papers

1. Eight papers were published in 1976-1977; see earlier reports for a listing.
2. P. C. Tellinghuisen, J. Tellinghuisen, J. E. Velazco, D. W. Setser and J. A. Coxon, "Spectroscopic Studies of Noble Gas Halides: Vibrational and Rotational Constants for XeF(B,D,X)." J. Chem. Phys., 68, 5187 (1978).
3. J. E. Velazco, J. H. Kolts and D. W. Setser, "Rate Constants and Quenching Mechanisms for the Metastable States of Ar, Kr and Xe," J. Chem. Phys., 69, 4357 (1978).
4. R. S. F. Chang and D. W. Setser, "Lifetime and Two-body Deactivation Rate Constants for Ar(4p) States," J. Chem. Phys., 69 3885 (1978).
5. H. C. Brashears, Jr., and D. W. Setser, "Transfer and Quenching Rate Constants for XeF(III, 1/2) and XeF(II, 3/2)," App. Phys. Lett., 33, 821 (1978).
6. D. W. Setser, T. D. Dreiling and J. H. Kolts, "Product Distributions from Quenching of Metastable Rare Gas Atoms," J. Photochem. 9, 91 (1978). Presented at IX International Conference on Photochemistry, Cambridge, England.
7. J. H. Kolts, J. E. Velazco and D. W. Setser, "Reactivate Quenching of Xe (6s³P₂) Metastable Atoms by Chlorine Containing Molecules," J. Chem. Phys. Aug. (1979).
8. D. W. Setser, T. D. Dreiling, H. C. Brashears and J. H. Kolts, "The Analogy Between Electronically Excited States and Alkali Metal Atoms," Faraday Disc. Chem. Soc., 67, In Press (1979).
9. R. S. F. Chang and D. W. Setser, "Radiative Lifetimes and Collisional Deactivation Rate Constants of Excited Ne(2p⁵3p) Atoms," J. Chem. Phys. Submitted (1979).
10. D. W. Setser, H. C. Brashears, Jr., and T. D. Dreiling, "Formation, Relaxation and Quenching of Rare Gas Halide Molecules," Presented to Congress of French Physical Society Toulouse, France, July (1979) and to be published in J. Phys. (Paris) (1979).
11. H. C. Brashears, Jr., and D. W. Setser, "Reaction of Xe(³P₁) and Kr(³P₁) Resonance Atoms with Halogen Donor Molecules," J. Phys. Chem. submitted (1979).
12. R. S. F. Chang, H. Horiguchi and D. W. Setser, "Radiative Lifetimes and Collisional Deactivation Rate Constants in Argon for Kr(4p⁵5p) and Kr(4p⁵5p') States," J. Chem. Phys. Submitted (1979).

Photosensitized Studied of Reactions of Xe(³P₁) and Kr(³P₁) with Fluorine,
Chlorine, Bromine and Iodine Donors

Mr. Brashears photosensitization studies, illustrated by the chemical equations below for Xe, have been highly successful.

The Xe(³P₁) state is produced by absorption of a resonance photon from a microwave powered resonance lamp. In addition to providing a method to study the reactions of the ³P₁ state atoms, the method provides a way of studying the relaxation of the XeX(B,C) molecules in the presence of He, Ne and Ar bath gases from 0.1 - 3000 torr. Thus we can study B - C transfer and vibrational relaxation over a wide range (v' = 0 - 100) of vibrational levels. Some results for XeF were presented in the second quarterly report and a communication mainly describing XeCl is included as part of this report. Therefore, only results for KrCl and KrF will be summarized. Results are in hand for XeBr and XeI but these will not be discussed in this report.

In general there is very little difference in the appearance of the XeX or KrX spectra from reactive quenching of the ³P₂ and the ³P₁ states for a given halogen donor (see preprint for XeCl and KrCl spectra). Thus, the B vs C distribution and the vibrational energy disposal are very similar for the two reactions. We also argue (see preprint) that the branching fractions for the metastable and resonance states must be quite similar for a given halogen donor. Although this has not been proven, we are fairly certain of this result. Once these general conclusions have been recognized, the most interesting aspect of the work is B - C electronic state transfer and vibrational relaxation in He, Ne and Ar bath gases for a wide range of vibrational levels.

Our objective is to utilize the B - X and C - A emission spectra at various pressures to (i) assign populations to the vibrational levels

of B and C and (ii) to model the variation of these populations with pressure in order to assign rate constants for vibrational relaxation and B - C transfer for several rare gas halides in He, Ne and Ar. The first step is computer simulation of the bound-free spectra. Fortunately we have developed this expertise in our laboratory. Since our experience is with the KrF and XeCl spectra, we began by simulating the XeCl emission because our potentials were more satisfactory for XeCl than for KrF. The simulation for the XeCl(B - X) spectra have been completed from 0.1 to 10 torr of Ar; and these distributions are shown in Figure 1. We also have simulated the C - A spectra over the same pressure region. Although the relaxation mechanism is different, the vibrational distribution for the C state is rather similar to that of the B state from 0.1 to 10 torr. The shape of the XeCl(C) distributions are satisfactory; however, the absolute vibrational energy is thought to be too low. Therefore, we currently are altering (slightly) the XeCl(A) potential and will resimulate the spectra. Based upon the work done so far, we expect no difficulty in meeting our goal of assigning state-to-state rate constants for B - C transfer and vibrational relaxation of XeCl, XeF and KrF in He, Ne and Ar. Based upon preliminary evaluations, the relaxation rate constants for high v levels of all these rare gas halides are similar for the same bath gas. The B - C transfer rate constants for a 300°K Boltzman vibrational distribution may vary slightly with rare gas halide for the same bath gas. However, the bath gas strongly affects the vibrational relaxation and the rate of B/C transfer for all vibrational levels.

A qualitative description of the relaxation mechanism is given in the preprint and this will not be repeated. By noting the vibrational distributions in Figure 1, the C/B ratio plot in the preprint and the discussion in the preprint, a fairly complete picture for XeCl relaxation should be evident.

A description of the variation of the KrF and KrCl B/C ratios vs pressure will end this section. As with XeCl, extensive vibrational relaxation occurs as the pressure is increased from 0.1 to 10 torr. At about 10 torr the distributions are Boltzmann like (several thousand degrees). With further increase in pressure, the Boltzmann temperature

VIBRATIONAL RELAXATION OF XeCl(B)

FIGURE 1. XeCl(B) vibrational distributions at various Ar pressure from formation by reactive quenching (solid curves). The dashed curve is the XeCl(B) distribution arising from B-C transfer in the 0.1-4.0 torr pressure range.

is reduced. The variation of the B to C steady-state ratios are displayed in Figures 2 and 3. The KrCl results appear to be straightforward, except for the need to subtract out the Cl_2^* emission, and the Ar data give a high pressure extrapolated limit of $\text{C/B} = 1.7$. The He and Ne data are not at the high pressure limit even for 3000 torr. Complications have been encountered which, so far, have prevented us from reliably measuring the high pressure limit for KrF. The data, as well as the comparison between XeF and XeCl, suggest that the KrF C/B ratio will be ~ 4.0 . The complications are as follows. With He and Ne the high pressure limit is not reached at 3000 torr. With Kr/Ar/ F_2 mixtures, weak ArF emission is observed at low pressure but this emission is converted to Ar_2F^* emission at higher pressures. The Ar_2F^* band overlaps the KrF(C - A) emission and prevents us from assigning a reliable C/B ratio above ~ 700 torr.

The source of the ArF emission is a puzzle. The interface between the lamp and cell is a MgF_2 window. Therefore, the $\text{Ar}(^3\text{P}_1)$ resonance line can not enter the cell even if the Kr lamp generates some Ar resonance emission. Further support that $\text{Ar}(^3\text{P}_1)$ is not the source of the ArF emission is that ArCl is not formed from Kr/Ar/ Cl_2 mixtures. An explanation that may be reasonable* is the following set of reactions.

We currently are in the process of obtaining the vacuum ultraviolet emission spectra from our Kr source lamp. This is the first step toward trying to identify the wavelength that may be responsible for the F_2 excitation. The reaction of excited state halogens to yield rare gas halide molecules has been observed in two other laboratories,^{a,b} so there is precedent for the above mechanism.

a) J. LeCalve, SACLAY Laboratories, Private Communication.

b) D. J. Ehrlich and R. M. Osgood, Jr., Lincoln Laboratory to be presented at the Ecimer Lasers Meeting September 12-14, 1979.

Another reasonable possibility is the reaction between ArKr^ and F_2 to give ArF^* (and KrF^*).

KRCL RATIOS

KRF RATIOS

REACTIONS OF THE $\text{Xe}(^3\text{P}_1)$ AND $\text{Kr}(^3\text{P}_1)$ RESONANCE STATES
WITH HALOGEN DONOR MOLECULES

Submitted J. Phys. Chem.

Sir,

With the advent of rare gas halide lasers has come interest in the formation, quenching, electronic state transfer, and vibrational relaxation processes of the rare gas halide B and C states. Although quantitative measurements of rate constants and branching fractions for the reactions of the metastable ($^3\text{P}_{2,0}$) rare gas atoms with halogen donors have been made¹⁻⁵; little information is available regarding the reactions of the ($^3\text{P}_1$) and ($^1\text{P}_1$) resonance states with halogen containing molecules. Existing measurements⁵⁻⁷ establish that the quenching rate constants for the resonance states should be comparable to or slightly larger than those for the metastable states.⁶⁻¹⁰ However, there are few¹⁰ measurements of the branching fractions for rare gas halide formation or product state distributions from reactions of the resonance states. In this work we report the formation of KrX^* and XeX^* ($\text{X} = \text{F}, \text{Cl}, \text{Br}$ and I) from the reaction of the ($^3\text{P}_1$) resonance states with halogen donors. The low pressure XeX and KrX emission spectra from these reactions is compared to that from the ($^3\text{P}_2$) metastable atom reactions. Relative rate constants for formation of $\text{XeCl}(\text{B}, \text{C})$ are obtained with a series of chlorinated reagents.

The experimental apparatus is essentially the same as that used by others^{11,12} for observing excitation transfer reactions of the resonance states. A microwave powered resonance lamp was interfaced via a MgF_2 window to a square stainless-steel reaction cell; the rare gas halide emission was observed through a quartz window at right angles to the light from the resonance lamp. The quartz discharge lamp, which has a 5-7 cm extension arm for cooling was attached to the cell via an O-ring seal. The extension was cooled with liquid Ar and with liquid N_2 for the Xe and Kr lamps, respectively. The spectra from the lamps, examined with a vacuum monochromator, consisted predominately of the ($^3\text{P}_1$) resonance lines (147.0 nm for Xe, 123.6 nm for Kr). Previously this apparatus was used for photolysis of XeF_2 .¹³ The rare gas halide emission was observed with the same computer interfaced monochromator used for study of the metastable atom reactions.

Each halide donor was photolyzed in the absence of rare gas to check for a photodissociation process which would give an interfering fluorescence. The cell then was evacuated and filled with mixtures of rare gas and donor. The

following equations describe the system for Xe:

Searches were made for rare-gas halide emission with rare gas/RX ratios of 0.1 to 10 at total pressures ranging from 0.03 to 1 torr. The relative RgX emission intensities from the $\text{Rg}({}^3\text{P}_1) + \text{RX}$ reactions closely resembled those observed from the metastable reactions, i.e., a good halogen donor for $\text{Xe}({}^3\text{P}_2)$ also was good for $\text{Xe}({}^3\text{P}_1)$. For $\text{X} = \text{F}$, the most intense emission was obtained from the reaction of F_2 , followed by CF_3OF and NF_3 . For $\text{X} = \text{Cl}$, Cl_2 was the best donor, followed by SCl_2 and COCl_2 . Based upon these observations and upon the large magnitudes of the quenching rate constants for the resonance state (and metastable atoms,^{1,6-10}) reaction 3c is thought to be unimportant. This was qualitatively confirmed by failure to observe any atomic absorption from $\text{Xe}({}^3\text{P}_2)$ using the source lamp previously used to monitor the metastable states.¹ The ${}^3\text{P}_1$ concentration in the resonance cell and the ${}^3\text{P}_2$ concentration in the flowing afterglow are estimated to be approximately equal. Since the KrCl and XeCl emission intensities from Cl_2 in the two experiments were comparable, this implies that the branching fractions for the resonance states are similar to those of the ${}^3\text{P}_2$ atom reactions, which are 1.0 and 0.9 ($\text{Cl}_2^* = 0.1$) for $\text{Xe}({}^3\text{P}_2)$ and $\text{Kr}({}^3\text{P}_2)$, respectively.³ Adjustment of experimental conditions gives XeCl emission intensities that were first order in $[\text{RCl}]$. For these conditions the relative intensities are proportional to the rate constants for XeCl formation; the values for Cl_2 , SCl_2 , COCl_2 and HCl were 1.0:0.2:0.1 and 0.01. Judging by the similarity of Cl_2^* emission from reaction of $\text{Xe}({}^3\text{P}_1)$ and $\text{Xe}({}^3\text{P}_2)$ or $\text{Kr}({}^3\text{P}_1)$ and $\text{Kr}({}^3\text{P}_2)$ with Cl_2 , and the reduced rate constants for XeCl formation for larger donor molecules, reaction 3b is important, just as for the $({}^3\text{P}_2)$ atom reactions.⁵ The high branching fraction for RgX formation with diatomic halogens found for $\text{Xe}({}^3\text{P}_1)$ and $\text{Kr}({}^3\text{P}_1)$ contrasts sharply with the claim¹⁰ of a low branching fraction for $\text{Ar}({}^3\text{P}_1)$ with F_2 .

The low pressure spectra of XeCl and KrCl from the $({}^3\text{P}_2)$ and $({}^3\text{P}_1)$ reactions are shown in Fig. 1. Only two minor features distinguish the emission of the $({}^3\text{P}_1)$ and $({}^3\text{P}_2)$ atom reactions:

- 1) In general the B-X spectrum from the ${}^3\text{P}_1$ reactions extends to shorter wavelength than does the spectrum from the ${}^3\text{P}_2$ atom reactions.

- ii) The C-A spectrum from 3P_1 reaction also shows, as revealed by the position of oscillations and redmost band, a generally higher vibrational excitation.

These differences are attributed to the 960 and 945 cm^{-1} greater energy of the $\text{Xe}(^3P_1)$, $\text{Kr}(^3P_1)$ states, respectively.

An important advantage of the photosensitization technique relative to the flowing afterglow technique, which is limited to 0.1-30 torr, is the ability to obtain XeX and KrX spectra with added Ar, Ne and He buffer gas from 0.1 torr to 4 atmospheres (the limit of the MgF_2 window). From the spectra at various pressures, the steady-state ratio of B to C can be obtained; some sample data are shown in Figure 2. The minimum in the C/B vs p^{-1} plot was not observed in the flowing afterglow⁴ studies because of the 30-50 torr high pressure limit. We are in the process of making a detailed model of the RgX electronic and vibrational relaxation observed with Ar, Ne and He. The vibrational and electronic state relaxation can be described qualitatively by consideration of 3 pressure regimes.

In the low pressure regime (0.1-5.0 torr for XeCl in Ar), apparent B state vibrational relaxation, C state vibrational relaxation and increase in the B/C ratio is observed. At these pressures the lifetime¹⁴ of the B state (~ 10 nsec) is shorter than the time between collisions; therefore, these observed changes result from collisions of the C state ($\tau \sim 120$ nsec)¹⁵ with the bath gas. Molecules in the C state are collisionally transferred to the B state and also are vibrationally relaxed.

In the intermediate pressure regime (5-50 torr for XeCl in Ar), the vibrational relaxation of the B and C states is rapid, while the B/C ratio increases slowly. Above 10 torr the XeCl(B and C) vibrational populations relax to a high temperature Boltzmann (several thousand K) distribution and by ~ 50 torr a 300°K distribution is attained. In the early part of this regime rapid transfer between the B and C states still occurs but vibrational relaxation within each manifold occurs much faster. As the vibrational relaxation becomes more complete, the B-C transfer rate constants become rather small and the ratio established at the high vibrational temperature is maintained.

In the high pressure regime (> 50 torr for XeCl in Ar), the C/B ratio increases due to the relaxation of the high temperature electronic distribution to a true 300K Boltzmann distribution. The slow transfer between the B and C states for the 300K distribution is responsible for the minimum in the p^{-1} plot of Figure 2. The requirement of high pressure for this relaxation is consistent with the B-C transfer rate constant of $\sim 10^{-12} \text{ cm}^3 \text{ atom}^{-1} \text{ sec}^{-1}$ for a 300K XeF^* distribution in Ar.¹⁶ A possible explanation for the strong dependence of the

B-C transfer rate constants upon energy is that the potential curves of the B and the C state are nearly coincident at the outer turning points for high v levels while for lower v levels the separation is larger.

For XeCl and XeF the limiting high pressure C/B ratios are ~ 3 and ~ 32 , respectively, corresponding to an energy separation of $230 \pm 30 \text{ cm}^{-1}$ for XeCl and $720 \pm 60 \text{ cm}^{-1}$ for XeF with the C state being the lower state. This confirms the XeF results reported earlier using photodissociation of XeF_2 as the XeF source.¹⁶ For KrCl, KrF and XeI the high pressure C/B ratios are 1.7, $\gtrsim 4.0$ and ~ 1.0 , respectively. Except for KrCl these values are lower limits, because for XeI and KrF the high pressure regime was not reached at 4 atm. In obtaining these ratios all of the broad band emission was assigned as C-A emission, except for XeI, for which the B-A and C-A are well separated. The calculated branching fraction for $\text{XeCl}(B \rightarrow A)$ is 0.06.¹⁵ Removing this from the apparent C-A intensity would reduce the XeCl B-C energy separation to $\sim 200 \text{ cm}^{-1}$. Although the B-A contribution to the apparent C-A emission intensity may be nearly insignificant for XeF and XeCl, it probably is important for XeBr and KrBr. Nevertheless, it generally appears that the C state is somewhat lower in energy than the B state for the rare gas halides. This general statement depends on the calculated C-state lifetimes used to convert the steady-state intensity ratio to a steady-state population ratio.

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Figure 1. Comparison of XeCl and KrCl emission spectra (corrected for wavelength response) from the metastable ($^3\text{P}_2$) and resonance ($^3\text{P}_1$) atom reactions with Cl_2 . Both XeCl spectra were obtained at ~ 0.1 torr; the KrCl spectra are shown from 0.5 torr because that was the lowest ($^3\text{P}_2$) atom spectrum available. The short wavelength cut-off for KrF arises from window and atmospheric absorption.

Figure 2. Variation of the XeCl(B) and XeCl(C) state ratio from $\text{Xe}(^3\text{P}_1) + \text{Cl}_2$ with pressure; C/B vs. pressure⁻¹ of Ar, Ne and He (upper) and B/C vs. pressure (lower). To obtain concentration ratios the measured intensity ratios are multiplied by the ratios of the lifetimes. For XeCl and XeF $\tau_{\text{C}}/\tau_{\text{B}} = 10.9$ and 9.4 , respectively. The strong band at 260 nm in the KrCl spectrum is the Cl_2^* emission. This comprises 10% of the emission intensity.

Radiative Lifetimes and Two-body Deactivation of the $\text{Kr}(4p^5p$ and $5p^1)$
States and $\text{Ar}(3p^5,5p)$ States.

In spite of the apparent simplicity, completing this laser induced fluorescence work has proven to be difficult for various technical reasons. Some of the radiative $\text{Kr}(4p^55p - 4p^35s)$ transitions are in the infrared and measuring the radiative branching ratios required special effort. These were remeasured during this quarter, and we now believe that they are satisfactory. The manuscript describing the $\text{Kr}(4p^55p)$ work is completed and the Abstract is attached as part of this report.

About two years ago we did some preliminary studies of the second set of p levels of Ar; i.e. $\text{Ar}(3p^55p)$. The laser fluorescence was observed with interference filters and we could not assign product states to the two-body quenching. We reinvestigated these levels and tried to use wavelength resolved fluorescence to establish the product states. We were making some progress when trouble developed with the N_2 laser; the power declined to $\sim 1/2$ of the proper level. For the $\text{Ar}(3p^5,5p)$ work all of the available power is needed. Until the laser is repaired, further progress is not possible. We have set up a kinetic analysis scheme and done a computer simulation of the radiative and collisional cascade. The published radiative branching fractions and calculated Einstein coefficients for the $\text{Ar}(3p^55p)$ levels lead one to expect that the experiments should be easy; however, our experience is contrary to this expectation. It is for this reason that we persist in trying to understand the kinetics of the $\text{Ar}(3p^5,5p)$ levels. Even a qualitative understanding may prove to be interesting and useful. With insight from the kinetic model and with a healthy N_2 -laser, we hope to finish this project in the near future.

Dr. Horiguchi also has had several other projects during the last three months. Our flash pumped dye laser Chromatix, (CMX-4) was delivered and he spent 2-3 weeks learning how to operate it. The CMX-4 was purchased by the University for use within the Chemistry Department. Our research group will be one of the principal users. In recent weeks Dr. Horiguchi has been testing the suitability of the resonance sensitization technique for use with pulsed dye lasers. We wish to use the technique to pump atoms from the $\text{Xe}(^3P_1)$ and $\text{Kr}(^3P_1)$

states to the $\text{Xe}(5p^5 6p)$ and $\text{Kr}(4p^5, 5p)$ states. The main advantage, relative to the flowing afterglow that we have been using for pumping the $(^3P_2)$ states, is that a greater variety of bath gases can be used. The main problem is that the microwave powered discharge lamp gives very strong scattered light in the same region as the laser fluorescence. We have purchased an interference filter which passes the vacuum U. V. resonance lines but not the red lines of Kr and Xe. The transmission, unfortunately is only ~25%. At the time of writing this report, the apparatus with the filter was being assembled. We already have shown $\text{Kr}(^3P_1)$ atoms are prepared in the cell by observing KrCl chemiluminescence from Kr/Cl_2 mixtures. Based upon our experience with the resonance sensitization technique and with laser fluorescence, we foresee no major difficulty other than the normal period required for development of technique.

RADIATIVE LIFETIMES AND TWO-BODY COLLISIONAL DEACTIVATION
 RATE CONSTANTS IN ARGON FOR $\text{Kr}(4p^5 5p)$ and $\text{Kr}(4p^5 5p')$ STATES

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ABSTRACT

The radiative lifetimes and collisional deactivation rate constants in argon of eight $\text{Kr}(4p^5 [^2P_{1/2,3/2}] 5p)$ levels have been measured by a time-resolved laser-induced fluorescence technique in a flowing afterglow apparatus. The measured radiative lifetimes are compared with other experimental values and with theoretical calculations based on jK and intermediate coupling schemes. Radiative branching ratios of these excited states also were measured in order to assign the absolute transition probabilities of the $\text{Kr}(5p, 5p' - 5s, 5s')$ transition array from the radiative lifetimes. In addition to the total deactivation rate constants, product states from two-body collisions between $\text{Kr}(5p$ and $5p')$ atoms and ground state argon atoms were identified from the laser-induced emission spectra and product formation rate constants were assigned. Two-body intermultiplet transfer from $\text{Kr}(4p^5 [^2P_{1/2}] 5p')$ to the $\text{Kr}(4p [^2P_{3/2}] 4d)$ levels occurs with ease. Intermultiplet transfer from $\text{Kr}(2p_{10})$, the lowest level in the $(4p^5 5p)$ configuration, to the $\text{Kr}(4p^5 5s$ and $5s')$ levels was fast despite the large energy defect. This was the only $\text{Kr}(5p)$ level that gave appreciable direct transfer to the $\text{Kr}(5s$ or $5s')$ levels. Generally the favored product states are within a few kJ of the entrance channel.

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