the relative importance of nonparabolic dispersion relation and many-body effects.

Unexpected oscillations under high magnetic fields and in the low carrier concentration region ($n_s < 8\times10^{11}$ cm^{-2}) have been observed in the transconductance. Such splittings appear to be similar to what has been termed "valley splitting" in a 2DEG.[17] However, it has been shown that the 2DHG in Si has only one valley. Therefore, we believe that these splittings may be of a more fundamental nature than the removal of valley degeneracy. We are in the process of investigating this further.

A more complete understanding of the 2DHG requires investigation of other aspects of the system. Among these are such studies as changes in capacitance turnon as a function of magnetic field to determine the number and energy distribution of surface states, direct transitions between sub-bands, and cyclotron resonance. It is hoped that such studies will be stimulated by this report.

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Optical Absorption Threshold in Dilute Alkali-Metal—Rare-Gas Alloys*

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We report the optical absorption of Kr and Xe impurities in alkali-metal hosts. While the absorption threshold can be predicted accurately, the edge profile cannot be reconciled with current Hartree-Fock theories of optical excitations in metals.

We report and interpret optical absorption associated with rare-gas impurities in alkali-metal hosts. The observed transitions have a $p^6 \to p^5 s$ character near threshold, but lack the singularities observed (and predicted by Hartree-Fock theory)[1-3] for $L_{2,3}$ x-ray transitions of pure metals.[4] The smooth profiles observed in this work vary in amplitude from one host to the next in a way that appears to reflect the density of conduction states near E_F. It has not been possible to reconcile the observations with the current Hartree-Fock theory of absorption edges in metals.

The impurities discussed in the present paper (Xe and Kr) have exceptionally elegant excited-state structures in alkali-metal hosts.[5] An excited Xe 6*s* electron has an atomic binding energy (3.81 eV) almost identical with that of the Cs 6*s* electron (3.89 eV).[6] Since the core structures are almost identical, the optical excitation process in effect *transmutes* Xe into Cs! Excited Xe therefore bonds into Cs with the cohesive energy ($E_c = 0.83$ eV) of Cs, and the excited configurations are those of the perfect Cs lattice. The ground-state binding may also be analyzed with good accuracy. Since the rare-gas valence levels at ~ – 15 eV lie far too deep to mix with host band states, the substitutional rare gas is just a neutral atom located in a vacancy requiring $\sim E_c/2$ to form. Allowing for some relaxation, one estimates that $E_g = 0.2 \pm 0.2$ eV is required to dissolve the Xe ground state in Cs. This prescription is compatible with the observed energies for dissolving He in Li (0.2 eV)[7] and Ar in Na (0.6 eV).[8]

If one neglects coupling to the phonon bath, excitation threshold in solution is therefore

$$\hbar\omega_0 = E_a - E_c - E_g = 7.4 \pm 0.2 \text{ eV}, \qquad (1)$$

with $E_a = 8.43$ eV the atomic $p^6 \rightarrow p^5 s$ excitation energy of Xe.[6] A Stokes shift comparable to the ground-state relaxation energy is expected to increase this excitation energy by ~0.2 eV.

Figure 1 shows the type of specimen used in this work. Rare-gas atoms (Xe and Kr) were codeposited with alkali metal (Li, Na, K, Rb, Cs) to make films ~2000 Å thick on a LiF window held at ~5°K to inhibit annealing. Lines originating from rare-gas pairs[9] in more concentrated samples revealed random-site occupancies that confirm the success of the sample preparation procedures. Sample deterioration in the 10^{-7} Torr vacuum was inhibited by a 50-Å transparent Ne overcoating. That half of the sample containing rare gas was covered in pure alkali metal to eliminate surface spectra (see Fig. 1). Light from an Hanovia-type hydrogen lamp and uv monochromator was passed through both half-samples simultaneously, chopped, and the intensity ratio recorded automatically from 6 to 11.5 eV.

The absorption (or, more precisely, the logarithm of the transmission ratio) per rare-gas atom for Kr and Xe at dilution in K, Rb, and Cs is shown in Fig. 2. These results were obtained by extrapolating to $c = 0$ spectra observed through the range $10^{-2} < c(\text{at.}\%) < 6 \times 10^{-2}$, thereby eliminating the spectra of impurity multiplets at higher energies. The threshold profiles are themselves insensitive to *c*. For Xe in Cs one observes $\hbar\omega_0 = 7.57$ eV, slightly Stokes shifted from the prediction of 7.4 eV from Eq. (1). For Kr in Rb one observes $\hbar\omega_0 = 9.18$ eV, while Eq. (1) predicts 8.9 eV. Since the relaxation of a rather open alkali-metal lattice should be similar for Kr and Xe impurities, one anticipates further that the Kr to Xe threshold splitting should approximate the predicted value of $\Delta = 1.52$ eV in all host lat-

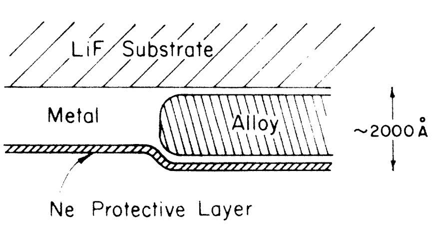

FIG. 1. Thin-film alloy samples deposited on LiF, showing the pure and alloy sample halves protected by a Ne overlayer.

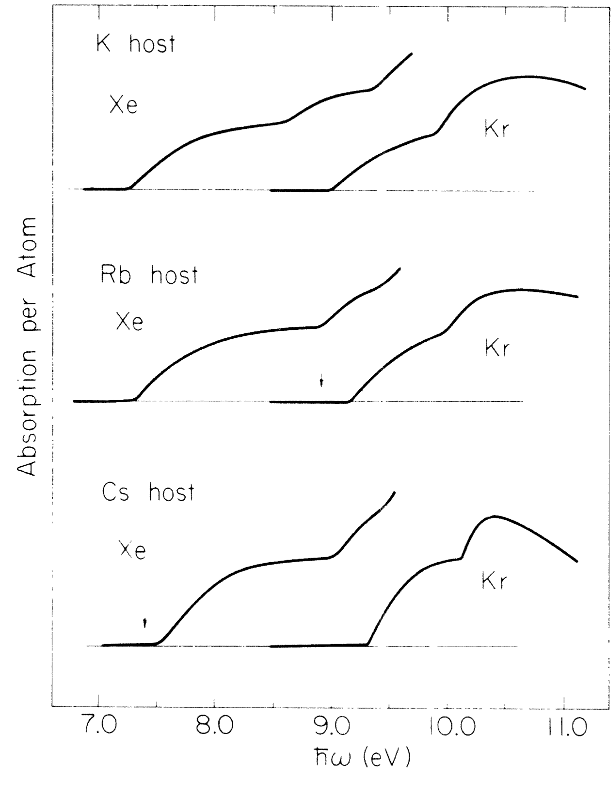

FIG. 2. Absorption per rare-gas atom in dilute alkali-metal–rare-gas alloys. The arrows indicate predicted thresholds for Kr in Rb and Xe in Cs, neglecting an expected Stokes shift to higher energies of ~0.2 eV.

TABLE I. Threshold energies $\hbar\omega_0$ (eV) for Kr and Xe in alkali metals, and the splitting Δ. The normalized heights of the edge profiles, ρ_A (see text), track with the ratio N_A/N_{Cs} of state densities at E_{F}.

	$\hbar\omega_0$			ρ_A		
Host A	Kr	Xe	Δ	Kr	Xe	N_A/N_{Cs}
Li	8.45	6.92	1.47	0.3	0.6	0.51
Na	8.62	7.06	1.44	0.3	0.4	0.43
K	9.05	7.30	1.65	0.63	0.62	0.65
Rb	9.18	7.38	1.70	0.83	0.78	0.75
Cs	9.36	7.57	1.79	1.00	1.00	1.00

tices. The observed thresholds listed in Table I confirm this expectation quite well. Imperfect matching of the impurity core to the host core does not disturb this relationship because the heats of intersolution among alkali metals, relevant to the impurity excited-state energies, are uniformly small (~ 0.01 eV).[10] Deviations from 1.52 eV therefore originate in dissimilar lattice strains.

With the nature and location of the impurity excitation threshold established beyond reasonable doubt, we can discuss the edge profile in the certain knowledge that recombination broadening plays no major role in determining the shape. In previous work the threshold energy, although calculable to excellent accuracy[11] (~ 1%), has remained uncertain to ~ 1 eV, since $\hbar\omega_0 \sim 100$ eV for typical core excitations. Figure 2 shows, in any event, that the absorption begins rather abruptly at threshold, which is incompatible with the Lorentzian broadening associated with short excited-state lifetimes. The observed L_2 to L_3 spin-orbit splittings are ~ 0.8 eV for Kr and ~ 1.4 eV for Xe as expected from the analogous atomic transitions. The question now is whether or not the existing theory of optical excitation edges in metals can explain the *rounded* edge profiles observed in this work.

The accepted description, based on determinantal wave functions for noninteracting band orbitals, gives the edge profile as[1,2]

$$f(E) = (E - E_t)^{-\alpha}, \quad E > E_t, \tag{2}$$

with

$$\alpha = 2\delta_0/\pi - 2\textstyle\sum_l (2l+1)\delta_l^2/\pi^2, \tag{3}$$

for $L_{2,3}$ transitions. Here, the δ_l are l-wave phase-shift changes caused by the modified screening of the excited state. Central-cell corrections are omitted from the derivation of Eq. (2), which depends only on the asymptotic phase difference between one-electron orbitals in the two determinants. Equation (2) therefore applies equally to core excitations and to the present problem. For the present case the ground state gives phase shifts similar to those of a partly relaxed vacancy, while the phase shifts in the excited state are essentially zero. For the unrelaxed vacancy one arrives at the estimates $\delta_0 = (0.6 \pm 0.2)\pi/2$, $\delta_1 = (0.3 \mp 0.2)\pi/6$, and $\delta_2 = 0.1\,\pi/10$ to satisfy the Friedel sum rule for one electronic charge repelled.[12] For a vacancy relaxed to half this volume one estimates $\delta_0 = 0.4\,\pi/2$, $\delta_1 = 0.1\,\pi/6$, and $\delta_2 \sim 0$. The unrelaxed vacancy therefore gives $\alpha \sim 0.38 \pm 0.10$ and the relaxed vacancy $\alpha \sim 0.32$. It is very hard to see how α could possibly fall much below 0.3 for the excitations of interest here.

In irreconcilable contradiction with these predictions is the fact that the observed threshold exhibits no singularity. Its smoothly rounded profile corresponds to α large and *negative*. A best fit of $\alpha = -0.8 \pm 0.2$ covers the cases of Kr in Rb and Xe in Cs near threshold. It may be noted that even for the case most favorable to the theory, namely an unrelaxed vacancy screened entirely by p-wave scattering ($\delta_1 = \pi/6$), one finds only $\alpha = -0.167$. For the half-relaxed vacancy, with $\delta_0 = 0$ and $\delta_1 = \pi/12$, the most negative exponent is $\alpha = -0.04$. In both cases the presumed scattering structure is totally unacceptable since the vacancy potential necessarily scatters s waves strongly. Thus, the present theory of optical transitions in metals offers no reasonable explanation of the observations.

The data do, nevertheless, exhibit significant physical trends of edge profile with host species. As a measure of the absorption coefficient per impurity we have taken the normalized absorption of the L_2 component at an energy of 0.75 eV above threshold. The ratio ρ_A of this absorption coefficient in host A to the analogous quantity in the Cs host is given in Table I for Kr and Xe impurities. These ratios follow very closely the trend of the ratio of host densities of states at the Fermi level, given in the last column of Table I. A scaling of this type is to be expected whenever the matrix elements vary negligibly from one host to the next, and the major effect then arises from the variation of energy with wave vector in the host conduction band. The implication is that *only a single excited quasiparticle is produced* in the optical excitation.

In summary we note that the absorption thresholds of rare gases in alkali metals, reported here, find a quantitative explanation in terms of elegant impurity structures. However, currently accepted theories of the edge profile offer no acceptable explanation of the observed absorption above threshold. It is worth remarking that the present case differs from the case of host core excitations in that the excited electron in our studies exists initially in a region lacking host band electrons. It is therefore possible that the correct explanation of edge profile in metals may involve a true many-body problem rather than the one-electron approximations employed in current Hartree-Fock studies of these interesting processes.

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Measurement of the g Factor for the 1.1-μsec Shape Isomeric State in ^{237}Pu

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The spin precession of the 1.1-μsec shape isomeric state in ^{237}Pu has been measured by the perturbed angular correlation method. From a measurement of the spin rotation frequency as a function of temperature of the target, the paramagnetic correction factor β has been determined to be in agreement with the theoretical value of 2.86 at room temperature for a 4^+ ionic state. The deduced value for g is $+0.14 \pm 0.02$.

Two spontaneous-fission isomeric states with half-lives of 100 nsec and 1.1 μsec, respectively, have been found in ^{237}Pu.[1-3] The long-lived state (1.1 μsec) has the higher spin,[1] and appears to lie approximately 0.30 ± 0.15 MeV above the 100-nsec isomeric state.[2] The conclusions drawn from these experiments[1,2] are that the 100-nsec isomeric state probably is the ground state in the secondary minimum whereas the 1.1-μsec isomeric state is an excited single-particle state with the γ decay to the ground state hindered because of selection rules for I and K quantum numbers.

Recently Specht *et al.*[3] measured the angular distribution of the delayed-fission fragments from the two isomers and found an anisotropy of 1.41 ± 0.14 for the (1.1 μsec) excited state and of 0.58 ± 0.16 for the (100 nsec) ground state. Two conclusions are drawn from this measurement: (i) A considerable fraction of the 1.1-μsec isomeric state decays directly through a fission channel with $K < I$ rather than decaying by γ emission to the ground state; and (ii) the 100-nsec isomeric state probably decays via a fission channel with $K = I$. The authors also suggest that a likely spin combination for the two isomers is $\frac{11}{2}$ and $\frac{5}{2}$. Such a spin combination is also suggested from relative-population cross-section measurements.[1] Furthermore, this spin combination is consistent with several theoretical