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XENON IMPURITY STATES IN SOLID ARGON*

G. Baldini
Institute of Optics, University of Rochester, Rochester, New York

and

R. S. Knox
Department of Physics and Astronomy, University of Rochester, Rochester, New York

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Recent measurements on solid rare gas films[1] have revealed unexpected absorption bands tentatively interpreted[1,2] in terms of Wannier[3] excitons. The present note reports the observation of similar "trapped excitons" in an Ar film containing small amounts of Xe. Thus the previous interpretation is supported, and, moreover, the first experimental determination of the effective mass of a conduction electron in a solid rare gas is achieved.

Films of argon containing various small percentages of Xe were prepared by deposition from a gas mixture onto a cold substrate, and the optical absorption spectra of the films were obtained using essentially the equipment previously described.[1] The temperatures involved ranged from 8 to 10°K and concentrations in the original gaseous mixtures ranged from 1 to 0.1 mole percent. Some enrichment in the Xe concentration is expected because of its lower vapor pressure, and we estimate that this enrichment is of the order of a factor of 3. Figure 1 shows the optical density of a film Ar:~0.003Xe between photon energies of 8 and 12 eV, a region which is featureless and generally transparent in pure argon films.[1] On the basis of estimated oscillator strengths in pure Xe,[4] it can be deduced that the film thickness in this experiment was ~5μ.

It is seen that a rich variety of absorption lines appear, in contrast to the simple pair of resonance lines in atomic Xe at 8.43 eV and 9.57 eV. These resonance lines belong to transitions of the type $5p^6(^1S_0) \rightarrow 5p^5 6s(^3P_1, ^1P_1)$. The absorption bands A_1 and B_1 are assumed to correspond to these atomic transitions, with a splitting in the solid of 1.31 eV due to a (somewhat enhanced)

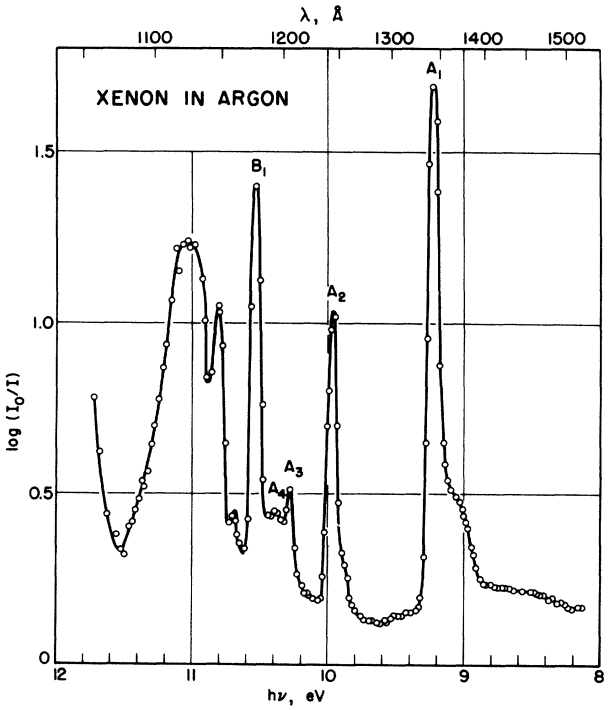

FIG. 1. Absorption spectrum of a film of Ar containing ~0.3 mole% Xe at 10°K.

spin-orbit interaction in the $5p$ shell. The shoulder on the low-energy side of the peak A_1 is probably due to pairs of Xe atoms. At higher Xe concentrations (~1%) the shoulder becomes a broad band that overlaps A_1 on the low-energy side. These two bands have been reported earlier by Dressler.[5]

The remaining absorption lines cannot be interpreted reasonably in terms of "perturbed atomic states," for reasons discussed in reference 1. They may be interpreted surprisingly well on a one-electron model illustrated in Fig. 2. We now visualize the excited state involved in transition A_1 as an electron in an excited orbital bound to a hole in the upper $5p^6$ level. There will exist more loosely bound states of the electron which can be treated as effective-mass impurity states[6]

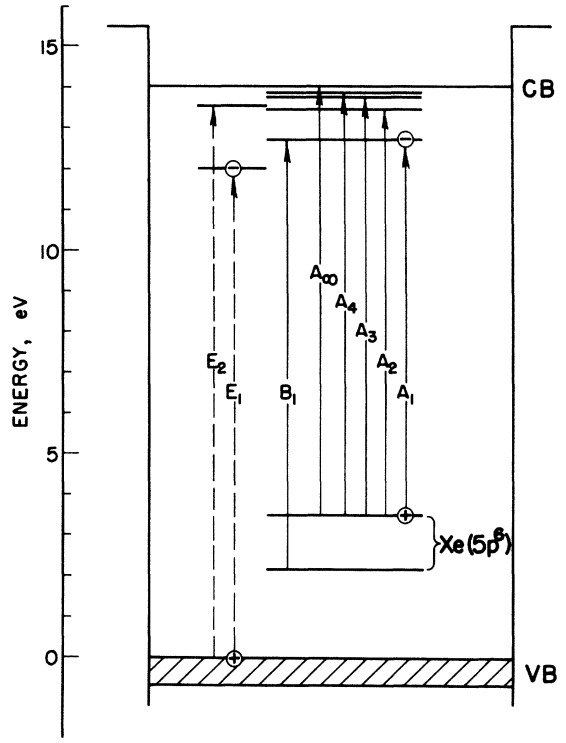

FIG. 2. One-electron energy level scheme used in the interpretation of the data of Fig. 1. The $5p$ levels of Xe have been positioned on the basis of the observed absorption energies. Because of exchange and other many-electron effects, these "one-electron" levels are to be regarded as having only heuristic value. The Ar band gap used, $E_G = 14$ eV, is based on the experimental results of reference 1, as are the energies of the transitions E_1 and E_2, which correspond to host-crystal exciton lines not shown in Fig. 1. No detailed consideration has been given to the question of locating the vacuum level (shown here at ~15.3 eV).

bound to $(5p^5)^+$ and which therefore have energies

$$-\frac{m_e^* e^4}{2\hbar^2\epsilon^2}\frac{1}{n^2} \equiv -\frac{G'}{n^2} \qquad (1)$$

relative to the bottom of the conduction band. Here ϵ is the dielectric constant of Ar, m_e^* is the effective electron mass, and n is a hydrogenic envelope function quantum number. The radii of the corresponding orbits are $(\epsilon/m_e^*)n^2$ Bohr radii, and the lowest ($n = 1$) state must be regarded as a "1s envelope" comprising little more than a 6s-like electron function centered at the Xe atom (see our further remarks on the $n = 1$ state below). The energy differences among the lines A_2, A_3, and A_4 obey Eq. (1) to within ±0.01 eV if G' is taken to be 2.23 eV. Therefore, since the dielectric constant of Ar is known[7] to be $\epsilon = 1.67$, the effective mass of the conduction electron is seen to be $m_e^* = 0.46$ electron masses,[8] in fair agreement with the computed value[9] of this quantity (0.56). This value is also consistent with that deduced from the Ar reduced exciton mass.[1]

As indicated in Fig. 2, the line B_1 is likely the first of a second series of lines arising from states in which a hole is left in the lower $5p$ level. Presumably the lines B_2, B_3, ··· are located somewhere above B_1 in energy (see Fig. 1) but we shall not at present attempt an analysis of this region of the spectrum, which may involve details of the electronic structure in the Ar conduction bands. It is interesting to note the resemblance of much of this spectrum to that of pure Xe.[1]

The radius of an orbit is given by $3.65n^2$ Bohr radii, which immediately rules out quantitative considerations of the $n = 1$ state on a simple effective-mass model. In fact, the predicted energy of the $n = 1$ level, using Eq. (1), is about one eV too low. For $n = 2$, 3, and 4, however, it seems quite reasonable to work with this model; even in the case $n = 2$, more than 40 lattice sites are included in a sphere whose radius is $3.65 \times 2^2 = 14.6$ Bohr radii.

Effective-mass states similar to those reported here have been observed in Ne-Xe mixtures, so it would appear that their occurrence here is not fortuitous. Well resolved spectra of RbCl-RbI mixtures, whose halide sublattices are "isoelectronic" to Ar-Xe, also reveal distinct effective-mass series of lines.[10] Since effective-mass methods appear to be applicable in both pure and impure rare gas crystals, it will be interesting and useful to study a wider range of spectra with

this fact in mind. It may be noted, for example, that the electronic configuration of an alkali impurity in a rare gas solid is precisely analogous to that of a donor in a semiconductor. Undoubtedly the effective masses of conduction electrons in other rare gas solids can be determined by proper choices of impurities.

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TERNARY FISSION OF U^{235} INDUCED BY THERMAL NEUTRONS*

M. Luis Muga
Chemistry Department, University of Florida, Gainesville, Florida
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Studies of the ternary fission process in which a heavy nucleus divides into three charged fragments of large mass have been reported using nuclear emulsion techniques and, in one instance, electronic counting methods.[1] However, the limitations of standard nuclear emulsion techniques make it difficult to distinguish between ternary fission events and recoil phenomena; likewise, past limitations on coincidence resolution times coupled with the infrequency of occurrence of ternary fission has heretofore prevented any direct measurement of this process. As a result, the existence of the ternary fission process at low excitation energies has not gained general acceptance.

The purpose of the present investigations is twofold: (a) to establish with confidence the existence of ternary fission, and (b) to study the mass-energy-angular correlations of tripartite mass division in the fission process. The present note is intended mainly to present preliminary data on the mass yield distribution and total kinetic energy release in ternary fission of U^{235} induced by thermal neutrons.

The experimental arrangement consisted of three solid state detectors positioned 120° apart in a plane about a fission source made by evaporating a film of $U^{235}F_4$ (5-300 $\mu g/cm^2$) onto a thin (60 $\mu g/cm^2$) nickel foil support. The detectors and source were enclosed in an evacuated aluminum chamber and placed in the thermal column of the University of Florida Training Reactor (UFTR). The detectors were of the surface barrier type fabricated from 300 ohm-cm silicon and operated at 30 volts back bias voltage. Calibration was accomplished before and after each experiment by comparing the binary fission fragment energy spectrum to that obtained from time-of-flight data[2] and extrapolating to lower energies using the average light- and heavy-mass energy positions. The output pulse of each of the three detectors was paralleled to a fast triple coincidence system and (after amplification) to a three-coincident-parameter analyzer[3] having $256\times256\times256$-channel resolution. The analyzer was triggered by the coincidence unit and, hence, recorded only those events in which a fission fragment entered each detector within the resolving time of the coincidence unit (5 nsec). This instrumentation and the experimental arrangement