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# Energy lost to ionization by 254-eV $^{73}$Ge atoms stopping in Ge[†]

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A 1-cm$^3$ Ge(Li) $\gamma$-ray detector was placed directly in a beam of thermal neutrons where the $^{72}$Ge$(n,\gamma)^{73}$Ge reaction produced 254-eV $^{73}$Ge recoil atoms in the detector. The primary capture $\gamma$ rays from the reaction were detected in a 7.6-cm × 7.6-cm NaI(Tl) detector placed at 90° to the incident beam. In addition to singles measurements a coincidence between the primary capture $\gamma$ ray and the $\gamma$ ray or conversion electrons from the decay of the 68.75-keV $^{73}$Ge third excited state was used to search for directional effects in the stopping and to check the value of the recoil energy deduced from the feeding of the 68.75-keV level. The level energy was remeasured and a value of 68.755 ± 0.005 keV was found, which when combined with the results of previous work gives a value of 68.7535 ± 0.0043 keV. The amount of energy lost to ionization in the stopping of the 254-eV $^{73}$Ge atom is found from the energy shift in the peak position for the 68.75-keV level. Our measurement of this shift gives a value of 39.2 ± 5.5 eV, which is then the energy loss to ionization by the stopping of the 254-eV $^{73}$Ge recoil atom. This result is (27 ± 3)% higher than the theoretical estimate made from an extrapolation of the Lindhard theory to this energy region. An attempt to observe a dependence of the ionization loss on the recoil direction in the Ge crystal was made, but no positive effect was observed.

## I. INTRODUCTION

The stopping of heavy ions in solids has been treated theoretically in some detail by Lindhard, Nielsen, Scharff, and Thomsen.[1] From their work it is possible to calculate the amount of energy lost to ionization by a germanium atom stopping in a germanium crystal as a function of the energy of the incident atom. The theoretical predictions have been compared with experimental results[2-6] in the energy range from 1 to 1000 keV. The agreement between theory and experiment is excellent over the entire energy range, although at the lowest energies the experimental values[6] seem to be higher by 35% than the predictions of the theory.

At energies less than 1 keV, some of the assumptions that are made by Lindhard *et al.* in their theoretical predictions start to break down. For example, they assume that the influence of atomic binding can be neglected, although this should be of increasing importance as the primary energy of the stopping atom decreases. It thus appears interesting to push the experimental results to as low as possible in energy to look for further deviations from the existing theory and perhaps to serve as the basis for more refined calculations.

In the present paper, an experiment is described which gives the energy lost to ionization by the stopping of 254-eV germanium atoms in a germanium crystal and a simple qualitative argument is given to explain the observed ionization as compared to the Lindhard theory.

## II. METHOD OF PRODUCING MONOERGIC RECOILS

We use the $^{72}$Ge$(n,\gamma)^{73}$Ge reaction as a source of very nearly monoergic Ge atoms with energies in the range of several hundred electron volts. When the capture reaction takes place, the emitted $\gamma$ ray carries an energy $E_\gamma$ and a momentum $E_\gamma/c$. As a result, the emitting nucleus must recoil with an energy given by $E_R = E_\gamma^2/2Mc^2$. For a capture reaction which utilized the full neutron binding energy, 6784.2 keV,[7] the recoil energy would be 336 eV.

Naturally, in actual practice, there are several difficulties which arise in applying this technique for producing low-energy Ge atoms in our experiment. We are interested, as will become clear in the following sections, only in capture reactions which populate the $^{73}$Ge state at 68.75 keV. This state, which is observed in Coulomb excitation,[8] has a spin and parity of $\frac{7}{2}^+$. It is therefore not populated directly from a thermal-neutron capture reaction which starts with the $J^\pi = 0^+$ $^{72}$Ge nucleus. Thus, to obtain monoergic recoils, it is necessary to look for capture $\gamma$ rays which populate low-lying states of $^{73}$Ge[9] which then decay to the 68.75-keV state with the emission of several low-energy $\gamma$ rays.

There have recently been several studies of the $^{72}$Ge$(n,\gamma)^{73}$Ge capture reaction[10-12] which have investigated capture $\gamma$ rays populating levels up to about 3-MeV excitation. It is found that a major fraction of the decays that populate low levels which then decay through the 68.75-keV level can be accounted for by captures to just two states at

915.2- and 931.5-keV excitation energy. The relative-intensity data are perhaps not as consistent as one might hope. Hasselgren[10] accounts for 100% of the feeding of the 68.75-keV state by these two primary capture $\gamma$ rays, while our own experiment[12] indicates that these two levels account for 60% of the total intensity. Both experiments, however, agree in finding *only* the 915.2- and 931.5-keV states as a source of feeding for the 68.75-keV state for states of excitation between 0 and 2 MeV which are also fed in the direct-capture $\gamma$-ray reaction. This situation is summarized in the simplified decay scheme shown in Fig. 1, which shows all the relevant $\gamma$ rays.

The direct-capture $\gamma$ rays to the 915.2- and 931.5-keV states result in recoil energies of 251.7 and 250.3 eV, respectively. In addition, the low-energy $\gamma$ rays which deexcite the two levels may also contribute to the recoil energy and this possible contribution must be assessed.

If the lifetimes of the low-lying states are long, compared to the stopping time of the recoil atom, each state will make its very own separate contribution to the total recoil energy. $\gamma$ rays with energies of 284.6, 430.1, 432.7, and 561.8 keV would give recoil energies of 2.3 eV at most, which are only a very small correction. At the other extreme, if all decays are essentially simultaneous, short with respect to the stopping time, the final recoil velocity must be calculated from a vector addition of three separate contributions to the total velocity, which are involved in each case. This could give a broad distribution in recoil energy extending from 178 eV to the maximum energy of 338 eV. For lifetimes of intermediate speeds the distribution of recoil energies falls somewhere between the two extremes. Therefore, in order to ascertain the width of the energy distribution, we must consider in some detail the stopping time of a 250-eV Ge atom in Ge and the lifetimes of the various levels involved in the decay scheme.

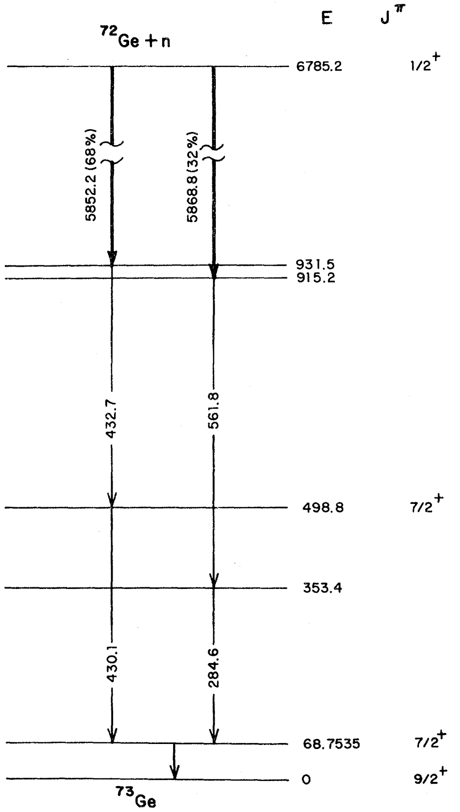

FIG. 1. Simplified decay scheme for the $^{72}$Ge$(n,\gamma)^{73}$Ge reaction. Only the decays of levels between 0 and 2-MeV excitation which populate the 68.75-keV excited state and which are also fed by primary capture $\gamma$ rays are shown. Data from Ref. 8–12 are summarized here.

The stopping time for such a low-energy atom can be estimated from the Lindhard theory.[13,14] Lindhard *et al.* chose to work with dimensionless energy and distance variables such that

$$\epsilon = \frac{E(aM_2)}{Z_1 Z_2 e^2 (M_1+M_2)}, \quad \rho = \frac{RNM_2(4\pi a^2)M_1}{(M_1+M_2)^2},$$

where $E$ is the particle energy, $a = 0.53 \times 0.8853(Z_1^{2/3}+Z_2^{2/3})^{-1/2}$ is the Thomas-Fermi screening parameter, $R$ the range, $N$ the total number of stopping atoms per cm$^3$ and, in our case, $M_1 = M_2 \cong 73$ and $Z_1 = Z_2 = 32$. It then follows that $\epsilon = (3.553\times10^{-6})E$, with $E$ expressed in eV and $\rho = (1.523\times10^{7})R$, with $R$ in meters. In the reduced units, the stopping power, which is given by the sum of a nuclear stopping power resulting from atomic collisions and an electronic stopping power, is given approximately by

$$d\epsilon/d\rho = 0.97\epsilon^{1/3} + 0.15\epsilon^{1/2} \quad \text{for } \epsilon < 0.02.$$

The first term is the nuclear term and fits the numerical calculations given in Refs. 13 and 14 to a few percent. The second term is the electronic stopping and it is negligible in importance compared to the nuclear stopping in this range of $\epsilon$. We therefore take $d\epsilon/d\rho = 0.97\epsilon^{1/3}$ and proceed to calculate the stopping time. Using the above information to evaluate the integral $t = \int dR/v$ gives a value for the stopping time of $(9.59 \times 10^{-15})E^{1/6}$ sec, with $E$ expressed in eV. In particular, it is then found that the stopping time of a 250-eV recoil is about $2.4\times10^{-14}$ sec. This appears to be a reasonable order-of-magnitude estimate even though we should not have extreme confidence in the validity of the theory in this very-low-energy region.

The lifetimes of the various levels involved in the decay scheme must now be considered. First, we give in Table I the single-particle estimates

TABLE I. Single-particle estimates in Weisskopf units for mean lives of $\gamma$ rays deexciting $^{73}$Ge levels at 68.752, 353.4, 498.8, 915.2 and 931.5 keV. [Values are calculated from Eq. 5 of S. J. Skorka, J. Hertel, and T. W. Retz-Schmidt, Nucl. Data A 2, 347 (1966).] The format $A$ $(n)$ means $A \times 10^n$.

| $E_\gamma$ (keV) | $\tau(E1)$ (sec) | $\gamma(M1)$ (sec) | $\tau(E2)$ (sec) | $\tau(M2)$ (sec) |
|---|---|---|---|---|
| 68.752 | 1.72 (−12) | 9.78 (−11) | 2.93 (−5) | 1.66 (−3) |
| 284.6 | 2.42 (−14) | 1.38 (−12) | 2.41 (−8) | 1.37 (−6) |
| 430.1 | 6.93 (−15) | 3.94 (−13) | 2.99 (−9) | 1.70 (−7) |
| 432.7 | | | | |
| 561.8 | 3.15 (−15) | 1.80 (−13) | 8.04 (−10) | 4.58 (−8) |

of the lifetimes for the various possible dipole and quadrupole transitions. It is seen that some of the $E1$ transitions have single-particle speeds which are comparable or shorter than the stopping time. In a very general way, without as yet discussing experimental information, it is well known that $E1$ transitions are strongly retarded with respect to the single-particle estimates. The survey by Perdrisat[15] shows a hindrance factor, i.e., the speed relative to the Weisskopf estimate, of ~$10^{-4}$ for $E1$ transitions in odd-$A$ nuclei around mass 70. The $M1$ transitions are an order-of-magnitude slower than the estimated stopping time, but are also expected to be hindered by a substantial factor.[16] We can conclude that the lifetimes are such that the nucleus, after it emits a $\gamma$ ray, has a great deal of time to stop before emission of a subsequent $\gamma$ ray. The contribution to the total recoil energy of the low-energy $\gamma$ rays can easily be calculated, and, including a weighting factor for the relative intensities, we find a recoil energy of 254.1 eV with a spread in energy which is only 1.5 eV.

Unfortunately, the existing lifetime and spin-parity data with which to substantiate the above arguments is limited. The state at 498.8 keV is seen in Coulomb excitation. The measured $B(E2)$ value implies a mean lifetime of $6 \times 10^{-10}$ sec. Little consistent information is available from stripping and pickup experiments. It is plausible to assume that many of the transitions are quadrupole since there will probably be a relatively large spin change between the initial state and the final 68.75-keV state.

### III. EXCITATION ENERGY OF 68.75-keV $^{73}$Ge THIRD EXCITED STATE

Our measurement of the energy lost by a low-energy germanium atom to ionization requires an accurate knowledge of the excitation energy of the 68.75-keV $^{73}$Ge third excited state. We have previously measured this excitation energy and found a value of 68.752 ±0.007 keV.[6] This value was found by averaging the results of four determinations made using the $^{73}$Ge$(p,p'\gamma)^{73}$Ge reaction, one determination with the $^{72}$Ge$(n,\gamma)^{73}$Ge reaction, and two determinations with the $^{73}$Ge$(\alpha,\alpha'\gamma)^{73}$Ge reaction. The results from the $^{73}$Ge$(\alpha,\alpha'\gamma)^{73}$Ge reaction were somewhat higher than the other measurements although well within the estimated uncertainties. Indeed, if these results were not used the level energy is found to be 68.746 ±0.009 keV. While this uncertainty in the level energy was of negligible importance in the previous experiment, for the present experiment it becomes a major contributor to the total experimental uncertainty. For this reason we have remeasured the excitation energy of the level during the course of the present experiment.

The level was excited by the $^{72}$Ge$(n,\gamma)^{73}$Ge reaction. A 720-mg sample of 90% enriched $^{72}$GeO$_2$ was irradiated with the thermal-neutron beam from the Brookhaven National Laboratory (BNL) high-flux beam reactor. The $\gamma$ rays of interest were detected with a Si(Li)x-ray detector which had a resolution of 225 eV for the Fe $K$ x ray. Calibration lines from the $^{241}$Am $\gamma$ ray at 59.537 ±0.001[17] and Pb $K$ x rays at 72.8042 and 74.9694 keV[18] which were fluoresced with a $^{57}$Co source were accumulated at the same time as the $^{73}$Ge $\gamma$ ray. The pulse-height spectrum is shown in Fig. 2. The energy of the $^{73}$Ge $\gamma$ ray and hence the excitation energy of the excited state was 68.755 ±0.005 keV, in good agreement with the previous values. The average of this value with the previous average value gives finally an excitation energy of 68.7535 ±0.0043 keV.

### IV. MEASUREMENT OF ENERGY LOST TO IONIZATION BY 250-eV Ge ATOMS STOPPING IN Ge

The general method used for measuring the amount of energy lost to ionization by the 250-eV Ge atoms stopping in Ge is very similar to the method used in a previous experiment.[6] In this case a small germanium $\gamma$-ray detector is placed directly in a thermal neutron beam from the BNL high-flux beam reactor with an estimated flux of $(2-7)\times 10^7$ $n/\text{cm}^2$ sec. Capture $\gamma$ rays from the $^{72}$Ge$(n,\gamma)^{73}$Ge reaction then produce $^{73}$Ge recoil atoms in the detector itself with an energy of 254 eV, as was described in Sec. II, and at the same time populate the 68.75-keV state by decays through low-lying states. In most cases the cascade $\gamma$ rays with energies of several hundred keV are not detected, but the very-low-energy 68.75-keV $\gamma$ ray or conversion electron will be detected with ~100% efficiency. The lifetime of the 68.75-keV level has been measured in the Coulomb excitation experiment of Salzmann *et al.*[8] and is

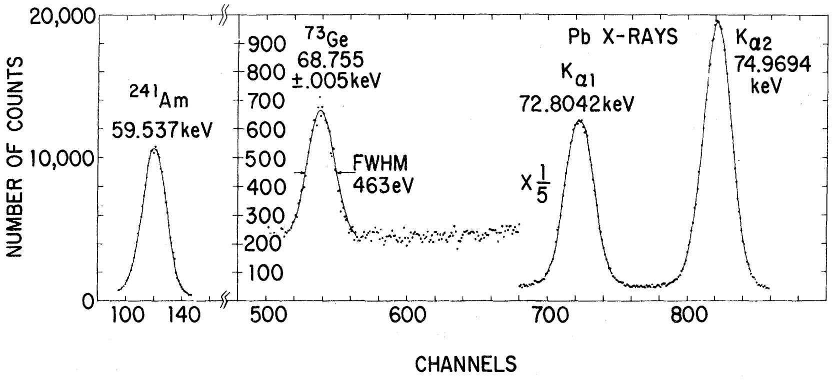

FIG. 2. Singles spectrum of the $\gamma$ rays from the $^{72}$Ge$(n,\gamma)^{73}$Ge reaction showing the unshifted 68.75-keV line as measured with a Si(Li) detector. The $^{241}$Am $\gamma$ ray and Pb x rays used for calibration are also present. The solid curves are Gaussian fits to the peaks with an assumed linear background.

$\sim 7\times 10^{-7}$ sec. When compared to the integrating time constants of the amplifier ($\sim 4$ $\mu$sec peaking time) the stopping time of the recoil and the subsequent decay of the 68.75-keV level are simultaneous. The ionization produced by the 68.75-keV $\gamma$ ray or conversion electron is then summed with the ionization produced by the $^{73}$Ge recoil atom and since the energy of the unshifted line has been measured independently the recoil ionization can be immediately deduced.

If the 68.75-keV state is fed only by initial decays to the states at 916 and 932 keV, a measurement of the peak position in a singles experiment would be sufficient. Because there appears to be some possibility that there is feeding from other levels, measurements were also performed in coincidence with the primary capture $\gamma$ rays with energies greater than 2.5 and 5.0 MeV. The latter bias very effectively selects decays only to the 916- and 932-keV states. An addition of a coincidence requirement also defines the direction of the recoil atom and makes possible an examination of possible self-channeling of the recoil relative to the known orientation of the crystal planes of the germanium detector.

A small Ge(Li) detector was used (except for one singles run for which a small, high-purity germanium detector was used) which was oriented with the $\langle 1,1,1\rangle$ plane in the horizontal plane. The resolution of this system was as good as 450 eV at the 59.54-keV $\gamma$ ray of $^{241}$Am; however, the in-beam resolution was somewhat worse and completely determined by the high-rate performance of the system. The detector was positioned in the beam so that the rate raised the preamplifier first stage dc level to $\sim 8$ V, which did not exceed the dynamic range of the preamplifier. The energy calibration for the detector again used the $^{241}$Am $\gamma$ ray and the Pb $K$ x rays which were fluoresced with a $^{57}$Co source. Effects from energy shifts were minimized by accumulating the calibration lines and the line of interest simultaneously. The technique is essentially identical to that described in Sec. III. In the coincidence experiments the calibration lines appeared as accidentals, but with sufficient intensity to be useful.

For the coincidence work the second detector was a $7.6\times 7.6$-cm NaI(Tl) $\gamma$-ray detector which could be placed at various orientations with respect to the Ge detector at a distance from the detector center of 5 cm. An *upper limit* to the angular resolution is then approximately ±arc tan(3.8/5) or ±37°. For a germanium recoil energy of 254 eV the estimated channeling angle is 110°. Measurements were made with bias levels of 2.5 and 5.0 MeV with the NaI detector oriented at 90° to the neutron beam in the horizontal and vertical planes relative to the Ge detector. An additional run was also made with a bias of 2.5 MeV at 45°. With the coincidence requirement added recoils were produced in the Ge-crystal (1, 1, 1) plane for the horizontal orientation and perpendicular to the (1, 1, 1) plane for the vertical orientation.

A typical coincidence spectrum is shown in Fig. 3. The solid lines are computer fits to the data which give the best least-squares fit to a Gaussian peak and linear background. The channel numbers shown are the centroids of the Gaussian fits to the peaks. Errors in the centroid determinations constitute the primary source of error for this experiment and are generally larger than uncertainties in the energies of the calibration lines and nonlinearities of the electronics and pulse-height analyzer.

Table II gives a summary of our experimental results. An examination of the energies found for the 68.75-keV peak under the various experimental conditions shows *no consistent* variation with the direction or energy selection of the capture $\gamma$ ray. The latter conclusion is consistent with the feeding of the 68.75-keV state only through the levels at 916 and 932 keV as discussed in Sec. II. We have therefore averaged the singles and coincidence data to find a value of $68.7927\pm 0.0034$ keV for the energy of the 68.75-keV $\gamma$ ray shifted by summing with the ionization produced by the germanium

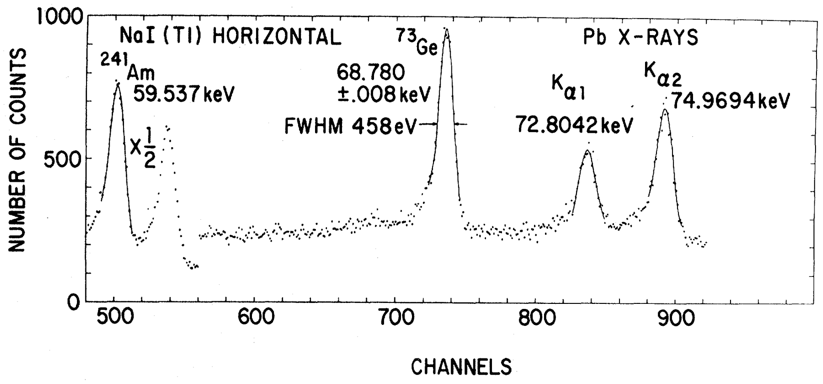

FIG. 3. Typical coincidence spectrum of γ rays produced in 1-cm$^3$ Ge(Li) detectors placed in a beam of thermal neutrons. The coincidence of the primary capture γ ray in a NaI(Tl) detector placed horizontally requires that only states in $^{73}$Ge between 0 and 2-MeV excitation are observed. Only the region of the 68.75-keV line and the calibration lines from Am and Pb are shown. The solid curves are Gaussian fits to the peaks.

recoil atom. A weighted average was used where the weighting is by the inverse of the variance which maximizes the probable value of the mean.[19] When this average is combined with the level energy of 68.7535 ±0.0043 keV a shift of 39.2 ±5.5 eV is found and we attribute this shift to the ionization produced in the stopping of the 254-eV germanium recoil atom in the detector. We have, of course, assumed that the energy required to make a hole-electron pair is the same for the germanium atom as for the electron. This is reasonable since the energy required to produce a hole-electron

TABLE II. Summary of experimental results.

| | $E_\gamma$ (keV) | $\chi^2$ | NaI(Tl) Bias (MeV) |
|---|---|---|---|
| Self-gated singles | 68.8019 ± 0.0062 | 2.95 | |
| | 68.7842 ± 0.0065 | 1.18 | |
| | 68.7814 ± 0.0088 | 1.25 | |
| | 68.7907 ± 0.0046 | 0.015 | |
| | 68.798 07 ± 0.007 | 0.95[a] | |
| | $\bar{X}$ = 68.7913 ± 0.0030, $\chi^2/(n-1) = 1.59$ ($P \sim 0.2$) | | |
| Coincidence—NaI(Tl) 45° | 68.8033 ± 0.0079 | | 2.5 |
| Coincidence—Na(Tl) horizontal, in ⟨1, 1, 1⟩ plane | 68.8092 ± 0.011 | 3.22 | 2.5 |
| | 68.7796 ± 0.0084 | 1.38 | 5.0 |
| | 68.7796 ± 0.0142 | 0.48 | 5.0 |
| | $\bar{X}$ = 68.7895 ± 0.0066, $\chi^2/(n-1) = 2.54$ ($P \sim 0.1$) | | |
| Coincidence—Na(Tl) vertical, perpendicular to ⟨1, 1, 1⟩ plane | 68.8158 ± 0.013 | 2.025 | 5.0 |
| | 68.7788 ± 0.011 | 2.777 | 2.5 |
| | $\bar{X}$ = 68.7973 ± 0.0085, $\chi^2/(n-1) = 4.80$ ($P \sim 0.1$) | | |
| Summary | | | |
| | Average weighted by $1/\sigma^2$: 68.7927 ± 0.0034 keV | | |
| Transition γ-ray energy (keV) | | | |
| Previous value | 68.752 ± 0.007 | | |
| Si(Li) run | 68.755 ± 0.005 | | |
| Average | 68.7535 ± 0.0043 | | |
| Recoil ionization energy loss: | 39.2 ± 5.5 eV | | |

[a] Data taken with Ge(HP) detector.

pair in germanium is 2.96 eV,[20] which is very close to the binding energy of the $N$-shell electrons. Hence, it is expected that the contribution of lower-lying shells or bands is not of major importance for either electron excitation (as in the energy calibration) or heavy-ion excitation (as in the $^{73}$Ge recoil-energy measurement). Any directional or channeling effects appear to have a magnitude less than about 10 eV for the present experimental conditions.

A summary of all our experimental results for Ge energies from 254 eV to 100 keV is shown in Fig. 4. The solid and dashed curves are calculated from the theory of Lindhard *et al.*[1] with two values, 0.15 and 0.20, of the electronic stopping constant $k$. Our result at 254 eV is fit quite well by the calculation which uses $k = 0.20$, as is the data on Ref. 6 between 1.0- and 1.8-keV energy. The higher-energy data[3-5] is best fit with $k = 0.15$. This result then confirms the apparent trend for an enhanced contribution to the electronic stopping as the Ge energy decreases.

## V. DISCUSSION

The results of the present experiment and our past work at recoil energies from 1 to 1.8 keV indicate a small trend to an electronic stopping fraction which is larger than that predicted by a fit of the Lindhard theory to the data at higher energies. It is *not* at all surprising that deviations of the data from the theory start to be observed, but it is of interest to inquire, in a qualitative way, if such an increase at low energies can be expected on general physical grounds. While there are several possible effects which can explain our observations, such as an energy-dependent value for the energy per hole-electron pair, we suggest another effect here which is not included in the standard Lindhard theory, and which may become of importance at low energies. Any detailed comparison of theory and experiment would require a thorough evaluation of the assumptions made by Lindhard *et al.*[1] and are beyond the scope of this paper.

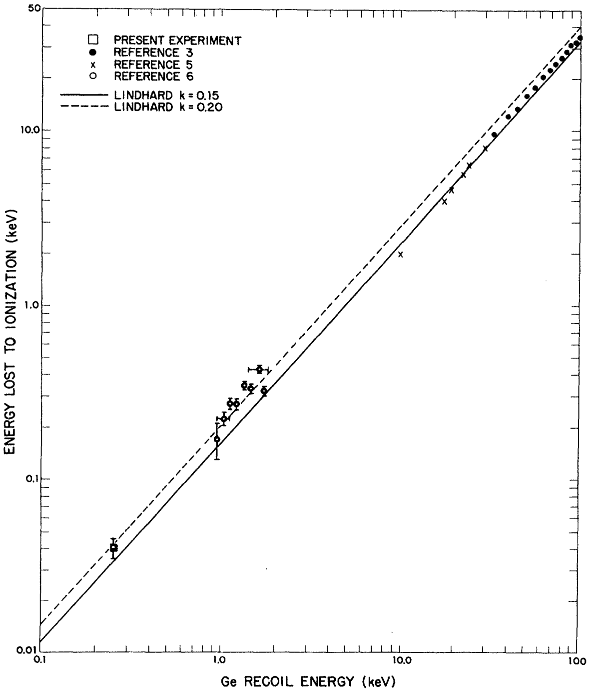

FIG. 4. Summary of all experimental results for the ionization produced by the stopping of germanium atoms in germanium. The solid and dashed curves are calculated from the theory of Lindhard *et al.* (Ref. 1) with $k = 0.15$ and 0.20.

Lindhard's predictions are based on the Thomas-Fermi (TF) model of the atom, with an electron density distribution that falls off as $r^{-6}$ for distances large compared to the TF radius, $a_{\mathrm{TF}} = 0.88 a_0 / Z^{1/3} \simeq 0.1$ Å. For atoms in crystals, however, the electron density reaches the nearly constant value of the mean valence-electron density between the atomic cores. We suggest that our low-energy recoil projectiles interact predominantly only with the outer fringes of the lattice atoms, where the valence-electron density is higher than for colliding TF atoms. Therefore, the electronic stopping power of atoms in a lattice for heavy ions of very low energy is enhanced relative to its value for colliding TF atoms under otherwise equal conditions.

The relative contribution of the valence electrons in the stopping process should become more important as the energy of the stopping germanium atom decreases. The distance of closest approach for a germanium atom with a laboratory energy of 254 eV and a charge +4, which results from the loss of four valence electrons, is about 1.8 Å $\gg a_{\mathrm{TF}}$. Nelson[21] shows the interatomic potential between two copper atoms as a function of their separation calculated with various potentials. The separations shown are, on the average, about 1 Å at 250 eV, while the TF radius of a germanium atom, Ge$^{4+}$, is ~0.1 Å and the Ge core radius is about 0.53 Å.[22] Hence, in this energy range it appears that the collisions are soft and the core-electron distributions of the two atoms do not overlap strongly in the collision. In the limit of $\epsilon \rightarrow 0$ one must expect only electronic stopping from the valence electrons. Further, if one considers that the displacement of a lattice atom requires ~25 eV, many collisions do not transfer enough energy to create a defect. The adiabatic limit of energy transfer in elastic collisions with bound atoms may also increase the fraction of energy lost to ionization by a very-low-energy Ge atom relative to that expected for a target of free atoms. Our measurement may indicate the onset of this regime of energy loss in solids. A specific theoretical calculation for very low energies, specifically incorporating such low-energy atomic and solid-state phenomena, should be useful and interesting.

*Note added in proof.* Oscillatory variations of the electronic stopping about the Lindhard theory have been observed as a function of projectile atomic number or energy. These effects have not been observed for systems in the much lower energy range with which we are concerned in this work.

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