lomb dissociation, (ii) the target dependence of σ_{WW}(expt), and (iii) the magnitudes of σ_{WW}(expt). The energy dependence of σ_{WW}(expt) is within the errors of this experiment and verification of this feature will have to await further experiments. The values of b_{min} derived from σ_{WW}(expt) limit the radial overlap, d, of the colliding nuclei to distances comparable to their charge-skin thicknesses t, a manisfestation of the effects of nuclear absorption. The Coulomb and nuclear fragmentation processes are related by the results that $\bar{d} \approx d'$, which shows that the maximum overlap distance that accounts for Coulomb dissociation is, in essence, tantamount to the nuclear overlap distance required to account for nuclear (direct-interaction) fragmentation.

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Two-Electron, One-Photon Transition Energies

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Wölfli's experiment about $K^{-2} \rightarrow L^{-2}$ two-electron, one-photon transitions was criticized by Nagel *et al.* in a recent paper. In the present Comment I discuss arguments of Nagel *et al.* and show that Wölfli's interpretation about cooperative x-ray transition is valid.

Nagel *et al.*[1] have recently published a paper about the experiment of Wölfli *et al.*[2] on cooperative ($K^{-2} \rightarrow L^{-2}$) x-ray emission observation, asserting that the energy of the line observed by Wölfli *et al.* has not the correct energy to be the $K^{-2} \rightarrow L^{-2}$ transition. I present a Comment giving a value of this energy deduced from our experiments and asserting that the Nagel calculation cannot invalidate the Wölfli interpretation.

Nagel *et al.* correctly assumed that the energy

of a $K^{-2} \rightarrow L^{-2}$ x-ray transition is equal to

$$E(K^{-2} \rightarrow L^{-2}) = E(K^{-2} \text{ state}) - E(L^{-2} \text{ state}) = \{E(K^{-2}) - E(K^{-1}L^{-1})\} + \{E(K^{-1}L^{-1}) - E(L^{-2})\},$$

i.e., is equal to $E(K\alpha^h) + E(K\alpha^s)$, where $K\alpha^h$ refers to a $K\alpha$ hypersatellite and $K\alpha^s$ to a $K\alpha$ satellite. In fact, Nagel refers to $K\alpha_{1,2}{}^h$ ($1s^{-2} \rightarrow 1s^{-1}2p^{-1}$) transitions and to $K\alpha^s$ ($K\alpha$ satellites: $1s^{-1}2p^{-1} \rightarrow 2p^{-2}$) transitions. The final state is then a $2p^{-2}$ state and he found that the $K^{-2} \rightarrow L^{-2}$ transition should have an energy equal to $2E(K\alpha_1)$ +294 eV in contradiction to the Wölfli value of $2E(K\alpha_1)$+153 eV in the case of iron. I also did such a calculation but using the experimental values of the $K\alpha_2{}^h$ hypersatellite line[3] and the $K\alpha_4{}^s$ satellite line[4] instead of the values given by semi-empirical formulas, and taking also into account that only $K\alpha_2{}^h$ lines are observed (the $K\alpha_1{}^h$, not observed, is forbidden in the LS coupling scheme). I found a value which was very close to the Nagel value but the problem is not here.

In fact, the $2p^{-2}$ state cannot be attained in the $K^{-2} \rightarrow L^{-2}$ transition because it violates parity conservation. Only $(2s)^{-1}(2p)^{-1}$ states are allowed, and in the LS coupling scheme, which is known to hold very well for the considered atoms, the allowed transition can only be

$$(1s)^{-2}\,{}^1S_0 \rightarrow (2s)^{-1}(2p)^{-1}\,{}^{1,3}P_1 \quad (L_1{}^{-1}L_2{}^{-1}).$$

The energy difference between the transition energy calculated for the $L_2{}^{-1}L_3{}^{-1}$ and $L_1{}^{-1}L_2{}^{-1}$ final states, which can be deduced from the KLL Auger energy difference, is then equal to 134 eV[5] or 142 eV.[6] The calculated value of Nagel or the value that one can deduce from my precise measurements (298 eV) has then to be reduced by ~140 eV, the correct value for the $K^{-2} \rightarrow L^{-2}$ transition being $2E(K\alpha_1)$+~160 eV in good accordance with the Wölfli result (a similar result is also obtained for nickel atoms).

If an intermediate coupling scheme has to be considered, the $1s^{-2} \rightarrow 2s^{-1}2p^{-1}$ transition can also lead to $^3P_1$ or $^3P_2$ final states (Fig. 1). It has been recently proved that for the clorine atom[7] the intercombination lines and magnetic quadrupolar transitions can be stronger than electric dipolar lines of the LS coupling scheme. The $^1S_0 \rightarrow {}^3P_1$ or $^1S_0 \rightarrow {}^3P_2$ two-electron, one-photon transitions have then to be considered in the case of Ni and Fe. These lines have an energy which is only 39 and 47 eV higher[5,6] than the $^1S_0 \rightarrow {}^1P_1$ transition (in the case of iron), i.e., far from the $1s^{-2} \rightarrow 2p^{-2}$ parity forbidden transitions and too close to the $^1S_0 \rightarrow {}^1P_1$ transition to be experimentally recognized using a SiLi detector.

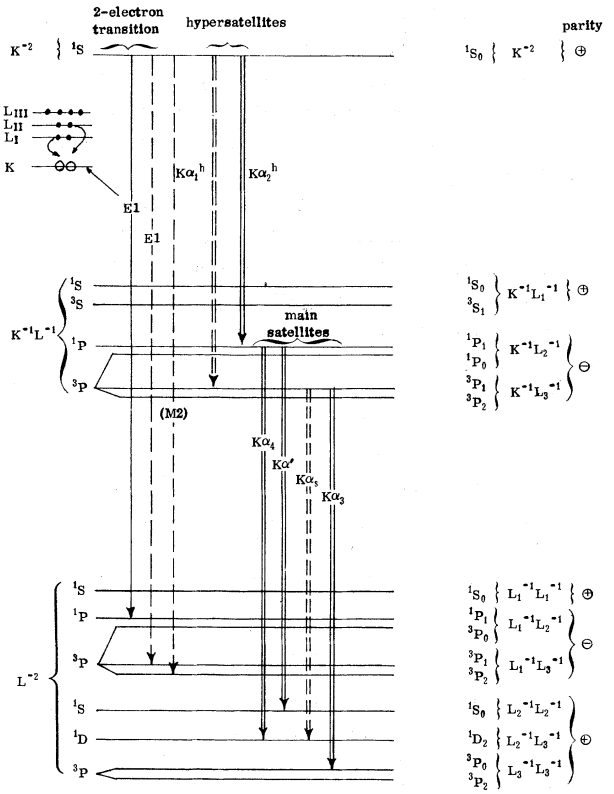

FIG. 1. Radiative decay scheme of K^{-2} states. Full lines, allowed electric dipolar lines in LS coupling; dash lines, $E1$ and $M2$ lines in jj coupling.

Another question has also to be discussed which is the influence of L-shell additional ionizations in the initial state on the energy of the transition. It has been demonstrated[8] that in heavy-ion collisions, K^{-2} as well as K^{-1}, ionization states are generally accompanied by few additional L vacancies. When n additional L vacancies are present in the initial state of the transition, the hypersatellite and the diagram lines split into n components. With solid-state detectors this splitting appears as a shift of the whole peak. However, it has been demonstrated by Richard, Hodge, and Moore for various elements (see Olsen and Moore[9]) that the energy shift for each component is the same for hypersatellites ($K^{-2}L^{-n}$

$\rightarrow K^{-1}L^{-n-1}$) *and* satellites ($K^{-1}L^{-n} \rightarrow L^{-n-1}$). These additional L vacancies have then no influence on the energy difference ΔE between the two-electron, one-photon transition and twice the value of the *measured* $K\alpha$ energy.

In conclusion, one can say that the energy value of the line observed by Wölfli *et al.* is in good accord with his proposed explanation. However, it should be considered that in most cases of heavy-ion bombardment, numerous additional M vacancies are observed during K^{-2} ionization[8] and that the discussed line observed in a SiLi detector should be broadened or shifted. These multiple additional M vacancies can also allow various $K^{-2}M^{-n} \rightarrow L_{ij}^{-2}M^{-n}$ two-electron, one-photon transitions.

Note added.—A similar conclusion about the assignment of the transition observed by Wölfli was also obtained by Hoogkaner *et al.*[10] and by Åberg, Jamison, and Richard,[11] these later authors having done a Hartree-Fock calculation for the considered elements which is in good accord with our present results.

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Calculation of Two-Electron, One-Photon K–X-Ray Transition Energies

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It is shown that recently reported two-electron, one-photon K–x-ray transition energies for collision-excited Fe and Ni ions can be described on the basis of Hartree-Fock calculations, provided that multiple ionic excitation and selection rules for $E1$ transitions are taken into account.

Investigations of x-ray spectra from heavy-ion–atom collisions have revealed unusual x-ray lines attributed to cases in which two K-shell vacancies in a single ion are filled simultaneously by two electrons with the emission of a single photon. Wölfli *et al.*[1] reported energies of such transitions with an accuracy of better than approximately ± 20 eV for Fe and Ni ions with transition energies near 13 and 15 keV, respectively. Recently, Nagel *et al.*[2] claimed that these transition energies reported in Ref. 1 are inconsistent with predictions based on empirical satellite and hypersatellite energies or with Hartree-Fock calculations. They conclude that the values of Wölfli *et al.*[1] for Fe and Ni are too low by ~150 eV. It is the purpose of this Comment to demonstrate that the assessment of Nagel *et al.*[2] cannot be supported mainly because the selection rules for radiative dipole transitions were not properly taken into account. Experimental transition energies can be reproduced in a consistent manner when $E1$ selection rules, electronic binding energies, and ionization states are duly considered.

Atomic binding energies are readily calculated with existing relativistic Hartree-Fock programs.[3] In the cases of present interest, it is sufficient to