An asymptotic extrapolation of the interaction of hollow atoms inside a solid: the fluorescence of implanted ions inside solids

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The purpose of the experiment was to study the energies of X rays emitted by Argon atoms, ionized in their K shell, and slowly moving or implanted inside various solids. We measured the fluorescence lines of Ar atoms implanted in solids and ionized in their K shell, by photons delivered by the ALS.

The problem addressed in this experiment is the interaction of a hollow atom, slowly moving inside a metal or an insulator, with the atoms of the solid. A bare ion, e.g., Ar^{18+}, entering a solid captures from the top layers of the surface a large number of electrons in its M and N shells, leaving empty, initially, the innermost K and L shells. While moving inside the solid, these inner shells are sequentially filled, mainly through Auger cascades. The last step of the cascade of Auger transitions filling these inner shells leads to an Ar atom with all its electrons except the remaining K hole. One then observes the emission, in flight, of the well-known characteristic K lines of a 'neutral' atom' slowly moving inside a solid. The remarkable property is that, by contrast to what is observed in beam-foil spectroscopy, the ion is moving at a velocity which is typically one hundredth of that of the conduction electrons of a metal. In such a case the interaction of the ion with the solid fulfills the Born-Oppenheimer approximation and must be very similar to that of an implanted atom inside a solid. We have observed, in some specific cases with hollow atoms slowly moving inside solids, the filling of the K shell of the ion by conduction electrons of the solid, a process which may be called Radiative Electron Capture (REC). More recently, in an experiment carried out with the AECR ion source of the 88-inch cyclotron, we surprisingly found that the energy of the K_α line emitted in flight by the hollow atoms, during the above-quoted last step of the cascade, was 2 eV lower in energy than that of the well-known line observed in conventional X-ray spectroscopy. This result obviously demonstrates that the ion, while moving inside or being part of this solid, interacts with the target, which changes the energies. We then concentrated during our experiment on the measurement of the energy of this Ar K line for atoms implanted inside various targets.

The main difficulty in this kind of experiment is the low counting rate due to the very low transmission of curved-crystal spectrometers and the natural limits of the density of implanted atoms inside a solid. We looked at the X-ray spectra emitted by Ar atoms implanted inside targets at levels of implantation ranging from 10^{15} to 10^{17} atoms per cm^2, which we compared to those emitted by a gas cell. With 10^{17} atoms cm^{-2} we have been able to successfully record a spectrum in 20 minutes and measure the energies at a precision of 0.3 eV. In that case the Ar atoms form high-pressure bubbles of gas or solid clusters of Argon. We then observed in most cases the same energy as in the gas cell (or slightly lower), except for Al substrates, but proved the feasibility of these difficult experiments. The next step will be to use targets at a level of implantation of 10^{14} cm^{-2}. This will be done during the next run in collaboration with the Simon Labov group in Livermore using a cryogenic detector of 20 eV resolution, and, in the future, with an improved version of our crystal spectrometer.

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