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AN X-RAY CRYSTAL SPECTROMETER FOR ION-INDUCED MULTIPLE IONIZATION STUDIES, PARTICULARLY FOR M SATELLITE STRUCTURE

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Abstract: After the short description of an X-ray crystal spectrometer three measurements are mentioned as examples of its performance:

a, relative intensities of Al K alpha and beta satellites;
b, Mg content determination in the presence of much Ca;
c, satellite structure of Ta M alpha and beta lines.

A simple Soller-type flat crystal X-ray spectrometer has been developed to measure the satellite structure of characteristic X-radiation arising from multiply ionized atoms created in energetic ion-atom collisions. The spectrometer is based on a rhombic goniometer mechanism. The home-built Soller slits provide 0.3 degree angular divergence. The detection of the X-rays reflected from the analyzer crystal is performed by a flow proportional counter.

An MCA based on a single card microcomputer controls the angular movements through a step-motor and analyses the signals from the proportional counter, either in pulse height analysis or in multiscaler mode, and a simple evaluation of the obtained data is also provided. The first tests of the system were performed by X-ray excitation of thick targets.

Later the spectrometer has been installed on the beam line of the 5 MV Van de Graaff generator of the ATOMKI. Test spectra were taken bombarding different elements by H+ and He+ ions. Thick targets of aluminium, silicon, quartz glass, natural chalk, titanium, stainless steel, copper and tantalum were used. Some of the preliminary results are presented in the followings.

a, The aluminium K alpha satellite structure has been studied already in details, e. g. Richards [1] measured it in the energy range of 0.1-3.0 MeV He+ ion bombarding, Sonobe [2] in the 5.42-40.6 MeV range. We measured it at the 3.2 MeV He+ ion energy. One of our Al K X-ray spectra is seen on Fig. 1. Fig. 2a shows the relative intensities of the diagram and the KL1 satellite peaks as a function of the bombarding ion energy (where the superscript i is the number of L vacancies). Our measurements fit well between the data of the mentioned authors, proving that our instrument can be used effectively in such measurements. This kind of representation of data reveals that the highest vacancy numbers are the most sharply sensitive on the energy change of the bombarding particle. Fig. 2b gives the BEA calculations of the K-shell and L-subshell ionization cross sections, qualitatively explaining the shapes of the curves in Fig. 2a.
Fig. 1.--The K X-ray spectrum of aluminium, obtained by 3.2 MeV He\(^+\) ion bombardment, taken with an ADP analyzer crystal.

Fig. 2a--The intensity distribution of KL\(^1\) X-ray lines of aluminium as a function of bombarding He\(^+\) ion energy (\(\bullet - K_\alpha\) Li; \(x - K_\beta\) Li).

Fig. 2b.--Cross sections for K- and L-subshell ionization of aluminium bombarded by He\(^+\) ions, calculated by a BEA code.

A byproduct of the Ca K\(_\alpha\) L\(^1\) satellite intensity investigation has a possible practical interest. Fig. 3. gives a part of the X-ray spectrum obtained from a natural chalk sample. In natural chalks there is always present a certain amount of magnesium. This spectrum taken at 2 MeV proton bombardment and using an ADP analyzer crystal offers the possibility to perform PIXE measurements of the relative Ca/Mg content when Mg is in a very little amount relative to Ca, since the Ca K\(_\alpha\) is measured in a weak third order reflection, while the Mg line in a strong first order one. Probably one-two order of magnitude enhancement can be obtained for the Mg K\(_\alpha\) using this method. This can be used e. g. to measure the dolomitization grade of chalks, or the Ca/Mg ratio in concretes, what is important in their corrosion resistance.
Fig. 3.--Third order reflection of Ca Kα₁,2 and first order reflection of Mg Kα X-ray lines, obtained from a natural chalk sample, bombarded by 2 MeV proton projectiles. The spectrum was taken with an ADP crystal.

c. A further investigation was to measure M alpha and beta X-ray satellite structure. We used a thick tantalum metall target. Fig. 4. gives the shape of spectra obtained at 2 MeV proton, 3.2 MeV He⁺ and 1.6 MeV He⁺ bombardment. The known satellite energies [3,4] are also shown. The resolution of the instrument is demonstrated by the Si Kα spectrum measured under the same conditions as the M spectra. The Si Kα energy is just between the energies of Ta Mα and Mg X-ray lines. Anyhow, it is interesting to compare the structure at the K and M shell at about the same binding energy. It is seen that the M satellite lines could not have been resolved, but from the shape of the lines it is obvious that the yields of the different satellites are changing with the bombarding particle and - in a less extent - with the bombarding energy. Much resolution enhancement would not has been expected using 2nd order reflections, because of the natural width of the M lines.

Our spectra show that probably other satellite lines than the known ones are exited mainly for the He⁺-ion bombardment. Many of the former authors investigating M X-rays assumed that the multiple ionization is not significant in the MeV bombarding energy range. Our observations do not support the above assumption. We found that in the case of the 2 MeV proton bombardment the contribution of the satellite lines to the M intensity is about 50 per cent of the intensity of the diagram line, and for the He⁺-ion bombardment this contribution is already approximately 100 per cent in accordance with the predictions of the so called geometrical model of ionization [5]. The Ta spectra are normalized to the maximum channel content. It is seen, that the Mα/Mβ ratio is changing with the bombarding particle and with its energy. Studies on ion induced M satellite lines are rather scarce [e. g. 6], but this field is worth for further experimental and theoretical investigations.
Fig. 4.—The Ta Mα and Mg lines obtained by 2.0 MeV proton and 3.2 and 1.6 MeV He⁺ ion bombardment. Insert: Si + 3.2 MeV He⁺ Kα spectrum for illustration of the resolution of the system. The energy axis of the Si spectrum has the same calibration as that of the Ta spectrum. All spectra were taken with an ADP analyzer crystal.

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