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STUDY OF THE MAGNETIC INTERACTION AT $^{129}$XE IMPLANTED IN IRON

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Résumé. — L’interaction magnétique du $^{129}$Xe a été étudiée par l’implantation de $^{129m}$Xe dans le fer aux doses de $5 \times 10^{14}$, $5 \times 10^{15}$ et $1 \times 10^{16}$ at/cm$^2$. Les spectres Mössbauer obtenus indiquent une superposition de plusieurs champs magnétiques liés aux atomes de Xe situés dans les différents environnements cristallins. La population relative des sites dépend de la dose d’atomes implantés. Pour le champ le plus important, correspondant au Xe en position substitutionnelle, nous obtenons la valeur $H_{h.o.b.} = 1480 \pm 80$ kG. Nous déduisons également le rapport $g_e/g_o = 0.25 \pm 0.04$.

Abstract. — The magnetic interaction at $^{129}$Xe was studied by implanting $^{129m}$Xe activity in iron foils at a dose of $5 \times 10^{14}$, $5 \times 10^{15}$ and $1 \times 10^{16}$ at/cm$^2$. The resulting Mössbauer spectra show a superposition of field values corresponding to Xe atoms imbedded at various lattice positions. The relative population of the different sites is found to be dose dependent. For the high field component, arising from the substitutionally implanted Xe fraction, we obtain the value $H_{h.o.b.} = 1480 \pm 80$ kG.

We also deduce the value of the $g$-factors ratio $g_e/g_o = 0.25 \pm 0.04$.

1. Introduction. — Although the Mössbauer resonance of $^{129}$Xe was discovered as early as 1963 [1], little work has been done on the magnetic interaction of this nucleus. This is mainly due to the fact that no known Xe compound exhibits magnetic hyperfine splitting. The only possibility was to apply external magnetic fields on unsplit $^{129}$Xe sources or absorbers [2], but the large linewidth of the $^{129}$Xe resonance ($2I_{\text{nat}} = 6.8$ mm/s) limits considerably the accuracy of this method.

The ion implantation technique has opened new possibilities in this area, as it allows to make use of the large internal fields which Xe nuclei experience when imbedded in a ferromagnetic lattice. Starting from implanted sources, the hyperfine field of Xe in iron was first deduced from nuclear orientation measurements [3]. However, the analysis of these results suffers from the fact that not all Xe atoms occupy regular lattice positions: the various hyperfine fields arising from different environments cannot be resolved directly in a nuclear orientation experiment [4]. Therefore, a direct study of Xe implantation in iron by Mössbauer spectroscopy became highly desirable.

2. Experimental procedure. — Of the two known Mössbauer isotopes $^{129}$Xe and $^{131}$Xe, the first one is the more favorable from the experimental viewpoint because of the lower gamma transition energy (39.6 keV compared to 80.2 keV) and of the longer lifetime. In the pioneering experiments of G. Perlow and co-workers [5], the activity was produced from $^{129}$I ($t_{1/2} = 1.7 \times 10^7$ y), but for implantation work this procedure has some disadvantages: the implanted ions are I and not Xe, and moreover, the specific activity of $^{129}$I is very low. It would therefore be more interesting to start from the isomeric state $^{129}$Xe ($t_{1/2} = 8.2$ d) which can be produced by neutron irradiation of $^{128}$Xe, but the problem here lies in the very unfavorable $^{128}$Xe/$^{129}$Xe abundance ratio, making it impossible to get highly enriched $^{129}$Xe.

We were able to solve this difficulty in a somewhat unusual way, starting from natural I and making use of the reaction

$$^{127}$I $\rightarrow$ $^{128}$I $\rightarrow$ $^{132}$I $\rightarrow$ $^{129m}$Xe $\rightarrow$ $^{129}$Xe $\rightarrow$ $^{129}$Xe.

Although the amount of stable $^{129}$Xe produced is much larger than that of $^{129m}$Xe, the specific activity is large enough to permit implantation doses lower than $10^{14}$ at/cm$^2$.

The activity was obtained by irradiation of 150 mg KI during 40 days in a neutron flux of $3 \times 10^{14}$ neu-

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trons/cm². In this way, samples of about 10 mCi of $^{129m}$Xe were prepared. The sources were implanted by the Leuven isotope separator at an acceleration voltage of 75 kV. All implantations were done at room temperature. The source was moved by a drive system of the Kankeleit type in the constant acceleration mode. The unsplit compound Na$_2$XeO$_6$·2 H$_2$O (obtained from Peninsula Chemical Research Inc., Gainesville, Florida) was used to make an absorber containing 22 mg Xe/cm². Both source and absorber were kept at liquid helium temperature. The detection system consisted of a Xe-filled proportional counter, with a window setting on the escape peaks of the 39.6 keV gamma-ray.

3. Experimental results. — Spectra were recorded from 3 sources, containing respectively $5 \times 10^{12}$, $5 \times 10^{13}$ and $10^{15}$ at/cm². The observed linewidths are close to $\Gamma = 12 \text{ mm s}^{-1}$, which is about 15% larger than the calculated value for the absorber thickness used. All three spectra show evidence for a high-field component, corresponding to substitutionally located Xe atoms. The field value as obtained from a least-squares fitting is

$$H_{\text{high}} = (1480 \pm 80 \text{ kG}) .$$

This result is in good agreement with the values so far deduced from nuclear orientation [4], and from Mössbauer spectroscopy on $^{131}$Xe (H. de Waard, R. L. Cohen, S. R. Reintsema and S. A. Drentje, to be published).

The other main contribution to the spectra comes from Xe atoms at non-substitutional lattice positions. The maximal value of the so-called « low-field component » does not exceed $300 \pm 50 \text{ kG}$, but this field may not be unique. An important point resulting from our measurements is the strong dose-dependence of the population of the low-field sites, as may be seen from figures 1, 2 and 4.

Apart from these main components, it appears necessary to postulate the existence of one or more intermediate fields in order to give a reasonably good fitting of the data. The existence of at least one intermediate field of about $1200 \pm 100 \text{ kG}$ seems very probable. However, the problem of the uniqueness of this intermediate field component is still open and further experiments will be needed to clear up the situation.

Because the nuclei are implanted in a thin foil, one may expect them to show preferential polarization in
the plane of the foil. Therefore, the intensity of the Mössbauer satellites was adjusted in the fit. The obtained values range between $3: 3: 1$ and $3: 3.5: 1$.

In the fitting procedure, the ratio of $g$-factors $g_e/g_0$ was left as a free parameter. The best fitting corresponds to

$$
g_e/g_0 = -0.25 \pm 0.04.
$$

The negative sign was deduced from a polarization experiment in which the source was immersed in a magnetic field of 20 kG applied parallel to the observation direction. The resulting suppression of lines 2 and 5 of the high field component leads to the unambiguous location of the $\Delta m = 0$ satellites (see Fig. 3).

Taking $\mu_{sf} = -0.77689 \mu_N$ [6, 7], we obtain for the magnetic moment of the 39.6 keV state

$$
\mu_e = +0.58 \pm 0.1 \mu_N
$$

the error being mainly due to the complexity of the spectra. This value agrees within the error limits with the earlier result of L. E. Campbell et al. [2], who quoted $\mu_e = +0.68 \pm 0.30 \mu_N$ and deduced the positive sign from theoretical considerations. Very recently, a P. A. C. measurement performed by G. Marest et al. [8] yielded $\mu_e = +0.88 \pm 0.26 \mu_N$. The same authors, starting from a weak coupling model for the low lying levels of $^{129}$Xe, calculate a theoretical value of $\mu_e = +0.752 \mu_N$.

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References