# AN ATTEMPT TO IDENTIFY THE PHYSICAL MECHANISM OF RADIATION DAMAGE

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Radiation damage effects have been given as the cause for reduction in polarization in polarized targets using LMN in experiments on p-p scattering at 150 MeV [1] and 20 MeV [2]. Since similar effects will be observed in experiments on e-p scattering and in addition because of the much lower cross-sections, a greater flux of incident particles will have to be tolerated in order to obtain results of commensurate statistical significance, it is important to try to identify the mechanism of radiation damage so that target materials can be chosen for electron scattering experiments which are more resistant to the cause.

The basic data are given in table I where energy dissipated in the target by ionization loss only is considered. Taking a combination of the two results and assuming a linear reduction in polarization with incident particle flux, then for 100 % full in polarization the energy release via ionization loss $E_i$ is :

$$E_i = (11 \pm 7) \times 10^{13} \text{ MeV/cm}^3 \qquad (1)$$

for a flux I of :

$$I = (2.6 \pm .4) \times 10^{12} \text{ protons/cm}^2 \quad . \qquad (2)$$

If the crystal lattice is damaged by the energy released via ionization loss then it is possible that any impurity in the crystal might be preferentially disturbed. In the case of LMN with paramagnetic ions of Nd X-ray analysis [3] has shown a 1/5 % concentration of Nd corresponding to density $J_{Nd}$ :

$$J_{Nd} = 3 \times 10^{18} \text{ Nd ions/cm}^3 \quad . \qquad (3)$$

<u>Harwell target</u> : P. Brogden [1], 150 MeV protons.
Size $(6 \times 6 \times 1)\ mm^3$
30 % fall in polarization for 4 x 10" protons
1 MeV ionization loss in 1 mm, i.e. <u>$1.1 \times 10^{13}$ MeV $cm^{-3}$</u>

<u>Saclay target</u> : D. Garreta [2], 20 MeV protons.
Size $(2 \times 2 \times 0.1)\ mm^3$
50 % fall in polarization for $1.5 \times 10^{12}$ protons $cm^{-2}$
0.6 MeV ionization loss in 0.1 mm, i.e. <u>$9 \times 10^{13}$ MeV $cm^{-3}$</u>

Table I

The energy absorbed per Nd ion which is often referred to as the displacement energy $E_d$, can be obtained from (1) and (3) giving :

$$E_d = (37 \pm 23)\ \text{eV} \quad . \qquad (4)$$

Atoms adjacent to the Nd ions bound in a lattice will oppose any removal of the Nd ions. If $E_c$ is the energy of sublimation of an atom then for crystal interiors :

$$E_d \sim 6E_c$$

so that from (4) :

$$E_c \sim (6 \pm 4)\ \text{eV}$$

which is the typical value for an atom or ion in a solid, when a Frenkel pair is produced. It is thus possible to account for the absorption of the energy liberated by ionization loss but only by a mechanism which allows preferential absorption of energy by the impurity.

Another more direct method of energy release inside the crystal could take place by a displaced ion moving through the crystal. Thus for a density of La atoms, $J_{La}$ ($J_{La} = 1.6 \times 10^{21}/cm^3$) where the cross-section for protons on La is $\sigma_{La} \sim 10^{-24}\ cm^2$ the number of displaced La ions (using 2) would be :

$$N_{La} = I\ \sigma_{La}\ J_{La}$$

$$= (4.2 \pm .8) \times 10^9/cm^3 \quad .$$

Each displaced La ion could be given a kinetic energy, T, by a 150 MeV proton of maximum value :

$$T_m \simeq 5\ \text{MeV}$$

and having a range of about 10 000 Å. This ion would cause a disturbance over a transverse region of up to 100 Å, in a manner similar to that described by Brinkman and called a "displacement spike". The displacement of other ions by the original displaced ion will cause the track of the original ion to be heated and any resultant annealing would cause dislocation loops and disorder. The total number of Nd ions in these disordered regions will be N :

$$N \sim 10^{12}/cm^3$$

or only $10^{-6}$ of the total number per $cm^3$. It does not seem likely that this mechanism can explain the observations of the fall in polarization although the observation of recovery of the polarization on annealing of LMN crystals to room temperature is contained in the mechanism.

The hope for hydrocarbon materials used in electron scattering experiments is that either paramagnetic centres can be produced with the right g-values and electron line widths by radiation damage as the experiment is being done and using the large ( $\sim 10^{15}$ electrons) fluxes necessary because of the low cross-sections or that more resistant materials are used such as the aromatic hydrocarbons whose radiation protection has been ascribed to the resonant structure of the benzene ring [5].

## References

1) P. Brogden, Harwell, Private communication.
2) D. Garreta, Saclay, Private communication.
3) H. Atkinson, Private communication.
4) J.A. Brinkman, see e.g. Radiation Damage in Crystals by L.T. Chadderton, (Methuen), 1965.
5) A. Charlesby, Atomic Radiation and Polymers, (Pergamon), 1960.