Modeling of channeling effect for deuterons in a TiD$_2$ crystal

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Problem statement

• dd reaction enhancement was experimentally observed in textured targets of titanium deuteride at ultralow energies [1]
• This effect can not be fully described by the electron screening due to unphysical $U_e = 131$ eV (15 eV in adiabatic models)

Development of a 3D channeling model for deuterons in TiD$_2$ crystal

Lindhard potential

Y(x) - continuous plane potential
- Scattering angles are assumed to be small
- Collisions are correlated
- Classical picture can be used
- Idealized lattice

Particles channeling along planes with a normal $i$ must obey:

$$\frac{p_i^2}{2m} < Y_{\text{max}}$$
Model assumptions

• Channeling deuterons has a lower energy loss. This defines higher thickness of the effective target.

• Average energy loss due to the electronic stopping power is proportional to the lower electronic density.

• Channeling deuterons are focused by titanium atoms to the area of target deuterons. This increases the effective deuteron flux density.
Plane potential

\( Y_D \) - deuterium plane
\( Y_1, Y_2 \) – titanium planes
\( Y_{\text{tot}} \) – resulting potential

Channeled particle can not approach to a plane closer than the \( r_m \) distance.
Renormalization of the potential and the $r_0$ parameter

The resulting potential was renormalized. Its width $r_0$ ($r_m < r_0 < r_{\text{max}}$) was varied to match the experimental data.
Modification of the stopping power

\[ S = S_e + S_n \]

\( S_e \) is proportional to the average electronic density along the track

\[ S_{chan} = S_{amorph} \cdot \frac{2Z_D}{2Z_D + Z_{Ti}} \]
Flux compression

\[ \frac{p_i^2}{2m} = Y(x_{\text{min}}) \rightarrow x_{\text{min}} \text{ – minimal distance to the Ti plane.} \]

Density of the channeled particles flux increases reverse proportional to the available volume.

Variation of the \( r_0 \) parameter changes the flux compression effect and can effectively take into account the imperfection of the crystal.
Multiple scattering

Geant4 multiple scattering for
  • Unchanneling particles
  • Channeling particles

Electron microscope image of a cleavage of the TiD$_2$
[NIMA 764 (2014) 42-47]
Approximation of angular distributions

Experimental angular distributions were interpolated for six energies 7 – 12 keV.

Experimental angular distributions

[Ref: NIMA 764 (2014) 42-47]

Interpolated angular distributions
Validation

Comparison of the enhancement factors calculated by TPT-EM with and without electron screening (solid and dashed curves respectively) and the experimental values

\[ \chi^2/n_s = 1.14 \quad \chi^2/n_s = 0.79 \]
Conclusion

The developed TPT-EM model describes experimental data for titanium deuteride. If the crystal is perfect the effect is expected to be a few times bigger.

Further development

• Develop TPT-EM multiple scattering process for channeling particles
• Develop TPT-EM dechanneling process
Thank you