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OBSERVATION OF GAS-SOLID DIFFERENCE IN THE STOPPING
POWERS OF (1 - 10) MEV/U HEAVY IONS
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Observation of a Gas-Solid Difference in the Stopping Powers
of (1 - 10) MeV/u Heavy Ions

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ABSTRACT

The stopping powers of (1 - 10) MeV/u Kr, Xe, Pb, and U ions were measured to be smaller in gases than in solids. This gas-solid difference is caused by smaller ionic charges of the projectiles in gases and was found to increase with energy and atomic number of the projectile.

Partially stripped energetic ions are slowed down in matter by a series of collisions in which excitation and ionization of both the projectile and the target atoms occur. It was postulated by Bohr and Lindhard [1] (BL-model) that while in gases deexcitation back to the ground state of the ion takes place before the next collision occurs, in solids the time between collisions may be too short to allow relaxation of excited states so that the excitation of the outermost electrons are increased until they are lost. A higher ionic charge in a solid would be expected and, therefore, also a larger stopping power than in gases. However, in the published experimental results no evidence was found for this gas-solid difference [2] and it is generally accepted that the higher ionic charges found for projectiles after a solid target were caused by Auger cascades after the projectile left the target, as suggested by Betz and Grodzins [3] (BG-model).

We used a time-of-flight spectrometer [4,5] for measuring stopping powers of heavy ions ($18 \leq Z, \leq 92$) provided by the UNILAC in the energy region (0.5 - 10.0) MeV/u in solids and gases ($2 \leq Z, \leq 92$).

The spectrometer consisted of a secondary electron start detector and a silicon surface barrier stop detector. The distance between the detectors could be changed to provide an absolute energy calibration of the system. The intrinsic resolution of the spectrometer

was about 100 ps fwhm. The energy losses in gases were measured by introducing a closed gas cell into the beam line. The cell had plastic windows with a thickness of $50 \mu\text{g}/\text{cm}^2$ each that allowed pressures of (10 - 100) torr. In order to get the highest uniformity all the solid targets were prepared by evaporation [6], and gases with a purity better than 99.99 % were used. The thickness determinations of the solid targets were done by α -particle energy loss measurements. The overall uncertainty of the measured stopping powers (S) in solids was obtained from the variance of S for different targets of the same element and found to be smaller than 5 %. In gases the uncertainty is (2 - 4) %.

In Fig. 1 we present the stopping powers of 3.6 and 7.9 MeV/u uranium projectiles in solids and gases. It is clearly seen that the S values in gases are lower by up to 20 % than those in solids. At these energies the Z_1 -oscillations in the S values of U projectiles are almost washed out [5], while the projectiles still have enough bound electrons (about 50 at 3.6 MeV/u and 40 at 7.9 MeV/u) to demonstrate the BL gas-solid difference. This is clearly shown when S is plotted vs. the specific energy of the projectile in gases and in solids with neighbouring atomic numbers. It is demonstrated in Fig. 2 for (0.5 - 10.0) MeV/u uranium projectiles and in Fig. 3 for (0.5 - 1.3) MeV/u Pb, Xe, and Kr projectiles for Ar, Ti, and Kr, Zr combinations. For these cases, without the gas-solid difference, the S values in the gases are expected to be larger than in the solids. It is seen that the

curves are crossing each other, showing smaller S values in gases than in solids for energies higher than 1 MeV/u, and that the difference increases with energy. We note that as expected the effect is more pronounced for the heavier projectiles. At energies where the ions are fully stripped we expect the curves to approach again each other. At energies up to 1 MeV/u the Z_1 -oscillations in S are strongly pronounced and mask the gas-solid difference. However, we have recently shown [7] that at these energies the position of the maxima in the oscillations are shifting with velocity. This can now be explained by the gas-solid difference that causes a different dependence of S on velocity for gases than for the neighbouring solids.

A higher charge in solids than in gases was recently found by analyzing the projectile M x-ray spectra [8]. It was also found [9] that a solidified gas has the same mean ionization potential I as in the gaseous state. We can exclude, therefore, the possibility that the gas-solid difference is caused by a difference in I.

From the stopping powers in Fig. 1 one finds that the effective charges of 7.9 MeV/u uranium ions in solids are larger by up to 5 units than those in gases. For this case the ionic charge after a solid [10] is larger by about 20 charge units than the experimental effective charge in a gas [5]. We conclude, therefore, that for this example, about 25 % from the additional charge measured

after a solid is caused by the gas-solid difference in the stopping powers (BL-model) and 75 % are caused by the Auger cascades after the solid target (BG-model).

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FIGURE CAPTIONS

Fig. 1 Stopping powers of 3.6 and 7.9 MeV/u uranium ions
in solids and gases.

Fig. 2 Stopping Powers of (0.5 - 10) MeV/u uranium ions in
solids and gases.

Fig. 3 Stopping powers of (0.5 - 1.4) MeV/u Pb, Xe, and Kr
ions in solids and gases.

FIG. 1

FIG. 2

FIG.3