W-value measurements for carbon ions

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The main error contribution in the absolute dose determination with ionization chambers in the heavy ion therapy comes from the uncertainty on the W-value, which is defined as the average energy required to produce an ion pair in air. For heavy ions, a theoretical approach to the W value is very complex and, moreover, there is a clear lack of experimental data in the energy range of interest in therapy (Fig 1). Even though experimental measurements are difficult if a precision of better than 5% is required, they are still by far the most important and accurate source of W-values.

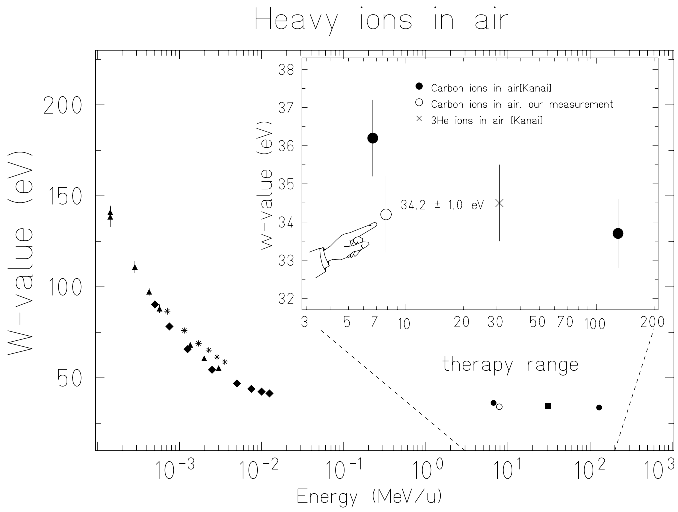

Figure 1: Compilation of the so far available W-value data for heavy ions in air.

In a measurement of the differential W value, three quantities have to be determined independently: the energy E of the incident ions, the mean energy ΔE deposited by one ion when traversing the gas gap and the mean number of ion pairs produced in the gas gap by one ion when dissipating ΔE. This last quantity can be obtained as the ratio of the number of primary ions N_{ions} and the chamber charge output Q, integrated during a certain interval. According to this, the differential W value can be expressed as:

$$w_E = \Delta E \cdot (N_{ions}/Q)$$

The measurements were carried out at the UNILAC target station X6. The beam passed through two double-slit collimators and a thin vacuum window (19 μm Hostaphan) in front of a parallel-plate ionisation chamber (IC) with 14 mm air gap and very thin entrance and exit foils (3,5 μm Mylar each). The energy lost in the vacuum window and in the air gap in front of the IC was calculated using the stopping power code ATIMA. Behind the IC the carbon ions were stopped in a 500 μm thick silicon detector. The energy loss in the air gap of the IC which enters into the w-value was determined as the energy difference observed in the silicon detector spectrum when moving it upstream by the IC gap distance using a precision linear drive.

In a second measurement, the ratio N_{ions}/Q was determined from the charge output of the IC, integrated by an electrometer with high accuracy, and the corresponding number of ions traversing the IC counted simultaneously in a fast scintillator. (Fig.2).

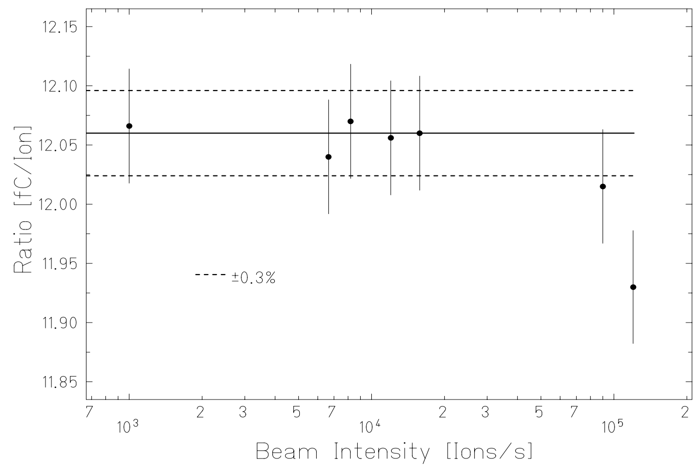

Figure 2: This plot shows the stability of the measured ratio charge per ion counted up to about 10^5 ions/s at the energy of 8 MeV/u. The decrease at higher intensities comes from the increasing relevance of the recombination effect in the chamber.

With this set-up we got the preliminary result :

$$w^{air}_{(7.6\pm0.3)MeV/u}\ {}^{12}C^{6+}ions = (34.2 \pm 1.0)\, eV$$

In comparison with the result of Kanai et al.[1], our value is 6% lower but still in agreement within the given uncertainties as can be seen from Fig.1. The only other data points in the energy range relevant for tumor therapy are those for ^3He at 30 and ^{12}C at 129.4 MeV/u.

For future measurements, an optimised experimental set-up including an ionisation chamber with variable gap length is presently being constructed. The use of a CR39 plastics or diamond detector for the counting of the ions is also being studied for future measurements.

First tests were made at the SIS energy of 200 MeV/u in Cave A. The main findings are the strong build-up effect of the dose (about 5%) and the much weaker initial recombination, as expected, amounting only to a few per mille. The energy loss in the IC for these beam energies is only calculated, becoming a critical point, however, due to the discrepancy between tables when high precision is required.

[1] Kanai et al, Rad. Res. 135 (239), 1993