International Atomic Energy Agency

INDC(CCP)-152/GA

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

THE "ATOS" EXPERIMENTAL DEVICE

V.A. Belyaev, A.P. Dorovskij, M.M. Dubrovin
and A.N. Khlopkin

I.V. Kurchatov Institute of Atomic Energy
Moscow, USSR

August 1980

IAEA NUCLEAR DATA SECTION, WAGRAMERSTRASSE 5, A-1400 VIENNA

Reproduced by the IAEA in Austria
August 1980
80-3917

L80-21820
Translated from Russian

INDC(CCP)-152/GA

THE "ATOS" EXPERIMENTAL DEVICE

V.A. Belyaev, A.P. Dorovskij, M.M. Dubrovin
and A.N. Khlopkin

I.V. Kurchatov Institute of Atomic Energy
Moscow, USSR

August 1980

L80-21820
Translated from Russian

THE "ATOS" EXPERIMENTAL DEVICE

V.A. Belyaev, A.P. Dorovskij, M.M. Dubrovin
and A.N. Khlopkin

I.V. Kurchatov Institute of Atomic Energy
Moscow, USSR

In the recommendations made in the summary report of the IAEA Advisory Group [1,2], further developed in the decisions of the Joint IFRC/INDC Sub-Committee on Atomic and Molecular Data for Fusion, an extensive programme of research was outlined on processes which require detailed study if the fusion problem is to be successfully solved.

An important component of this programme is the study of processes of change in charge and mass composition with collisions between heavy atomic particles and multiply-charged ions of impurity elements and among such processes particular attention needs to be paid to charge exchange and collision ionization of hydrogen atoms:

$$H_1^o + A^{n+} \longrightarrow H_1^+ + A^{(n-1)+}$$

$$H_1^o + A^{n+} \longrightarrow H_1^+ + A^{n+} + e$$

Together with hydrogen-on-proton resonance charge exchange, these two processes may to a large extent determine the physics of beam heating of plasma. Also of particular interest in this connection is the process of ionization of the multiply-charged ion

$$H_1^o + A^{n+} \longrightarrow H_1^o + A^{(n+1)} + e,$$

which causes the channel of plasma energy losses through radiation to become wider.

These processes need to be studied in detail for all possible charge states of impurity ions (A^{n+}) at energies of atoms of hydrogen (and its isotopes) from tens to several hundreds of keV.

Because of the importance of such processes for corpuscular diagnostics, a larger number of collision partners needs to be studied by means of those neutral particles whose beams can be used for diagnostic purposes, and the lower limit of the energy range shifts into the region of a few hundred eV.

This energy range also includes the process of loss of an electron by hydrogen atoms, which are always present as a result of recombination even in the centre of the plasma column.

In the zone near the wall and in the divertor, elementary processes occur at even lower energies (~ 0.1 eV-1 keV). These may have a considerable effect on the mean lifetime of an impurity ion in a specific (here, as a rule, low) charge state, which means in the final analysis that the composition of impurities in the plasma column is also affected. The number of collision partners increases here even more because of molecules and molecular ions of hydrogen and its isotope and, possibly, also because of a number of other very simple molecular formations which enter the chamber from its walls [4]. The picture of the elementary processes becomes even more complex where a cold gas blanket is used in thermonuclear reactors for reducing the passage of impurities from the walls into the plasma column [5] or for creating an artificial atmosphere in the chamber in order to remove the helium ions which are formed as a result of the thermonuclear reaction and have become cold by neutralizing them in the chamber.

A large set of particle pairs, the interaction of which is to be investigated in a wide range of energies from 0.1 eV to several MeV (this upper energy limit is determined by the processes of interaction with helium ions with an energy of 3.5 MeV which have formed as a result of the thermonuclear reaction), needs extensive study from different points of view and involving different experimental techniques. In this connection we believe that it is best to apply the "merged beam" method, which has proven itself and is now fairly widely used. The characteristics of processes leading to changes in the charge states and masses of particles in binary collisions are determined here by analysing the change in composition of two monokinetic particle beams which move in the same direction and interact with each other as a result of their spatial superposition. As has been shown [6], it thus becomes possible to study the collisions of two unstable formations (atoms of molecular gases, atoms in metastable and highly excited states [7], ions and chemical radicals), and sufficiently accurate measurements can be made even at energies lower than the energy spread in the beams. This makes it possible to go down to energies inaccessible to other techniques. For example, in Ref. [8] measurements were performed at energies of 0.001 eV with an energy resolution of 0.006 eV.

On the other hand, the technique is not subject to any theoretical limitations on measurements at high energies.

Use of the merged beam method should make it easier to study a number of the points put forward in the IAEA programme on which the number of experimental data at present available is clearly insufficient. These include, in particular:

(1) Elementary processes involving multiply-charged ions at energies of 0.1 eV-1 keV;

(2) Processes of change in charge states in collisions of multiply-charged ions with atoms of molecular gases;

(3) Processes of stripping of atoms of hydrogen and its isotopes present in metastable and highly-excited states on multiply-charged ions.

At the I.V. Kurchatov Institute of Atomic Energy construction of the ATOS experimental apparatus, which is designed for performing such studies, has been completed [9]. The unit is designed in accordance with the merged beam principle.

The problem of merging beams in such devices is solved in different ways, depending on the charge state of the beams. Thus, in each particular case the design of the merging system limits the range of possible studies by means of one of the four possible charge ratios of interacting particles:

(a) Both particles - ions with the same charge sign;

(b) Both particles - ions with different charge signs;

(c) One particle neutral;

(d) Both particles neutral.

The ATOS device is based on version (c). The beams interact here in a high-vacuum (a few units x 10^{-9} mm mercury) measuring chamber ("MC" in figure) containing the system for directing them, the collision chamber (CC) and the system for analysing reaction products. The neutral particle beam I_1 and the multiply-charged ion beam I_2 pass into the measuring chamber (MC) through sets of diaphragms (D) which operate as vacuum resistances and are used for differential pumping of the measuring chamber.

The beam direction system consists of three cylindrical capacitors (C_1 - C_3). C_1 is for shifting the focus of the multiply-charged ion beam to the input slit S_2 of the capacitor C_2, which is a Hughes-Rozhanskij energy analyser (deflection angle 127.2°). The ion monokinetic beam separated by the capacitor C_2 is spatially shifted by the capacitor C_3 with the beam of neutral particles which pass through the hole of D_2 into the inner plate of this capacitor. The cross-section of the multiply-charged ion beam on emergence from C_3, which is determined by the dimensions of the slit S_3 and by the angle of divergence of the beam in the horizontal plane (defined by the variable-width slit S_1), enables it to pass without obstruction through the diaphragm D_3. In the region in which beams pass through D_3 together, the ion beam is entirely inside the neutral-particle beam since this diaphragm determines its cross-section.

The plane-parallel condenser C_4 serves for removing ions from the beam I_1 and for causing metastable and particular highly-excited states to disintegrate.

Passing through D_3 the beams enter the collision chamber (CC) which is supplied with a potential different from that of the surrounding space. Thus, a certain difference becomes established between the energies of ions and of neutral particles, which is required by the conditions of the experiment. It then becomes possible to detect only those secondary ions (ions generated by the effect produced) which are formed within the collision chamber [6]. Because of the presence of fringing fields at the input to the collision chamber and of a finite section of beam divergence after they have passed through the chamber, the effective distance over which the beams interact depends on the ratio between the potential of the collision chamber and the particle energies in the beams. The distance of interaction is therefore determined in the course of the experiment, for which purpose the collision chamber is constructed in two sections: a large (main) and a small section, into which potentials can be supplied independently. The arrangement and geometry of the hole pairs D_3 - D_4 and D_5 - D_6 are entirely identical. Thus, successive measurements of the effect current for one and the same potential in the basic section of the collision chamber first connecting (i) and then not connecting (i') the small section to it give results that differ by a value corresponding with that of the length (l') of the small section, which is exactly known. The effective distance of beam interaction (l) when both sections are connected is determined by the formula $l = il'/(i-i')$.

The ions produced by the effect studied are separated from the total particle flux in an electrostatic energy analyser. For a complete set of these ions it is necessary to take into account the presence in them of energy and angular spreads arising during their formation and depending on the specific process involved. The energy analyser must therefore have both directional focusing and energy focusing within a given range that can be varied in the course of the experiment. For this reason the energy analyser was arranged in accordance with a two-step scheme (E_1 - E_2) with zero total dispersion and an intermediate focus on the variable-width slit S_6. In this way it is possible to vary the energy range of ions let through by the analyser to the detector (De), since the dispersion of one first step E_1 differs from zero.

Unlike measurements of absolute cross-sections, the study of the formation mechanism of secondary particles does not require a full set of them. Here, the main effort is devoted to determining kinematic links between angles of emission, energies and the probability of secondary particles appearing. The effect of angles of emission "collapsing" in relation to the direction of the total movement of collision partners in the merged beam method leads to a reduction in the accuracy with which these angles can be measured. In these conditions the measurement of the energy distribution of those secondary particles which have preserved the direction of movement of the collision partners is of particular importance. For these measurements it is advantageous to use a Hughes-Rozhanskij cylindrical analyser, since it does not have focusing in the vertical plane.

Accordingly, for the first step (E_1), a capacitor has been chosen with an angle of deflection of 127.3°, variable-width slots (S_4 and S_5) in its focuses and a variable-geometry field, which makes it possible to change over from directional focusing to focusing only in the cylindrical plane during the experiment. With directional focusing, when E_1 is connected, its focus shifts to the slit S_6. In this case S_5 moves completely apart and does not obstruct the passage of the beam.

The second step (E_2) differs from the first only in the angle of deflection, the E_1 angle being increased to 180°.

The focus of the whole system with directional focusing (the trajectory of the beams is shown in the figure) coincides with the input window of the detector De. With cylindrical field focusing the focus is shifted.

However, this does not play an important role because of the small angle of divergence made by the slots S_4 and S_5 in the horizontal plane in order for the energy resolution to be increased.

At all points of the main trajectory of the beam in the energy analyser from the collision chamber to the detector, the potential is the same and is equal to the potential of the collision chamber. This makes it unnecessary to reset the analyser for variations in collision chamber potential if ions arising from particles of the I_1 beam are detected.

The outer plate of E_1 has a hole to enable particles of the I_1 beam which have not reacted to pass into the neutral-particle detector (N).

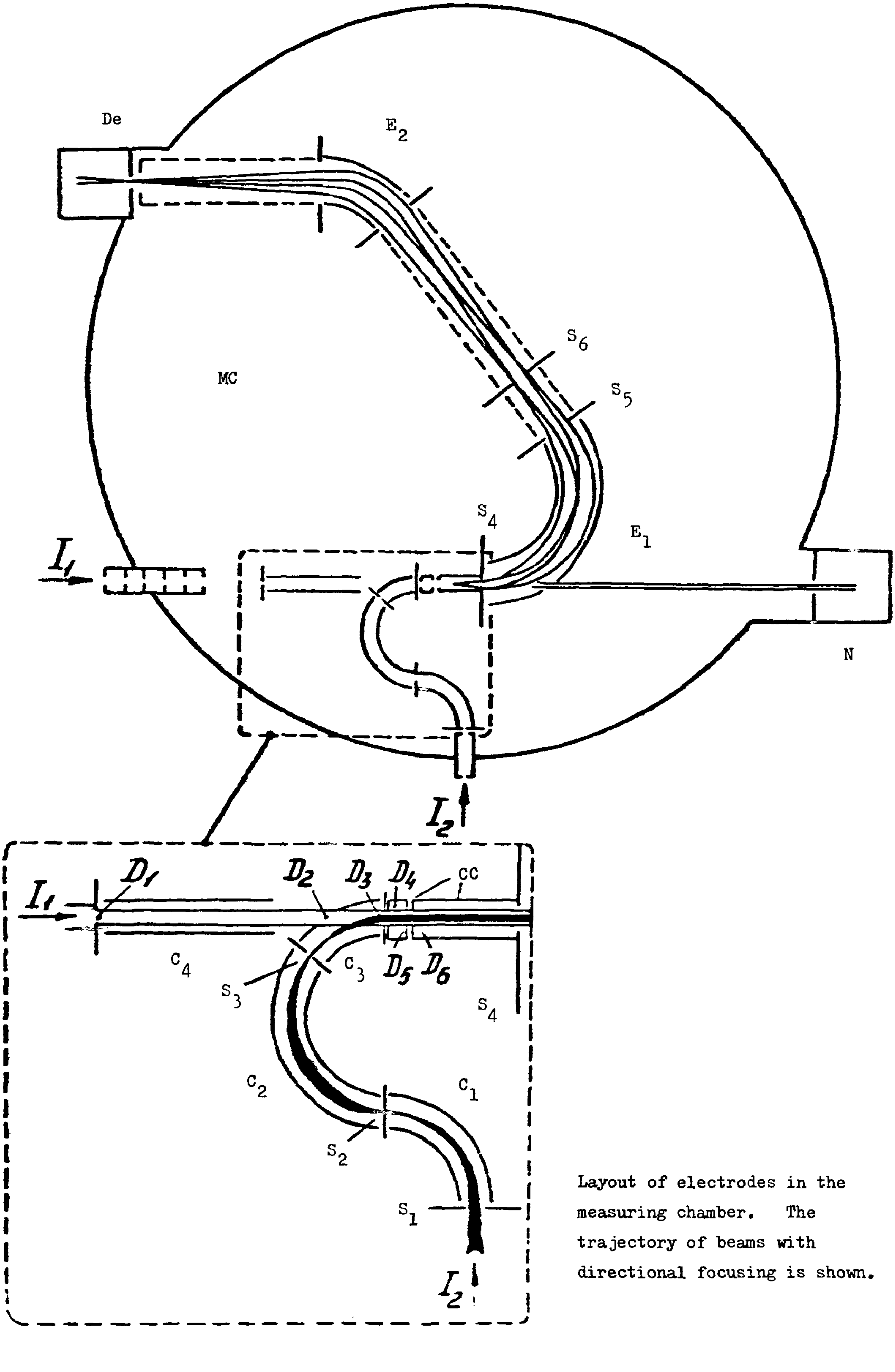
The I_1 beam of neutral particles passing into the measuring chamber is produced by neutralization on a gas target of a pre-formed ion beam with known characteristics. The source used is either a high-frequency one (especially for producing a proton beam) or is of the magnetron type [10]. The same potential as that of the body of the device may be supplied to the neutralization chamber. As a result, the particle energy in the I_1 beam, which is determined by the sum of the basic potential of the source and the potential of the neutralization chamber, can reach 40 keV per primary ion charge. The system for determining the population of excited levels is in general terms the same as that described in Ref. [11].

The multiply-charged ion beam I_2 is formed from the flux of particles extracted from a gas-discharge ion source which is similar to that described in Ref. [12] but modernized for the conditions of the ATOS device. The maximum energy of multiply-charged ions is 20 keV per charge.

In the near future regular experimental studies will be begun with the ATOS device on elementary processes of interest for the development of fusion.

REFERENCES

1. IAEA Advisory Group Meeting on At. and Mol. Data for Fusion, Summary Report, INDC(NDS)-82/GB, Culham, 1976
2. M.R.C. McDowell, Comm. At. Mol. Phys., v.7, N 1/2, p.23, 1977
3. K. Katsonis, F.J. Smith, Intern. Bull. At. Mol. Data for Fusion, N 10, p.29, 1979.
4. H.W. Drawin, Intern. Bull. At. Mol. Data for Fusion, N5, p.48, 1978.
5. B. Lehnert, Nucl. Fusion, v.13, p.781, 1973.
6. V.A. Belyaev, Phys. of Ionized Gases, Proc. of Intern. Summer School, Hercegnovi, Yugoslavia, p.133, 1970.
7. P.M. Koch, J.E. Bayfield, Phys. Rev. Lett, v.34, p.448, 1975.
8. G. Poulaert, F. Brouillard, W. Claeys, P. Defrance, J.W. McGowan, XI ICPEAC, Kyoto, Abstr., p.876, 1979.
9. Novosti termoyadernykh issledovanij v SSSR 3(13) (1979) 8.
10. B. Čobič, D. Tošic, B. Perović, Nucl. Instr. and Methods, v.24, p.358, 1963.
11. M. Burniaux, F. Brouillard, A. Jognaux, T.R. Govers, S. Szucs, J. Phys. B., v.10, p.2421, 1977.
12. B.N. Makov, IEEE, v. NS-23, N2, p.1035, 1976.



Layout of electrodes in the measuring chamber. The trajectory of beams with directional focusing is shown.