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H atom detection and energy analysis by use of thin foils and TOF technique

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Abstract. It has been shown experimentally that detection and energy analysis of H atoms with energy 600–3000 eV can be performed successfully by means of a time-of-flight technique using secondary electron emission detectors and thin foils. The registration of particle fluxes in the presence of a superior ultraviolet background is possible. This technique may be applied to diagnostics of high-temperature and space plasmas.

The problem of registration and energy analysis of hydrogen atoms with energies higher than several hundred electron volts in the presence of strong background radiation is an urgent issue in various fields of physical experiment, e.g. in diagnostics of hot plasmas and space plasmas. The present approach to the solution of the problem is by neutral atom stripping in gaseous or plasma targets or thin foils, and by consequent deflection and energy analysis of the ions produced (Petrov 1976). This method provides rather good energy resolution. The separation of particles to be registered from the photon flux is essential because the secondary electron multipliers used for detection are sufficiently sensitive to ultraviolet and x-ray radiation (Freeman *et al* 1976). Also the flux of such photons is effectively more intense than the particle flux. The use of scanning technique or alternatively of an array of up to ten independent ion detectors for energy analysis may be considered as a disadvantage of this method. It should be noted that detectors are required to function in unfavourable conditions with high noise levels, in such hostile environments as space, fusion machines, etc. Therefore it is not possible to use the existing devices to register very weak particle fluxes when their intensities are compared with count rates of detector noise.

The shortcomings mentioned above may be overcome by virtue of the coincidence technique. Though this approach apparently results in rather poor energy resolution, the technique may be useful in a number of applications. To achieve coincidence the arrival of a particle at the detector must produce two independent detectable physical phenomena (e.g. electron emission), whereas only one occurs when a background photon arrives. The only events that signal particle arrival are those that occur when two independent physical phenomena are detected simultaneously, i.e. during a certain time interval τ_0. Background counts arise from detection of two photons that arrive during τ_0. Therefore, signal count rate $S \sim I_n$ and the noise $N \sim I_\nu^2 \tau_0$, where I_n and I_ν are the fluxes of particles and photons respectively. The signal-to-noise ratio is then $S/N \sim (I_n/I_\nu)/I_\nu \tau_0$. The ratio I_n/I_ν may be considered as independent of the aperture. Hence the signal-to-noise ratio may be increased by a decrease in the aperture (and consequently in I_ν). This is the way neutral particle flux registration may be performed in the presence of an essentially superior photon flux.

The time-of-flight (TOF) technique is widely used in nuclear physics experiments with heavy ions having energies of several MeV (Wiza 1979). The ion penetrates the thin foil causing emission of electrons and after flying a certain distance reaches the particle detector. Electron registration triggers the START signal for the TOF analyser and heavy-particle detection triggers the STOP signal. This technique permits the velocity (and energy if the mass is known) of the particle to be determined, and is essentially a type of coincidence method. An analogous technique was proposed to detect protons in the energy range 50–80 keV (Brocken and van der Ven 1980). The purpose of this paper is to show that a similar method may be applied for registration and energy analysis of H atoms with essentially lower energy (down to 600 eV).

Several types of analysing device have been constructed and their performance investigated. Type A of the detector–energy analyser (DEA) is shown in figure 1. It consists of a thin carbon foil F (8 nm thick) at the DEA entrance and the detector D (two microchannel plates (MCP) in a chevron configuration) placed 25 mm behind it. The MCP diameter is 28 mm and the channels diameter is 12 μm. The first MCP input potential U_i can be varied in the range -100 to $+100$ V and a high voltage (~ 2 kV) is applied to the collector. While the H atom penetrates the foil transmission secondary electron emission may occur. If it is high enough, accelerated by the input potential U_i secondary electrons will outrun the heavy particle and be registered by D. Only then does the heavy particle reach D where it may be registered. Thus two pulses are run from D and the time interval between them depends mainly upon the velocity of the heavy particle. The influence of $U_i = 100$ V on the TOF spectra may be disregarded for $|eU_i| \ll E_0$ (e, charge of electron; E_0, incident atom energy) and ions constitute only a small fraction ($\leqslant 10\%$) of the flux beyond the foil (Overbury *et al* 1979).

The DEA under consideration corresponds to the single-channel mode of TOF analysis. The measurement of the time intervals between pulses is performed by commercially available

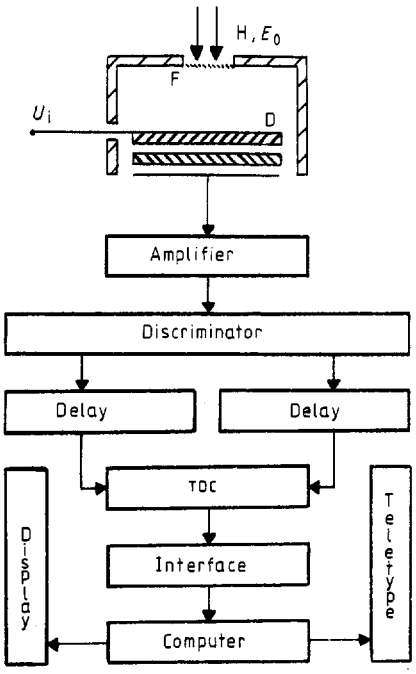

Figure 1. The DEA type A. D, particle detector (chevron MCPs); F, foil; TDC, time-to-digital converter. Single-channel mode of TOF analysis is used.

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modules of the system 'Vector' (similar to CAMAC). A time-to-digital converter (TDC) is connected via a laboratory-made interface with a mini-computer which both controls the experiment and provides storage and processing of information and its output by display and teletype. For the use of the single-channel model of TOF analysis the delay in the START line of the TDC should exceed the delay in the STOP line (by $\Delta\tau$). Otherwise the TDC will inevitably perform the conversion for any (even a single) pulse from the detector and its result will be always equal to the difference in delay times.

Characteristic TOF spectra for the detection of monokinetic (E_0) H atom fluxes are shown in figure 2(*a*). Similar spectra were obtained for H_2 and He fluxes. The particle TOF inside the DEA is determined by the sum of the measured time interval between pulses τ, the difference in delay times $\Delta\tau$ (4 ns in our case) and t_e, the TOF of emitted electrons from the foil to D (8–10 ns). The TOF of the particles can be seen clearly to increase as E_0 decreases (figure 2(*a*)). The TOF spectrum width is determined by the scatter in energy losses and different angular deviations during foil penetration as well as fluctuations in electron transit time t_e. Additional distribution broadening arises from imperfections inherent to the detector and its associated electronics, i.e. electronic jitter. This jitter was measured by the following procedure. The collector of the detector D was divided into two equal semicircles. Each was connected to the identical chain of amplifier–discriminator–delay line. The signal from one part of the collector was directed to the START input of the TDC and from the other to the STOP input. The particle impinging on the centre of the first MCP resulted in pulses running along both chains. The width of time interval distribution obtained corresponds to the broadening due to electronic jitter. The broadening equalled 5 ns but may be lowered to 1 ns (e.g. Wiza 1979).

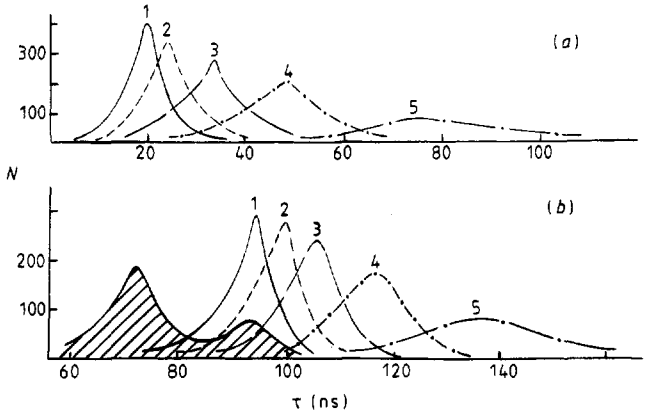

Figure 2. Characteristic TOF spectra for registration of monokinetic H atom fluxes obtained by devices of type A (*a*) and type B (*b*). 1, $E_0 = 3$ keV; 2, $E_0 = 2$ keV; 3, $E_0 = 1.5$ keV; 4, $E_0 = 1$ keV; 5, $E_0 = 600$ eV. $U_i = 100$ V (*a*) and -20 V (*b*). The hatched distribution corresponds to $E_0 = 3$ keV, $U_i = 100$ V.

The atom detection efficiency (relative) of the DEA is defined as the ratio of coincidence count rate to that of the monitor inserted in the incident beam. The funnelled channel electron multiplier which can intercept all the flux is used to monitor and adjust the beam. The efficiency diminishes from 15 to 1% as the incident beam energy decreases from 3000 to 600 eV (figure 3). The energy resolution is defined as $E_1/(E_1 - E_2)$, where E_1 and

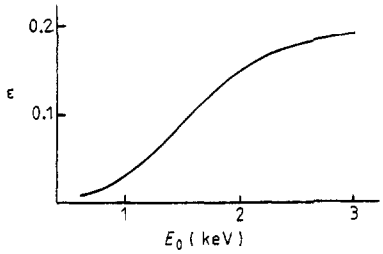

Figure 3. Detection efficiency, ε, of H atoms by DEA-A against particle energy, E_0.

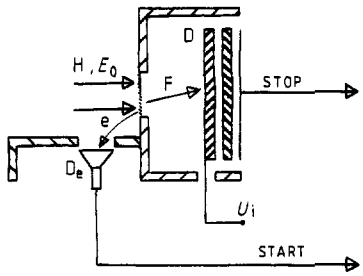

Figure 4. The DEA type B. D_e is the electron detector. Two-channel mode of TOF analysis is achieved by the use of two independent detectors.

E_2 are the energies of monokinetic beams with clearly distinguishable TOF spectra, and is about equal to 2. Let us assume that τ_0 does not exceed 100 ns. Then, as can easily be shown, the false coincidence count rate is only 10 s^{-1}, provided that the count rate of D due to photons is 10^4 s^{-1}. Thus the noise is suppressed by a factor of 10^3.

The advantages of a DEA of type A are its simple construction, compactness and the use of only one detector. However, the single-channel mode is the cause of some limits to its performance. The time interval to be measured diminishes as E_0 increases, and this results in more rigorous demands on the electronics. The afterpulses observed in secondary electron multipliers may become a serious problem for such DEA applications.

These limits can be eliminated by the use of the two-channel mode of TOF analysis, i.e. the mode when START and STOP pulses run in different lines. In the DEA of type B the funnelled channel electron multiplier is placed in front of the foil to attract and register electrons emitted from its input surface bombarded by the incident flux (figure 4). Electron detection by the multiplier gives rise to a START signal and particle detection by D gives a STOP signal; $U_i = -20$ V. The characteristic TOF spectra of registered monokinetic H atom beams by the DEA-B are shown in figure 2(*b*). The zero of the τ axis is determined by the difference in delay times between START and STOP lines which is the same for all spectra. The hatched distribution corresponds to registration of H atoms with energy 3 keV and $U_i = 100$ V. The hatched hump on the left corresponds to the STOP pulse produced by the registration by D of electrons emitted from the output surface of the foil simultaneously with electrons triggering START. The hump on the right corresponds to the case when the STOP signal results from heavy particle registration by D. The electrostatic field in the real construction of this type of the device (figure 4 does not show it) does not favour attraction to D of transmission secondary electrons. This fact seems to

produce the considerable width of the hump on the left. Figure 2(*b*) shows clearly that the probability of simultaneous electron emission from both sides of the foil is rather high. This fact permits further noise suppression to be achieved by shaping the START signal only when simultaneous registrations of electrons emitted from both sides occur (an additional detector is needed for this). The H atom detection efficiency and energy resolution of the DEA-B are approximately the same as for the DEA of type A. Thus the two-channel mode of TOF analysis is brought about by the use of two independent detectors. However, this makes the device more bulky and complex (two high-voltage sources are needed, etc).

The alternative is to use only one detector with the collector divided into two parts as shown for DEA type C in figure 5. The shift of the MCP detector D from the axis and the addition of an electrode E at a potential U^* create an electrostatic field configuration such that electrons are registered primarily by the lower part of the collector (START) and heavy particles primarily by the upper part (STOP). To avoid the appearance of simultaneous signals in both lines arising from particles impinging on the centre of the first MCP the shield strip S of 3 mm width is placed in front of D. Therefore two-channel mode of TOF analysis is achieved using only one detector. The detection efficiency and energy resolution of the DEA-C are similar to those of types A and B.

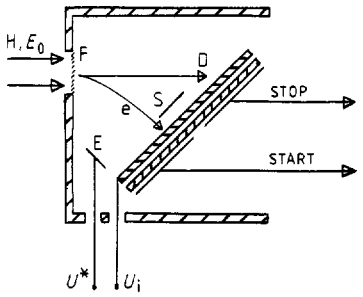

Figure 5. The DEA type C. E, special electrode; S, shield strip preventing registration of those particles that results in simultaneous signals in both lines. Two-channel mode of TOF analysis is achieved by the use of one detector only.

The experimental study of the performance of the DEA has shown that they provide detection of hydrogen atoms of energy 600–3000 eV with an efficiency of 1–15% and an energy resolution of about 2. Particle registration in the presence of a superior radiation background is also feasible.

Several possible applications of the DEAs considered are worth outlining. For example, the use of such devices instead of conventional detectors for ions of a certain energy in existing multichannel analysers for hot plasma diagnostics would permit mass identification of the particles registered to be performed. Another possibility lies in the field of particle–matter interaction research. Simultaneous measurements of particle energy loss and scattering (including anisotropic scattering) in thin foils may become feasible provided that D is replaced by a position-sensitive detector. It should be noted that such measurements are now performed by double scanning – in angle and energy range.

An interesting possible application of the technique considered is to measure absolute intensities of neutral or charged particle fluxes without preliminary detector calibration, provided that there is no background. The particle arrival in the detector may result in two independent events: (i) the emission of electrons from the foil and their detection and (ii) heavy-particle registration by D. Let I_0 be the intensity of the flux to be measured and P_1 and P_2 be the probabilities, which are unknown *a priori*, of registering events 1 and 2. Then $I_1 = P_1 I_0$, $I_2 = P_2 I_0$ and $I_{1,2} = P_1 P_2 I_0$, where I_1 and I_2 are respectively the count rates of events 1 and 2 measured experimentally and $I_{1,2}$ is the measured coincidence count rate of events 1 and 2. Hence the value of I_0 may be derived from measured quantities as $I_0 = I_1 I_2 / I_{1,2}$, and P_1 and P_2 may be derived from these measurements likewise. It can be seen that no preliminary calibration is necessary.

Several other possible applications of the technique considered and more details about DEAs built and their performance are given by Gruntman and Morozov (1981).

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