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A METHOD OF MEASUREMENT AND DISPLAY OF A TIME VARYING PROTON ENERGY SPECTRUM OF ENERGY BETWEEN 2 keV AND 1 MeV

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A B S T R A C T

A method is described of measuring the energy distribution of fast neutral atoms emitted from a plasma. Three methods of display are used, either separately or simultaneously, to provide

(a) a time resolved display of pulse height,

(b) spectra integrated over predetermined periods,

(c) continuous display of count rate in a given energy interval

The energy range from 2 keV to 1 MeV is covered and count rates up to 2×10^4 particles sec^{-1} may be handled.

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C O N T E N T S

INTRODUCTION

The measurement of the time dependent proton energy spectrum and the correlation of changes in the energy spectrum with other plasma phenomena has been an important area of study in the PHOENIX Neutral Injection experiments at Culham. The plasma is usually produced by the injection into a mirror field of 20 keV neutral H atoms, obtained by the dissociation and neutralization of 40 keV H_2^+ ions. A fraction of the beam is ionized by the Lorentz $v \times B$ process and trapped to produce a nominally 20 keV proton plasma: densities of the order of 10^8 cm^{-3} are attained. At times, mixed beams of H_3^+ and H_2^+ ions are used; neutral atom energies of 1/3 and 1/2 the ion energies are thus obtained. The general features of the PHOENIX devices and the observed characteristics of the flute and ion cyclotron instabilities have been described previously (KUO, et al, 1964; BERNSTEIN, et al, 1966). The proton energy spectrum is derived from an analysis of the fast neutral particles leaving the plasma; these neutrals are produced as a result of charge exchange with the background gas.

The requirements for useful energy measurements include:

1. The continuous recording and display of the spectrum for the duration of the plasma (1-3 sec)
2. The extraction of a statistically significant spectrum from any 5m sec time interval during the pulse.
3. An energy range from 2 keV - 1 MeV
4. Resolution of better than 20% throughout the energy range
5. An ability to provide a geometrical scan of the plasma
6. The background pressure in the plasma region must not be perturbed by the measurement technique.

DETECTION SYSTEMS

The region above 60 keV is studied with conventional scintillation counter (CsI - T1) techniques (RIVIERE and SWEETMAN, 1963). A thin Al foil is placed in front of the scintillator to remove particles with energy less than 40 keV and permits the use of a large aperture without excessive counting rate effects from the 20 keV component. The energy response of the foil-scintillator assembly and the proton energy equivalent to the calibration source (Cd^{109}) are determined with a laboratory proton accelerator. The display system for the high energy region is a simplification of the film display described by (HUNT et al, 1954).

The low energy region (2 - 80 keV) is studied with the electrostatic analyser shown in Fig.1. The resolution of this instrument as it has been used is $\simeq$ 9% and is constant throughout the desired energy range. Better resolution may be obtained at the sacrifice of count-rates. The outer case for the instrument is mild steel and the instrument is located sufficiently distant from the PHOENIX apparatus so that stray magnetic field effects are unimportant. Some of the incident neutral particles are recharged in transit through the water vapour cell; water vapour is selected as the recharging medium because it is easily frozen out on the liquid nitrogen cooled surfaces and thus does not contribute to the center chamber pressure. The charging efficiency of the cell as a function of neutral H atom energy is shown in Fig.2. All measurements are performed at 40 microns H_2O pressure. Also shown is a typical charging efficiency dependence on H_2O vapour pressure. The energy of the resultant protons is determined by applying a triangular waveform sweep voltage to one of the deflection

plates; the frequency is between 1 and 10 kc/s. This provides many scans of the desired energy range during the required 5 msec sampling interval yet is sufficiently low that all transit time effects may be neglected. A suitable DC voltage is applied to the other deflection plate to select the energy region to be studied.

The circuit for producing the 3,000 V peak to peak triangular waveform sweep voltage is shown in Fig.3. The output from a Marconi TF885 Square Wave Generator is stepped up to 7·5 kV. A transformer with a turns ratio of 1·125 nominally for use on a 2,400 c/s power line introduces little distortion over the frequency range in use. To produce a triangular waveform the secondary voltage is integrated by an RC circuit with a time constant equal to only about 10% of the oscillation period. The high output capacity of the waveform generator eliminates loading effects associated with the analyser and cable capacities. A capacitive potential divider allows 1% of the voltage to be available for the various display facilities.

CsI - Tl scintillation detectors are used to detect the deflected charged particles and to monitor the remaining straight through neutral particles. The low energy protons of less than 12 keV cannot be resolved by the normal scintillator-photomultiplier system due to the background noise of the photomultiplier. By applying a negative potential of 20 kV to a grid system placed 1 mm in front of the scintillator, the proton energy is increased by 20 keV producing a corresponding increase in output signal with negligible increase in photomultiplier noise. The photomultiplier, whose photocathode is at earth potential, is placed 7 cm away from the grid system and connected to the crystal with a perspex light guide. The transmission of the grid system is

about 90%. In this way with 20 kV acceleration, 2 keV protons have been well resolved from the noise.

In order to obtain the energy spectrum of the neutral particles entering the analyser, correction must be made for the charge exchange cross section in the water vapour cell and for the proportional change of channel width with energy. The energy spectrum is then given by

$$N(E)dE = \frac{K\,N(V)dV}{E\,\sigma_x\,(E)},$$

where

N is number of protons

E is the energy of the protons

K is a constant

V is voltage applied to the analyser plates

σ_x is charge exchange cross section

DISPLAY

Three different recording and display techniques have been employed with the electrostatic analyser and are shown in the block diagram in Fig.4. In the film recording technique the sample of the triangular deflection plate voltage is applied to the vertical plates of an oscilloscope. The spot is intensified for about 0·25 μsec at the time an event is detected. Thus each event is recorded as a dot, the vertical deflection of which is proportional to particle energy. Both moving film-stationary spot and stationary film-moving spot techniques are employed.

A second display technique utilizes a multichannel analyser for the storage and subsequent display of the spectrum information. Here,

pulses are generated whose amplitude is proportional to the deflection plate sweep voltage at the time events are detected. Fig.5 illustrates the arrangement. An output from the discriminator following the photomultiplier is used to trigger the pulse generator which produces a 1 μsec negative pulse. The amplitude is diode limited at a level determined by a bias derived from the analyser deflection plate sweep voltage.

The multichannel analyser technique is best suited to the study of stable plasmas where no variation in the energy spectrum is expected. Fig.6 shows spectrum data simultaneously recorded with both the stationary film-moving spot and the multichannel arrangements. In this case the injected beam consists of both 13 keV and 20 keV neutral H atoms. In this particular experiment the full width at half maximum is about 16% and is attributed to fluctuations in the energy of the injected particles.

It is possible to limit the period for which information is stored in the multichannel analyser by an external signal applied to the preceding pulse generator. For stable cases, a simple time gate is satisfactory. However, attempts to record only during a selected period of a particular plasma instability have been rather unsuccessful because of the uncertainty in the selection of particular unstable intervals. Thus, in general, the film presentation, which permits the subsequent selection of the intervals to be examined, has been somewhat preferable.

In the film and multichannel analyser displays, the instrument is operated as a rapidly scanned single channel analyser with a minimum effective channel width equal to the instrument resolution. A third presentation utilizes a relatively small amplitude sweep voltage and

a counting rate meter, with a 1 msec integration time, to record the instantaneous counting rate. With the counting rate meter display the instrument is operated as a fixed position single channel analyser with a channel width given by the amplitude of the deflection plate sweep voltage. This technique is most useful for the study of the behaviour of selected regions of the spectrum with excellent statistical accuracy but requires a high degree of pulse to pulse reproducibility to yield a meaningful spectrum. In Fig.7, the temporal behaviour of the 20± 4 keV and 60± 4 keV regions are shown for two pulses; also shown is the rectified RF signal which indicates the presence of plasma instability.

Significant distortions to the spectrum can arise because of the instrument dead time. For the present instrument, the measured dead time is $\simeq 5$ μsec; thus significant but not large corrections are required at the maximum observed counting rate, 5×10^4 c/s.

The described instrument and display system enables the determination of a complete energy spectrum from 2 keV to 1 MeV. The film display is most useful for recording and display throughout the entire plasma duration and permits a 5 msec sampling time. The multichannel analyser display is most useful for the study of non time varying conditions and the counting rate meter display permits a detailed study of the time dependence of particular spectrum features with good statistical accuracy.

ACKNOWLEDGEMENTS

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REFERENCES

BERNSTEIN, W., et al., 1966. IAEA Conf. on Plasma Physics and Controlled Nuclear Fusion Research, Culham, 1965. Proceedings, 2, 23-44.

HUNT, W.A. et al., 1954, Rev. Sci. Instrum., 25, 268-274.

KUO, L.G., et al., 1964, Phys. Fluids, 7, 988-1000.

RIVIERE, A.C. and SWEETMAN, D.R., 1963, Rev. Sci. Instrum., 34, 1286.

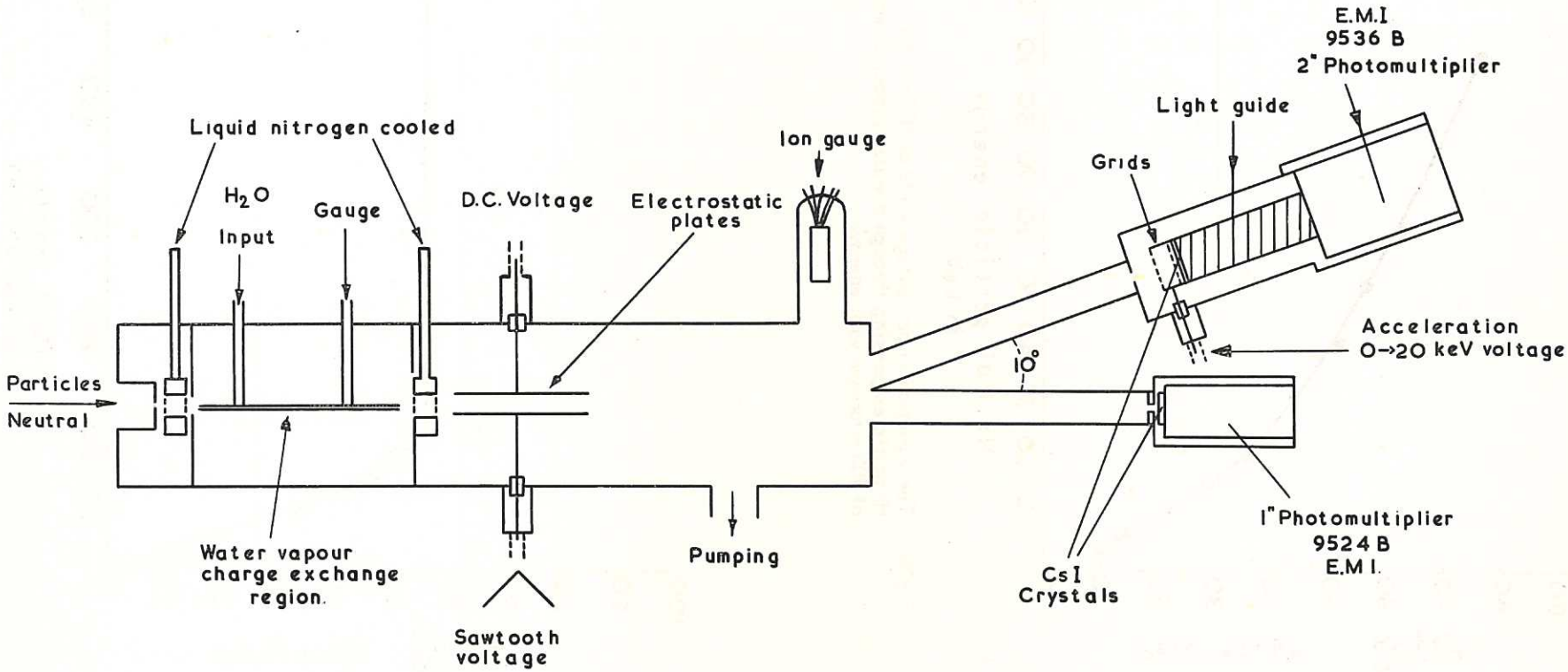


Fig. 1 Spectrum analyser

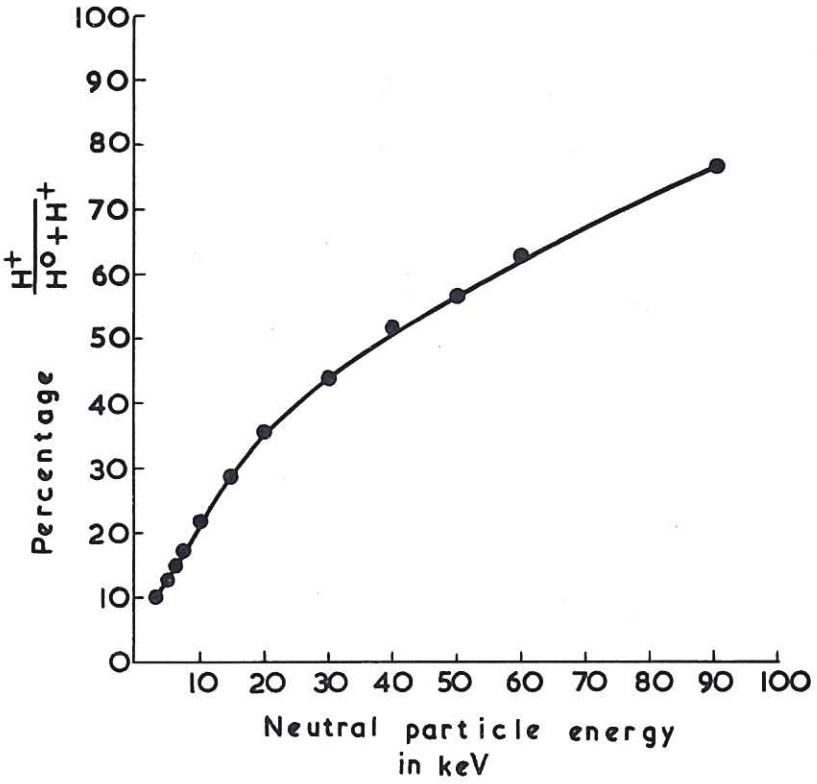


Fig.2a The variation in percentage yield of H^+ ions for H° particles passing through a water vapour chamber of 200 mtorr-cm with energy.

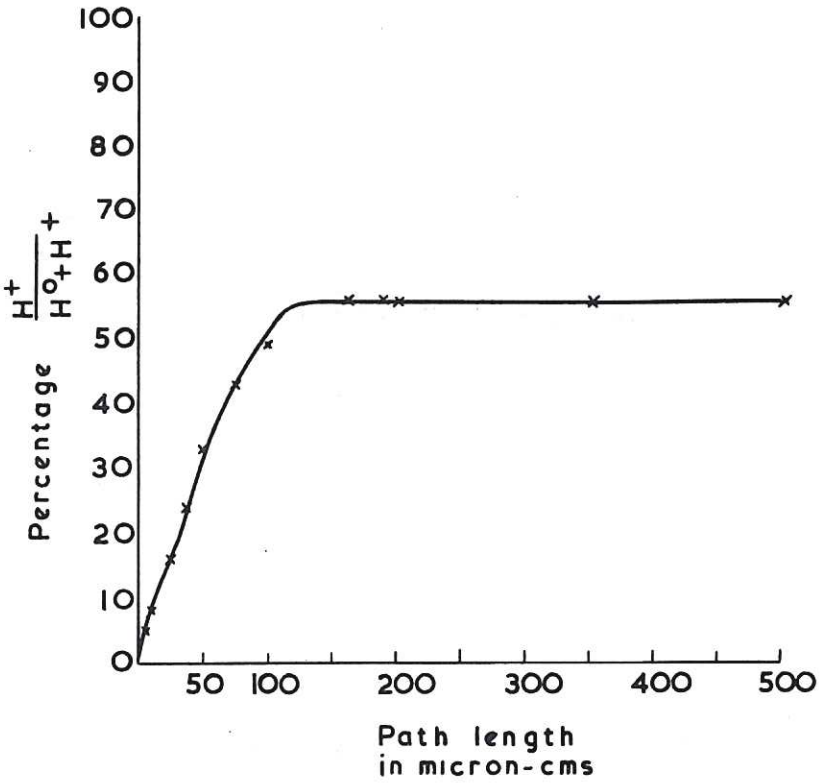


Fig.2b Typical plot of charge exchange efficiency with pressure

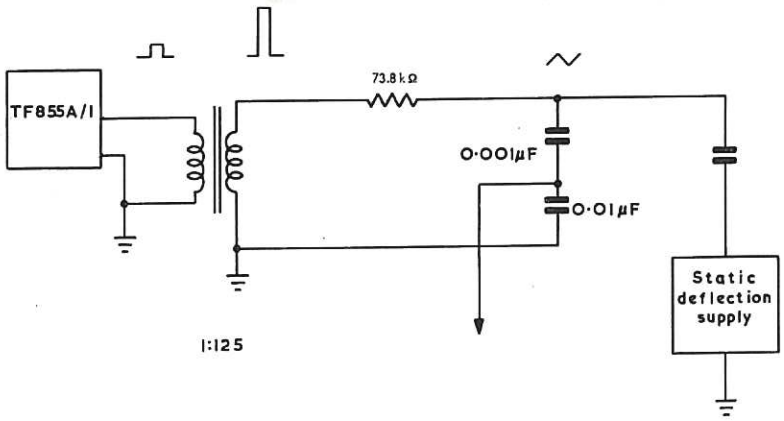


Fig.3 Circuit for producing a 3000V peak to peak triangular waveform sweep voltage

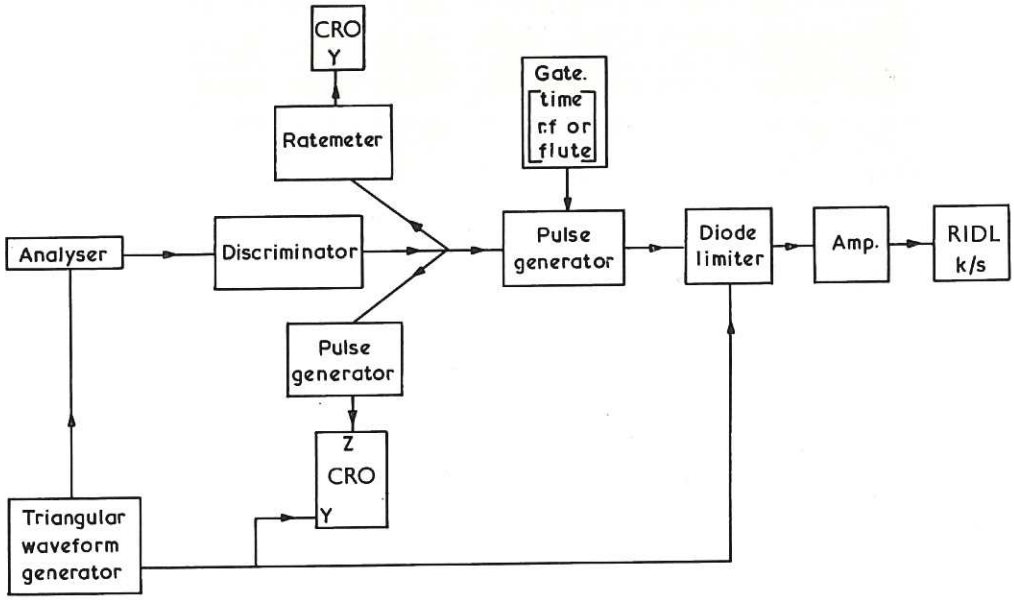


Fig.4 Block diagram of the various recording and display techniques

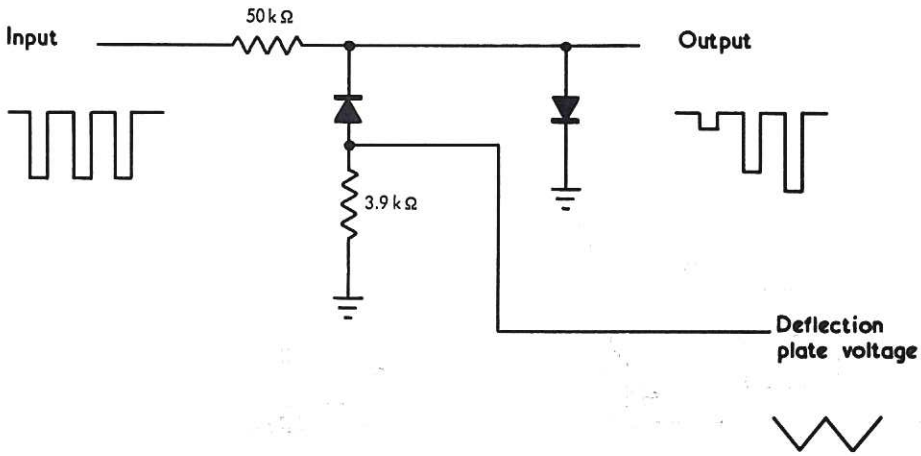
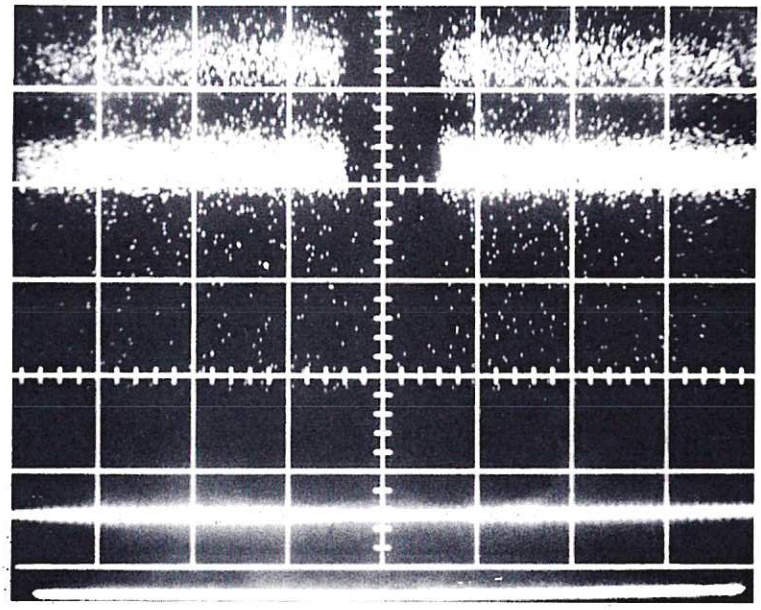


Fig.5 Multichannel analyser display technique



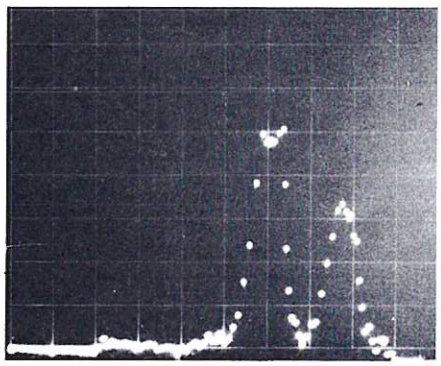
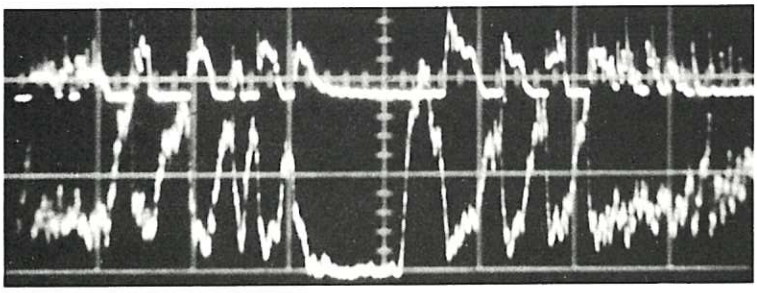
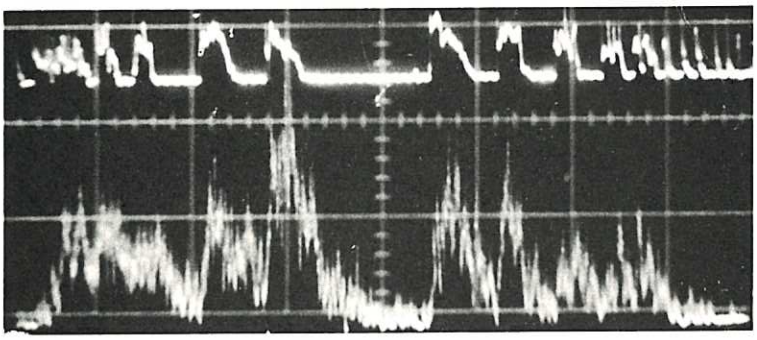


Fig.6 Energy spectra for stable pulse recorded with both film and multichannel analyser techniques. A mixed beam of 20 keV and 13 keV H atoms is injected. The film time scale is 200 msec/div. The multichannel analyser was gated on for 600 msec.



(a) 2.5×10^4 counts/div.



(b) 5×10^3 counts/div.

Fig.7 Time dependent counting rates in the energy ranges, (a) 20 ± 4 keV, and (b) 60 ± 4 keV. The time scale is 200 msec/div. Also shown is the rectified RF amplitudes for both pulses.