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ANALOGUE DETECTION DEVICE FOR SCATTERING EXPERIMENTS AND VELOCITY ANALYSIS (*)

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Résumé. — On décrit un système de détection pour des expériences de faisceaux moléculaires qui peut être utilisé aussi bien pour la détection de flux de particules très faibles que pour l'éta-lonnage de faisceaux de flux plus élevé.

Le système a été testé dans des mesures de sensibilité et de temps de vol.

Abstract. — A detecting system for molecular beam experiments is described which may be used for the detection of very small particle fluxes as well as for beam calibration (higher flux). The system is tested for sensitivity and for time-of-flight measurements.

1. Introduction. — Molecular beam research in general requires the detection of extremely weak fluxes of particles. This may be done with some kind of electron bombardment detector combined to a mass selector and a proper counting device [1] or another suitable current measurement. In a certain contrast to residual gas analysis the main problem in detecting these particle fluxes is to separate the weak and always very noisy flux signals from the signal originating from the background residual gas of the same mass number. Due to limited pumping capability of the vacuum system, the background signal may be larger than the flux signal by several orders of magnitude. Difficulties which arise from this fact are usually overcome by means of beam modulation techniques. These techniques allow the separation of the modulated flux signals from unmodulated background parts of the mass spectrometer output by a suitable narrow band detection system (e. g. lock-in detector). In reactive scattering experiments with crossed molecular beams it would be most convenient to have only one detecting system for scattered particles (very weak particle fluxes) as well as for calibration and control of the primary beams (strong signals). Counting devices may not be so useful in beam calibration because of their limited double pulse resolution (τ_d of about 30 ns). It is necessary that, at a given mass, signals from the

beam (and from the background) be so small that correcting the measured rates N^* by

$$N_{\text{true}} = \frac{N^*}{1 - N^* \cdot \tau_d}$$

will give results of sufficient precision.

In this paper a device is described which achieves a combination of high sensitivity and wide range intensity capability, by means of analogue detection of signals (current measurement instead of particle counting) [2].

2. Sensitivity experiments. — High sensitivity (e. g. for the very small signal case in scattering experiments) is attained by the following process (Fig. 1).

FIG. 1. — Schematic view of the apparatus for sensitivity experiments. (QUAD : quadrupole mass filter, SEV : multiplier, PSD : phase sensitive detector, ADC : analogue digital converter, DAC : digital analogue converter.)

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The weak particle flux of interest is first modulated in a suitable manner for example by periodic chopping of one of the primary beams of a scattering experiment. After ionisation and mass separation of the entering particles in a quadrupole mass filter QUAD of the Paul-Steinwedel type [3] (Extranuclear), the ion current is amplified by a multiplier SEV and a fast preamplifier. The modulated part of the signal is then separated from the background and most of the noise by passing a coherent filter (Brookdeal 467) and a phase sensitive detector PSD with a rather low time constant (about 0.1 s), (Brookdeal 411). The capability of noise suppression is limited for phase sensitive detectors when operating in the $1/f$ — noise region [5]. In our case mainly this kind of noise is relevant, thus giving rise to certain restrictions in sensitivity. The sensitivity of the detection system may be further improved only by using time averaging processes [5, 10]. Therefore our detection system is under the control of an on-line-computer (Digital Lab 8/e) which has a double function: *a*) to set the QUAD to a certain value on the mass scale, *b*) to accept digitised readings of the PSD output which in the very low flux case are still disturbed by noise. After the QUAD is set to a certain mass value the detection system (under control of the computer) is caused to wait for a certain delay time which is sufficiently long compared to the time constant of the PSD.

Then several readings (time interval Δt) of the PSD output are digitised by an ADC and added to a certain memory address corresponding to the mass value chosen. After the final reading for a given mass the computer (by a DAC) sets the QUAD to a new mass value and a new cycle is performed.

Thus it is possible to check any interesting region of the mass spectrum. The whole procedure consists of one cycle for each given mass value and may then be repeated several times beginning again at the given starting point of the mass scale.

Similar processing is successfully used (but with much higher sweep frequencies) in NMR and microwave spectroscopy [4, 5].

The sensitivity was tested with a collimated Kr beam, which was produced by means of an effusive beam source at variable low source pressure. In this case intensities and energy distribution are well known. For refinement the known relative abundance of Kr isotopes was used to simulate very low intensities of a certain mass. It was possible to detect a flux of ^{80}Kr particles corresponding to 8.5×10^{-13} torr partial pressure in the ion source in an unmodulated background of about 10^{-8} torr. In terms of the flux this means that about 10^7 particles/s are detected. For the mass filter used (conventional ion source) the detection probability was found to be 2.5×10^{-6} , so that the lowest signal for ^{80}Kr which could be detected corresponds to an ion current of about 10^{-17} A at the first dynode of the

SEV. The highest sensitivity attained is of the same order of magnitude as when particle counting is normally used. The advantage of the analogue device described here lies in the possibility of also obtaining measurements in the *high flux* region (strong background) without falsification on account of limited pulse resolution. Another advantage is that it is not necessary to change the detecting system when going from low flux to high flux signals in the same experiment. It is only necessary to lower the high voltage for the SEV and to reduce the amplification in a suitable manner. This may be adjusted empirically.

The final sensibility can be further improved by using a more efficient ionizer (efficiencies up to about 10^{-2} are reported [1]) and by improving the vacuum conditions to reduce the noisy background signal.

The achievable flux sensitivity also depends on the geometry of the ionizer and on the angular resolution wanted in a scattering experiment [2].

3. Time-of-flight experiments. — Almost the same device was used for measuring time of flight distributions in a particle flux by the *pseudostatistic chopper method* [6, 7, 8].

The particle flux was simulated by an effusive beam, the velocity distribution of which is known. So the distribution found experimentally could be compared to the distribution expected for the effusive beam. The flux was chopped by a so-called *pseudostatistic chopper* which consists of a small circular disc ($\varnothing$ 36 mm, high elasticity steel, 0.05 mm thick).

By precise photo etching, the periphery of the disc was provided with teeth and gaps so that two sets of pseudorandom sequences [9] each of 47 elements were obtained.

The elements a_i of a pseudorandom sequence satisfy eq. (1)

$$\sum_{i=1}^v a_i a_{i+j} = \begin{cases} k & \text{for } j = 0 \\ \lambda & \text{for } j \neq 0 \end{cases}, \quad (k > \lambda; a_i \in \{0, 1\}). \quad (1)$$

The time dependence of the signal is given by

$$S(t) = \int h(t - t') \cdot g(t') dt', \quad (2)$$

where $h(t)$ is the window function derived from the pseudorandom function and $g(t)$ means the time of flight distribution of the particle flux. The cross correlation $K_{S,h}(t)$ is

$$K_{S,h}(t) = \int K_{h,h}(t - t') \cdot g(t') dt'. \quad (3)$$

Because $h(t)$ is derived from a pseudorandom function it follows from eq. (1) that the auto-correlation $K_{h,h}(t)$ may be taken as a proper approximation to a δ -function. So eq. (3) represents the convolution of this narrow *resolution function* with the time of flight distribution in question. The rotational fre-

quency of the chopper could be chosen between 15 and 500 rps and was stabilised to about 0.1 to 0.3 rps. The whole device is shown schematically in figure 2. The procedure was as follows.

FIG. 2. — Schematic view of the apparatus for time of flight measurements.

The QUAD is set to the mass value of the flux particles whose velocity distribution is to be measured. As soon as the beginning of a chopper period is

monitored, the real time clock of the computer (1 MHz) is started, and after a certain delay time (minimum $1 \mu\text{s}$) the ADC is activated. The momentary value of the signal is digitised and added to a memory address corresponding to the delay time. Then the clock is reset and programmed to the next longer delay time etc. So, for each revolution of the chopper two points of the time scale were sampled. After the sum of delay times equals the time for one sequence (τ_c ; half time of rotation) the sampling procedure was repeated. So, the time dependence of the signal $S(t)$ is registered point by point. From $S(t)$ the time of flight distribution may be calculated by means of the cross correlation as indicated above. Time of flight spectra are shown in figures 3 and 4. The experimental time of flight distribution (—) is compared to the theoretical distribution as expected for an effusive beam (...).

Though the chopper used here is very small and compact its resolution is rather good. This is a consequence of the relatively high transparency of the pseudostatistic chopper as compared to any other type of time of flight device or velocity selector.

FIG. 3. — Time of flight spectrum of an effusive N_2 beam (computer plot). Source temperature : 295 K ; — experimental distribution, theoretically expected distribution.

FIG. 4. — Time of flight spectrum of an effusive Ar beam (computer plot). Source temperature : 295 K ; — experimental distribution, theoretically expected distribution.

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