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THE SPECTROPHOTOMETER WITH A FABRY-PEROT ETALON

By A. Bielski*, S. A. Kandela**, J. Wolnikowski*

Institute of Physics, Nicholas Copernicus University, Toruń

And Z. Turło***

Astrophysical Laboratory, Polish Academy of Sciences, Toruń

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A spectrophotometer with a Fabry-Perot etalon for weak line profile investigations is described. Using this instrument the spectrum can be scanned at a number of discrete equidistant points changing the gas pressure in the F–P etalon. The Jamin interferometer is coupled with a Fabry-Perot plates chamber to control the pressure. The signal from each point of line profile is integrated in a electronic counter and recorded in computer compatible form. The operation of this instrument has been automatized. Results of the practical test of this spectrophotometer are also included.

The spectrophotometer described here, has been designed primarily for investigation of the spectral lines emitted by cold low density plasma produced in the low pressure electrical discharge. In typical experimental circumstances, one has to deal with very narrow, faint spectral lines, moreover in order to account for corrections for different instrumental and secondary effects, a rather extensive reduction procedure was necessary. Under such conditions the basic requirements for the spectrophotometer were;

1) high spectral resolution with linear dispersion
2) high sensitivity and speed of operation
3) output data in a computer readable form.

We have designed, built and tested a spectrophotometer with a Fabry-Perot etalon in which the optical path length is changed by discrete steps by the change of the gas

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* Address: Instytut Fizyki, Uniwersytet Mikołaja Kopernika, Toruń, Grudziądzka 5, Poland.

** Permanent address: Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq.

*** Pracownia Astrofizyki, PAN, Toruń, Sienkiewicza 30, Poland.

pressure. A uniform and linear scale of dispersion of the Fabry-Perot etalon has been obtained by connecting Jamin's interferometer with the Fabry-Perot etalon. Pressure in both these instruments is set to change automatically with a discrete step corresponding to the change of the optical path length in the Jamin interferometer by a preset number of half wavelengths. In order to optimize the signal to noise ratio, we used the photon counting technique [1] which also gives output data directly in a digital form convenient for the further reduction in digital computer.

According to data in the literature a change in the optical path length of the Fabry-Perot etalon can be achieved by several methods. The most convenient and commonly used are:

1) change of the distance between the plates of the Fabry-Perot etalon, for example by using electrostrictive spacers,

2) change of the gas pressure in the Fabry-Perot chamber.

The first method enables fast scanning of the investigated line profile to be achieved with the obvious advantage of reduction of errors caused by time variation of the light output of the source. Unfortunately, this advantage can be fully exploited only at the expense of a substantial complication of the data recording equipment (fast multichannel analyser).

The second method described by Jacquinot and Dufour [2], [3], has been widely used in several configurations [4], [5] differing mainly the method of calibration of the gas pressure and light detection technique. The spectrophotometer similar to ours has been described by Steudel and Walther [6]. In their spectrophotometer gas pressure in Fabry-Perot etalon and auxiliary Jamin interferometer was changed periodically in preset limits using a piston driven by reversible motor. The signal from the Fabry-Perot etalon was amplified and integrated in an analogue form and then digitized and stored in a multichannel analyser. To allow for nonlinearity of the wavelength scale Steudel and Walther recorded along with the signal, also the readings of the channel counter at the moments of zero crossing of Jamin interferometer fringes. During subsequent data reduction in the digital computer, the linear dispersion scale could be in principle restored by interpolation.

1. The optical system

The optical system of the spectrophotometer has been designed to operate in a time sharing mode with Fabry-Perot etalon or with Jamin's interferometer. Referring to Fig. 1, light from the source K_1 is focused using lens L_3 on the slit S_1 and passes through a Fabry-Perot etalon with collimation lenses L_1 and L_2. After reflection by mirror M_3 the light beam is focused on the entrance slit of the grating spectrograph type DFS-8, with aperture 1:35. The entrance slit of spectrograph is fitted with a diaphragm shown on Fig. 2.

In the Jamin interferometer mode, light from an auxiliary incandescent lamp K_2 is reflected by the concave spherical mirror M_4 so as to produce the image of K_2 on the slit S_2. The light beam passes then through a system of two concave spherical mirrors O into Jamin's interferometer. In the light beams between platas P_1 and P_2 two identical gas tight tubes are introduced one of which is connected with the Fabry-Perot etalon chamber and the other can be connected to the vacuum system or opened to atmospheric pressure. The optical system can be switched between Fabry-Perot and Jamin interferometers by means of two electromagnetic shutters D_1 and D_2.

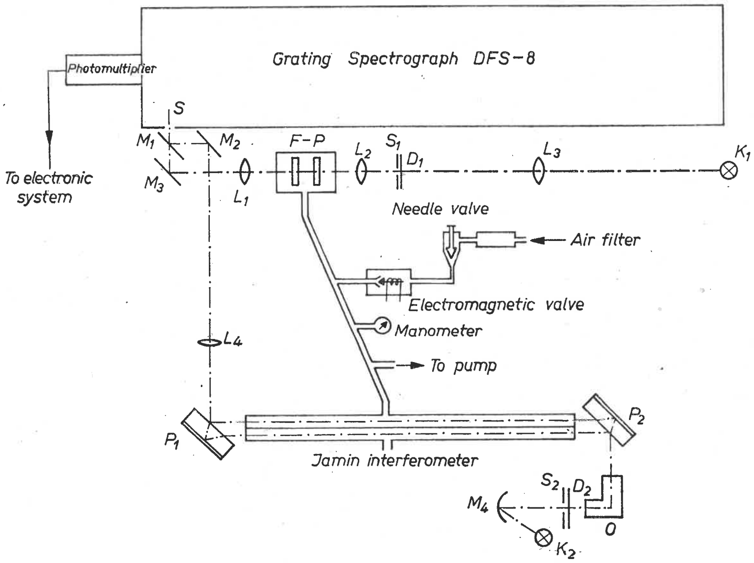

Fig. 1. Diagram of the optical system of spectrophotometer M_1, M_2, M_3 — mirrors, L_1, L_2, L_3. L_4 — lenses, S, S_1, S_2 — slits, D_1, D_2 — shutters, F–P — Fabry-Perot etalon chamber, M_4 — spherical mirror, P_1, P_2 — plates of Jamin interferometer

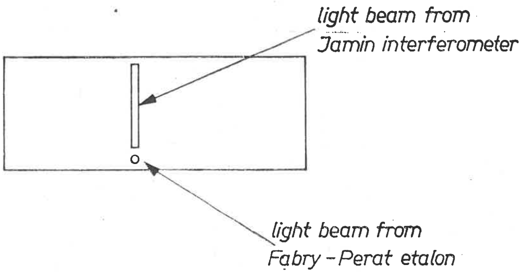

Fig. 2. Diaphragm at the entrance slit of spectrograph

The optical path length in the Fabry-Perot etalon is changed by varying the gas pressure in the Fabry-Perot etalon chamber and one tube of the Jamin interferometer under the control of an electronic circuit. For this system the number of the sampling points within one order of the Fabry-Perot etalon is given by:

$$S = \frac{h}{tm}$$

where: h — length of the Jamin interferometer
t — distance between plates of the Fabry-Perot etalon
m — selected number of halfwavelengths $1 \leqslant m \leqslant 8$.

This procedure assures uniform sampling of the spectrum with good linearity independent of the wavelength.

2. Data recording and pressure control circuits

In order to speed-up measurements of line profiles and to be free from tedious and error prone procedures, data recording as well as pressure control in the Fabry-Perot etalon has been automatized. The spectrophotometer used, operates on the time sharing principle in two modes:

1) Integration of the signal from the Fabry-Perot etalon at discrete points of the line profile.

2) Change of the gas pressure in the Fabry-Perot etalon and Jamin interferometer by discrete and equal increments.

To detect very low light intensities from the Fabry-Perot etalon an electronic counter preceded by a linear wide band preamplifier with a pulse normalization circuit is used.

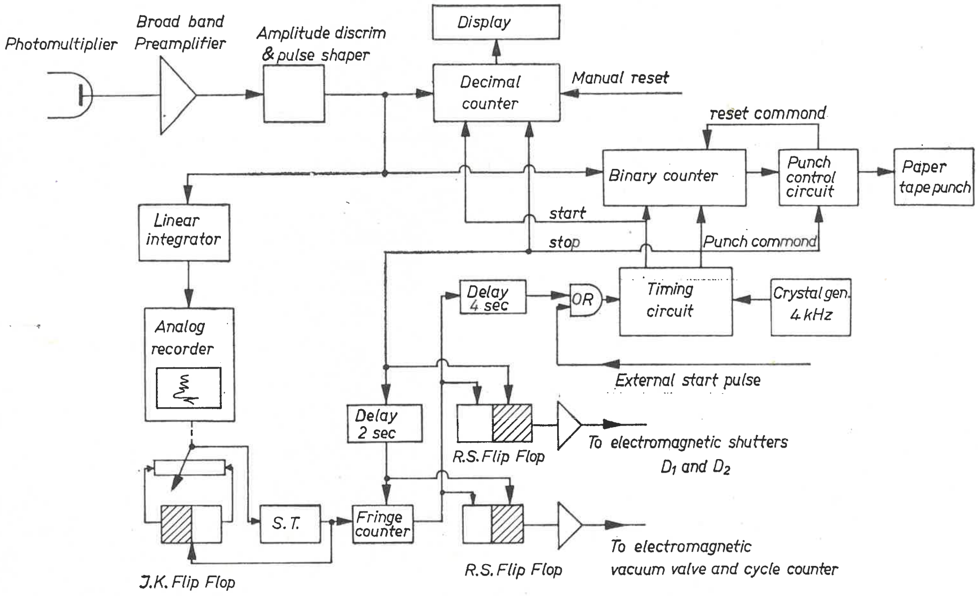

Fig. 3. Block diagram of the electronic control and data recording circuit

This procedure offers the highest possible signal to noise ratio and gives results of measurements directly in the digital form.

Referring to Fig. 3, the signal from Fabry-Perot's etalon is integrated within preselected time intervals in a binary counter followed by a paper tape punch. For fast cursory control and initial adjustments we have used a decimal counter with an easily readable visual display, connected parallelly with the binary counter.

The time base circuit was designed so as to give a number of selectable counting intervals, in range 0.1 to 30 sec. with repeatability better than 1×10^{-5}.

In the pressure control mode the signal from the Jamin interferometer is integrated in a simple analogue linear integrator and amplified in the analogue recorder. A potentiometer driven by the analogue recorder is used to control the electronic circuitry changing the gas pressure in the Fabry-Perot etalon and Jamin interferometer. In each cycle, the vacuum valve operated by pressure control system admits to the Fabry-Perot etalon chamber as well as to one tube of the Jamin interferometer (see Fig. 1) the amount of gas corresponding to the differential change of the optical path length in Jamin's interferometer by a constant number of half wavelengths.

The data recording and the pressure control electronic circuits were designed so as to enable manual as well as closed loop operation. In order to avoid errors due to switching the optical and detection systems between Fabry-Perot's etalon and Jamin's interferometer, it was necessary to add in the loop, some delay circuits to allow for the relaxation of the transient phenomena. In the closed loop configuration after initial set up and external start pulse, the whole system will scan the preselected portion of the spectrum in equidistant discrete points and punch the results on a paper tape automatically without any additional control. The time diagram in Fig. 4 shows the consecutive elementary steps of the closed loop cycle.

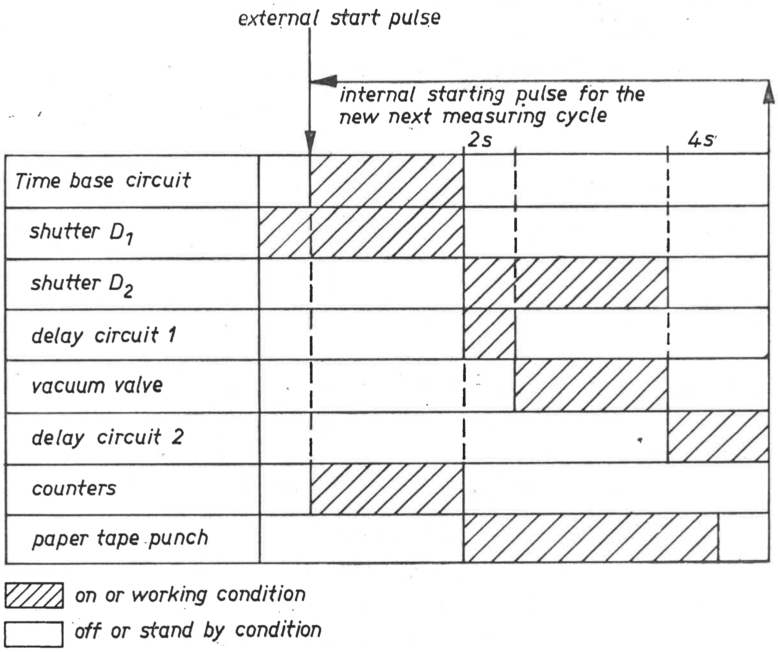

Fig. 4. Time sequence of the single measuring cycle of the spectrophotometer

Some experimental difficulties have been encountered in the pressure control system due to the presence of noise and occasional external interferences in the signal from the Jamin interferometer. In order to avoid any ambiguity we have designed a circuit characterized by the two alternatively active discrimination levels placed symmetrically around the mean level. At each time when the signal due to interference fringe from Jamin interferometer reaches the active discriminating level, a short pulse is generated in the Schmidt triger which turns on the other discriminating level and adds one to the fringe counter. If the noise and occasional interferences are not excessive (smaller than the difference between the discrimination levels) the number of the pulses generated in this circuit is equal to the number of half wavelengths passed in the interference pattern of the Jamin interferometer. After a preset number of pulses, the fringe counter turns off the vacuum valve admitting gas to the system and after an appropriate delay, a new signal integration cycle starts.

In Table I we have listed some relevant technical parameters of the data recording and pressure control circuits.

TABLE I

Preamplifier	Gain ~ 20 db, Bandwith ~ 18 Mc/s
Discriminator and pulse shaper	Threshold voltage 0.2 V, pulse duration 50 ns time resolution 140 ns
Binary counter	20 bit, time resolution 140 ns
Decimal counter	time resolution 1 μsec, commercial type PT-67a.
Analogue recorder	Commercial type G1B1 Zeiss
Paper tape punch	5 channel, modified teletype type punch

3. *Testing of the spectrophotometer*

The performance of the spectrophotometer was thoroughly tested under different conditions by measuring a number of profiles of different spectral lines. It was practically demonstrated that the spectrophotometer gives reliable results of measurements, and is capable of extended trouble free operation. We have noted that in some circumstances, there were slight differences in the number of sampling points per one order of the Fabry-Perot etalon. This effect is caused by small temperature differences between the Jamin interferometer and Fabry-Perot etalon due to the gas compression and is most pronounced at low pressures. It was found experimentally that this effect could be diminished to a negligible level by stabilizing the temperature of the Fabry-Perot etalon and Jamin

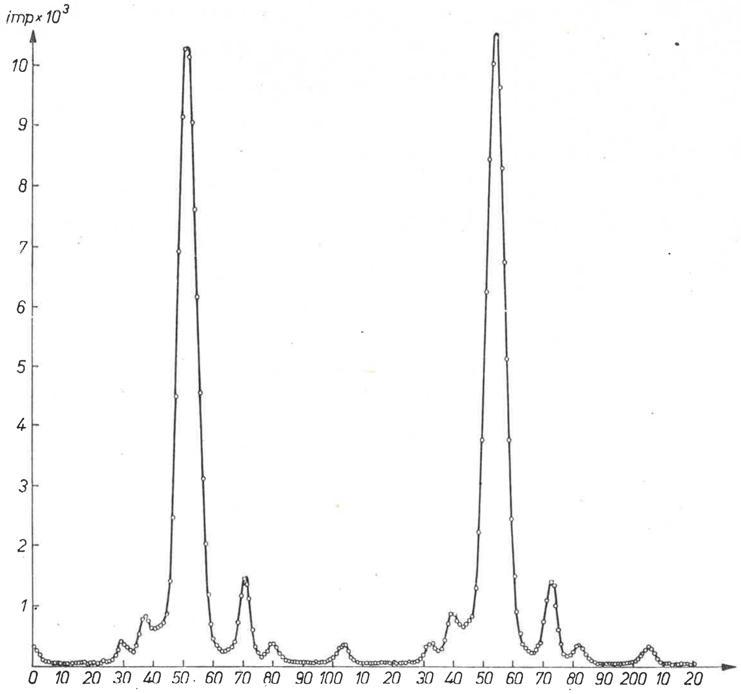

Fig. 5. Hyperfine structure of the $\lambda = 546.1$ nm line of the natural mercury. Distance between plates of the Fabry-Perot etalon $t = 3.16$ mm, reflection coefficient $R = 0.95$, length of the Jamin interferometer $l = 632$ mm, sampling interval $m = 2$. Spectrum was sampled in one hundred points within time interval of about 30 minutes

interferometer and varying the gas pressure in the system at a slow rate. It is also advantageous to start the measurements at pressures not lower than 30–50 torr.

In Fig. 5 we show the hyperfine structure of the $\lambda = 546.1$ nm line of natural mercury, as an example of the typical record obtained with described spectrophotometer. As a light source we used hollow cathode discharge tube operated at temperature about 12°C with current 100 mA.

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