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Microcomputer-assisted spectrum analyzer with thermionic diode detector *

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A simple computerized spectrum analyzer constructed for the absorption spectroscopy of atomic and molecular vapours is presented. It consists mainly of a tuned pulsed dye laser, an absorption cell (thermionic diode) and an on-line data acquisition and control system based on a popular Commodore 64 microcomputer. The essential part of the system: a home made flexible 8 channel interface, providing communication between computer and laboratory devices, is presented. Some details of the applied software are also discussed. As an example a fragment of an absorption spectrum of caesium vapour recorded with the help of apparatus is shown.

1. Introduction

There is a significant demand in optical laboratory for equipment which would be able to perform a number of diversified experiments sharing some common requirements, concerning the improvement of S/N ratio, data acquisition and transformation, counting, tuning, and so on. Many specialized instruments are already produced (i.e., signal averagers, multichannel analyzers, scanning spectrometers etc.), but they are expensive and frequently out of reach of small groups of experimentalists. With the appearance of small computers the possibility of performing at least some of the required functions by one piece of hardware became real. There is a great number of computer-assisted experiments, in most of them, however, a commercially available, advanced and expensive hardware is used.

In this paper a simple spectrum analyzer constructed in our laboratory is presented. It is intended for the absorption spectroscopy of gas media by the selective photoionization method. Our apparatus consists of devices which in majority either make up the equipment of any optical laboratory or were purchased at relatively low cost or built without great difficulty. The main components of the apparatus are: i) tunable pulse laser, ii) thermionic diode, iii) popular Commodore 64 (C-64, CBM) microcomputer communicating with the laboratory devices via a home made interface. The modular from, electronic simplicity and variety of applications determine the advantages of the presented apparatus.

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2. Outline of the method and the apparatus

In the recent years an increasing attention has been focused on the (photo)ionization methods in an atomic and molecular spectroscopy (see [1] for multiphoton ionization (MPI) and [2] for resonant ionization spectroscopy (RIS), see also [3], [4]). This interest stems among others from high selectivity and efficiency of ionization process obtainable with those methods (RIS). The research in this field is also stimulated by the existence of very efficient ion detectors. An example of such a detector is the thermionic diode, a simple sensitive and popular hybrid device of broad application in laser spectroscopy, combining an absorption cell with an ion detector [4].

Our experiment (see Fig. 1, for scheme of the apparatus) is aimed at examining an absorption spectrum of Cs_2 dimers in the violet-blue-green (ca 24500–19200 cm^{-1}) spectral range. The caesium vapour contained in the thermionic

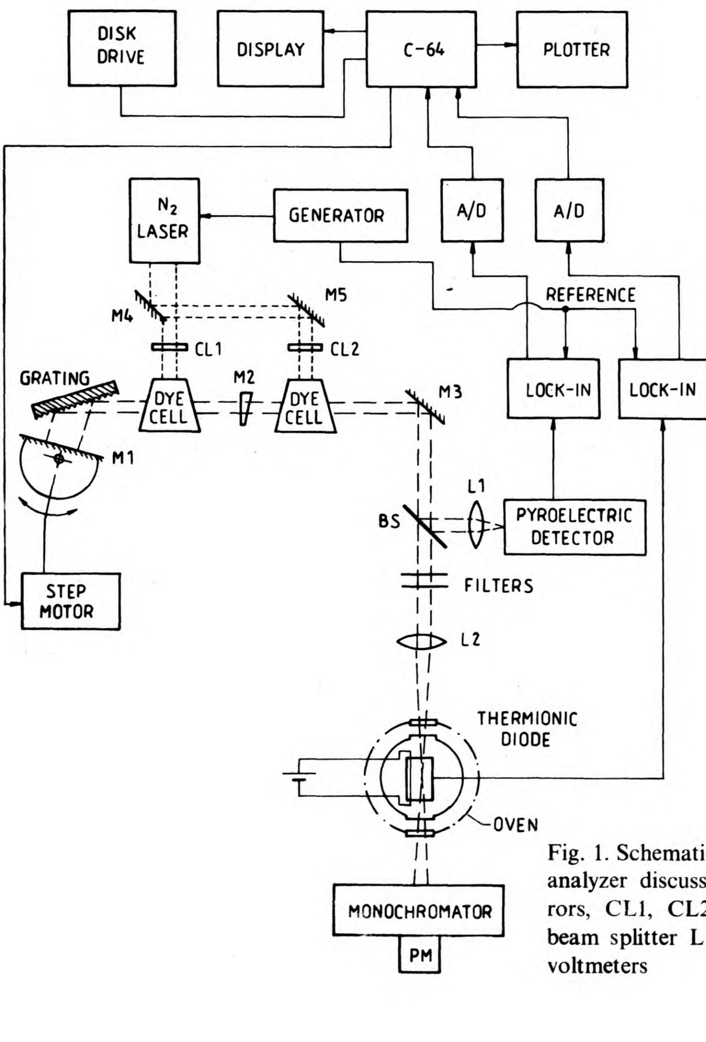

Fig. 1. Schematic representation of the spectrum analyzer discussed in this paper. M1–M5 mirrors, CL1, CL2 – cyllindrical lenses, BS – beam splitter L1, L2 – lenses, A/D – digital voltmeters

diode is excited (and ionized) by the laser light of a tunable wavelength. The method applied consists in a two-photon (stepwise) ionization of the molecules, from their ground state through resonant intermediate molecular states of interest. Ionized molecules can be detected as an anode current proportional to the average number of ions produced per time unit. The obtained spectrum, normalized to the square of laser intensity, corresponds mainly to the absorption probability of the intermediate states, thus it reveals the molecular absorption spectrum [5].

In what follows the description of individual components of the apparatus is given.

2.1. Laser

The dye laser consists of an oscillator and an amplifier both pumped by the same pulsed nitrogen laser whose beam is split into two parts of approximately equal intensity and focused inside the respective dye cells connected to a dye circulator.

As a dispersive element of the laser cavity the grating (1300 grooves/mm, Zeiss Jena) working at a grazing incidence angle is used [6]. To tune the laser wavelength the mirror M1 close to the grating is swiveled with the help of micrometer screw driven by step motor. The latter can be advanced by signals from the computer.

Usually, the dye laser radiation is coupled out through mirror M2 (an uncoated, wedged, glass flat) and amplified in the amplifier cell. When the amplifier is not in use (in some cases it can be a preferable option) the glass wedge is replaced by a fully reflecting aluminium-coated mirror and the output is taken from the zeroth order beam reflected from the grating.

The linewidth of the output from the laser is about 1 cm^{-1}. The laser wavelength calibrated with the help of a double monochromator (GDM 1000, Zeiss Jena) can be tuned in approximately 1 cm^{-1} steps (which is not the ultimate resolution which can be reached with the system).

2.2. Thermionic diode

The thermionic diode used in this experiment (see Fig. 2) comprises a Pyrex glass sealed off vacuum cell, filled with an amount of substance to be studied (caesium). It is outfitted with glass/tungsten feed-throughs (tungsten wire ca 2 mm thick) and a spot-welded cathode (ca 0.1 mm thick tungsten filament) surrounded by a cylindrical anode (made of ca 0.2 mm thick tantal foil). The cell is heated in a two chamber oven. The lower part of the oven (the cold finger) is kept at a lower temperature than the upper one (220°C and 260°C in our case) to prevent the condensation of metal on the windows and inner surfaces. The cathode filament is directly heated and the heating current is selected for the best S/N ratio of the device. The laser beam is focused in the volume between cathode and anode. To avoid the saturation of the diode signal (which in discussed case is manifested by the deviation of the signal from its quadratic dependence on the laser intensity), neutral density filters are inserted into the laser beam.

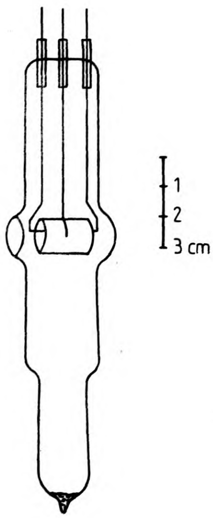

Fig. 2. Scheme of the thermionic diode used in the experiment

2.3. Data acquisition, control and measurement process

As mentioned earlier, data acquisition and control is performed with the help of a popular 8 bit microcomputer C–64. Auxiliary elements which support its operation are: disk drive (VIC–1541, CBM) and monitor (MTU 6171, UNITRA). Additionally, a plotter (NE–2000, Videoton) can be used. To provide link between C–64 and laboratory devices, such as voltmeters, an 8 channel (24 bits each) interface was constructed. Parallel interface modules (MCY 7855, CEMI integrated circuits) are the main parts of its electronic scheme. In order to simplify procedures servicing the interface, the modules are working in a mode using no interrupts (mode 0). This method has proved to be entirely sufficient for all our needs. An essential feature of the interface is that, due to its direct connection with the Commodore address and data buses (Expansion Port), the program deals with laboratory devices as if they were parts of computer memory beginning from the address $DE00. Thus, to communicate with those devices Assembler's Load and Store or Basic's PEEK and POKE instructions can be used alternately. In order to optimize the data processing and to save memory, some solutions are adapted, of which the following are given:

– device handlers and crucial subroutines are written in Assembler,

– the main program, on the contrary, is written in Basic, thus allowing an easy introduction of modifications,

– only long (3 bytes) integers are used for storing measurement results.

The system presented (C–64 and interface) allows a very flexible adaptation, on the software level, of different requirements imposed both by the device to be connected to the interface and by the user's needs. It seems that the only constraint on the device is that it should possess digital output in the TTL standard.

In our experiment the signals from the thermionic diode and the pyroelectric detector (P1–12, Molectron) are measured by lock-in amplifiers (232 B, UNIPAN). The two dual slope digital voltmeters (V 543, MERATRONIK) measure the lock-ins' DC output voltages (proportional to the photoionization signal and the laser intensity, respectively) and convert them into 4-digit BCD code numbers (conversion time ca 60 ms) which subsequently are directed via interface to the microcomputer. The step motor (and its controller, step motor EDS 11, controller ADI–21–M–01, MERA–ZAP) is supplied by C–64 with signals which set direction of the motor revolutions (DC) and the number of steps to be executed (pulse train) for a proper tuning of wavelength.

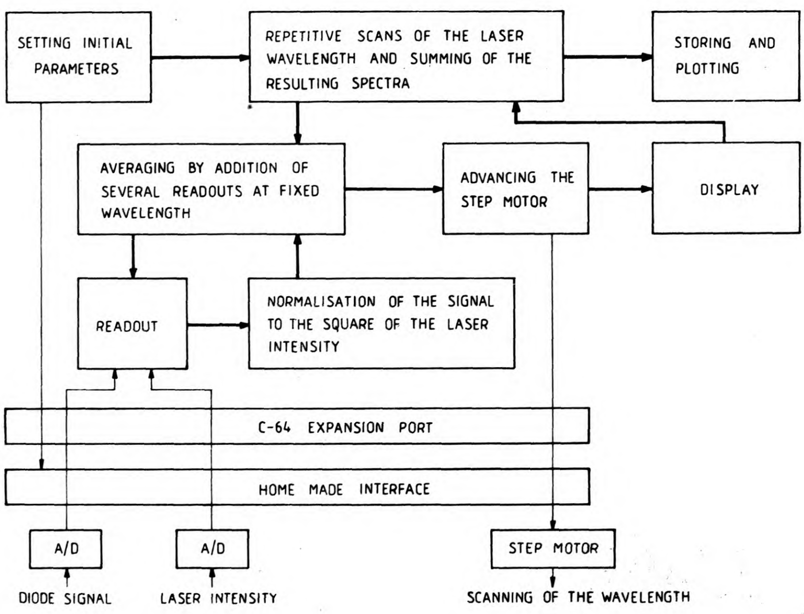

Fig. 3. Chart of the data acquisition, flow and transformation. Main functional blocks are specified. For discussion see text

The measurement procedure consists of the following steps (see Fig. 3):

i) The laser light wavelength is calibrated vs. step motor position before the measurement is made.

ii) Initial parameters, such as number of readings to be averaged, number of wavelength steps to be performed, etc. are set from the keyboard.

iii) The readings of voltmeters being averaged during a predetermined sampling time (ca 25 laser pluses per wavelength step) are stored in arrays S (photoionization signal) and L (laser intensity), at the same time the signal normalized to the square of the laser beam intensity (S/L^2) is computed, averaged and stored (by this method the effects of pulse to pulse variation of laser intensity are substantially removed).

iv) After sampling time is terminated the data values are displayed on the monitor and the step motor advances the laser wavelength.

v) While waiting for stabilization of the system in new conditions, several dummy readouts of voltmeters are performed, thereupon the procedure is continued as in (iii). In this way the whole spectrum can be obtained.

vi) Because of the long-lasting drifts of the signals the procedure of scanning over the spectral range of interest (iii–v) is repeated several times to provide sufficient S/N recovery.

vii) Finally, subsequent points of the measured spectra are stored (in a binary form) on a diskette and plotted.

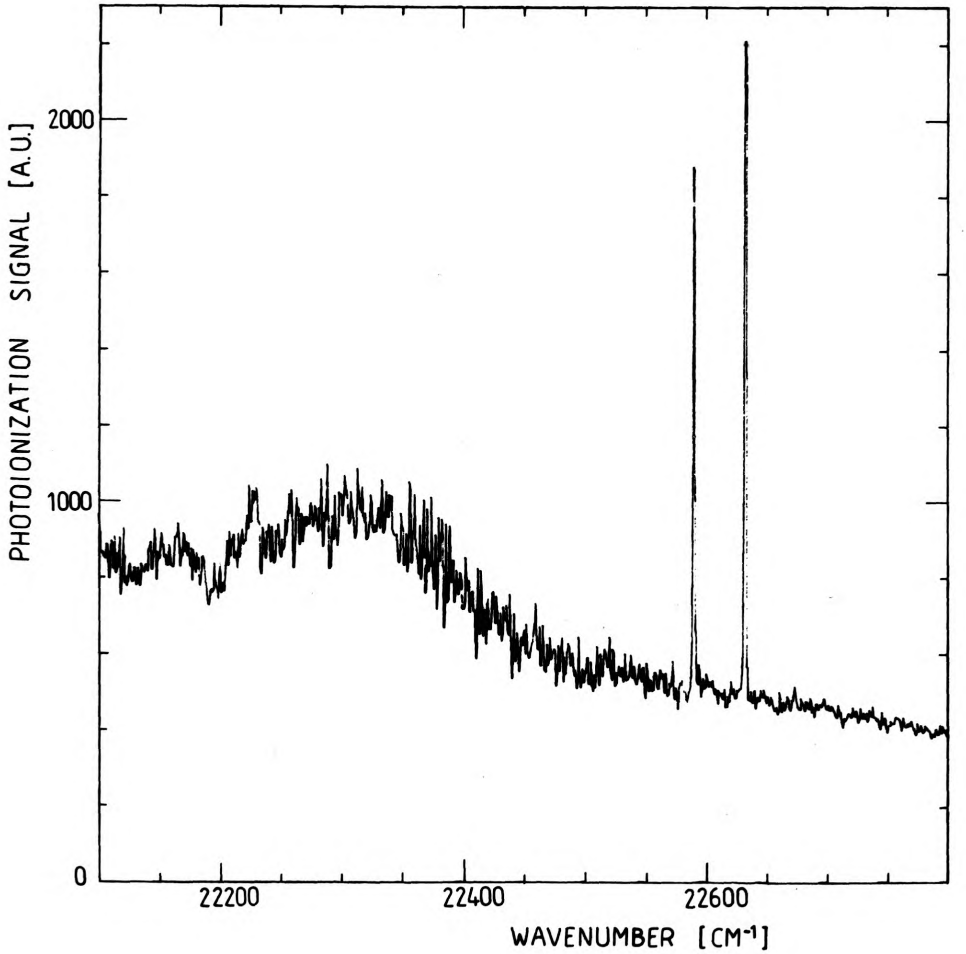

Fig. 4. Illustrative example: fragment of the absorption spectrum of caesium vapour obtained with the apparatus

3. Example of application

Figure 4 shows a portion of the caesium vapour absorption spectrum obtained with the apparatus. Beside the broad profile of the molecular (Cs_2) origin one sees also the atomic lines corresponding to quadrupole transition $6^2S_{1/2} \rightarrow 6^2D_{3/2,5/2}$. Although results of 15 independent scans averaged the visible fluctuations of signal are still significant, further improvement of S/N ratio requires a more stable laser output. More detailed presentation of the results and their discussion will be included in a forthcoming paper.

4. Final remarks

The example of caesium vapour does not exhaust the possibilities of application of the apparatus. At least 20 elements were studied with thermionic diode detector (for some media stainless steel structures are used instead of glass or quartz to enable stronger heating or to protect against corrosion) by several authors [4]. The real advantage of the apparatus (namely its electronic part) consists in its adaptability to the changing requirements of the user. In the discussed experiment only two out of eight channels of the interface are used. Thus, a greater number of external devices can be connected in order to perform other tasks. Relatively long conversion time of the used digital voltmeters slows down the speed of the data acquisition but with faster A/D and D/A converters, limiting frequency of the C–64 can be much higher (e.g., 40 kHz for photon counting device). On the other hand, there is a possibility of constructing a low frequency lock-in amplifier [7].

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Анализатор спектра с детектировочным диодом управляемый микрокомпьютером

В Статье представлен компьютерный анализатор спектра предназначенный для измерений адсорбции атомных и молекулярных пар. Главные части аппаратуры это: перестраиваемый импульсный лазер на красителях, адсорбционная ячейка, составленная из термоэлектронного диода и компльютерная система собирания данных и контроля, базирующая на микрокомпьютере Commodore C–64. Представлен существенный элемент этой системы, сделанный в нашей лаборатории — интерфейс соединяющий компьютер и внешние устойства. Рассмотрены также некоторые подробности программного обеспечения. В качестве примера показана часть полученного спекктра поглощения пар цезия.