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Device for measurements of optical atomic spectra applying a pulse dye laser

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A setup for the measurement of optical spectra applying a pulse dye laser of the type LZh–504 is described. The setup is designed for the excitation and recording of the laser resonance fluorescence of atoms. The atomic beam is produced by heating the sample in a tantalum crucible. For the 576 nm optical line of EuI, the frequency resolution reached 1.1 GHz at a minimal recordable atomic flow from the crucible of the order of 10^7 atoms/s.

1. Introduction

With the coming of lasers with tunable wavelength, methods of optical resonance spectroscopy have found numerous applications in the fields of fundamental as well as practical studies. These methods, on the one hand, permit the analysis of ultra-small admixtures of a vast variety of elements and, on the other, allow high-accuracy measurements of various atomic and nuclear parameters, in the first place – the charge radii and electromagnetic moments of the nuclei, the magnitudes of which are obtained from measurements of the isotopic shifts and hyperfine structure of the optical lines. Using continuously operating lasers in these measurements, frequency resolution as high as 1–3 MHz has been achieved at a sensitivity permitting work on as few as 10^6-10^7 atoms under investigation [1],[2].

However, in a number of cases, the use of pulse lasers appears to be promising. These lasers, though characterized by a broader emission line and, consequently, lower frequency resolution, nonetheless allow measurements on atomic beams with greater Doppler broadening. Moreover, the measurements can be synchronized with the light pulses which significantly lowers the background from the foreign sources.

In the present work, we describe a novel setup for the measurement of optical spectra of atoms with stable as well as radioactive nuclei constructed on the basis of modernized home-made pulse dye LZhI–504 type [3] lasers (equivalent to Lambda Physics, mod. FL 2001).

2. Experimental setup

Figure 1 shows the functional diagram of our laser spectrometer. The pumping source consists of a Kryostat–1 pulse laser producing simultaneously radiation of the two wavelengths 510.8 nm (60%) and 578.2 nm (40%) with the 20 ns pulse duration, 11 kHz pulse repeatability and 3.5 W average power. The laser wavelength

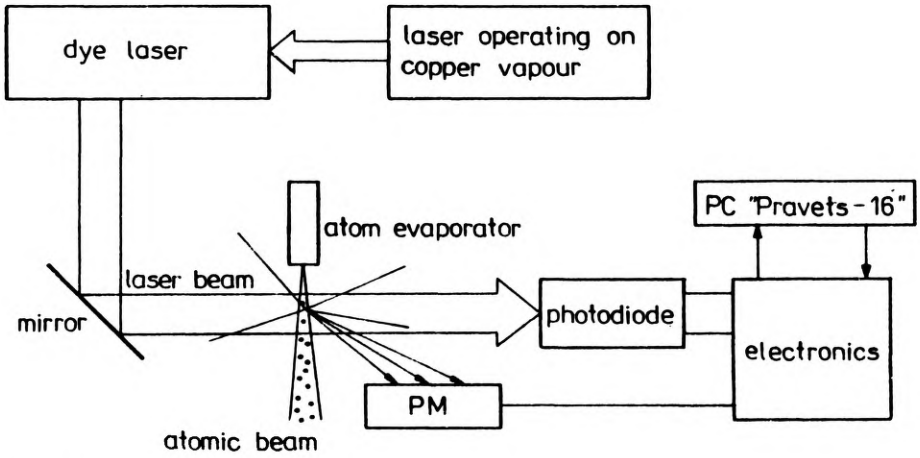

Fig. 1. Functional diagram of the laser spectroscopy

is tunable in a range of 530-710 nm, whereas the maximum range of continuous scanning is 2 cm^{-1} (60 GHz). The dispersion element consists of a diffraction grating causing both wavelength selection and a narrowing of the line generated by the dye [4]. To obtain a narrower line of 0.03 cm^{-1} (1.1 GHz) width, a Fabry-Perot interferometer is inserted into the cavity the rotation of which is synchronized with that of the grating. The coefficient of radiation intensity conversion varies from one dye to another; as a rule, it equals no more than 10%, attaining maximally 20% only in the case of the dye R6G. The pulse duration of laser generation dye amounted to 20 ns at the most.

The method of measurement of the atomic spectra is based on resonance fluorescence from the atoms under the action of the laser radiation. We measure the intensity of scattered laser radiation as a function of its wavelength. An interaction of the laser radiation and the atomic beam takes place in the vacuum chamber, evacuated down to a pressure of 10^{-5} mm Hg. The laser beam, 2 mm in diameter, enters the chamber through optical glass windows, disposed at Brewster angle with respect to the beam. The atomic source is situated at a distance of 10 cm from the laser beam and is isolated by a valve gate from the rest of the chamber which is evacuated by a separate pump, so that the samples can be exchanged rapidly in the crucible without impairing the vacuum.

Free atoms emerge as the tantalum crucible is heated. This is achieved either by

light radiation from an AC conducting tungsten spiral (the temperature of the crucible then rises to 1300 °C) or by means of electron bombardment arising due to application of a negative voltage of 300–600 V to a preheated tungsten spiral (the crucible is earthed in this case), giving a maximum temperature of 2100 °C.

The crucible is cylindrical with a diameter of $d = 5$ mm and length $l = 30$ mm,with a thin capillary of $d = 1$ mm and $l = 15$ mm. The choice of the capillary to form the atomic beam was due to the circumstance that if the atomic beam flows freely at $K > 0.3d$ (K – the free path), the beam is formed only at the expense of collisions of the atoms with the wall of the capillary. Hence, the longer the latter, the narrower the directional diagram is and the greater the number of atoms reaching the region of interaction with the laser radiation. The above has been confirmed by specially performed measurements of the angular distribution of copper atoms evaporated from the crucible. It has been found that 90% of the atoms were emitted within a body angle of 0.6 sr; this is by one order of magnitude better than for isotropic distribution.

Due to interaction with the laser radiation, the photons of resonance fluorescence arising in transition of the atoms from the excited state to their ground state (during a time of $10^{-6}-10^{8}$ s), are focused by a light collecting system onto the photocathode of a PhM–100. The atomic beam, the laser beam, and the PhM-axis are positioned mutually at right angles with respect to each other.

The light collector consists of a spherical and an ellipsoidal mirror. The radius of the sphere amounted to 37 mm while the interfocal distance of the ellipsoid – to 52 mm. The centre of the sphere, one of the focuses of the ellipsoid, and the region of interaction, coincide. The light collected concentrates in the other focus of the ellipsoid. This construction ensures the collection of 60% of the photons. The PhM–100 has a quantum efficiency of 5–7 within the 560–590 nm range of the R6G dye and operates in a single photon counting regime. The pulse duration taken from the PhM anode amounted to about 10 ns.

The resonance fluorescence is recorded with a delay of 20 ns after the passage of the laser pulse. This delay is necessary in order to exclude the recording of photons coming from the laser flash and to record only photons from atomic transitions. The recording time is imposed by the duration of the trigger pulse and is determined by the lifetime of the atomic level excited. Usually, it amounts to 0.1–1.0 μs, permitting an essential (by a factor of some tens) lowering of the background radiation from the hot crucible. The diameter of the sensitive zone of the PhM amounted to 9 mm. In front of the PhM window a filter was placed, made of volume 05–12 glass which cut off the short wave part of the spectrum at 530 nm.

While the laser wavelength varied continuously, the spectra (the dependence of the fluorescence intensity of the atoms on the laser wavelength) were taken in multiscalar regime of photon conducting. The control of the experiment and collection of the data were carried out on the basis of PC of the Pravets–16 type.

Gross tuning of the dye laser to the required wavelength was carried out with a photodiffraction spectrometer and a lamp with hollow cathode made of the

element under investigation. Fine tuning has a recourse to the optogalvanic effect in the lamp (the rise in discharge resonance).

3. Testing measurements

In order to tune the device and optimize its regime of operation, we performed measurements of the spectra of neutral europium atoms on a wavelength of 576 nm, using samples of metallic Eu and its oxide Eu_2O_3 weighing altogether up to 30 pg (10^{11} atoms). The oxide samples were prepared by putting a drop of the respective solution of a well known concentration upon the tantalum foil and subsequent annealing.

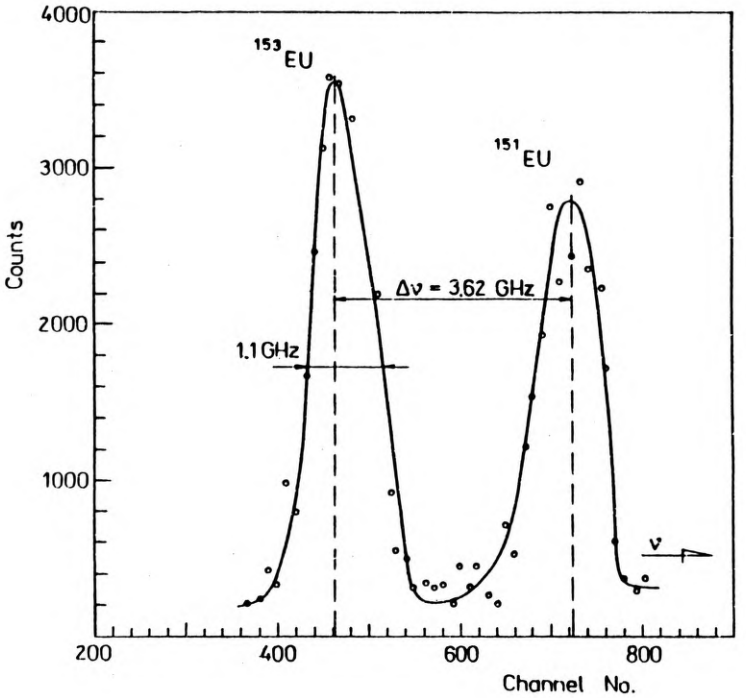

Fig. 2. Optical spectrum of natural Eu mixture, at a laser wavelength $\lambda = 576.5$ nm

One of the Eu spectra measured by us is shown in Figure 2. It exhibits peaks, corresponding to the isotopes ^{151}Eu and ^{153}Eu (their content in the natural mixture amounted to 48% and 52%, respectively). From the available isotopic shift of Eu, equal to 3.62 GHz[5] on its 576 nm line, we determined the laser linewidth as 1.1 GHz (its Doppler broadening does not exceed 50 MHz), characterizing the frequency resolution of our setup. Notwithstanding the fact that this resolution is considerably worse than that for continuously operating lasers, it is fully adequate for the resolution of lines from different isotopes and hyperfine components of various elements (lanthanides, actinides, as well as heavy basic and basic-earth ones).

4. Conclusions

The sensitivity of our setup (the minimal recordable flow of atoms outgoing from the crucible) is determined by a number of factors, such as:

1. The fraction of atoms reaching the region of interaction with the laser beam (it makes 5.10^{-4}).

2. The fraction of atoms traversing that region throughout the duration of the laser pulse (4.10^{-2}).

3. The effectiveness in recording the resonantly scattered photons ($3{\cdot}10^{-2}$).

4. The fraction of atoms being in that quantum state, during excitation (it is dependent on the system of the atomic levels, in the case of Eu it amounts to 0.3).

5. The background level (being dependent on the temperature of the crucible, at $T \approx 1400$ °C it does not exceed 1 pulse/s).

With these parameters our setup permits measurements to be performed on sufficiently weak atomic beams (e.g., in the case of Eu down to beams with as few as 10^7 atoms/s).This minimal beam intensity can be further lowered by several orders of magnitude in the case of elements that evaporate at lower temperatures and allow the crucible to be placed closer to the region of interaction with the laser beam.

Thus, we hope to have shown that the setup proposed and checked by us enables the obtaining of promising results when it comes to solving a wide range of problems, comprising the determination of the isotopic contents in various samples as well as the measurement of optical spectra from atoms with radioactive nuclei arising in low yield reactions, and others. Moreover, the applicability of our device can be easily extended to the study of molecular beams.

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