Laser detection of single atom fluorescence

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The intensity of a beam of sodium atoms was measured by a procedure in which the fluorescence signal of a single atom was detected and resolved. The minimum observable flux is 10 atoms/sec, corresponding to 10^{-4} atoms in the recording region.

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1. We report here, for the first time that a near-maximum sensitivity has been reached in the detection of atoms by an optical method; this sensitivity corresponds to observation of sodium atoms in an atomic beam of intensity 10 atoms per second, the equivalent to an average of 10^{-4} atoms in the recording region. The experiment is based on the well-known method of resonance flurescence,[1–4] using a new procedure for obtaining and resolving the fluorescence signal from a single atom. The method consists of receiving the fluorescence signal from two independent photodetectors and recording their coincidences so as to discriminate acts of scattering by a single atom against the background of the scattered light.

2. The experimental setup is illustrated in Fig. 1. The sodium atoms were excited with a Spectro-Physics M375 cw dye laser, with a Fabry-Perot interferometer, in the form of a plane-parallel glass plate 2 mm thick, placed in its resonator to narrow down the lasing line. The lasing line width was 0.16 cm^{-1}. Using the fluorescence signal from a control cell (15 in Fig. 1), the laser wavelength was tuned to the sodium D_1 line. The laser beam was directed into a cell (3) in which a sodium oven (16) was mounted. The oven temperature was varied in our experiment from 45 to 90 °C. The sodium-atom beam intersected the laser beam (0.57 mm dia) at an angle 8°. The cell construction was such as to provide maximum elimination of the scattered laser light. The cell was evacuated to 10^{-4} Torr. The resonance-fluorescence signal was registered simultaneously by two FÉU-79 photomultipliers (4). The counting rate of the photons recorded by the photomultipliers was measured with rate meters in each individual channel as well as after the coincidence circuit. The discrimination level was chosen such as to record only single-electron and multielectron pulses.

3. Figure 2 shows the change of the pulse counting rate in one channel (upper curve) and after the coincidence circuit with increasing laser-beam intensity, keeping the flux of atoms constant.

The counting rate of the pulses from sodium atoms, whether in one channel or in coincidence,

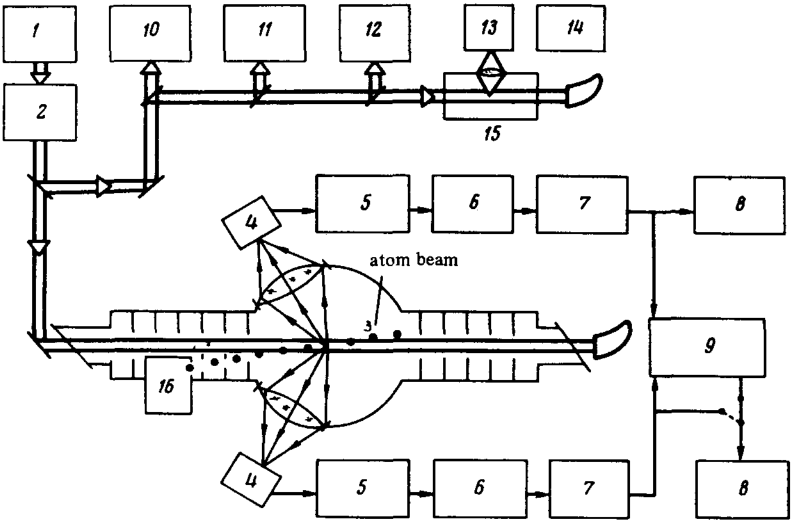

FIG. 1. Diagram of experimental setup: 1—Ar II laser; 2—cw dye laser; 3—cell; 4,13—photomultipliers; 5—amplifier; 6—discriminator; 7—pulse shaper; 8—rate meter; 9—coincidence circuit; 10—spectrometer; 11—Fabry-Perot interferometer; 12—power meter; 14—oscilloscope; 15—control cell with sodium vapor; 16—oven.

was obtained by subtracting the counting rate for pulses due to the laser radiation scattered by the cell and the dark background of the photomultiplier (in this case the laser frequency was tuned off resonance). As seen from Fig. 2, at a laser-radiation intensity in excess of 20 W/cm^2, which exceeds the intensity for saturation of the D_1 transition of the sodium atom, the counting rates of the pulses in the individual channels and past the coincidence circuit become equal. Thus, during the time of flightof the atom across the beam (20 μsec) a signal is produced simultaneously in the two photomultipliers. Under operating conditions when the signal rate is low, this corresponds to recording the emission from one atom. Each atom interacting with the radiation is therefore

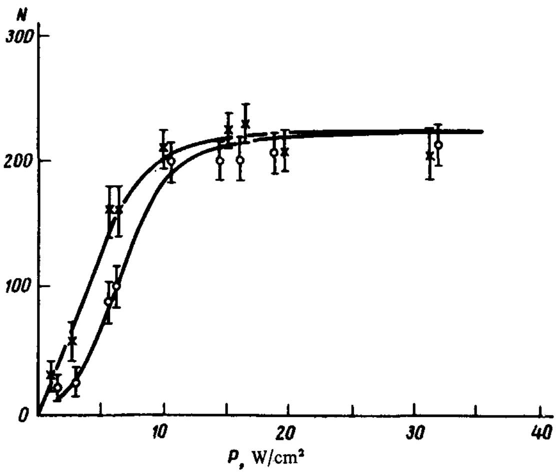

FIG. 2. Counting rate of the pulses from the sodium atom when the laser intensity is varied: crosses—in a single channel, circles—in coincidence.

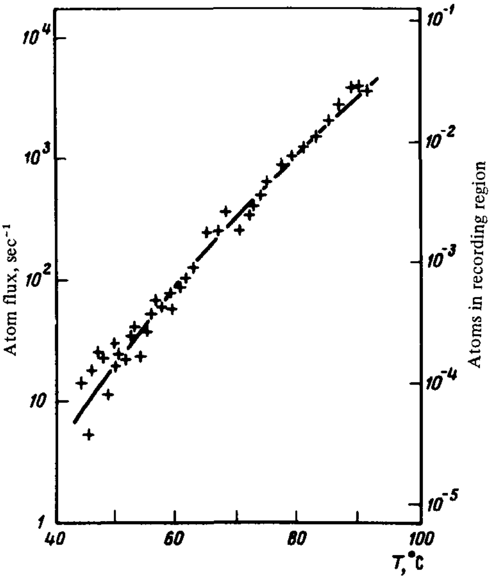

FIG. 3. Dependence of the flux of the interacting sodium atoms on the oven temperature; right-hand scale—number of sodium atoms in the registration zone.

accounted for by the recording system. In the case shown in Fig. 1, the flux of such atoms was 210 atoms/sec. The error was determined by the fluctuations of the light scattered by the cell.

We investigated in the experiment the dependence on over temperature coincidence of the counting rate at a laser intensity 20 W/cm^2 (in this case the pulse counting rate equals the flux of interacting atoms). This dependence is shown in Fig. 3. The left-hand ordinate scale measures the flux of sodium atoms interacting with radiation, and the right-hand ordinate the number of these atoms in the recording region. The minimum observed flux of atoms through the recording regions was about 10 atoms/sec, and the minimum detectable number of atoms in the interaction region was approximately 10^{-4}. The time for recording the flux was 10 sec. The flux of background pulses was 500 per second. The threshold for detection of atoms in our experiments was determined by the fluctuations of the laser radiation scattered by the cell.

4. If the efficiency of collecting the resonantly scattered photons were raised and the quantum yield of the photomultiplier at the registration wavelength increased, it would be possible to obtain from an atom pulses with an amplitude larger than that of the applied illumination pulses, and this would make it possible, by using the procedure developed by us, to record the passage of one atom through the laser beam.

Owing to its high sensitivity, the method can be used to search for superdense nuclei[5] by determining the shift of the absorption line of a single atom, to investigate the structure of isotopic nuclei obtained with accelerators,[5] and for experimental searches for superheavy elements and other atomic or nuclear systems that are available in limited or ultrasmall amounts.

[1]W.M. Fairbank, Jr., T.W. Hänsch, and A.L. Schawlow, J. Opt. Soc. Am. **65**, 199 (1975).
[2]V.I. Balykin, V.S. Letokhov, V.I. Mishin, and V.A. Semchishen, Pis'ma Zh. Eksp. Teor. Fiz. **24**, 475 (1976) [JEPT Lett. **24**, 436 (1976)].
[3]V.S. Letokhov, Usp. Fiz. Nauk **118**, 199 (1976) [Sov. Phys. Usp. **19**, 109 (1976)].
[4]V.S. Letokhov, Laser Spectroscopy, Akademie Verlag, Berlin, 1977.

[5]V.A. Karnaukhov and S.M. Polikanov, Pis'ma Zh. Eksp. Teor. Fiz. **25**, 328 (1977) [JETP Lett. **25**, 304 (1977)].
[6]CERN Courier **17**, N 1/2, 15 (1977).