IV. ATOMIC RESONANCE AND SCATTERING

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A. SUPERRADIANCE AND COHERENCES IN SMALL SYSTEMS

U. S. Air Force Office of Scientific Research (Contract F44620-72-C-0057)

Daniel Kleppner, Theodore W. Ducas, Michael G. Littman, Myron L. Zimmerman

Our investigations of superradiant phenomena in excited complexes of Na_2^* continue. A supersonic atomic beam is being used to reduce the effects of collisions in the sodium vapor. The spectrum and decay rate of fluorescence from pulsed laser-excited Na_2^* is observed over a wide range of wavelengths. Preliminary results indicate the presence of broadband rapid decay (~9-10 ns lifetime) which is characteristic of the desired bound→free superradiant emission. In addition, we have observed lifetimes in bound-bound Na_2 transitions that are shorter than has been predicted. We are studying the detailed spectrum of superradiant emission, as well as bound→bound fluorescence.

B. INVESTIGATIONS OF HIGH-LYING LEVELS OF ATOMS

U. S. Air Force Office of Scientific Research (Contract F44620-72-C-0057)

Daniel Kleppner, Theodore W. Ducas, Richard R. Freeman, Michael G. Littman, Myron L. Zimmerman

We have begun an effort to investigate very high-lying levels of atoms near the ionization limit. These atomic states are interesting because of their large polarizabilities and Stark shifts, low ionization potentials, and large dimensions. Theoretical studies of the properties of these essentially hydrogenic states continue.

The experimental work thus far has been on high Rydberg states of sodium. Two-pulsed tunable dye lasers are used to excite sodium in an atomic beam to the high-lying state in a stepwise fashion ($3s_{1/2} \rightarrow 3p \rightarrow ns, nd$). Since the upper levels are so close to the ionization limit, a small pulsed electric field of several hundred volts/cm can be used to ionize the atoms subsequent to their excitation. The detection of these ion signals has enabled us to look at resolved levels up to $n = 40$. In addition to measuring the energies of these levels, we have investigated the ionization process itself. Stark shifts

of the levels in a dc electric field have also been observed. Future plans include performing RF spectroscopy, accessing higher n-levels, and more detailed studies of ionization.

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C. NEW TECHNIQUES FOR DETECTION OF RADIATION

Joint Services Electronics Program (Contract DAAB07-74-C-0630)
U. S. Air Force Office of Scientific Research (Contract F44620-72-C-0057)

Daniel Kleppner, Theodore W. Ducas

A gas of highly excited atoms (see Sec. IV-B) can provide a means of detecting optical, infrared, and microwave radiation with very high efficiency. To establish the feasibility of this detection, investigations of the transition moments to the high levels and of the influence of collisions on high levels are being undertaken. We have already established our ability to ionize high-lying states selectively. For example, the value of the pulsed electric ionizing field can be set to ionize level ns without ionizing level (n-1)s. Also, the large signal strengths that we obtain from detecting ions make further work in this area very promising.

D. OPTICAL FREQUENCY STANDARD

Joint Services Electronics Program (Contract DAAB07-74-C-0630)

Riad N. Ahmad, David E. Pritchard

1. Introduction

Single-mode tunable lasers such as the one recently developed by S. Ezekiel and his co-workers[1] are ideal sources of monochromatic radiation of extremely high spectral purity at optical frequencies. For many applications in the areas of spectroscopy, communication, and metrology, these sources must also possess the ability to sweep frequency smoothly, and some system must be devised to measure the frequency of the light with high accuracy. To achieve these objectives at reasonable expense, we chose to modify a commercially available tunable dye laser and to develop a system based on interferometric techniques to measure the frequency.

2. Frequency Generator

The laser source is a Model 580 Spectra-Physics cw dye laser system which includes a pump laser (argon ion laser) and a tunable dye laser. The tunable dye laser is constrained to operate on a single mode by three different independent adjustments:

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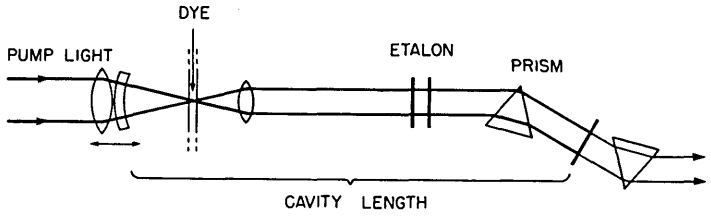

Fig. IV-1. Tunable dye laser showing prism, etalon, and cavity length adjustments.

the prism, the intracavity etalon, and the cavity length. These tuning elements provide coarse, medium, and fine frequency adjustments, and can change the frequency by 1500, 5, and .015 cm^{-1}, respectively (1 cm^{-1} = 0.3 Å at the frequency of the laser). (See Fig. IV-1.)

In order to sweep the laser frequency smoothly, the three tuning elements must be adjusted in coordination. A sawtooth waveform is applied to the piezoelectric transducer that controls the cavity length. The central frequency of the etalon is then locked to the cavity length by a phase-sensitive feedback loop. The time constant of this loop is chosen so that the etalon does not follow the flyback of the cavity length sawtooth modulation. Thus the laser frequency suffers no change when this flyback occurs if the amplitude of the length modulation is exactly a half-wavelength, as it is adjusted to be.

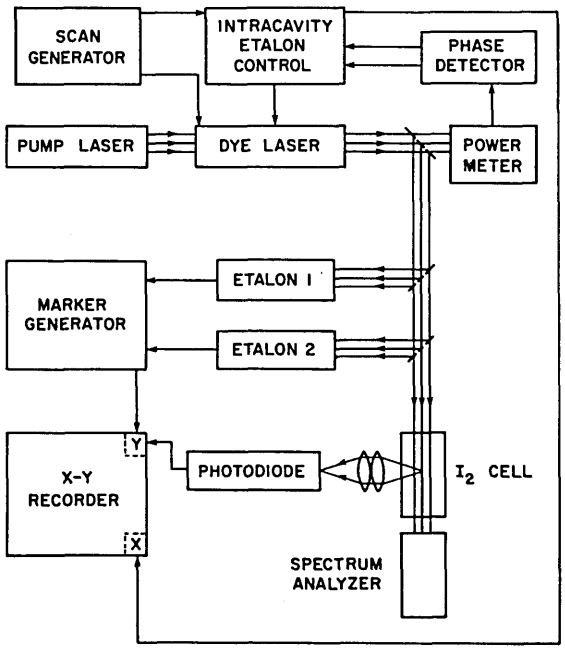

Fig. IV-2. Laser frequency generator system and frequency measurement system used to measure I_2 spectrum.

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The prism is driven in proportion to the etalon so that it stays in step with the smooth scan. The experimental arrangement is shown in Fig. IV-2. We have been able to sweep the frequency continuously over more than 9 cm^{-1} (~2 Å) when using this system.

3. Frequency Measurement System

The frequency measurement system has several etalons. Each etalon transmits light only at a series of evenly spaced frequencies (modes) whose separation is called the free spectral range of the etalon. As the laser frequency is swept, each etalon will transmit light in a series of pulses that indicate when the laser frequency passes through the transmission peaks of that etalon. These pulses (suitably processed electronically) can serve as frequency reference marker pulses.

There is no way of determining the mode number associated with a particular transmission peak of an etalon. Hence, in order to measure frequency absolutely, it is necessary to use a series of etalons of successively smaller free spectral ranges, with each etalon serving to determine the mode number of the etalon with the next smaller free spectral range. In our present system we use the dial calibration of the laser prism adjustment to identify the mode number of the intracavity etalon, and then use this etalon to identify the mode number of two finer etalons which comprise the rest of the frequency reference system. These etalons, which are located outside the cavity (see Fig. IV-2), have free spectral ranges of 0.8 and 0.08 cm^{-1} and should ultimately be able to measure the laser frequency with an accuracy of 0.002 cm^{-1} (60 MHz).

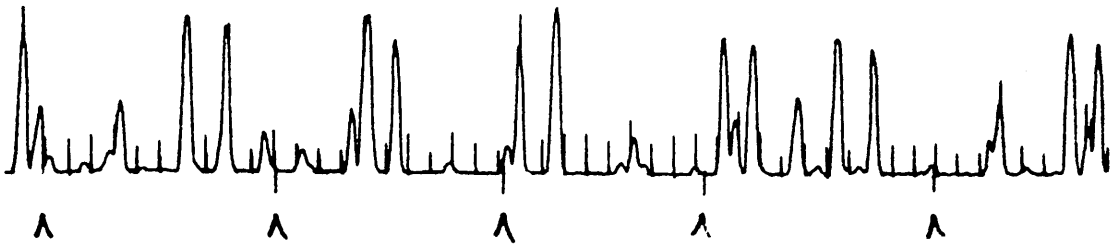

Fig. IV-3. I_2 absorption spectrum showing frequency markers.

Figure IV-3 shows a portion of the I_2 fluorescence spectrum between 16961 and 16965 cm^{-1}. These data were obtained by shining the laser into a small cell containing I_2 vapor and measuring the fluorescence with a photodiode. The 0.8 cm^{-1} marker pulses are negative and the 0.08 cm^{-1} marker pulses are positive. The width of the iodine fluorescence lines results from Doppler broadening and hyperfine structure of the lines; the spectral width of the laser is approximately 50 times less than this width.

We are now studying the reproducibility of the frequency markers relative to a stable spectrum. Once we have attained good day-to-day stability of the frequency

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marker system we should be able to calibrate this system and to use it in further investigations. JSEP

References

1. R. E. Grove, F. Y. Wu, and S. Ezekiel, "Frequency Stabilization of a cw Dye Laser," Opt. Eng. 13, 531-533 (1974). JSEP