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Authors

Hadeishi, Tetsuo
Neirenberg, William A.

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Tetsuo Hadeishi and William A. Nierenberg

April 8, 1965

Direct Observation of Quantum Beats
Due to Coherent Excitation
of Nondegenerate Excited States
by Pulsed Electron Impact*

Tetsuo Hadeishi and William A. Nierenberg[†]

Lawrence Radiation Laboratory
University of California
Berkeley, California

April 8, 1965

We have observed a modulation of exponential decay of resonance luminescence arising from the interference of coherently excited non-degenerate states $m_J = +1$ and -1 of 7^3P_1 of Cd excited by a sharply pulsed electron impact. The excitation by a sharply pulsed electron impact whose pulse width is much shorter than the lifetimes of the excited states enabled us to observe directly the consequence of atomic fluorescence decay. Similar results were observed by Aleksandrov by means of a modulated electron-beam excitation rather than a single pulsed excitation.¹ Also, the coherent excitation of nondegenerate states by optical excitation was recently observed by various authors.²⁻⁴ We believe that this is the first time that the modulation of the exponential decay of the resonance luminescence was observed directly by pulsed-electron-impact excitation.

Breit has shown a possibility of coherent excitation of nondegenerate sublevels if the exciting resonance radiation is pulsed in time much shorter than the decay time of the excited states,⁵ since under this condition the exciting light has a very broad range of spectral frequencies. Similar excitation is possible by a pulsed electron impact since the electron, with its energy corresponding to the energy of the threshold of excitation, can excite the atom in a time of the order of 10^{-16} sec, if we assume an electron speed of 10^8 cm/sec and an atomic diameter of about 10^{-8} cm.

In the case of Cd whose ground state is 7^1S_0 and whose excited state is 7^3P_1 , the $m_J = +1$ and -1 states of 7^3P_1 can be coherently excited when the direction of the propagation of the exciting electron is perpendicular to the externally applied magnetic field at the excitation energy slightly above the threshold of excitation. Under such excitation the probability of photon emission is described by a damped-oscillator-type function^{1, 5, 6} $e^{-t/\tau} \{A + B [\cos (\Omega t + \phi)]\}$, where A, B, and ϕ are time-independent constants, τ is the lifetime of the excited state, and $\Omega = |E_2 - E_1| / \hbar$, with E_2 and E_1 being the energy of the $m_J = +1$ and -1 states of 7^3P_1 , respectively.

A Pierce-type electron gun using an impregnated dispenser-type cathode was constructed. With the energy near the threshold of excitation the electron current was quite low, resulting in a very low photon flux. Therefore, the photon counting technique was employed. The well-distilled Cd metal was sealed into the envelope of the electron gun, which is enclosed in an oven with a quartz window. The electron gun was operated at an oven temperature of about 200° C. A solution of 14 g of nickel sulfate and 10 g of cobalt sulfate in 100 cc of water with a Corning glass filter type 7-54 was used to filter the λ_{3261} resonance luminescence corresponding to the 7^3P_1 to 7^1S_0 transition. This filter combination had a bandpass width of 200 Å centered at 3200 Å and was quite effective in blocking off the light radiating from the cathode.

The electron pulse was obtained by pulsing the grid of the electron gun, whose pulse width is about 5 nsec.

The λ_{3261} photons were detected through filters and a Glan-Thompson quartz polarizer by a RCA type-1P28 photomultiplier tube. To observe the quantum-beats phenomena, we used a multi-channel delayed-coincidence analyzer to measure the arrival time of photons

following the pulse applied to the grid of the electron gun.⁷ The electron gun was pulsed at the rate of 10 kc/sec. The count rate was very low, so that the probability of two photons arriving during the duty cycle of the time-to-height converter was negligible. The schematic of the apparatus is shown in Fig. 1.

Figure 2 shows the effect of quantum beats at 0.88 gauss. The data-accumulation time, because of the low count rate, was 10 h. The period of oscillation corresponded to 270 nsec, resulting in $g_J = 1.5$. The lifetime measured from the exponential decay is 2.2×10^{-6} sec. Similar results were also observed in the 4^3P_1 state of Zn for the transition between 4^3P_1 and 4^1S_0 at 3076 Å, but with a much weaker signal owing to the lower vapor pressure of Zn. It seems that some interesting application of this type of detection method may be realized in the near future.

We wish to acknowledge the aid of Ron Keller of Huggins Laboratory, Inc. who supplied the parts of the traveling-wave tube and advised us on construction of the electron gun. William Berlund of the Lawrence Radiation Laboratory glass shop constructed the electron gun.

REFERENCES AND FOOTNOTES

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†Present address: Scripps Institution of Oceanography, San Diego, California.

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FIGURE LEGENDS

Fig. 1. Schematic diagram of the apparatus.

Fig. 2. Quantum beats at 0.88 gauss.

Fig. 1

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Fig. 2

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