Title

OBSERVATION OF RESONANCE EFFECT IN MODULATED FLUORESCENT LIGHT FROM COHERENTLY EXCITED 42S1/2 AND 42P1/2 LEVELS IN 4He+

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OBSERVATION OF RESONANCE EFFECT IN MODULATED FLUORESCENT LIGHT FROM COHERENTLY EXCITED $4\ ^2S_{1/2}$ AND $4\ ^2P_{1/2}$ LEVELS IN $^4He^+$

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LAWRENCE RADIATION LABORATORY
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OBSERVATION OF RESONANCE EFFECT IN MODULATED FLUORESCENT LIGHT FROM COHERENTLY EXCITED 4 $^2S_{\frac{1}{2}}$ and 4 $^2P_{\frac{1}{2}}$ LEVELS IN $^4He^+$.*

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Abstract

We have observed a resonance phenomenon in the fluorescent light from $^4He^+$ at a frequency corresponding to the interval between the non-degenerate Zeeman components β and f of the 4 $^2S_{\frac{1}{2}}$ and 4 $^2P_{\frac{1}{2}}$ states excited by an electron beam modulated at the corresponding frequency (uhf-microwave). The observations can be interpreted as "quantum beats". An observation which we recently described in this way is better considered as a time-dependent level-crossing effect.

We recently reported[1] our observation of S-P level crossings by means of detection of variation of the amplitude of modulation of resonance fluorescence as the level-crossing points are swept through by changing the magnetic field. Unfortunately, the words "quantum beats" used in the title was not an appropriate description of the phenomena we reported. The physical basis of the S-P level crossing experiment is related to the differential damping of the excited states in such a way that the amplitude of modulation of the fluorescent light reflects the amount of mixing of the state. More detailed explanation of the mechanism behind the experiment will be reported by Dr. G. W. Series. Recently, it was pointed out by Eck and Huff[2] that Hadeishi's earlier observation[1] of a modulated signal in the region of level-crossing would contain a component originating from the modulation of a D.C. signal. A similar D.C. signal was also observed by L. L. Hatfield and R. H. Hughes.[3]

In this Letter, we shall present experimental observations which represent the real quantum-beats phenomena which can be considered as due to the interference of electromagnetic fields in the spontaneous decay of $^4He^+$ from coherently excited, non-degenerate, states 4 $^2S_{1/2}$ and 4 $^2P_{1/2}$ mixed by a static electric field (the levels β and f of Fig. 2). The states are excited from the ground state of neutral helium atoms by a modulated electron beam. The main interest at the present state of the work is in demonstrating a phenomenon and the experiment in its present form is not a precision measurement. Under these conditions it is predicted (Refs. 1 and 4) that the intensity of the fluorescent light will be given by

$$I(t) \propto B_2 \cos ft + C_2 \sin ft$$

where $B_2 = \dfrac{\frac{\Gamma}{2}}{\left(\frac{\Gamma}{2}\right)^2 + \nu^2}$, $C_2 = \dfrac{\nu}{\left(\frac{\Gamma}{2}\right)^2 + \nu^2}$, $\nu = |q - f|$, the off resonance variable, f is the circular frequency of modulation of the electron beam, and q is the Stark-perturbed interval between the levels β and f.

The experimental observation of I(t) was made by rectification of the photo-current using a superheterodyne technique. Under such detection methods, the signal one expects to observe is given by

$$I(t) = B_2 \cos ft + C_2 \sin ft = \left(B_2^{\,2} + C_2^{\,2}\right)^{1/2} \cos (ft + \phi)$$

and what one measures is the amplitude of oscillation given by

$$\left\{B_2^{\,2} + C_2^{\,2}\right\}^{1/2} = \left\{\left[\frac{\frac{\Gamma}{2}}{\left(\frac{\Gamma}{2}\right)^2 + \nu^2}\right]^2 + \left[\frac{\nu}{\left(\frac{\Gamma}{2}\right)^2 + \nu^2}\right]^2\right\}^{1/2}$$

$$= \left[\frac{1}{\left(\frac{\Gamma}{2}\right)^2 + \nu^2}\right]^{1/2}$$, the square root of a Lorentzian.

Figure 1 shows an experimental arrangement similar to that used in Ref. 1, with the exception of high frequency modulation of the electron beam at uhf to microwave frequency instead of rf frequency ranging from 3 to 60 MHz and modified detection system to detect these high-frequency light beats. In the modulation frequency up to 500 MHz, an inexpensive photomultiplier tube 1P21 operated at the maximum allowable voltage was quite satisfactory. In the microwave frequency region (1 to 2 kMHz) we used a RCA C40045C photomultiplier tube.

Figure 2 shows the relevant energy levels showing the region of the observation of light beats along with a typical experimental result of amplitude variation of high frequency modulated resonance fluorescence (light beats) in uhf region when the Stark effect perturbation

$$\frac{|\langle 4\ ^2S_{1/2},\ m = -1/2|\underset{\sim}{E} \cdot \underset{\sim}{p}|4\ ^2P_{1/2},\ m = -1/2\rangle|}{\hbar} > \frac{\delta}{4}\ .$$

The calculated energy separation between the level β and f corresponding to 416 MHz is about 2.34 kG, using the Lamb shift order of Lea, Leventhal, and Lamb.[5] The light beat, when the electron beam is modulated at 416.47 MHz, occurred at the magnetic field slightly less than 2.34 kG as is shown in Fig. 2. This is due to the repulsion of the energy levels by the Stark effect. Similar phenomena were observed at the higher modulation frequencies up to 1.7 kMHz at the appropriate higher magnetic field values.

We believe that the observations of light beats at high frequency and that of the level-crossing effect we observed in Ref. 1, complete the confirmation of Series' proposal of 1964.[4] At present, we are working on reproduction of the phenomena we reported using the University of Arizona Van de Graaff generator. We expect to observe the variation in the beat frequency first observed by Bashkin[6] as we vary the magnetic field.

I would like to thank Dr. G. W. Series for numerous helps in clarifying interpretation of this experiment and that of the level-crossing experiment we reported previously.

References

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† On leave of absence from Lawrence Radiation Laboratory, Berkeley, California.

1 T. Hadeishi, Phys. Rev. Letters 21, 957 (1968).

2 T. G. Eck and R. J. Huff, Phys. Rev. Letters 22, 319 (1969).

3 L. L. Hatfield and R. H. Hughes, Phys. Rev. 156, 102 (1967).

4 G. W. Series, Phys. Rev. 136, A684 (1964).

5 K. R. Lea, M. Leventhal, W. E. Lamb, Jr., Phys. Rev. Letters 16, 163 (1966).

6 S. Bashkin, W. S. Bickel, D. Fink, and R. K. Wangsness, Phys. Rev. 162, 12 (1965).

Fig. 1. Experimental arrangement. Interference filter with $\lambda = 4685\text{Å}$ was used to detect $n = 4 \rightarrow n = 3$ transitions.

Fig. 2. a) Relevant energy level diagram. The dashed line shows the Stark-shifted energy level when

$$\frac{|\langle 4\ {}^2S_{1/2}\ m = -1/2\,|\underset{\sim}{E} \cdot \underset{\sim}{p}|\,4\ {}^2P_{1/2}\ m = -1/2\rangle|}{\hbar} > \frac{\delta}{4}\text{, when } \underset{\sim}{E}$$

is parallel to the magnetic field, where δ is the difference of damping constant between S and P levels. The arrow indicates the pair of levels that gives the maximum amplitude of light beats shown in (b).

b) A typical experimental observation of the variation of light oscillation (light beats) as a function of the externally applied magnetic field when the electron beam is modulated at 416.47 MHz.

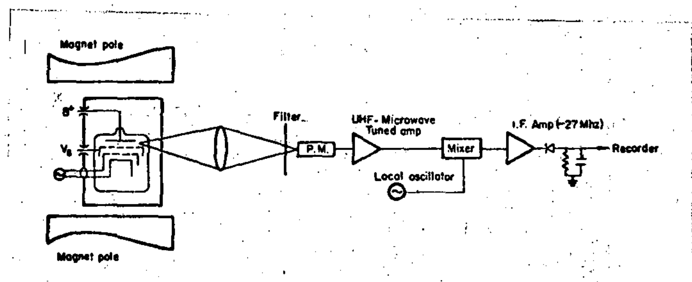

Figure 1

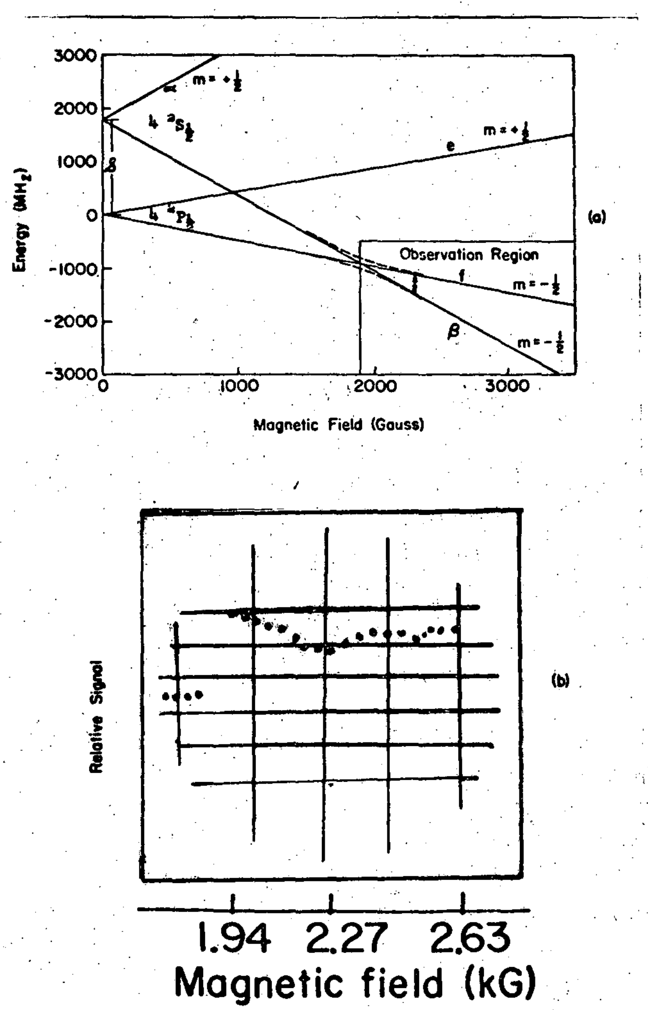

Figure 2

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