Hyperfine Spectrum of Rubidium: optical pumping experiments

Physics 480W
(Dated: Spring 2020)

I. PERSPECTIVE AND OBJECTIVE

This experiment aims to measure a quantum number. Two actually: for each of the two Rb isotopes, ${}^{85}Rb_{37}$, and ${}^{87}Rb_{37}$, we determine the nuclear spin, $\mathbf{I}$; really just I. It is important to distinguish between the vector, which has a quantum operator associated with it, and the quantum number I associated with the operator. How is the experiment designed to do this? From a modeling point of view, a perturbation to the equilibrium helps us, the so-called hyperfine perturbation, which 'couples' two angular momenta, $\mathbf{I}$ and the total angular momentum of the optically active electron, $\mathbf{J}$. The perturbing Hamiltonian may be written, $H_{hf} = A\mathbf{I}\cdot\mathbf{J}$, which represents the (tiny) extra trouble given to the Rb atom's energy eigenstates because of the magnetic moment of the nucleus. We recall that in quantum theory, a magnetic moment also entails an associated mechanical angular momentum (think of the gyromagnetic ratio of the electon or proton), and so spin angular momenta may sometimes be used as a theoretical proxy for magnetic effects. This magnetic perturbation then involves quantum addition of angular momentum, and so a new angular momentum is important, $\mathbf{F} = \mathbf{J} + \mathbf{I}$. The hyperfine spectrum of a spectral line then provides a way of determining the magnetic moment and angular momentum of a nucleus.

Obviously we are not connecting all the dots in this brief introduction. But there are two more introductory points to observe (at least). It helps to know that like the spin-orbit effect, the hyperfine Hamiltonian creates a set of degenerate manifolds of states, the kets $|FM_F\rangle$'s, within which the degeneracy may be lifted by subjecting the atom to an external magnetic field, through the Zeeman effect. Transitions between the M_F states may be effected by energies of order $10^{-9}eV$, whereas the transition creating the optical spectra line (said to possess hyperfine structure) itself has a term energy difference of about 1.5eV, so any experimental technique able to produce these minuscule transitions cleanly has enormously high resolution. [e.g., see figure 1]). The readings below are critical for grasping the experimental situation in the lab. Use these readings to prepare yourself for the first tutorial session prior to and subsequently after the first lab meeting.

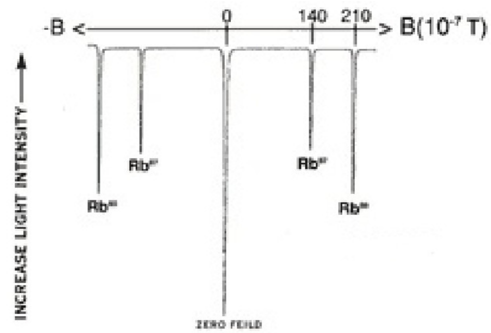

FIG. 1. This plot of detector signal vs. magnetic field demonstrates optical pumping for zero and very low magnetic fields. Both the Rb^{85} and Rb^{87} isotopes produce only unresolved single lines in these low fields. Which dip is which, and according to theory, what must be the frequency of excitation to produce these dips?

II. PRE-TUTORIAL AND PRE-LAB READINGS

1. TEXT[1]
   (a) Ch6.1-6.3, and 6.6, while not directly about Optical pumping, nevertheless provide a good discussion of atomic energy states directly related to our experiment, and to the Rubidium neutral atomic ground state in particular.
   (b) Section 3.3 Help with DAQ and DSO's, (data acquisition, digital storage oscilloscopes, respectively)
   (c) Section 10.3,10.4 Data fitting, and experimental uncertainty (help with, though we will adopt different conventions), and error propagation
   (d) Appendix B: Brief Matlab introduction, somewhat dated, but still useful
   (e) view "Introduction to Fitteia" video
2. Manuals[2]
   (a) The Optical Pumping manual. You will want to read the introduction and theory sections. It may then make sense to read the experiment description sections (4-B and 4-C in our case) first, and then go back to the apparatus sections (sections in Chapter 3). A nice overview of this particular experiment can be found on-line at TeachSpin's website, `http://www.teachspin.com`, and follow the links to the optical pumping apparatus, and particularly take note of 'the conceptual tour'. Review this as well.
   (b) Gaussmeter manual.
   (c) TEKTRONIX tds2XX manual.
   (d) 480WDataAcquisition, version 3 (find this too on our public course site).
3. From the research literature
   (a) A. Kastler, *Optical Methods for Studying Hertzian Resonances,* Science, New Series, Vol. 158, (1967), pp. 214-221
   (b) R. Benumof, *Optical Pumping Theory and Experiments,* American Journal of Physics 33, 151 (1965)

(c) W. Happer, *Optical Pumping,* Rev. Mod. Phys., Vol. 44, 162-249 (1972)

III. PROCEDURE

We will do the experiments described in sections 4-B, and 4-C. Note well, although it must be reported, finding g_F is *not* a primary result. The primary result is I.

IV. TUTORIAL QUESTIONS

These are found on our public course web site. You are responsible for all of them! There will not be sufficient time in any single tutorial session to discuss them all, so for the sake of definiteness, be ready to stand and deliver on the first 10 tutorial questions for optical pumping at the first tutorial meeting of the semester (especially this business of 'good' quantum numbers, how to get the data in the first place.

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[1] A.C. Melissinos Jim Napolitano, *Experiments in Modern Physics*, 2nd. Ed., Elsevier Science (USA), 2003; see Chapter 6, sections 1-4.

[2] See our BB course site, folder "Some Manuals and Guides".