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The Relaxation Times

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COHERENT POPULATION TRAPPING

'Quantum Fun' with your Diode Laser Apparatus

Although the manual for the Diode Laser Spectroscopy (DLS1-A) apparatus outlines more experiments than most students can possibly carry out in the time they are allotted, we have uncovered an entirely new class of experiments which can be done with essentially the same equipment. They all fall under the category of what is called in the research literature 'Coherent Population Trapping' (CPT). This is currently one of the 'hot' areas of optical and atomic physics research. Your students should have some 'Quantum Fun' examining this phenomenon. All you need is TeachSpin's DLS1-A, and a decent digital frequency synthesizer that will sweep frequency with a range up to a few Megahertz.

Coherent Population Trapping occurs in gas samples when there is ***simultaneous excitation of a pair of ground states to a common excited state*** (Figure 2). CPT manifests itself as a resonant change in optical transparency of the gas. CPT has been of growing interest to both the research and technology communities since it was first observed in 1976. It has been extensively studied in alkali atoms as it is related to phenomena like electromagnetically induced transparency and absorption, sub-recoil laser cooling, ultra-low group velocity propagation, and atomic frequency standards. Recent applications of CPT include the chip scale atomic clock made by Symmetricon. Here the two ground states are different hyperfine levels separated by several GHz. See Am.J.Phys. 77, 988-998 (2009).

This newsletter will focus on ground states that are separate Zeeman levels. A good reference for this kind of CPT is 'Two-Color Coherent Population Trapping . . .', Andreeva et.al., Applied Physics B **76**, 661 – 675 (2003). Clearly, this physical phenomenon will find its way into many areas of technology and physics in the future. Perhaps one of your students will discover a new application.

With TeachSpin's DLS1-A, we observed CPT in both isotopes of rubidium vapor, Rb^{85} and Rb^{87}. Recall that the Doppler broadened absorption features for both isotopes can easily be observed in transmission spectroscopy as shown in Figure 1.

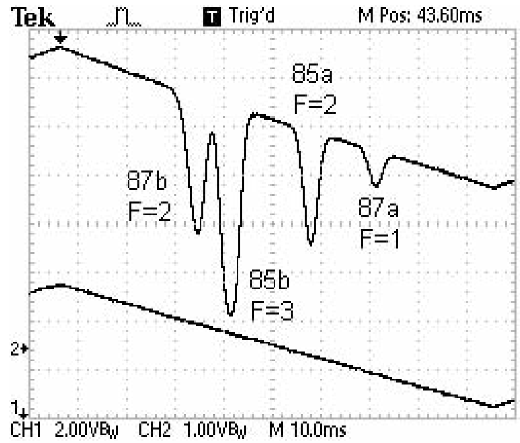


Figure 1. Transmitted light vs. laser frequency

Suppose we consider looking for CPT in the rubidium feature labeled 87a. The simplified energy level diagram showing Zeeman states and CPT transitions is shown in Figure 2.

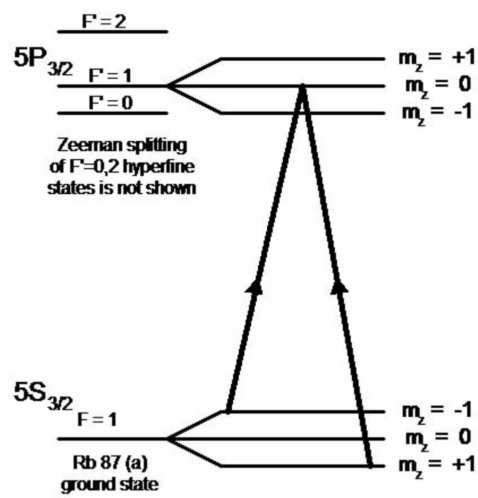


Figure 2. Abbreviated Rb^{87} atomic energy levels

It indicates two simultaneous transitions from two different ground states to a single F' = 1, $m_z = 0$ excited state. These transitions require two different laser light frequencies. (Note: the diagram is ridiculously NOT to scale!)

The two 'colors' of laser light are created by frequency modulating the laser, thus creating sidebands of several orders, the first of which are the frequencies $f_{laser} \pm f_{modulation}$. The DLS1-A is designed for frequency modulation by an external signal generator. A block diagram of the apparatus is shown in Figure 3. Note the 'double mirror' in the lower left hand corner of the diagram. This mirror combination is used to flip the laser polarization so that it is transverse to the magnetic field. This is a necessary condition for detecting CPT.

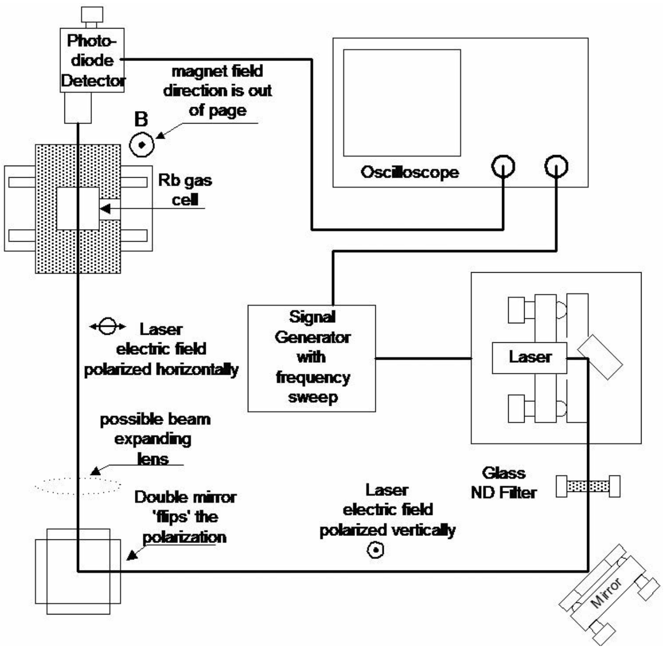


Figure 3. Schematic block diagram of CPT experimental setup

If we 'park' the laser on the Rb^{87}(a) F = 1 transition (see Figure 1, far right) and linearly sweep the modulating frequency from 100 kHz to 1.1 MHz using 70 mV (p-p) into the SMA connector on the laser, we observe CPT features shown in Figure 4. This represents about a 10% change in the optical transmission.

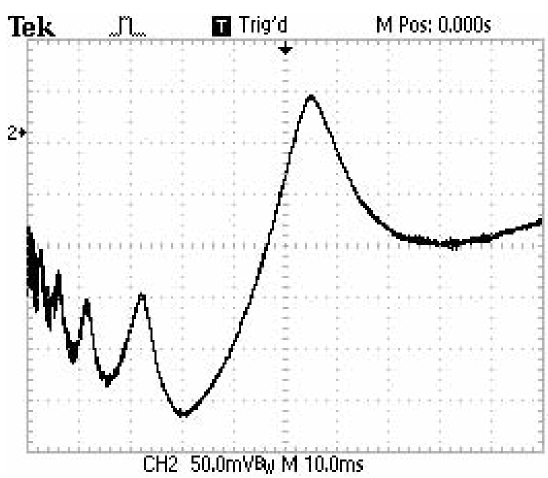


Figure 4. CPT spectrum for Rb^{87} F = 1, Horizontal scale; linear frequency sweep from 100 kHz to 1.1 MHz

'Parking' the laser on the Rb^{87}(b), F = 2 transition, using the same frequency modulation sweep gives inverted features (Figure 5) but with only about 0.5% change in transmission.

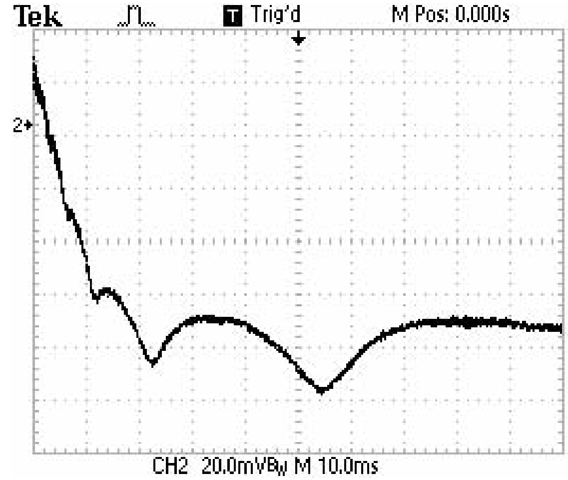


Figure 5. CPT spectrum for Rb^{85} F = 2, Horizontal scale; linear frequency sweep from 100 kHz to 1.1 MHz

Returning to the Rb^{87}(a) F = 1 feature, but using a lens in the laser beam path to expand the beam, we observe a distinctly sharper set of CPT features. This narrowing occurs because the Rb atoms spend a longer time in the laser beam since it is distributed over a larger volume in the vapor cell.

Figure 6 shows the CPT features in two different applied magnetic fields with the expanded laser beam.

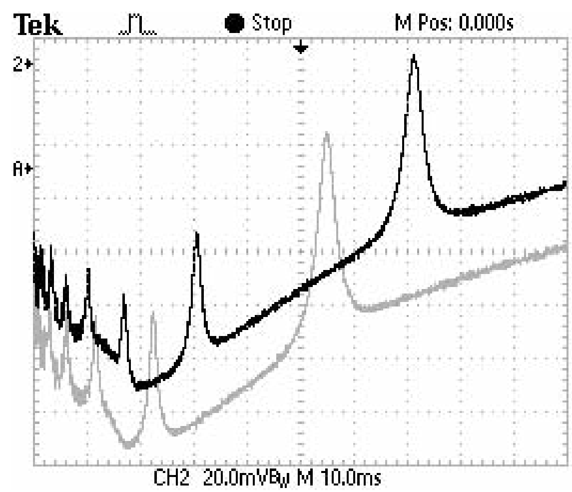


Figure 6. Magnetic field dependence of CPT Spectrum with expanded laser beam. Linear frequency sweep 100 kHz – 1.1 MHz. The gray line represents the Earth's magnetic field and the dark line was taken with an additional applied field.

The experimental parameter 'space' is quite impressive for these CPT measurements. It gives the students a large 'playground' for their 'quantum fun'. Let me just list them below:

1. Two laser frequencies – choice of range
2. Polarization of laser field
   a. Linear
   b. Circular (No CPT signal)

3. Relative polarization between B and E-laser fields. (No signal for B parallel to E)
4. Line width of features – expanded beam
5. Amplitude of modulation
6. Laser power

As you might guess, we here at TeachSpin are also learning about this fascinating quantum phenomenon. Not all the details of the experiments yielding the data we have shown here are included in this article. If you want to have your students try to perform CPT, it might be wise to check with George Herold to fill in some of the gaps. We hope to complete a mini-manual on CPT experiments with our DLS1-A by the summer of 2012. If we don't, bug us! We like hearing from you, no matter what the reason.

AWARD FOR QUANTUM ANALOGS

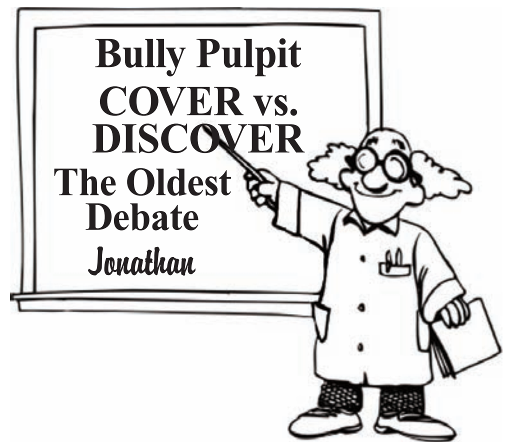
On September 21, 2011, TeachSpin's Quantum Analogs, designed with Pr. Dr. Rene Matzdorf of the University of Kassel, received the first ever Certificate of Quality created to honor and encourage innovative experiments developed in a university setting and made available to the entire advanced laboratory community through a commercial collaboration. Quantum Analogs, with its emphasis on conceptual understanding, as well as theoretical analysis, and an opportunity for open ended exploration, was a perfect fit for TeachSpin.

Receiving Award at PLT 2011

And what makes this award particularly special is that it was presented to an American company by a German physics association, the Arbeitsgruppe Physikalische Praktika, a section of the prestigious German Physical Society or DPG. The certificate, presented by AGPP president Pr. Dr. Ilja Rueckmann, was jointly accepted by Dr. Matzdorf and TeachSpin President Dr. Jonathan Reichert at a special ceremony during the PraktikumsLeiterTagung, which was held this year at the University of Chemnitz.

At the conference, the apparatus was introduced by Dr. Bernd-Uwe Runge of the University of Konstanz, whose students were the first in Germany to use the apparatus. But this was not the first time many of the members were hearing about QA. Dr. Matzdorf had been invited to present a workshop on the instrument at a previous spring meeting of the AGPP which is focused on academic development.

Dr. Runge's 'Lauditorio', which would make even stronger egos blush, is posted on our website. For those of you who do not read German, we've also posted Barbara's rough translation of the student comments which, for us, were incredibly satisfying. This experiment not only helped students get their heads around many abstract aspects of the Schroedinger equation, it also left the students wanting more time to 'play', more time to create and test their own predictions. (Barbara always warns faculty that QA can be addictive!)



Why is there this expensive and time-consuming course in almost all of our curricula, usually called 'The Advanced Lab'? It may also be the most difficult course to teach in the undergraduate program, since it requires both experimental and theoretical skills in many areas of physics, as well as a command of a wide variety of instrumental techniques. Yet, almost all physics programs have some version of an advanced lab because there is a shared vision in the physics community for the goals of this program.

Although I believe we share a common vision for the expected outcomes for our efforts in upper division labs, there are significant differences in the programs offered to our students. This difference is especially obvious with some of our European colleagues. Why is there such a wide range of programs when we have such similar visions for the goals? This question has perplexed me for a long time. Now, I want to share some of my thoughts with you.

Let me begin with two examples that illustrate the variance. School A has purchased the Noise Fundamentals 'kit'. The professor has read the manual, played with the apparatus and has selected four topics to be studied by the students. Using parts of the manual, she has written a student manual appropriate for her students. Students will work with one partner, be required to study the literature, assemble the apparatus, make certain choices of experimental parameters, decide how to organize the data, and are given three weeks, two complete afternoons each week, as well as some off-hours access to the lab, and expected to submit their own individual reports.

School B has purchased the same Noise Fundamentals unit. After studying the apparatus, the faculty member has

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created a student guide, which guides the student through several types of measurements. Students will have one, sometimes two, four-hour sessions to complete their tasks. Typically, the equipment is already assembled, and the required measurements usually outlined. The students rarely have time to play with the equipment or try out some of their own, often crazy, ideas.

As you may suspect, I am not a fan of the School B program, and, as some of you already know, I have challenged some of these programs in discussions with our customers at various conferences and at their own universities. What I hear in response is that they would love to have more time to spend on each experiment, BUT they have so many experiments to cover in the semester, or year, that four hours is all that can be devoted to this topic. The classic 'yes… but' answer.

I could list the goals I believe we share for this program, but that would simply rehash ideas we agree on. I want to explore what I will call the ***basic premise, the starting point*** that each department begins with when conceptualizing this part of its academic program. The starting point is NOT a shared value, as I have witnessed over many years, especially since creating TeachSpin. Here, we have real and important differences, and I would like to strongly argue for one point of view over the other.

Suppose you begin by thinking about all the important experiments you feel your students need to have experienced. You and your colleagues create such a list. Most of us carry one about almost subliminally. There is certainly a long list of classic and modern experiments that would benefit your students. If this is where the discussion begins, if this is your initial premise, you are very likely to become School B.

But suppose you start at a ***different*** point. Suppose one asks 'What is the objective of the advanced lab?'. If the object is to develop experimental scientists, physicists or others, then you will have a different written or mental list. You will want students to develop independence, data organization and analysis skills, mastery of some instrumental techniques, discover the fun of discovery, learn how to support and analyze results, etc. And, if you use certain carefully chosen experiments to teach these skills, that might make a very short list of experiments, with sufficient time allotted for students to develop these skills.

I am not suggesting that students focus on just one or two experiments. I believe that exposure to a variety of areas is important. That is why I think it is important to have an advanced lab, even if students then go on to research experiences. And each area offers an opportunity to explore not only distinct aspects of physics, but also to develop different skill and mind sets.

But, developing these skills takes time! Students need time to do things wrong (without doing too much damage), and time, after finding mistakes, to attempt the experiment again. They need time to develop confidence in experimental skills, time to take ownership, time to choose parameters, time to try their own samples, time to try new ideas, time to try a 'what if?', time to get the thrill of 'discovery'. They need time to try out being an experimental scientist!

I've tried often to make this point to schools that have students doing ten to twelve experiments every semester. The response is usually – 'We agree – BUT. . . '. I ask these faculty to rethink their ***starting point*** *– how you begin the discussion, how you begin conceptualizing the program, determines, to a large extent, the outcome.*

If the choice is to cover or to discover – you know how I would vote!