Forecast:
The Sound and Fury
Signifying Everything

The Relaxation Times

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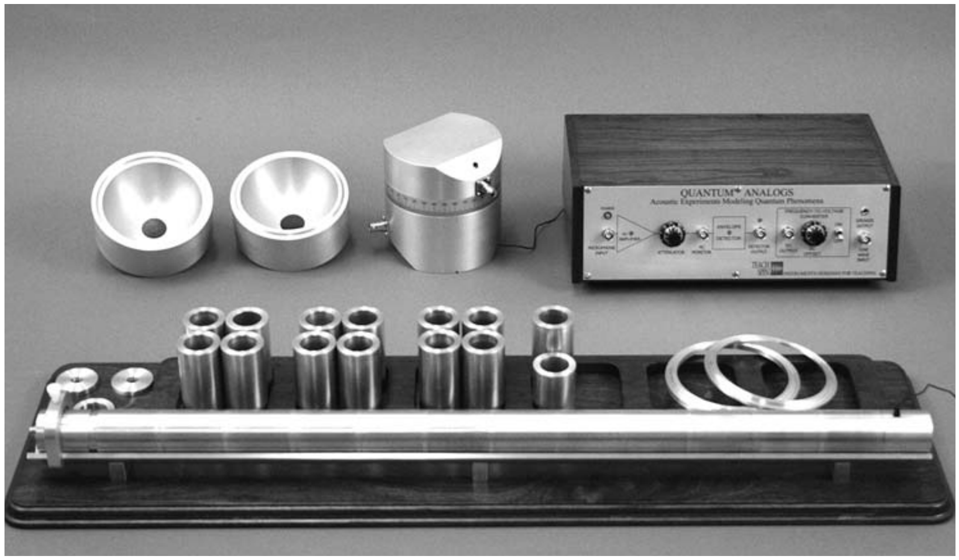
VOL. II No. 12 *NEWSLETTER OF TEACHSPIN, INC.* *FEBRUARY 2008*

QUANTUM ANALOGS

Acoustic Experiments Modeling Quantum Phenomena



Our first European collaboration has all of us at TeachSpin really excited. It is not that this is new physics, but it is a new way to use "old" physics to aid in the teaching of Quantum Mechanics – maybe the most difficult concepts for students to master. Professor Rene Matzdorf came to our booth at the March APS meeting several years ago to inquire if TeachSpin was interested in some sound experiments he had developed for his advanced students at the University of Kassel in Germany. We were more than delighted to learn about Rene's original and creative ideas. His own apparatus was shown at the 2007 DPG meeting in Regensburg and we are now ready to demonstrate the TeachSpin version at the **February DPG meeting in Berlin and the March APS meeting in New Orleans.**

The tag line, "Acoustic Experiments Modeling Quantum Phenomena" best sums up what these new experiments are about. Any one of us who has taught quantum mechanics knows how difficult it is for students to "wrap their heads around" the subtle predictions of this remarkable theory. TeachSpin is now offering real help in the form of a set of hands-on experiments, done on the human scale, that uses audible sound. These sound waves are constrained to propagate in bounded geometries. Let's discuss some highlights of the many experiments that students can perform with this apparatus.

MODELING HYDROGEN

The eigen function solutions to the Schroedinger equation for a radially symmetric potential have a direct mapping to the solutions to the Helmholtz differential equation for sound propagating in a spherical boundary. Our sphere consists of two aluminum hemispheres precisely machined to mate together to form a sphere. The lower half has an imbedded speaker and the upper half a microphone. A signal generator with a 0.1 Hz resolution drives the speaker. The rms amplitude of the amplified signal picked up by the microphone is plotted against the frequency in Figure 2. The eigen values are labeled by two subscripts (n,*l*) corresponding to the quantum numbers of the same notation in the hydrogen atom.

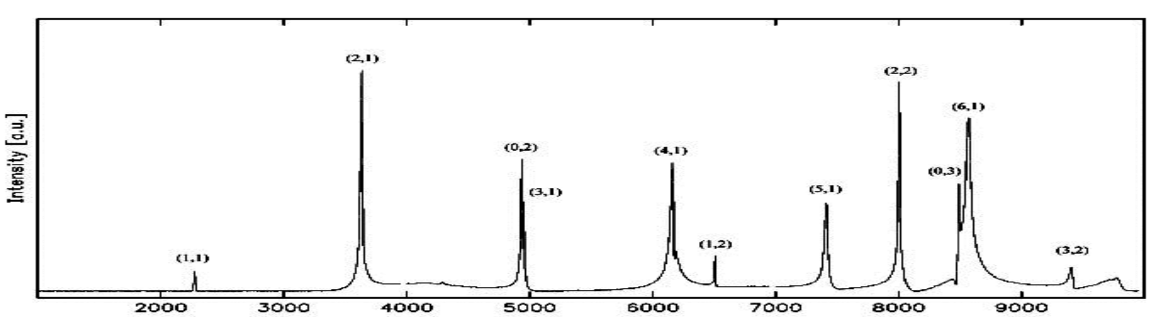


Figure 2: RMS amplitude of microphone signal vs. Frequency

This apparatus allows students to explore the polar angular dependence of any given eigenstate and compare these sonic functions to the wave functions of the hydrogen atom. One example of such a comparison is shown in Figure 3. These measurements are carried out at a fixed frequency. The polar angle is varied by rotating the top hemisphere with respect to the bottom one. One can show that with the speaker placed at 45 degrees with respect to the vertical axis, the polar angle θ is related to the relative angle of the two hemispheres α by the equation:

$$\theta = \arccos(\tfrac{1}{2}\cos\alpha - \tfrac{1}{2})$$

The angular dependence of the Legendre Polynomials that represent these acoustic states can easily be observed by the students. In Figure 3 we have plotted data for the n = 1, *l* = 7, state as dots. The line shows the theoretical expression:

$$P_7(\cos\theta) = \frac{1}{16}(429\cos^7\theta - 693\cos^5\theta + 315\cos^3\theta - 35\cos\theta)$$

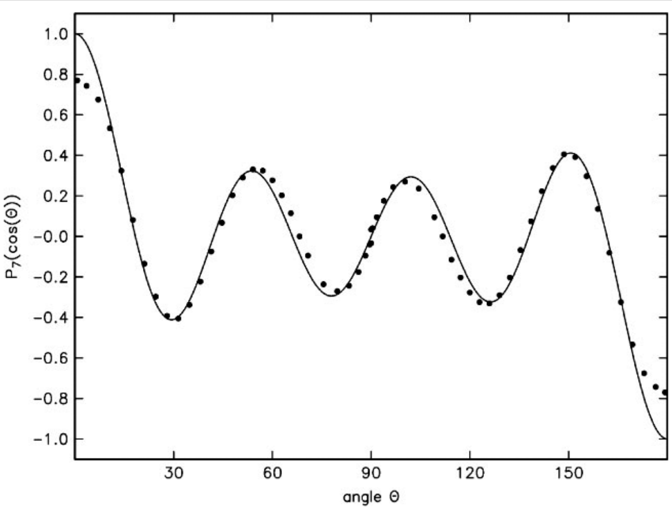


Figure 3: Angular dependence of n = 1, *l* = 1 resonance

In an applied magnetic field, the degeneracy is lifted in some eigen states of the hydrogen atom. For our sonic analog, the degeneracy is lifted by perturbing the spherical symmetry of the cavity.

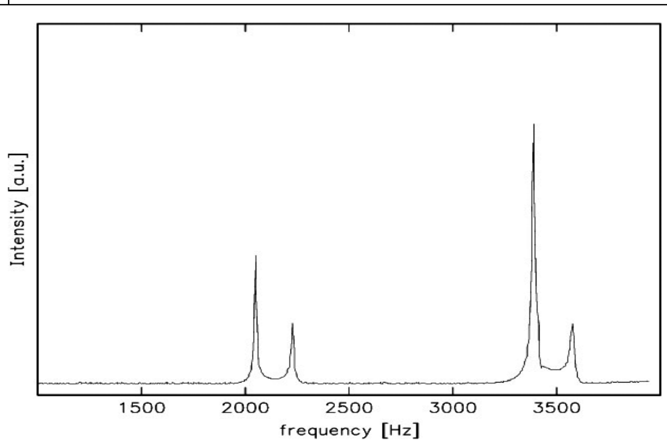


Figure 4: Resonances Split by 10 mm Spacer

This is accomplished by two large spacer rings that fit between the hemispheres. Since the rings have different thicknesses, they can create three different spacings between the hemispheres. Figure 4 shows two resonances which are split by the 10 mm spacer. Students will discover that the splitting is directly proportional the width of the spacers.

THE HYDROGEN MOLECULE

Suppose you were to put two of these "Hydrogen Atoms" together to create a hydrogen molecule. That is what Professor Matzdorf did in a very clever way. If you look carefully at the photograph on the cover page, you will see two hemispheres, each with a large hole in its crown. These hemispheres can be inserted between the hemispheres of the original "atom" to form a diatomic molecule. Changing the size of the iris connecting the two spherical resonators alters the sonic coupling between them. Figure 5 compares a single resonance n = 1, *l* = 1 for the atom to that for the molecule with three different irises.

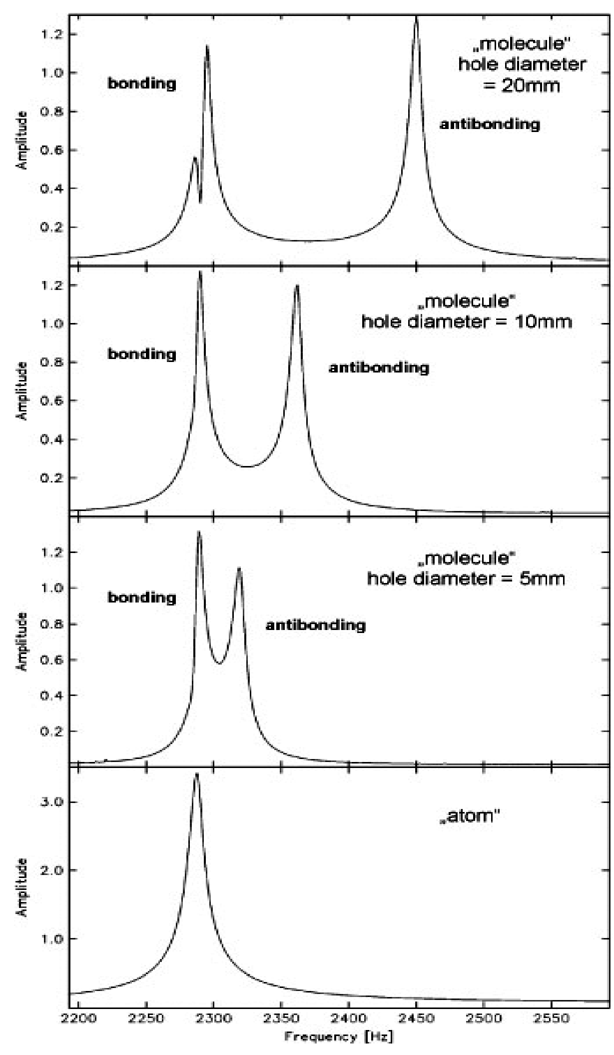


Figure 5: Bonding/Antibonding of n = l, *l* = 1 Resonance for atom and for molecule with 5, 10 and 20 mm irises

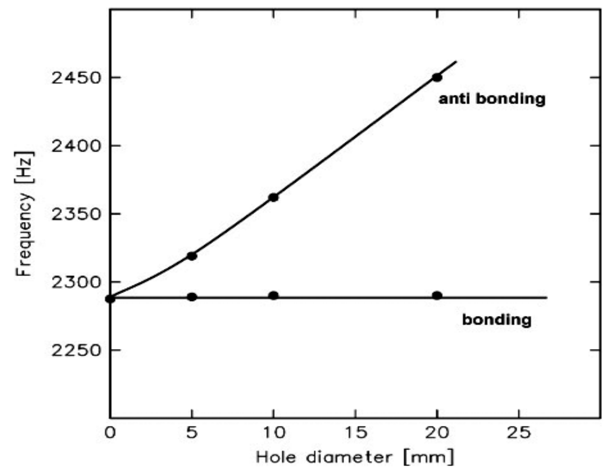


Figure 6: Resonance Frequency vs. Iris Diameter

A plot of the frequency of the resonances as a function of the coupling iris diameter (Figure 6) clearly shows the "bonding" and the "anti-bonding" eigenstates of this synthetic molecule. Again, there is a remarkable analogy to the real quantum mechanical solutions to the hydrogen molecule.

BAND GAPS IN SOLIDS

In condensed matter physics, the periodic potential in a solid plays a crucial role for the electronic structure. The approach to teaching the band structure of an electron in a periodic potential usually starts with a free electron and then introduces a periodic potential, which opens up a band gap. This a general wave phenomenon and not something special to quantum mechanics. Band gaps can be demonstrated with sound waves propagating inside the boundary of a tube by introducing periodic perturbations in the form of irises. The tube is used to provide quasi one-dimensional wave propagation.

The "tube," in our case, is made up of a series of tube sections with irises placed between the sections. The unit comes with three different sizes of irises and two different lengths of tube sections. A speaker is attached at one end, and a microphone at the other. There are many interesting configurations that students can create with these components. Data from one of them is shown in Figure 7.

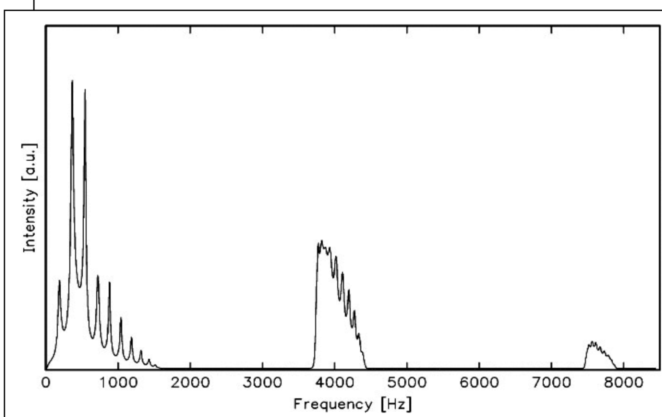


Figure 7: Band Gaps of Sound Intensity vs. Frequency

Professor Rene Matzdorf

Figure 7 shows the transmitted sound intensity as a function of frequency from 0 – 8 kHz. The data clearly shows two major band gaps. The students can rather easily replace the microphone with his or her ear and actually hear (or not hear) the frequency gaps in the spectrum. This can help make the idea of band gaps in the energy spectrum of electrons in solids understandable.

SPEED OF SOUND V. TEMPERATURE

An accurate measurement of the speed of sound as a function of temperature can be made using the single spherical resonator. The large thermal mass of the resonator assures that the gas inside is at the ambient temperature of the resonator.

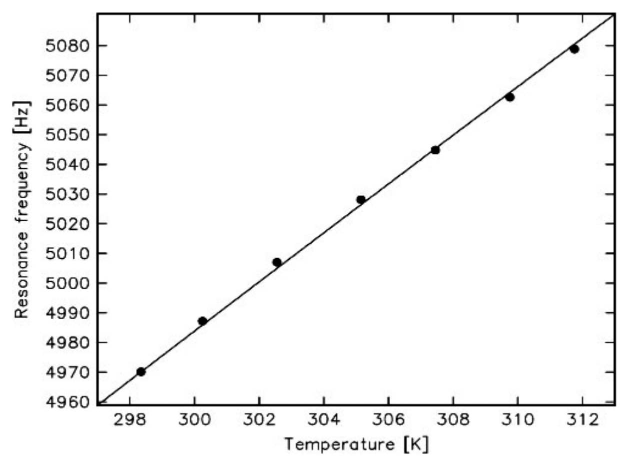


Figure 8: Resonant Frequency of air vs. Sphere Temp.

Figure 8 shows the data for the resonant frequency of air inside the sphere as a function of the temperature of sphere. Over the temperature range shown, the velocity of sound changes from 347.5 to 354.7 m/s with an experimental error of 0.035 m/s.

Let Quantum Analogs enrich your students' understanding of quantum physics.

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ALPHA WANTS YOU! Please join this international effort to support and enhance advanced laboratory instruction You can join ALPHA by contacting any of the officers or going to the Advanced Laboratory Physics Association page on the TeachSpin Website.

The Advanced Laboratory Physics Association (ALPhA) has completed its first elections. Many wonderful people offered to serve this new organization and their expertise and enthusiasm will be recruited as various projects get underway. TeachSpin is proud of the role it was able to play in helping ALPhA get started by contributing over $1,000 in matching funds to its treasury as well as subsidizing the first receptions and providing initial organizational support.

President Gabe Spalding called the first face-face meeting to order on Sunday, January 20 at the AAPT winter meeting in Baltimore and an open gathering was held Monday evening. Board member Dick Peterson reported that ALPhA has been asked to collaborate on the topical meeting on the advanced laboratory which will take place just before the 2009 summer meeting of AAPT to be held at the University of Michigan, Ann Arbor.

ALPhA's mission to be a major advocate for advanced laboratory education will not only serve our TeachSpin constituency well but will also provide a venue through which they can share their own hard-earned expertise. Rather than "reinventing" the wheels of existing experiments, future advanced laboratory practitioners will be adding to the efficacy of those already developed or creating entirely new instruments for students to explore the ever widening range of physical phenomena.

Open Meeting of Advanced Lab Instructors
APS March Meeting – New Orleans
Tuesday, March 11 5:50 – 7:00 pm
Marriott, Bacchus Room