The Quantum Harmonic Oscillator in Uranyl Acetate

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The quantum harmonic oscillator has an evenly spaced energy spectrum. In this lab we will record and fit the flourescent spectrum of Uranyl Acetate which approximates the qauntum harmonic oscillator for its first few energy levels. We then consult the fits to the data to determine whether the spectrum is equally spaced in wavelength or in frequency. This sheds light on the nature of the quantum hypothesis of Planck.

The uranly species in a solid acts like a tightly bound, massive particle (acetate groups or oxygen groups) in a tight harmonic well (by uranium atom) locked in inside the solid lattice. When excited optically the system flouresces as it de-excites. This explains the broad utility of uranyl acetate in the staining and identification of biological specimens. The goal of this lab is to test whether the even spacing of the spectra we find it better understood as even in wavelength or even in frequency and what that determination might indicate about the Planck hypothesis of the quantum nature of the harmonic oscillator. That hypothesis leads to the expectation that the energy levels of the system should be

$$E_n = (n + \frac{1}{2})\hbar\omega \qquad\qquad n \in \mathbf{Z}^+ \tag{1}$$

where

$$\omega = \sqrt{\frac{K}{M}} \tag{2}$$

is the (classical) frequency of the harmonic oscillator. In our experiment the M is (according to Fig.1) the oxygen atom and we can actually use that ultimately to estimate K. But a more basic question is does the explanation of the energy differences as sugested by Eq.1 really comport to reality for this system.

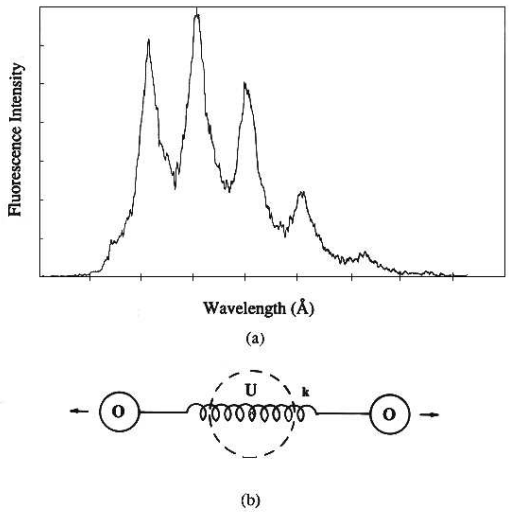

Fig. 1. A uranly flourescence spectrum and the oscillator model.

1. Proceedure:

Our test of this proceeds as follows. Align a pump source (405nm laser or UV diode, but you might for fun try other pumps like the bright 480nm and 532nm sources) and a uranyl-acetate sample and and the high-resolution spectrometer and save a spectrum. You may need to put a longpass filter between the sample and the spectrometer input to kill the pump reflection. The spectrum will contain some number (3-5) peaks called "resonances" associated with energy differences between levels in the uranyl-acetate.

Next fit the spectral peaks, one at a time, ideally with skew gaussians. One skew gaussian form you might try is of the form

$$y(x) = a + e(x - c) + be^{-\frac{(x-c)^2}{2s(s+d(x-c))}} \tag{3}$$

where the fit parameter c is the center wavelength of the resonance, b is the amplitude of the spectral response, d is a skew parameter, s is the spectral width of the resonance and a is an overall constant. You may want to set e to zero when you first fit a peak, as there may be too many parameters with it included which will make convergence to a 'best fit' difficult. The e parameter is meant to account for the slope in the 'pedestal' that the resonances rise out of.

Fit the data for the center wavelength c of each peak. Let peak #1 be the peak with the shortest wavelength and number the wavelengths in increasing wavelength. Then plot that center wavelength c versus the peak number. Fit those data with a straight line.

Next redo the analysis in terms of frequency by fitting $1/c$ versus peak number. Now the #1 peak will be the one with the smallest $1/c$ value. Fit these data with a straight line.

2. Analysis/Discussion:

What does the goodness of the fits for both linefits imply about the Planck quantum hypothesis assuming that the resonance pattern is due to uranyl acetate being pretty close to that of a harmonic oscillator?

Does the pattern change with different pump wavelengths? What can you say/note about the pattern of resonance heights? Widths?

Finally, using the formula Eqs.1 and 2, can you determine a value for the spring constant K? Do you get a reasonable value? Compare it to a typical macroscopic spring.