

**Physics 220, Spring 2009**  
**Lab 6 (or 7): Isotope shift in hydrogen**

**Background:**

The isotope shift is the difference in atomic spectral line wavelength for two isotopes of the same element due in part to their different (finite) nuclear mass, which causes a difference in reduced mass between the two isotopes. We'll look at the spectrum of two hydrogen isotopes, "ordinary" hydrogen ( $^1\text{H}$ ), and deuterium ("heavy hydrogen,"  $^2\text{H}$ ). You'll use a research-grade diffraction grating spectrometer to make the measurement. This is exactly how the  $^2\text{H}$  isotope was discovered (by Harold Urey in 1931, who won the 1934 Nobel Prize in Chemistry for this discovery).

**Prelab questions** (to be done in your lab book):

1. a) TZD section 5.8 discusses the effect of the finite nuclear mass on the atomic energy levels in the Bohr model, and in Example 5.4 calculates the wavelengths of the Balmer  $\alpha$  line for  $^1\text{H}$  and  $^2\text{H}$  to 5 significant digits (note that this example gives  $R$  to six significant figures rather than the three in the inside front cover of the book—you need to use the greater number of significant figures). Calculate the wavelengths for the Balmer  $\beta$  line for these isotopes to five sig figs. Repeat for the Balmer  $\gamma$  line.

b) See Urey's Nobel Prize lecture (online, below) for a table of values that he calculated for use in his experiment. Do your calculations agree with his to 5 sig figs? If not, what's changed since 1934?  
[http://nobelprize.org/nobel\\_prizes/chemistry/laureates/1934/urey-lecture.pdf](http://nobelprize.org/nobel_prizes/chemistry/laureates/1934/urey-lecture.pdf)

c) Which isotope's lines are slightly shorter in wavelength,  $^1\text{H}$  or  $^2\text{H}$ ?

2. Compare the size of the isotope shift for adjacent isotopes of a heavier element to that of hydrogen. Is it easier or harder to measure the isotope shift for hydrogen than it is for heavier elements? Explain your reasoning.

Background and Procedure:

For a diffraction grating in which the incident light is normal to the grating, the maxima in a diffraction pattern are found at  $d \sin \theta = m\lambda$ , where  $d$  is the diffraction grating line spacing and  $m$  is the order number (0, 1, ...). The grating in our spectrometer is in what's called a Littrow mount, which means that the light is incident at an angle  $\theta_i = 18.8^\circ$ , and is diffracted at an angle  $\theta_m \approx -\theta_i$ . In this case, the locations of the maxima are given by

$$d (\sin \theta_i - \sin \theta_m) = m\lambda. \quad (1)$$

Rather than measuring the angles of diffraction directly, we'll measure the difference in angles of the diffracted beams for  $^1\text{H}$  and for  $^2\text{H}$ : that is, we'll measure  $\Delta\theta_m = \theta_m(^1\text{H}) - \theta_m(^2\text{H})$ . Then we can relate this difference in angle to the difference in wavelength  $\Delta\lambda$ ; one way to do this is by finding  $\frac{d\lambda}{d\theta_m}$  (using Eq. (1)) and setting the expression for  $\frac{d\lambda}{d\theta_m}$  equal to  $\frac{\Delta\lambda}{\Delta\theta_m}$ .

**Embedded question:** Use the information given to derive (in your logbook) an expression for  $\frac{d\lambda}{d\theta_m}$  in terms of  $\theta_i$  and  $\lambda$ . Then set it equal to  $\frac{\Delta\lambda}{\Delta\theta_m}$  and rearrange to find an expression for  $\Delta\lambda$ . This is what we are going to determine experimentally.

We'll be using a Jarrell-Ash 3m diffraction grating spectrometer to measure the difference in wavelength between the  $^1\text{H}$  and  $^2\text{H}$  spectral lines. This spectrometer is used in the first order. Two different gratings are available, one with 30000 lines/in and one with 15000 lines/in.

Before actually attempting to measure the isotope shift, we'll verify that our spectrometer is actually capable of resolving the difference between the two wavelengths. The theoretical resolving power of a spectrometer (wavelength divided by smallest resolvable difference in wavelength at that wavelength). is given by  $\mathcal{R} = \frac{\lambda}{(\Delta\lambda)_{min}} = mN$ , where N is the number of illuminated lines of the grating and m is the order number of the diffraction.

Make the appropriate measurements to determine the resolving power of the spectrometer. Record in your lab book what measurements you made, how you made them, and then use them to calculate the resolving power. Then, based on the value you obtained for the resolving power and your calculations of the wavelength differences, show (by calculation) whether you expect to be able to observe the separation (wavelength distance) between the  $^1\text{H}$  and  $^2\text{H}$  lines for the first three lines ( $\alpha$ ,  $\beta$ ,  $\gamma$ ) of the Balmer sequence.

Assuming you've concluded that the isotope shift can be measured, we'll now measure it. For at least one of the lines (discuss with me which one to use), make the measurements needed to determine the isotope shift. Do this in a way that allows you to estimate the uncertainty in your result. Again, record your detailed procedure. Compare your measured value (with uncertainty) to your calculated value. Comment on the agreement.

Congratulations! You've discovered deuterium!