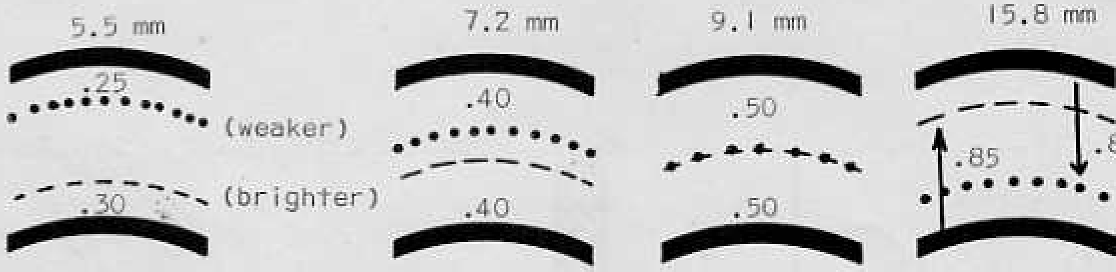
accomplished by carefully laying a millimeter scale across the top of the mirror frames and sighting downward. Parallax errors can be mimimized by moving the head back and forth and taking the scale reading at the point where the mirror surface disappears from the eye's view. With care, accuracies of 0.1 mm can be achieved. Some typical observations appear below.

Mirror Spacing



Portions of two adjacent bright fringes are shown with the relative position of the fainter fringes between them.

<u>Discussion</u>: Mercury in nature consists of about 70% of isotopes having even mass numbers and 30% having odd mass numbers. The hyperfine structure observed here is due to the nuclear spin possessed by the odd isotopes Hg^{199} and Hg^{201}. The energy level diagrams are shown below.

$$\lambda\ 5461\ (6^3P_2 - 7^3S_1)$$

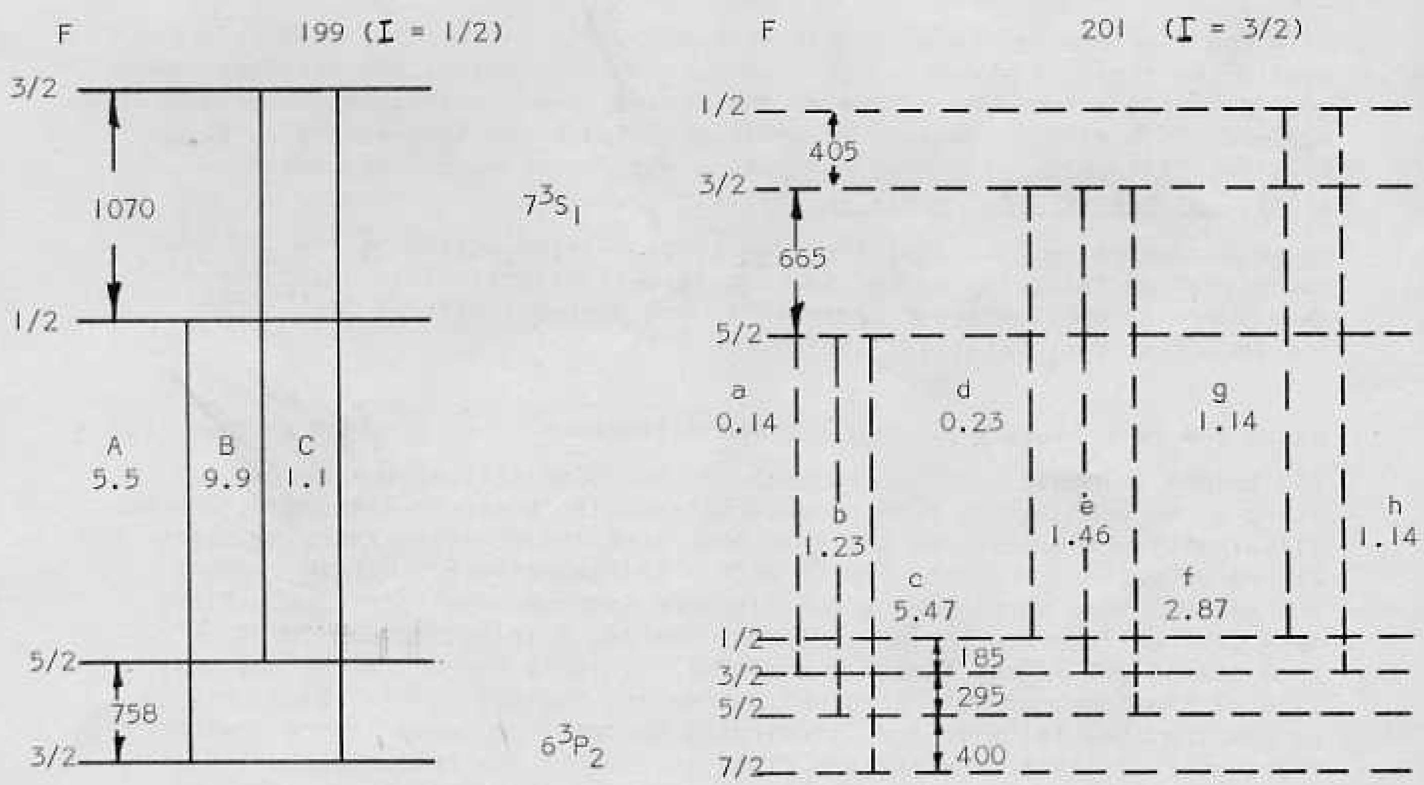


Fig. 3

F represents the vector sum of the nuclear spin and total electronic angular momentum vectors. I is the nuclear spin. The numbers between **levels** indicate level separations in thousandths of wave numbers (wave number = $\frac{1}{\text{wave length in cm.}}$.) The numbers below the letters indicate the percentage intensity of the hyperfine spectrum line due to that transition. With the above level structure, a diagram of intensity appears as follows:

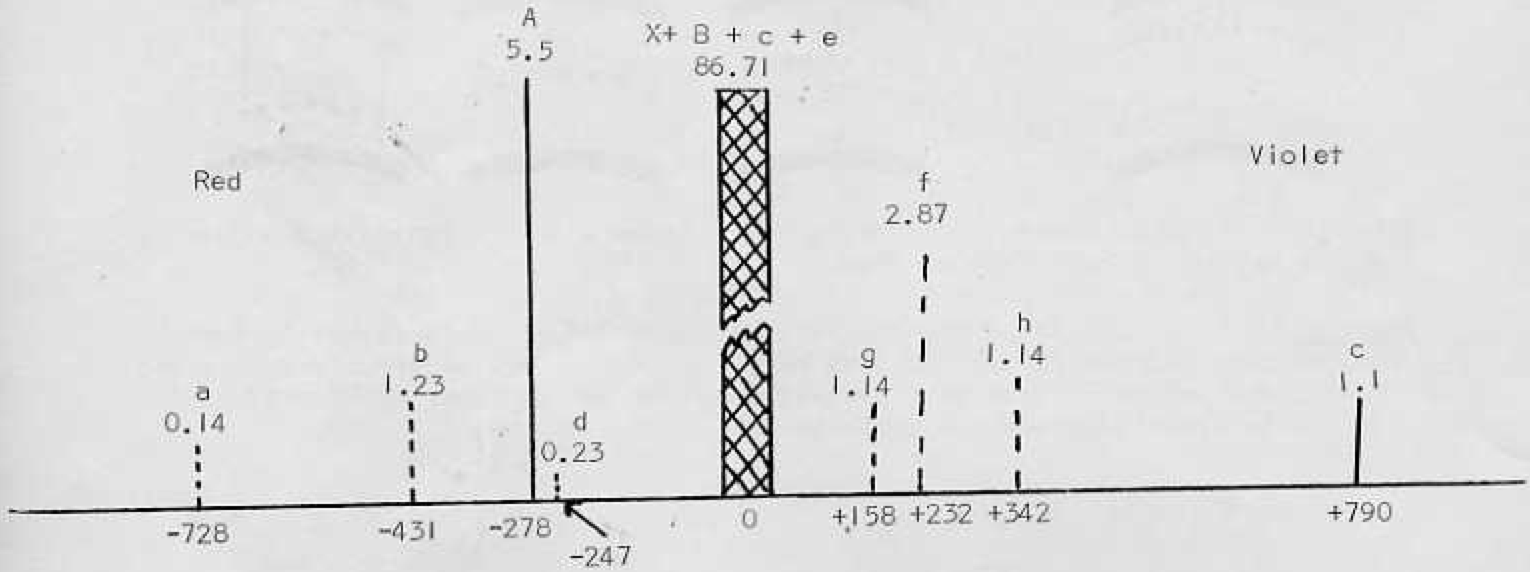


Fig. 4

X is the line due to the even mass isotopes. The letters and numbers are similar to those of the previous diagram. The numbers on the abscissa represent deviations from the center of the intense line in thousandths of a wave number. This research may be found in articles by H. Schüler and J. E. Keyston, Zeitschrift für Physik 72, 423 (1931), and H. Schüler and E. G. Jones, Zeitschrift für Physik 74, 631 (1932).

In wave numbers we find that the free range between orders is the reciprocal of twice the mirror spacing in centimeters. That is, since $m\lambda = m/\sigma = 2t\cos\theta$, where σ represents wave number (units of $cm.^{-1}$) then for $dm = 1$ we have $d\sigma = 1/2t$ (note $\cos\theta \cong 1$).

Using the relationship $d\sigma = \frac{1}{2t}$ for the difference in wave numbers between two bright fringes, the relationship of the faint fringes can be found. Using as an example the typical observation with a mirror spacing of 5.5 mm illustrated previously, we see that the faint fringe illustrated by dashes has moved outward from the center of the fringe pattern (that is, toward the violet) some three tenths the distance between bright fringes. Since $d\sigma = 0.91\ cm^{-1}$ between bright fringes, the faint fringe is some $0.27\ cm^{-1}$ from the bright fringe toward the violet. This is approximately the position of the components "f" and "h" due to the isotope Hg^{201}. Similarly we see that the faint fringe illustrated by dots has moved inward toward the center of the fringe pattern (that is, toward the red) about one-fourth the distance between bright fringes. The faint fringe is thus some 0.23 cm^{-1} from the bright fringe toward the red. This is approximately the position of the component "A" due to the isotope Hg^{199}.

EXPERIMENT 3: Determination of Wave Length Differences for the Balmer Lines of Hydrogen and Deuterium.

Procedure: For this experiment a Heavy Water Balmer Tube Light Source is used. A Number 16 Wratten filter or equivalent is needed for observation of the red Balmer lines and a Number 45 Wratten filter or equivalent is necessary for observation of the blue Balmer lines without interference from the other lines of the Balmer series. A cylindrical lens of about 2.5 inches focal length placed approximately 2 inches from the Balmer tube is necessary in order to provide reasonably uniform illumination to the field viewed through the interferometer. A diffuser plate (ground glass or waxed paper) and the appropriate filter are located between the cylindrical lens and the interferometer. A viewing telescope of six to ten power having a graduated reticle is used in making measurements of the fringe pattern. A reticle containing 10 millimeters graduated in tenths of a millimeter or containing 0.4 inches graduated in 0.005 inches is suitable.

Obtain a good fringe pattern with the Fabry-Perot Mirrors practically in contact. The distance between the mirrors should be between 0.1 mm and 0.2 mm. Turn the micrometer head some ten to fifteen revolutions toward higher readings while watching the fringe pattern. The initial somewhat broad fringes will separate into pairs of somewhat narrower fringes. The outer fringe of each pair is due to deuterium and the inner fringe is due to hydrogen.

One side of the fringe pattern is to be measured using the telescope with a graduated reticle. This is accomplished by moving the telescope so that there is a slight angle between the axis of the telescope and the normal to the Fabry-Perot plates.

With both the hydrogen and the deuterium fringe patterns well resolved from each other, and with the fringe patterns as sharp as fine adjustment of the adjusting screws will permit, measure radially from the center of the pattern the position of at least eight fringes, starting with a deuterium fringe several fringes from the center of the pattern. After measuring the fringes locate the first fringe measured to be sure the fringe pattern has not altered while the measurements were being made. Thermal equilibrium and absence of vibration are necessary for obtaining stable fringe patterns. Read the micrometer.

Turn the micrometer head some eight to ten revolutions toward higher readings while watching the fringe patterns. The outer (deuterium) fringe of each pair will separate further from the inner (hydrogen) fringe. Again measure radially from the center of the pattern the position of at least eight fringes, starting with a deuterium fringe several fringes from the center of the pattern. Check the location of the first fringe measured to determine stability of the pattern. Again read the micrometer.

Analysis of the data is accomplished as described in Experiment I. However, the formula for the difference in wave length is:

$$\Delta\lambda = \lambda^2 \frac{dm_f - dm_i}{2 \times 2 \times 10^{-3}\,(D_f - D_i)}$$

since the initial value of the fractional order, dm_i, has been measured in the same sense as the final value, dm_f.

An example of data taken and its reduction is given below. The W's (for weak) of Experiment I have been replaced by D's (for deuterium), and the S's (for strong) have been replaced by H's (for hydrogen). The Δ's (Δ_1, Δ_2, etc.) represent the distance from a hydrogen fringe to the next deuterium fringe outward from the center of the pattern for measurements taken at both the initial and final micrometer readings.

<u>D_i = 18.17 millimeters</u>

$D_1 = 4.90$			
$H_2 = 6.00$		$\Delta_{1D} = 1.70$	
	$\Delta_2 = 0.60$		
$D_2 = 6.60$			$\Delta_{2H} = 1.50$
$H_3 = 7.50$		$\Delta_{2D} = 1.40$	
	$\Delta_3 = 0.50$		
$D_3 = 8.00$			$\Delta_{3H} = 1.30$
$H_4 = 8.80$		$\Delta_{3D} = 1.20$	
	$\Delta_4 = 0.40$		
$D_4 = 9.20$			$\Delta_{4H} = 1.10$
$H_5 = 9.90$			

$$dm_i = \frac{1.20}{3.20} = \frac{1.00}{2.70} = \frac{0.80}{2.30} = 0.364$$

<u>D_f = 23.50 millimeters</u>

$D_1 = 4.30$			
$H_2 = 5.40$		$\Delta_{1D} = 1.90$	
	$\Delta_2 = 0.80$		
$D_2 = 6.20$			$\Delta_{2H} = 1.60$
$H_3 = 7.00$		$\Delta_{2D} = 1.50$	
	$\Delta_3 = 0.70$		
$D_3 = 7.70$			$\Delta_{3H} = 1.40$
$H_4 = 8.40$		$\Delta_{3D} = 1.20$	
	$\Delta_4 = 0.50$		
$D_4 = 8.90$			$\Delta_{4H} = 1.20$
$H_5 = 9.60$			

$$dm_f = \frac{1.60}{3.50} = \frac{1.40}{2.90} = \frac{1.00}{2.40} = 0.452$$

$$\Delta\lambda = (6.56)^2 \times 10^{-10} \; \frac{0.452 - 0.364}{2 \times 2 \times 10^{-3}\,(23.50-18.17)}$$

$$= 4.30 \times 10^{-8} \; \frac{0.088}{0.213}$$

$$= 1.78 \times 10^{-8} \text{ cm.}$$

= 1.78 Angstrom Units with a probable error of 0.20 Angstrom Units.

Vrey, Brickwedde, and Murphy (Phys Rev 40, 1, 1932) measured $\Delta\lambda$ to be 1.79 Angstrom Units in discovering the presence of the deuterium isotope. The calculated value for $\Delta\lambda$ is 1.787 Angstrom Units.

With the Number 45 Wratten filter or equivalent in place, the experiment may be performed for the blue Balmer lines. An example of data taken and its reduction in this case is given below.

D_1 = 10.62 millimeters

$D_1 = 1.00$			
$H_2 = 3.30$		$\Delta_{1D} = 3.10$	
	$\Delta_2 = 0.80$		
$D_2 = 4.10$			$\Delta_{2H} = 2.10$
$H_3 = 5.40$		$\Delta_{2D} = 1.90$	
	$\Delta_3 = 0.60$		
$D_3' = 6.00$			$\Delta_{3H} = 1.60$
$H_4 = 7.00$		$\Delta_{3D} = 1.50$	
	$\Delta_4 = 0.50$		
$D_4 = 7.50$			$\Delta_{4H} = 1.30$
$H_5 = 8.30$		$\Delta_{4D} = 1.20$	
	$\Delta_5 = 0.40$		
$D_5 = 8.70$			$\Delta_{5H} = 1.20$
$H_6 = 9.50$			

$$dm_i = \frac{1.60}{5.20} = \frac{1.20}{3.50} = \frac{1.00}{2.80} = \frac{0.80}{2.40} = 0.335$$

$\underline{D_f = 16.88 \text{ millimeters}}$

$D_1 = 3.40$			
$H_2 = 4.40$		$\Delta_{1D} = 1.80$	
	$\Delta_2 = 0.80$		
$D_2 = 5.20$			$\Delta_{2H} = 1.50$
$H_3 = 5.90$		$\Delta_{2D} = 1.30$	
	$\Delta_3 = 0.60$		
$D_3 = 6.50$			$\Delta_{3H} = 1.20$
$H_4 = 7.10$		$\Delta_{3D} = 1.10$	
	$\Delta_4 = 0.50$		
$D_4 = 7.60$			$\Delta_{4H} = 1.10$
$H_5 = 8.20$		$\Delta_{4D} = 1.10$	
	$\Delta_5 = 0.50$		
$D_5 = 8.70$			$\Delta_{5H} = 1.00$
$H_6 = 9.20$			

$$dm_f = \frac{1.60}{3.30} = \frac{1.20}{2.50} = \frac{1.00}{2.20} = \frac{1.00}{2.10} = 0.474$$

$$\Delta\lambda = (4.86)^2 \times 10^{-10} \frac{0.474 - 0.335}{2 \times 2 \times 10^{-3}\ (16.88-10.62)}$$

$$= 2.36 \times 10^{-8} \frac{0.139}{0.250}$$

= 1.31 Angstrom Units with a probable error of 0.14 Angstrom Units.

Vrey and his co-workers measured $\Delta\lambda$ to be 1.33 Angstrom Units for the blue Balmer lines. The calculated value for $\Delta\lambda$ is 1.323 Angstrom Units.

Discussion: In applying quantum theory to his theory of the hydrogen and hydrogen-like atoms, Bohr made the assumption that the frequency of a spectrum line is proportional to the difference between two energy states. This, combined with his assumptions regarding the electron's orbits in a coulomb field about the nucleus and the quantization of electronic orbital angular momentum, leads to the expression:

$$\frac{1}{\lambda} = \frac{2\pi^2 me^4 Z^2}{ch^3} \quad \frac{1}{n_1^2} = \frac{1}{n_2^2}$$

Where:
- λ is the wave length of the spectrum line in cm.
- m is the mass of the electron = 9.035×10^{-28} gm.
- e is the electronic charge = 4.770×10^{-10} abs. e.s.u.
- h is Planck's constant = 6.62×10^{-27} erg sec.
- c is the velocity of light = 3.0×10^{10} cm/sec.
- Z is the nuclear charge (one for hydrogen, two for ionized helium, three for doubly ionized lithium, etc.)

n_1 is the quantum number of the initial state.
n_2 is the quantum number of the final state.
$R = \frac{2\pi^2 me^4}{ch^3}$ is the Rydberg constant for an atom with nucleus of infinite mass = R_∞.

In general, the electron and the nucleus both rotate about a common center of gravity. The so-called reduced mass should be used in the equation for the Rydberg constant. The expression for the reduced mass is:

$$\mu = \frac{m}{1 + \frac{m}{AM_p}}$$

Where M_p is the atomic mass unit and A is the atomic weight.

Then the Rydberg constant becomes:

$$R_A = \frac{R_\infty}{1 + \frac{m}{AM_p}} = \frac{R_\infty}{1 + \frac{1}{1837\ A}}$$

since $\frac{M_p}{m} = 1837$.

Substituting the appropriate constants:

$$R_\infty = 109737.303$$

Z = 1 for hydrogen. Solving an equation for the difference in wave length between isotopic hydrogen lines we have :

$$\Delta\lambda = \frac{1}{R_\infty \frac{M_p}{m}\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)} \left(\frac{A-1}{A}\right)$$

Or, solving for A:

$$A = \frac{1}{1 - \Delta\lambda R_\infty \frac{M_p}{m}\left(\frac{1}{n_1^2} \quad \frac{1}{n_2^2}\right)}$$

For the Balmer lines $n_1 = 2$, for the red Balmer line $n_2 = 3$, and for the blue Balmer line $n_2 = 4$. Thus, a measurement of the wave length difference provides an estimate of the atomic weight of deuterium.

EXPERIMENT 4: The Zeeman Effect may be observed using the M-4 Interferometer with Fabry-Perot Optics. For this experiment it is necessary to produce a magnetic field of 3,000 to 9,000 gauss in the region of the discharge of a monochromatic mercury light source. Either the Atomic Laboratories Laboratory Electromagnet or the Research Aluminum-Foil Electromagnet (cat. nos. 79641 and 79637 respectively) are suitable for this use. Atomic Laboratories also offers a Zeeman Effect Apparatus (cat. no. 79661) consisting of a specially designed Mercury vapor tube in a convenient holder and a set of the proper filters and optics for installation on any magnet having tapered pole faces.

References:

H.E. White, Introduction to Atomic Spectra, McGraw-Hill, 1934, pp. 27-38.

G. Herzberg, Atomic Spectra and Atomic Structure, Dover, 1944, pp. 19-26, 182-183.

PART III

Replacement Optics: As stated previously, the M-4 Interferometer may be ordered with Michelson Optics, with Fabry-Perot Optics, or with a combination of both. If one set of optics is ordered (such as the Michelson Optics) and the customer later wishes to order the Fabry-Perot set, this may easily be accomplished. All sets are shipped mounted in frames and ready for insertion in the holes that are already drilled and tapped. Simply remove the masking tape on the M-4 chassis and carriage, and the optics are ready for immediate installation. The necessary screws are included in each shipment. Because of the difficulty of mounting the optics and frames, they are never sold unmounted.

Michelson Optics mounted (Complete Set). $150.00

Fabry-Perot Optics mounted (Complete Set). $175.00

Individual Optics, mounted:

A. Front surface mirror . . . . $ 40.00

B. Beam Splitter. $ 40.00

C. Compensator. . . . . $ 30.00

D. Fabry-Perot Mirror $100.00

NOTE: All Michelson optics are guaranteed to be flat to within 1/4 wave length of green light over their entire surfaces (front surface mirrors over mirrored surfaces). Fabry-Perot mirrors are guaranteed to be within 1/6 wave length of green light over their matching surfaces.