1935

The interferometer in wave-length determination

BOSTON UNIVERSITY

GRADUATE SCHOOL

Thesis

THE INTERFEROMETER IN WAVE-LENGTH DETERMINATION

by

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(B. S. in Ed., Boston University, 1934)

submitted in partial fulfilment of the
requirements for the degree of
Master of Arts

1935

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INTRODUCTION

Hydrogen, being the most elementary of all elements, is therefore most suitable for checking any theories concerning elements; for, such theory must be competent to explain the spectra to the finest detail. For this reason, it has become very important to determine with the greatest degree of accuracy possible the frequencies of lines in the molecular spectrum of Hydrogen. This need has been occasioned by the fact that the analysis of the molecular spectrum of Hydrogen has brought about the break down of the Bohr theory which was thought to have explained so well the atomic spectrum of the element.

Although the frequencies of the lines in the spectrum of Hydrogen have been determined so accurately by such investigators as Gale, Monk and Lee, Merton and Barratt and Finkelnberg, it was only Gale, Monk, and Lee who employed the interferometer and then only to a part of this spectrum. Therefore this work, being done by Lacount under the direction of Dr. Norton A. Kent, has been undertaken to redetermine with a greater degree of accuracy of which the interferometer is capable, the frequencies of a few of the lines in the secondary spectrum of Hydrogen which have not yet been determined by this method.

HISTORICAL DEVELOPMENT

In 1814 Fraunhofer, by using a lens between the slit and the prism of a prism spectroscope, and by using several different prisms of varying degrees of refinement, was able to prove that the black lines in the spectrum of sunlight had a definite position and were due to a lack of light of certain wave lengths. He mapped about 700 of them, eight of which still bear his name.

He also constructed the first grating, using a silver wire wound around a brass frame. Later, he ruled evenly spaced scratches on a flat glass plate and with it made accurate (5890Å) measurements of the D-line of Sodium.

In 1860 Kirchoff proved these dark lines to be caused by absorption of the corresponding wave lengths of light in the outer layers of the sun.

In 1868 Ångström published his map of the solar spectrum based on measurements which he had made with three accurate glass gratings. The unit of wave lengths which he used was 10^{-10} meter, referred to the standard in Paris. This unit bears his name and is called the "Ångström Unit". This standard meter is defined as the distance between two lines on a certain platinum-iridium bar kept at the International Bureau of Weights and Measures in Paris when this bar is at 0°C. or 32°F.

Spectroscopy received a very powerful instrument when in 1885 Rowland invented his concave grating and special mount known today as the Rowland Mount. With this instrument he made

as accurate measurements of the D-lines of sodium as were possible at that time, and using the value he obtained for the D-line as standard, he published a new map of the solar spectrum which replaced that of Ångström.

Nine years later, in the invention of Michelson's Interferometer, an even greater contribution was made to spectroscopy. Using this instrument, Michelson accurately referred the wavelength of the red line Cadmium to the length of the standard meter and obtained 6438.4722 Å. U., a value which with slight changes, became the basis of all our present day determinations of wavelengths.

Until the year 1904 there were no common standards of wavelength to which spectroscopists could refer. In that year the International Union for Cooperation in Solar Research was formed to set up such standards.

The following year the Union met at Oxford and resolved to choose and adopt a spectroscopic line which was sufficiently monochromatic to be used as a primary standard. It also adopted the resolution to set up secondary standards, not more than 50 units apart which should be measured with an interferometer in reference to the primary standard.

In 1907 the Union adopted the Cadmium red line as the primary standard of wave length. The wave length was designated at 6438.4696 Ångström units in dry air at 15°C. and 760 mm. pressure.

A very important meeting took place in 1922. The International Astronomical Union, as it was now called, met in Rome

and adopted a list of secondary standards from the spectrum of iron, and a few from the spectrum of neon. These were the means of the results of three observers who had compared them with the primary standard by interferometer methods.

The union also adopted a list of 302 stable lines from the iron spectrum, not included among the secondary standards, as tertiary standards. They were determined from the secondaries by interpolation in photographs of the latter.

Another important step was the adoption of the Pfund arc [1] as a standard source used under the following specifications. Namely, that the arc be run at a current of 5 amperes at 110-250 volts D. C.; that the arc should be 12 to 15 mm. in length; that only 1 to 1.5 mm. of the central portion taken at right angles to the axis of the arc should be used; that the positive pole, composed of an iron rod 6 to 7 mm. in diameter should be the upper pole, and a bead of iron oxide the lower and negative pole.

In 1927, H. D. Babcock[2], of Mount Wilson Observatory published a table of wave lengths of iron lines corresponding to the lines already adopted as secondary standards. Their values were systematically less than the standards by about .0022 A. U. and Mr. Babcock recommended that his values replace the values then in use. He had measured 286 iron lines and 11 neon lines in terms of the primary standard of Cadmium. His differences were partly due to improvement in photography, partly to the

1. Report of International Astronomical Union...1922.
2. Astrophysical Journal #66,256...1927.

latest specifications for producing the iron spectrum, and partly to the procedure of transmitting the light from the neon lamp through the entire apparatus and onto the same plate with iron lines.

In 1928, the Astromomical Union adopted a slight revision of the secondary standards. The new values were between those obtained by Babcock, and the old values, and included lines between 3370 and 6750. They were about .001 A. U. less than the old values and were given to seven figures.

A table of standard solar wave lengths from 3592 and to 7122 was also adopted at this time. They were based on measurements made by St. John, Babcock, and the Allegheny Bureau of Standards[1]. The neon lines adopted as standards in 1922 remained.

1. Trans. of International Ast. Union...1927.

PREVIOUS WORK IN THE SECONDARY SPECTRUM OF HYDROGEN

The first tables of wave lengths in the secondary spectrum of hydrogen were made by Hasselberg[1] in 1882. His measurements were made visually and hence were not very accurate.

From that date until 1922 there were a considerable number of measurements made of this spectrum, but none of them were of any particular importance, with the possible exception of those of Watson[2] who measured most of the lines in the red, yellow, and ultraviolet in the year 1909.

In 1922 Dr. T. R. Merton and Mr. S. Barratt[3] made measurements of the secondary spectrum of hydrogen which included 1200 lines extending from 3375 to 6540. For a source they had a vacuum tube of the H type, in which the capillary tubes were replaced by tubes whose lengths were 20 and 50 cm., and whose diameters were between 5 and 8 mm. The electrodes were spirals of aluminum ribbon. They used an Anderson concave grating with 20,000 lines to the inch and a dispersion of about 10 A. U. per mm. The mounting was of the Eagle type.

For comparison they used a Pfund arc as source, and referred their measurements to the values of the International Secondary Standards then in use.

The observers claimed that their final measured values were correct to .02 A. U.

1. Mem. Acadl, St. Petesburg (7), 30, No. 7...1882.
   Phil. Mag., (5) #17, 329...1882.
2. Proc. Roy. Soc., A. #82, 189...1909.
3. Phil. Trans. Roy. Soc., (A) #222, 369...1922.
4. Astrophys. Journal #31, 120...1910.

T. Tanaka[1] published a table of six figure wave lengths of this spectrum in 1925. They were mostly weak lines measured on two plates taken by Professor Merton. He used the latter because the lines were much better resolved than on his own plates, having been taken using an Anderson Concave grating. Furthermore, the current density in the tubes used to make the plates was at least seventy-five times that of the tube used by Merton and Barratt in obtaining their measurements, referred to previously. Tanaka believed that this was one of the chief reasons why the lines he measured were not observed on their plates. For standards, he used sharp hydrogen lines and the values assigned to them in Merton and Barratt's tables. All lines were remeasured and in most cases deviated less than 0.04 Å. U. from the first measurements. The table consists of 565 lines between 6572 and 3295, none of which appear in the tables of Merton and Barratt.

The next year D. B. Deodhar[2] working at King's College on spectrograms of a low pressure discharge at low potential, noticed many lines not contained in Tanaka's or Merton and Barratt's tables of wave lengths. After investigation it was found that these lines were not traceable to impurities, but to hydrogen.

After carefully measuring the plates of Professor Merton, Deodhar discovered that there were 450 lines not recorded by Merton and Barratt or by Tanaka. These lines he therefore

1. Proc. Roy. Soc.(A) #108, 592...1925.
2. Proc. Roy. Soc.(A) #113, 420...1926.

measured, using his spectrograms, and obtained a table of six figure wave lengths from 6601 A to 3357 A.

Since his standards were taken from values given in Merton and Barratt's tables, as well as from those of Tanaka, their accuracy was somewhat dependent on that of the previous observers. However, Deodhar believed that, considering the weakness of the lines, the values were fairly accurate.

One of the most important of recent measurements in the secondary spectrum of Hydrogen was the table of wave lengths published in 1928 by H. G. Gale, G. S. Monk, and K. O. Lee[1]. For a source, they used electrolytically prepared hydrogen, dried over calcium chloride and phosphorous pentoxide, and used a tube of 8 mm. inside diameter, having a distance of 30 cm. between aluminum electrodes. The pressure in the tube when sealed was greater than 0.1 mm. of mercury. Later the pressure decreased to a steady state. A one k.w. Thordarson radio transformer gave a potential difference between the electrodes of 1500 volts.

Using a Fabry-Perot interferometer, and a concave grating in a Wadworth mounting for auxilliary dispersion, they measured 95 lines between 4171 and 6527, with neon lines as standards. They calculated that for none of the 95 lines was the probable error greater than .0035A. and for the majority it was less than .0012 A.

Then, using these lines as standards, they measured 2969

1. Astrophys. Journ. #67, 89...1928.

other lines by interpolation. These lines were obtained by using a Rowland Mount with a 21-foot grating. The latter had a dispersion of 2.637 Å. per mm. in the first order, and an actual resolving power of 45,000. Every plate had the spectrum of a standard Pfund arc photographed on it to aid in places where hydrogen standards were far apart. Exposures from one or two hours up to forty hours were successful. The mean error of most of the lines was less than 0.01 Å. U. The high resolving power gave more accurate measures than were possible before. It is interesting to note that, although some parts of the work were done over a year before other parts, the overlapping regions agreed well.

Probably the most interesting part of the previous work done in measuring this spectrum was that of Wolfgang Finkelnburg[1] in 1928, while working at Bonn. His source was a quartz tube, 8 mm. in diameter, and silvered inside. He had found by experiment that the silver adsorbed atomic hydrogen which combined with the H atoms flowing in the tube and formed H_2 molecules, thus giving a bright H_2 spectrum with a moderate H spectrum. The tube had a constant flow of hydrogen through it, the gas having been previously dried over phosphorous pentoxide and pumped out by a two stage rotary high vacuum pump. In this way, the tube was constantly purified and the pressure of 0.1 to 0.5 mm. of mercury was controlled by three stopcocks in the feeding tube. The discharge tube was 40 cm. long and was placed

1. Zeitschrift For Physik #52, 27...1928.

in a glass tube of equal length and 20 mm. in diameter. The latter tube was placed in another glass tube of 45 mm. diameter, and held in place by 5 mica rings which prevented the direct conduction of heat from the inner tube. All these tubes were separated from each other by tightly packed glass wool.

Tubes containing cup shaped aluminum electrodes were joined to the ends of the inner tube at right angles. The tube was placed in a water bath, the protruding tubes being cooled by wicks from the bath and a stream of air. One end of the discharge tube was extended out through the side of the water tank, and closed with a quartz window through which the light from the spectrum was taken. The intake and outlet ports for the gas were provided in the sides of the electrode tubes. Finally an alternating current of 700 M. A. at 200 volts was impressed on the electrodes.

His photographs were of the first order spectrum, taken on a Rowland Mount. His concave grating had a radius of curvature of 6.60 meters and 120,000 in 15 cm. of length. It had a dispersion of 1.98 Å. U. per mm. Exposures lasted from six to ten hours, and the temperature change varied 0.4^{0} to 0.8^{0} C. during that time.

He measured 3667 lines between 4681 and 3314, 2000 of them never having been measured before. He calculated that the error was about .0035 Å. U. for the strong lines and about twice that amount for the weak lines. The values for his standards were taken from the old lists adopted by the International

Astronomical Union.

DESCRIPTION OF LABORATORY

The Rumford Committee room in the Massachusetts Institute of Technology is located in the Eastman Spectroscopy Laboratory. A complete description of this laboratory is given by K. T. Compton[1]. In particular, the room was designed to be as free from vibration and thermal fluctuations as possible. The floor which supports the instrument piers is about twenty inches thick and floats free from rigid connections with the walls or adjacent floors. The room is approximately 40'x8'x8'. At the further end, two massive concrete blocks, approximately 2'4"x2'2"x2'2" capped by a stone slab 4'9"x2'4"x2¼" support the grating, and at the other end of the room, a single block of similar dimensions supports the combined slit and camera. A housing of wooden framework covered with wall board, encloses the grating. The top of the housing is removable, and a means of access to the grating is also provided through the side. The camera box proper is approximately 2 feet square in cross section, and extends between the grating housing and the slit pier. It is supported entirely by three wooden supports, no contact being made with the grating or slit pier. Access may be had to the interior of the box through the top which is removable in sections. The grating housing, camera box, slit and plate holder mechanism are made light tight by folds of black cloth. A small concrete pier supports the projection lens, and a heavy laboratory table near the entrance to the room, supports the

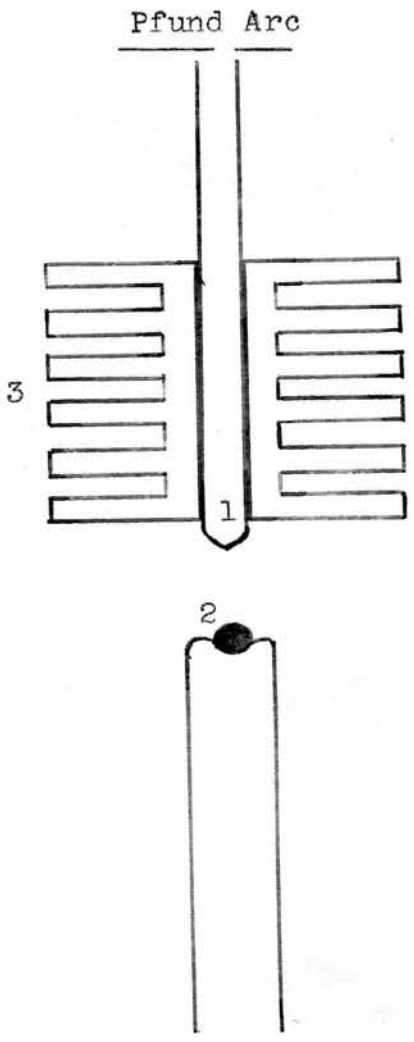
electrolysis apparatus, diffusion pump and the Hydrogen tube. Upon three I beams supported free from contact with the isolated floor, a platform permits the experimenter to make necessary adjustments during exposure without danger of vibrational disturbances. The room is divided into two sections by a light tight partition erected on the platform between the small pier and the source table with a heavily curtained doorway permitting passage between the sections. The smaller section, serving as a source room, is also provided with a stone sink, thus making the room available for the developing of the photographic plates. The temperature of the room is thermostatically controlled. Two thermocouples are used, their reading being recorded on a Brown recording Potentiometer. One of the thermocouples is hung in the middle of the room and the other within the grating box. The circulation in the room was improved by the use of two fans, run at low speeds, heating elements being placed in front of each. One such element was operated by an automatic switch which also controlled the influx of cold air to the room. When the temperature fell the heating element would operate while the cold air supply would be cut off, and vice versa.

The transformer was located in the special platform in the source room. The temperature within the grating box was, during an exposure kept within 0.05° F.

SOURCES OF LIGHT

Pfund Arc

The Pfund Arc in air, was operated at 220 volts and 4 amperes the poles of the arc being 1 cm. apart. The image of the arc 13 cm. long formed by a lens was focused on the diaphragm which permitted a central zone of 8 mm. to be used. The light then went to a mirror mounted in a rotating bed plate which was sprung into position to collect the light from the arc whenever an exposure was made with the arc. The rest of the time it was swung away from the optical axis allowing the light from the tube to pass through the system. The upper pole, the cathode was of Bessemer steel .25 in. in diameter. For the purpose of cooling and thus preventing the formation of a pendant drop of metal or oxide on the cathode, a heavy brass grooved cylinder was fitted over the rod which projected 2 or 3 mm. below the bottom of the cylinder. The anode consisted of a bead of iron oxide resting in a shallow cavity at the upper end of an iron rod .5" in diameter.



1. Positive pole

2. Bead of iron oxide
   Negative pole

3. Heavy brass grooved cylinder for cooling

HYDROGEN TUBE

The hydrogen used in this investigation passed from the hydrogen generator through two drying tubes, one containing phosphorous pentoxide and the other calcium chloride, and then to the hydrogen supply tank from which it is fed through a spiral capillary tube into the hydrogen tube, the flow being controlled by a stop-cock. The Hydrogen Tube consists of a long quartz capillary 8 mm. in diameter enlarged to 18 mm. at one end to contain one of the aluminum electrodes through which the discharge is viewed. A quartz window covers and seals this end of the tube. A side tube from this end leads to a McLeod Guage and the evacuating system which consists of a mercury diffusion pump and an electrically driven vacuum pump. The other end of the tube is not expanded and is sealed off by a 90° prism. This arrangement makes it possible to line up the tube with the optical system with the minimum amount of effort, and provides an opportunity of passing light from an exterior source (e.g. a secondary standard) down the tube so that both source and standard may be photographed simultaneously. A side tube leads from the capillary after a right angle bend, through a ground seal to a pyrex tube into which a cylindrical aluminum electrode is sealed. It is into this tube that the hydrogen enters from the supply tank.

For cooling, the tube is provided with a pyrex water jacket extending from just behind the front electrode to the rear end of the capillary. In addition the rear electrode with its tube

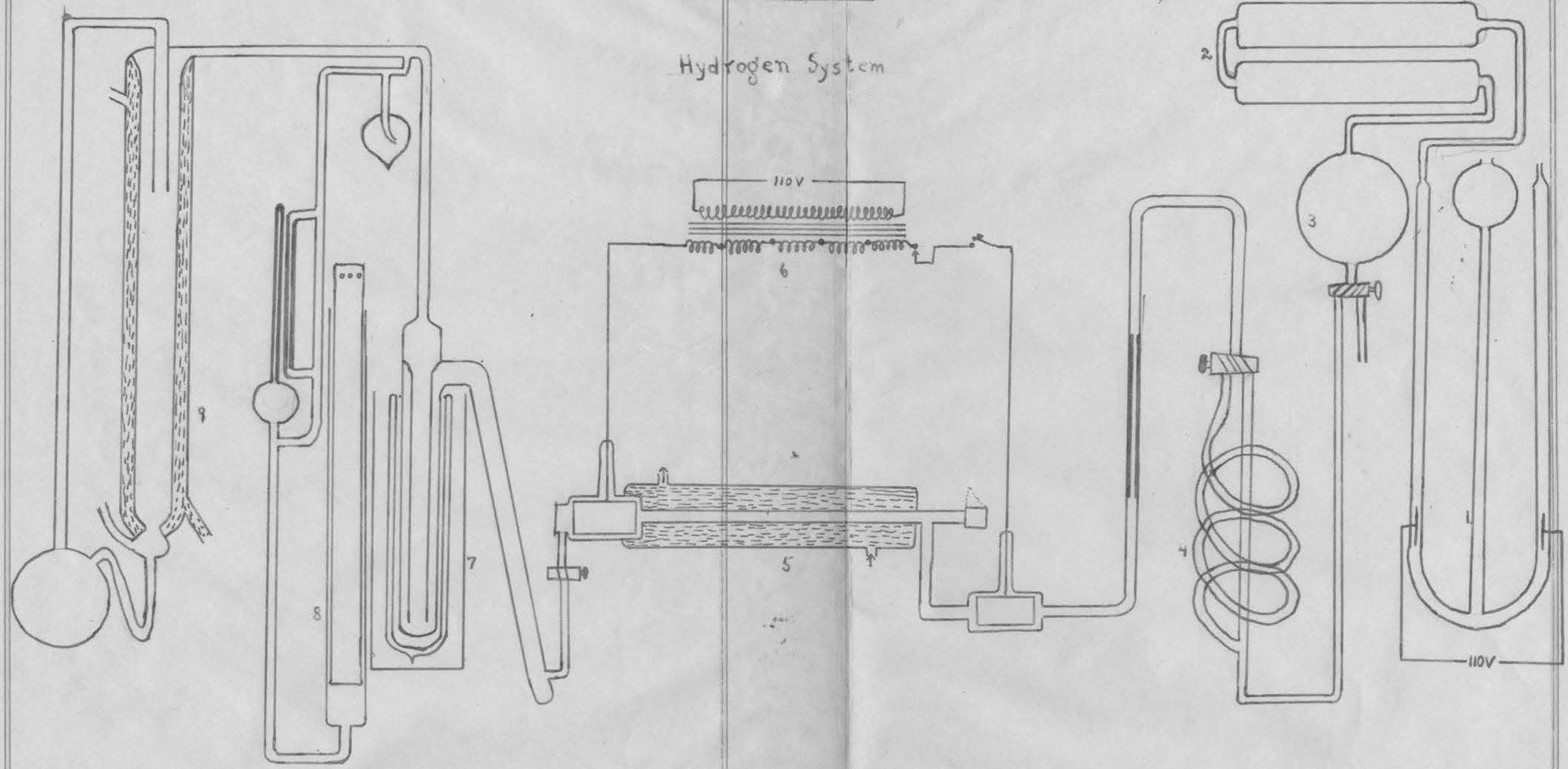
is jecketed by cotton over which there flows a steady stream of water from holes in the side of a piece of rubber tubing connected with the water supply. This arrangement made possible satisfactory cooling of the tube under all working conditions up to 175 m.a. to 30,000 volts.

Naude[1] and Kistiakowsky[2] have shown that the presence of a metal in the hydrogen discharge tube causes the relative enhancement of the molecular spectrum of hydrogen, therefore, the interior of the tube was platinized by use of Liquid Bright Platinum according to the method of Kistiakowsky. The liquid is allowed to flow over the interior of the capillary and a current of oxygen or air is passed through the tube while heating to redness in the flame of a blast lamp.

1. Naude S. M. Phys. Rev. 36,333...1930
2. Kistiakowsky

Plate II:

Hydrogen System



1. Hydrogen Generator
2. Drying Tubes
3 Hydrogen Supply Tube
4 Capillary Coil
5 Hydrogen Discharge Tube
6. Transformer
7. Liquid Air Trap
8 McCleod Guage
9. Mercury Pump

OPTICAL SYSTEM

The dispersive system consisted of an etalon, a lens, and a plane grating mounted as a Littrow. The arrangement of the parts being shown in Plate III. The grating had a ruled surface of 9.7x12.9 cm. and 12,542 lines to the inch. Because of the inability of this grating to give a good line form it was found necessary to occult 2.5 cm. on one side of the ruling.

The grating was mounted on a heavy steel member resting by leveling screws on the slabs covering the grating piers. The grating was fixed in its holder by screws pressed against wax pads placed near the edges of the grating. Screws at the side of the grating holder permitted it to be rotated slightly in the plane of the ruled surface. So that the lines in the grating might be made vertical: a screw at the rear allowed the grating to be given the necessary tilt. The holder was mounted in a vertical column and could be rotated by a tangent screw thus enabling the desired region or order of the spectrum to be brought into position in the photographic plate.

The autocollimating lens used with this grating was a 30' achromatic doublet with uncemented surfaces. It was mounted in front of the grating on a steel member attached by leveling screws which permitted the lens to be given the proper orientation.

The plate holder, mounted beneath the slit is capable of horizontal rotation about a vertical axis near the center of the plate. The proper tilt having been obtained by such rotation, the plate holder was clamped into position by a nut in the vertical screw about which it turns.

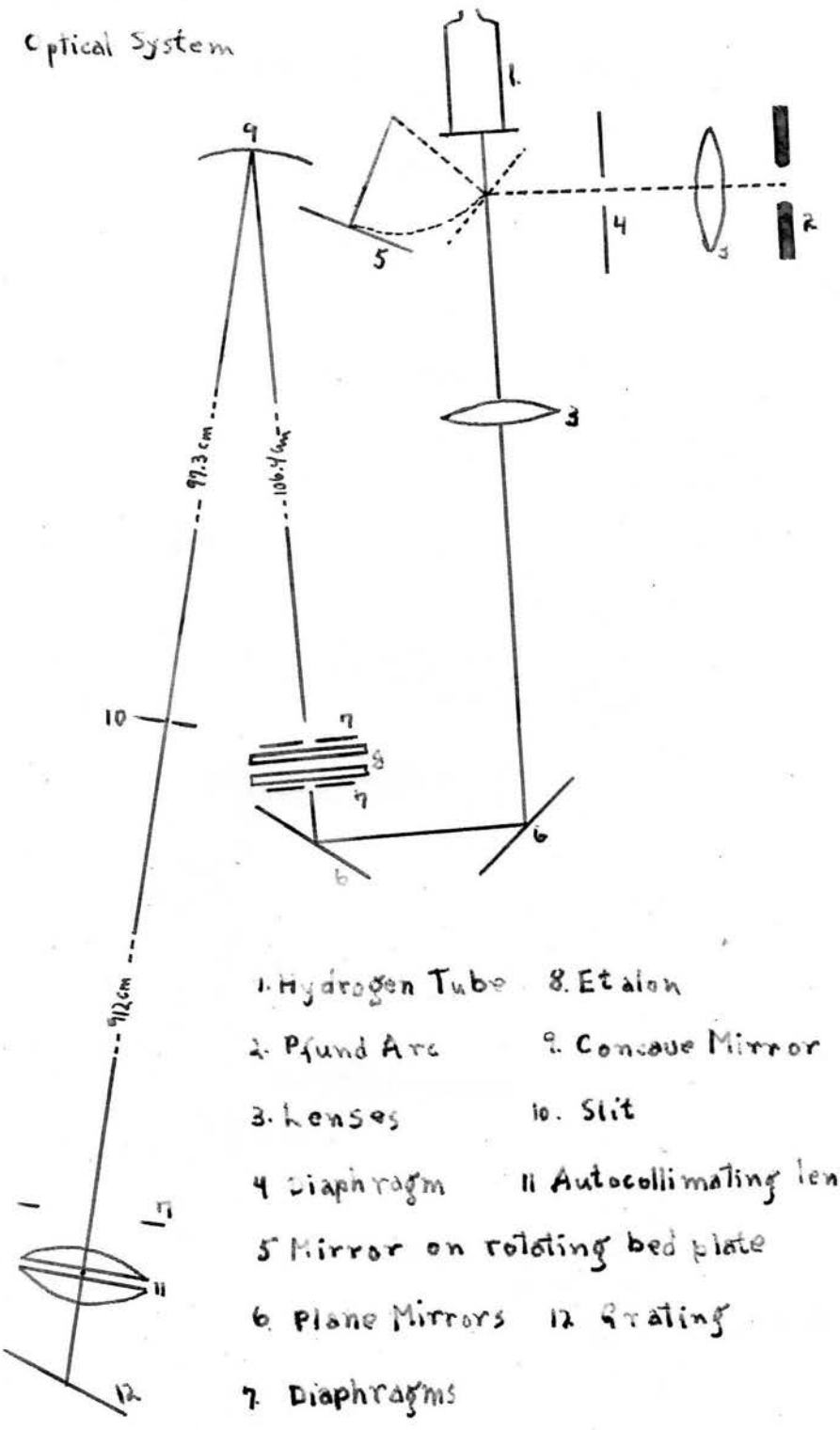
The instrument accommodates a plate 22"x2" which rests against flexible brass strips which may be bent and held to any desired curve by means of adjusting screws.

The light coming from the Hydrogen tube, or arc if the mirror is swung into position, passes through a condensing lens so placed that it brings the light to a focus at the front plate of the etalon after the light has suffered two 90° bends by Mirrors M_1 and M_2.

The light from M_2 passes through a diaphragm which is of such aperture that it cuts out all light except that passing through the second diaphragm back of the etalon. This second diaphragm is at such a position that light from it which passes to a concave mirror and then to the slit, forms a real image of the diaphragm in the grating, after passing through the collimating lens which is at its focal distance from the slit. The size of the diaphragm is such that its image just falls inside of the outlines of the ruled portion of the grating. The rings from the interferometer are localized at infinity so that the concave mirror, which collects the light from the etalon, placed at its focal distance from the slit (97.3 cm.) brings the rings to a focus on a slit.

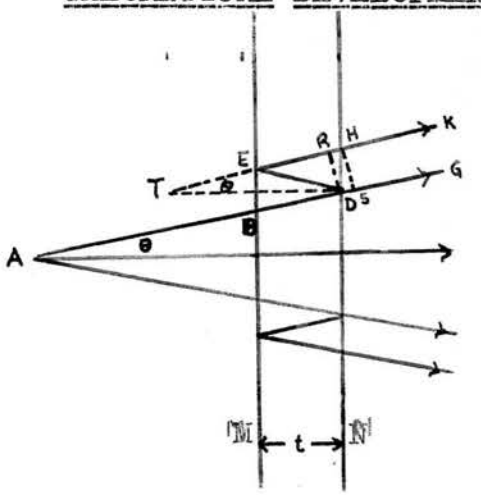
Plate III

Optical System



1. Hydrogen Tube
2. Pfund Arc
3. Lenses
4 Diaphragm
5 Mirror on rotating bed plate
6 Plane Mirrors
7 Diaphragms
8. Etalon
9. Concave Mirror
10. Slit
11 Autocollimating lense
12 Grating

THEORETICAL DEVELOPMENT



Let M and N be the etalon plates and A, the source of light.

The ray BD gives rise to the transmitted ray DG, together with the reflected ray DE. The ray DE is reflected at E, thus producing the ray EH, which in turn gives rise to the transmitted ray HK. Draw HS perpendicular to DG, and DR perpendicular to EH. Produce HE to T, making ET=ED. Then the internally reflected wave may be supposed to start from T at the instant when the transmitted wave starts from D. The distance in advance of the plane HS, covered by the transmitted wave, at the instant when the internally reflected wave passes through that plane, may be found as follows:- The path TH in a medium of refractive index μ, is equivalent to a path equal to $\mu \cdot TH$ in air, also $\mu \cdot RH = DS$. Thus the distance retardation of the internally reflected wave behind the transmitted wave is equal

to: $\mu \cdot TH - DS = \mu\,(TR + RH) - DS = \mu \cdot TR$

$$\text{now } TR = 2t \cos\ \theta$$
$$\therefore\ \mu \cdot TR = 2\ \mu\ t \cos\theta$$

The only source of phase difference between the rays DG and HK is the retardation due to the difference in their paths. Thus, for the rays DG and HK to interfere $2\mu t \cos\theta = (p + \frac{1}{2})\lambda$ where p is any positive integer including 0. For the rays DG and HK to reenforce each other $p\lambda = 2\mu t \cos\theta$.

Thus, p, the order of interference, is greatest when $\cos\theta = 1$ or when $\theta = 0$ which corresponds to the center of the ring system, and p decreases in going to the outer rings.

In air $u = 1$

$\therefore P\lambda = 2t \cos\theta$

at the center of the ring system $\cos\theta = 1$

$\therefore P\lambda = 2t$ where P is equal to the number of wave-lengths in the path difference, but in general the order is not integral unless a bright spot is given at the center. Thus, at the center

$p = P + e$ where P is equal to the whole number of wave-lengths and e is the fraction of an order at the center

$\therefore$ making a substitution we get, $p = \frac{2t}{\lambda}$

$P = \frac{2t \cos\theta}{\lambda} = p \cos\theta = p \cos(\frac{x}{2})$ where x is the angular diameter of the ring.

Expanding $\cos(\frac{x}{2})$ into the cosine series and retaining only the first two terms since x is very small we get:

$$P = p\,(1 - \frac{x^2}{8})$$

or $p = \frac{P}{(1-\frac{x^2}{8})} = P(1+\frac{x^2}{8})$ to a close approximation, since x is small.

$$e = p-P = P - \frac{Px^2}{8} - P$$

Now, $\frac{x}{\theta} = \frac{\tan x}{\tan \theta} = \frac{D'/F}{L'/F} = \frac{D'}{L'}$

where: x is the angular distance of the spectral lines on the slit;

θ is the angular distance of standard guage marks in front of the slit, as seen from the mirror which projects the rings on the slit;

L' is the linear distance of the photographed guage marks for the same spectral line;

D' is the linear distance of the spectral line on the slit.

$$x = \frac{\theta D'}{L'}$$

$$\frac{D'}{L'} = \frac{D}{L}$$

where: D and L equal the photographed diameters of guage marks on the plate.

$$x = \frac{\theta D}{L}$$

$$\therefore e = \frac{P\theta^2 D^2}{8L^2}$$

This requires, in addition to the photograph of the interference pattern, an exposure to the spectrum with the etalon removed and the gauge plate inserted in front of the slit, from which the value of L is obtained. The quantity θ has also to be determined from independent observations.

A simple transformation of this equation, however, makes possible a marked saving in labor and offers other advantages.

Let m equal the magnification of the line, then:

$$mL' = L$$

where: L' equals the diameter of the guage marks on the slit and L equals the photographed diameter of the guage mark.

$$L' = \frac{L}{m}$$

$$\frac{L'}{F} = \theta$$

where: F is the focal length of the concave mirror and $\frac{L'}{F}$ equals the tangent of the angle for which the angle may be substituted since the angle is small.

$L/mF = \theta$

and $\theta \sim L \quad 1/mF$

$\therefore e = PD^2/8m^2F^2$

also $p(1-x^2/8) = P$

$e = p-P = p-p+px^2/8$

but $e = Px^2/8$

$\therefore e = Px^2/8 = px^2/8$

and $e = PD^2/8m^2F^2 = pD^2/8m^2F^2$

Let K equal $p/8m^2F^2$

$\therefore e = KD_1^2$ for the first ring

and $1+e = KD_2^2$ for the second ring

and in general $(n-1)+e = KD_n^2$ for the n^{th} ring

Now $e = KD_1^2$

and $1+e = KD_2^2$

Subtracting, we get

$$1 = K(D_2^2 - D_1^2)$$

$$K = 1/(D_2^2 - D_1^2)$$

It is evident that both e and K may be determined from this equation if two diameters are measured. For any two consecutive rings, for example the first and second, it is seen that

$$K\lambda = \lambda/(D_2^2 - D_1^2)$$

but if m is assumed to be constant then

$$K\lambda = p\lambda/8m^2F^2 = 2t/8m^2F^2 = \text{constant}$$

$K\lambda$ is called the Plate Constant.

METHOD OF PROCEDURE

The various parts of the apparatus were arranged as shown in Plates I, II, and III. The optical system was carefully lined up and focused. The Hydrogen discharge tube was operated at 30,000 volts and 175 m.a. from the secondary of a 5 kw. Acme Transformer. A large rheostate limited the power input to the primary. By adjustment of the rate of production of Hydrogen in the electrolytic generator it was found possible to maintain the optimum condition throughout the period of exposure. Frequent examinations of the discharge were made with a direct vision spectroscope while the spectrum was being photographed. In order to increase the intensity of the tube on the slit, a small mirror was lightly pressed against the right-angled prism at the end of the tube so that the tube light emitted to the rear would be reflected down the tube. To reduce errors to a minimum, the arc exposure, which due to greater intensity was considerably less than that of the tube, was divided into thirteen exposures spaced at equal intervals throughout the Hydrogen exposure. The spectroscope was focused visually and then by photographic methods the other parts of the plate were brought into the focal plane of the instrument.

The plates used in this research were supplied by the Kodak Research Laboratories and were of the type 1-O. These plates were of high speed but only of medium contrast. The emulsion was coated on thin glass and all plates were backed. The plate

size was 2"x22". The exposure for the Pfund Arc was 10 minutes and for the Hydrogen discharge, 12 hours. Development of the plates took place immediately after exposure in contrast developer D-11[1]. Plates were developed for 6 minutes at a temperature of 65°F. This time yielded the maximum contrast possible without the appearance of fog. The plates were fixed in and acid-hardenerfixing solution.

The plates were measured on a comparator. The diameter of the second and fifth rings were measured. The position of each of the measured arcs of the ring system was measured four times, being approached twice from one direction and twice from the other. The plate was then reversed and the diameters were again measured in a similar manner. In order to determine the thickness of the etalon, the diameters of iron standard were measured. This thickness having been determined, it was possible to calculate the wave-lengths of the Hydrogen lines.

1. Elementary Photographic Chemistry--Eastman Kodak Co. 1929.

Plate #238-B.

Ring	Iron Standard	Red Upper Left	Red Upper Right	$L_m - R_m = D$
2	4118.549	2.793	4.402	
		2.784	4.401	
		2.805	4.395	
		2.808	4.402	
		m 2.798	m 4.400	1.602
5		2.226	4.963	
		2.232	4.970	
		2.232	4.968	
		2.232	4.971	
		m 2.231	m 4.968	2.737
2	4143.871	2.656	4.524	
		2.650	4.522	
		2.655	4.517	
		2.663	4.519	
		m 2.656	m 4.521	1.865
5		2.147	5.042	
		2.145	5.041	
		2.144	5.046	
		2.144	5046	
		m 2.145	m 5.044	2.899
2	4202.038	2.644	4.467	
		2.642	4.465	
		2.646	4.473	
		2.641	4.471	
		m 2.643	m 4.469	1.826
5		2.114	5.005	
		2.116	5.006	
		2.115	5.002	
		2.118	5.006	
		m 2.116	m 5.005	2.889
2	4216.186	2.721	4.380	
		2.715	4.387	
		2.710	4.389	
		2.713	4.385	
		m 2.715	m 4.385	1.670
3		2.487	4.609	
		2.490	4.603	
		2.490	4.609	
		2.490	4.600	
		m 2.489	m 4.605	2.116

Plates #238-B.

Ring	Iron Standard	Red Lower Left	Right	$L_m - R_m = D$
2	4216.186	3.055	4.722	
		3.056	4.731	
		3.056	4.729	
		3.057	4.727	
		m 3.056	m 4.727	1.671
3		2.844	4.943	
		2.840	4.953	
		2.836	4.959	
		2.841	4.958	
		m 2.840	m 4.953	2.113
2	4202.038	2.964	4.789	
		2.960	4.795	
		2.965	4.799	
		2.964	4.792	
		m 2.963	m 4.794	1.831
5		2.438	5.326	
		2.436	5.328	
		2.432	5.330	
		2.438	5.330	
		m 2.436	m 5.329	2.893
2	4143.871	2.924	4.789	
		2.924	4.786	
		2.928	4.791	
		2.928	4.797	
		m 2.926	m 4.791	1.865
5		2.410	5.308	
		2.406	5.308	
		2.408	5.309	
		2.409	5.310	
		m 2.408	m 5.309	2.901
2	4118.549	3.052	4.642	
		3.058	4.649	
		3.058	4.649	
		3.058	4.648	
		m 3.057	m 4.647	1.590
5		2.499	5.231	
		2.493	5.231	
		2.499	5.230	
		2.497	5.232	
		m 2.497	m 5.231	2.734

Ring	Iron Standard λ	D (Red lower / Red upper)	Mean D	D^2	$\frac{D_\alpha^2 - D_\beta^2}{\alpha - \beta} = \frac{1}{K}$	$\frac{\lambda}{\frac{D_\alpha^2 - D_\beta^2}{\alpha - \beta}} = K\lambda$	Dev. from mean
2	4118.549	1.590					
		1.602	1.596	2.547			
5		2.734					
		2.737	2.736	7.486	1.646	2502.	10.
2	4143.871	1.865					
		1.865	1.865	3.478			
5		2.901					
		2.899	2.900	8.410	1.644	2521.	9.
2	4202.038	1.831					
		1.826	1.829	3.345			
5		2.893					
		2.889	2.891	8.358	1.671	2515.	3.
2	4216.186	1.671					
		1.670	1.671	2.792			
3		2.113					
		2.116	2.115	4.473	1.681	2508.	4.

Plate constant Mean $K\lambda$ = 2512.
Average deviation = 6.5
Probable error = Average dev./2 = 3.
Percentage probable error = 3/2512 = 0.1%

Ring	Iron Standard	$K\lambda/\lambda$	$(K\lambda/\lambda)D^2 = e_1$	Mean e_1	$p_1' = 2t/\lambda$	$p''\lambda = (p_1' + e)\lambda = 2t$
2	4118.549	.6099	1.553			
5			4.565	.559	45026.	18544409
						$2t/\lambda$
2	4143.871	.6062	2.108			
5			5.098	.103		44751.41
2	4202.038	.5978	2.000			
5			4.996	.998		44131.94
2	4216.186	.5958	1.663			
3			2.665	.664		43983.84

Micrometer thickness $9.272 = t$

$2t = 18,544$ mm.

$S = (e_1' - e_1)/(1 - \lambda/\lambda_1) = 52$

$p_1' - S = 44974.$

Iron Standard λ	$p\lambda = (p'+S+e)\lambda = 2t$ (45078.559)	$p\lambda = (p'+S+e-1)\lambda = 2t$ (45077.559)	$(2t/\lambda)\lambda = 2t$
4118.549	18.565825	18.565414	18.565414
	$2t/\lambda$	$2t/\lambda$	
4143.871	44803.09	44802.10	18.565414
4202.038	44182.90	44181.92	18.565443
4216.186	44034.64	44033.66	18.565412

Optical thickness = mean $2t$ = 18.565421 mm.

Ring	H_2 (Approximate λ)	Red Upper Left	Red Upper Right	$L_m - R_m = D$
2	4212.498	2.885	4.817	
		2.887	4.818	
		2.889	4.814	
		2.889	4.816	
		m 2.888	m 4.816	1.928
5		2.383	5.330	
		2.385	5.327	
		2.380	5.331	
		2.380	5.332	
		m 2.382	m 5.330	2.948
2	4195.669	2.935	4.759	
		2.938	4.761	
		2.933	4.756	
		2.942	4.762	
		m 2.937	m 4.760	1.823
5		2.413	5.294	
		2.417	5.291	
		2.414	5.290	
		2.411	5.291	
		m 2.414	m 5.292	2.878
2	4177.111	3.022	4.649	
		3.023	4.656	
		3.027	4.649	
		3.032	4.656	
		m 3.026	m 4.653	1.627
5		2.468	5.221	
		2.471	5.217	
		2.470	5.219	
		2.468	5.219	
		m 2.469	m 5.219	2.750
2	4171.306	3.060	4.615	
		3.068	4.620	
		3.067	4.611	
		3.063	4.620	
		m 3.065	m 4.617	1.552
5		2.500	5.201	
		2.499	5.202	
		2.498	5.202	
		2.497	5.206	
		m 2.499	m 5.203	2.704

Ring	H2 (Approximate λ)	Red Lower Left	Red Lower Right	$L_m - R_m = D$
2	4171.306	2.776	4.317	
		2.779	4.322	
		2.778	4.313	
		2.782	4.324	
		m 2.779	m 4.319	1.540
5		2.197	4.902	
		2.203	4.897	
		2.198	4.903	
		2.198	4.899	
		m 2.199	m 4.900	2.701
2	4177.111	2.720	4.349	
		2.726	4.359	
		2.728	4.357	
		2.727	4.355	
		m 2.725	m 4.355	1.630
5		2.174	4.920	
		2.170	4.922	
		2.170	4.922	
		2.173	4.920	
		m 2.172	m 4.921	2.749
2	4195.669	2.628	4.444	
		2.619	4.443	
		2.627	4.443	
		2.623	4.445	
		m 2.624	m 4.444	1.820
5		2.100	4.973	
		2.100	4.974	
		2.097	4.973	
		2.104	4.975	
		m 2.100	m 4.974	2.874
2	4212.498	2.558	4.482	
		2.554	4.488	
		2.553	4.484	
		2.558	4.487	
		m 2.556	m 4.485	1.929
5		2.056	5.001	
		2.058	5.004	
		2.058	4.998	
		2.059	5.005	
		m 2.058	m 5.002	2.944

Ring	H_2 (Approximate λ)	D (Red Lower / Red Upper)	Mean D	D^2
2	4171.306	1.540 1.552	1.546	2.390
5		2.701 2.704	2.703	7.306
2	4177.111	1.630 1.627	1.629	2.654
5		2.749 2.750	2.750	7.563
2	4195.669	1.820 1.823	1.822	3.320
5		2.874 2.878	2.876	8.271
2	4212.498	1.929 1.928	1.929	3.721
5		2.944 2.948	2.946	8.679

Ring	λ_1 = approx. λ	$K\lambda/\lambda'$ (K 2512)	$(K\lambda/\lambda')D^2 = e$	Mean e
2	4171.306	.6022	1.439	
5			4.400	.420
2	4177.111	.6014	1.596	
5			4.548	.572
2	4195.669	.5987	1.988	
5			4.952	.970
2	4212.498	.5963	2.219	
5			5.175	.197

$2t/\lambda' = p$ (2t 18.565421)	$2t/p = \lambda$	Mean Values Kent & Lacount	Diff.
44507.45	4171.309	.307	.002
44445.60	4177.113	.112	.001
44249.01	4195.673	.671	.002
44072.23	4212.501	.501	.000

SUMMARY

In the introduction there is stated briefly the reason why it is so extremely important to determine with a great degree of accuracy the wave-lengths of lines in the Secondary Spectrum of Hydrogen. There is given a brief resume of the historical development of spectroscopy, particularly of the development of standards. This is followed by a survey of the earlier work done on the secondary spectrum of Hydrogen.

There is given a rather detailed description of the laboratory in which this research was carried on and also a detailed description of the sources of light.

The equations used in determining the wave-lengths of the Hydrogen lines are carefully derived and a few sample calculations are made, the results being compared with those obtained by Dr. Kent and Lacount.

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