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The completion, adjustment, and operation of a grazing incidence vacuum ultraviolet spectrograph

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THE COMPLETION, ADJUSTMENT, AND OPERATION OF A GRAZING INCIDENCE VACUUM ULTRAVIOLET SPECTROGRAPH

BY

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A

THESIS

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INTRODUCTION

Most gases, and particularly oxygen and nitrogen, are nearly opaque to radiation in the region from about 1800 Å downward to about 2 Å [1]

1. Boyce, J. C., Spectroscopy of the Vacuum Ultraviolet, Rev. Mod. Phys., Vol. 13, p. 2, Jan. 1941.

and hence, for spectroscopic work in this region, the removal of these gases is mandatory. Popular usage generally refers to the range mentioned above as the vacuum ultraviolet. That there remains much experimental work to be done in the vacuum ultraviolet has been pointed out by Boyce in his exhaustive survey of vacuum ultraviolet spectroscopy.[2] In order to fill in some of these

2. Ibid, pp. 1-53.

gaps, Mr. L. H. Chapin,[3] in the spring of 1950,

3. Formerly an Instructor in the Physics Department of Missouri School of Mines, now with Minneapolis Honeywell.

undertook the construction of a grazing incidence vacuum spectrograph for use in the region 100 Å to 1,000 Å. Due to circumstances beyond his control, Mr. Chapin was unable to complete the instrument in the time available to him, and the

present author was assigned to the project in September, 1950.

REVIEW OF LITERATURE

The Spectrographic Components

The pioneer work in spectroscopy of the vacuum ultraviolet was done by Schumann[4] who first removed the opaque air and lenses from his system and the opaque gelatin from his photographic plates. Schumann found that an optical system of fluorite would enable him to reach wave lengths since found to be on the order of 1200 Å. Later workers[5] have found that lithium fluoride might be used to wave lengths as low as 900 Å, but little work has been done with this material. A popular prism instrument which makes use of these materials is mentioned by Boyce.[6] This instrument uses either fluorite or lithium fluoride prisms and lenses and is adequate for the so-called Schumann region (down to about 1200 Å). By far the greatest volume of work in the vacuum ultraviolet region has been done with two types

4. Sawyer, R. A., Experimental Spectroscopy, N.Y., Prentice-Hall, pp. 288-289, 1946.

5. Schneider, E. G., Phys. Rev., Vol. 49, p. 341, 1936.

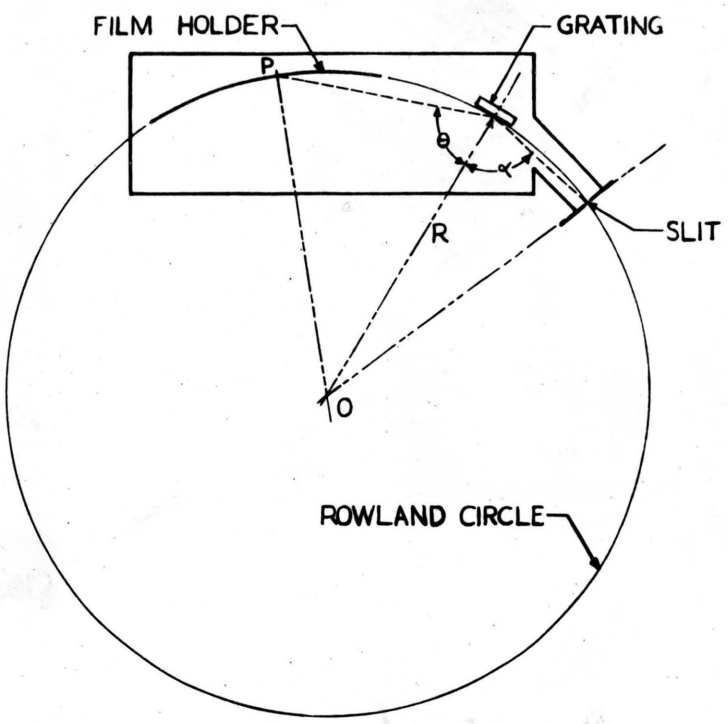
6. Boyce, J. C., Op. Cit., p. 11.

of concave grating spectrographs--those using a grazing angle of incidence (75° to 90°) and those using a nearly normal incidence angle.

The normal incidence instruments, when compared with those of grazing incidence, have the advantages of accuracy and the ability to include a very wide range on a single photograph, while the grazing incidence instruments are able to obtain greater dispersion with higher intensities and, in general, smaller physical size. FIG. 1 shows a diagram of the typical grazing incidence spectrograph which is described in this paper.

Of particular importance to spectroscopy of the vacuum ultraviolet is the source of the radiations. These, in general, are ordinary light sources complicated by the vacuum operation that is necessary, and by the opacity of most window materials to the desired wave lengths. A popular type of source for this region is the condensed vacuum spark as developed by Edlen[7]

7. Edlen, Bengt., Zeits. f. Physik, Vol. 100, p. 621.



F I G. I

Schematic of A Typical Grazing Incidence Spectrograph

and others, in which a condenser, charged anywhere from 5,000 volts to 80,000 volts, is periodically discharged between electrodes surrounded by or containing the material to be studied. Another type of source is the Schuler tube,[8] which uses the negative glow of a

8. Sawyer, R. A., and Paschen, F. Ann. d. Physik, 84, 1.

continuous discharge. This negative glow is kept inside a hollow tube of the material to be studied and there is no positive column.[9]

9. Boyce, Op. Cit. p. 19.

Low pressure gas sources, such as a neon tube, have been used. Such a source would be good for the first two spectra of most elements, but the inherent difficulties of using this type of source in a vacuum spectrograph might prove troublesome.

Vacuum grating spectrographs present special difficulties in their adjustments. They have all the quirks of adjustment of ordinary grating spectrographs, as described in Sawyer[10]

10. Sawyer, Op. Cit., pp. 159-171.

and in Harrison, Lord and Loofbourow,[11] but in

11. Harrison, G. P., Lord, R. C., Loofbourow, J. R., Practical Spectroscopy, N.Y., pp. 109-114, 1948.

addition, most of the adjustments must be made in a vacuum and tested photographically. Rathenau and Peerklamp[12] discuss at great length

12. Rathenau, Gert and Peerklamp, P. K., Zur Justrierung des Konkavgitters in Striefunder Inzidenz Physica, Vol. 2, pp. 125-143, Feb. 1935.

the adjustment of grazing incidence vacuum spectrographs.

The Vacuum System

The vacuum system which, of necessity, must accompany a vacuum ultraviolet spectrograph deserves special care in design. Much work on vacuum systems in general was done during the recent war and many of the results so obtained have been described in detail by Guthrie and Wakerling.[13] Other good references to

13. Guthrie, H., and Wakerling, R. K., Vacuum Equipment and Techniques, N.Y., McGraw Hill, 1949.

vacuum technique are Strong[14] and Dushman.[15]

14. Strong, John, Proceedures in Experimental Physics, N.Y., Prentice Hll, Chapter III, pp. 93-150, 1946.

15. Dushman, Saul, Scientific Foundations of Vacuum Technique, N.Y.: John Wiley, 1949.

Careful attention to the details of design and use mentioned by these authors should make the problem of obtaining a proper vacuum relatively minor. For satisfactory work in the vacuum ultraviolet a pressure of the order of 10^{-4} mm of mercury is considered essential.[16] It is, of course,

16. Boyce, Op. Cit., p. 5.

necessary that all the operating parts of the spectrograph be inside the evacuated chamber. This means that special arrangements for mounting the slit and shutter, and for any operating adjustments, must be made. Unfortunately, the available literature on such technical details is negligible and the experimenter is left pretty much to his own devices.

Detection of Radiation

For many years, "Schumann" photographic plates were the only practical means of spectrographic detection of short wave length radiation. These plates were first developed

by Schumann in 1901 [17] after a great deal of

17. Boyce, Op. Cit., p. 8

experimentation. They consist of a very delicate emulsion of silver halide and a small amount of gelatin. The preparation of these plates is discussed at some length by Lyman [18] and by

18. Lyman, T., Spectroscopy of the Extreme Ultraviolet, N. Y., Longmans, Green and Co.

Hopfield and Appleyard [19] who suggest modifications

19. Hopfield, J. J., and Appleyard, A Simplified Method of Preparing Schumann Plates, J. Opt. Soc. Am., Vol. 22, p. 488, 1932.

in the preparation procedure. Variations in the Schumann procedures are used by the British firm of Ilford, Ltd., to produce Ilford Q. plates which contain a high concentration of silver bromide grains at the surface of the emulsion (this process is a trade secret) and have been very popular among experimenters.

In the early nineteen twenties, Duclaux and Jeantet [20] developed the process of coating

20. Duclaux, J., and Jeantet, J de Phys et rad., Vol. 2, p. 154, 1922.

an ordinary photographic plate with a thin layer of fluorescent oil and this was adapted to the vacuum ultraviolet by Lyman.[21] In this country,

21. Lyman, Op. Cit., P. 125.

Eastman has been producing their Kodak O Ultraviolet (O U.V.) plates, which are ordinary O type spectroscopic plates coated with an ultraviolet sensitive fluorescent material.[22] Coated plates

22. Boyce, Op. Cit., p. 9.

have the disadvantage that they must be carefully washed before development to remove the fluorescent coating. Recently, Eastman has produced a new emulsion,[23] designated as Kodak

23. Schoen, A. L., and Hodge, E. S., Photographing Spectra in the Vacuum Ultra-violet, J. Op. Soc. Am., Vol. 40, pp 23-24, Jan.1950.

S.W.R. (Short Wave Radiation). This emulsion is available at present only on a film base and the instrument discussed in this paper was designed especially for use with this film in 35 mm size. The problems involved in the use of this film will be discussed in detail later.

Other methods of detection, chief among them being photoelectric procedures, are briefly

discussed, with references, by Boyce.[24]

24. Boyce, Op. Cit., p. 10.

Interpretation of Results

Before interpretation of the results of experimentation in the vacuum ultraviolet region can be undertaken, the various lines obtained must be identified and classified. By far the most complete works of this sort have been done by Edlén[25] and Söderqvist[26] in Sweden,

25. Edlén, Bengt, Wellenlägen und Termsysteme zu den Atomspektren der Elemente Lithium, Beryllium, Bor, Kohlenstoff, Stickstoff, und Saurstoff. Nova Acta Regiae Societatas Scientiarum Upsaliensis. Ser. IV, Vol. 9, No. 6, 1934.

26. Söderqvist, Jonas, Vakuumfunkenspektren der Elemente Natrium, Magnesium, Aluminum, und Silicium. Nova Acta Regiea Societatas Scientiarum Upsaliensis. Ser. IV, Vol. 19, No. 7, 1934.

and by Boyce and his associates[27] in this country.

27. Boyce, Op. Cit., Appendix C, p. 35.

Boyce and Moore[28] have prepared for private

28. Boyce, J. C., and Moore, J. T., Provisional Wavelength Identification Tables for the Vacuum Ultraviolet, Private Publication, 1941.

distribution a most detailed tabulation of the more intense lines listed in Boyce's review of vacuum spectroscopy.[29] In the event that none of

29. Boyce, Op. Cit., Appendix C, p. 35.

the previous references are immediately available, a much shorter listing by Boyce and Robinson in the Journal of the Optical Society of America [30]

30. Boyce, J. C., and Robinson, H. A., Wavelength Identification Lists for the Extreme Ultraviolet, J. Opt. Soc. Am., Vol. 26, No. 4, p. 133, April 1936.

might prove useful.

By 1941, the efforts of, primarily, Boyce and his various collaborators to produce wave length standards and tables of spectrographic lines for the vacuum ultraviolet had reached a state where a great deal of work by other experimenters was possible. Apparently the war provided more interesting fields of endeavor, for almost no papers dealing with vacuum ultraviolet spectroscopy have appeared in this country since that time. This means, then, that there is a tremendous amount of work yet to be done in this region. The tabulations made by Boyce [31]

31. Boyce, Op. Cit., pp.22, 23.

in 1941 are still applicable. They show that the spectra of most of the lighter elements, through cadmium, have been investigated in some detail, although there are glaring omissions in the first spectra of boron, magnesium, aluminum and chlorine and in the second spectra of magnesium, chlorine and cadmium. Only what Boyce calls reconnaissance surveys have been made of these spectra. Almost no work has been done with elements of atomic number greater than 21. Here then, lies a most rewarding field of endeavor to those who work in the vacuum ultraviolet. It is believed that the instrument discussed in this paper will have great possibilities in this service.

PROBLEMS OF CONSTRUCTION, ADJUSTMENT AND OPERATION

The basic theory of grazing incidence concave grating spectrographs has been adequately covered by Sawyer [32] and by Harrison, Lord, and Loofbourow,[33] among others, and the specific design of the present instrument has been covered by Chapin.[34] Hence, the author feels that a detailed coverage of this material is unnecessary. A brief summary of the theory of such a spectrograph is in order, however. As the reader will remember, most concave grating mountings make use of the fact, first explained by Rowland, that the spectrographic slit, the center point of the grating, and the focused images of the slit in the various orders and wavelengths all lie on what is now called the Rowland circle-- a circle the center of which coincides with the focal point of the grating. (See FIG. I.) As its name implies, the grazing incidence spectrograph has its source so placed that the incident light

32. Sawyer, Ralph A., Experimental Spectroscopy N.Y., Prentice Hall, pp. 126-141, 291-294, 1946.

33. Harrison, G. R., Lord, R. C., Loofbourow, J. R., Practical Spectroscopy, N. Y., Prentice Hall, pp 73-85, 538-39, 1948.

34. Chapin, L. H., A Grazing Incidence Vacuum Grating Spectrograph, Missouri School of Mines unpublished Masters Thesis, 1950.

strikes the surface of the grating at an angle of 70° or more with the grating normal. The basic formulae which are applicable are:[35]

35. Sawyer, Op. Cit., pp. 123, 131.

(1). $n\lambda = d(\sin\alpha - \sin\theta)$

(2). $\frac{d\theta}{d\lambda} = \frac{n}{d\cos\theta}$

(3). $\frac{ds}{d\lambda} = \frac{n}{d(\cos\theta)} \cdot \frac{R\sin\phi}{2\sin\alpha\sin(90°-\theta)}$

Equation (1) is the well-known grating formula in which n is the spectral order, λ the wavelength, d the distance between grating rulings, α the angle of incidence and θ the angle of diffraction. For the grating used in the instrument under discussion, which is ruled 22,000 lines to the inch,[36] d is found to be

36. Private communication to Dr. Harold Q Fuller, Physics Department, Missouri School of Mines.

1.141×10^{4}A. A variation of formula (1) which is useful when the linear distance on a photograph between two known lines, or between a known

line and an unknown line can be measured is obtained as follows: referring to FIG. II, the measured distance

$$P'P = P'G - PG$$

$$= R(\gamma - \beta)$$

$$= R(180 - 2\theta' - 180 + 2\theta)$$

or

(4). $$P'P = 2R(\theta - \theta').$$

But, from formula (1),

$$\theta = \text{arc sin} \left(\frac{n\lambda}{d} - \sin\alpha\right)$$

$$\theta' = \text{arc sin} \left(\frac{n\lambda'}{d} - \sin\alpha\right)$$

(where is the wavelength of the line closest to the central image).

(5). $$P'P = 2R\left[\text{arc sin}\left(\frac{n\lambda}{d} - \sin\alpha\right) - \text{arc sin}\left(\frac{n\lambda'}{d} - \sin\alpha\right)\right]$$

Formula (2) is the common formula for angular dispersion and formula (3) is the formula for linear dispersion for the instrument under discussion as developed by Chapin.[37] All of the

37. Chapin, Op. Cit., p. 17.

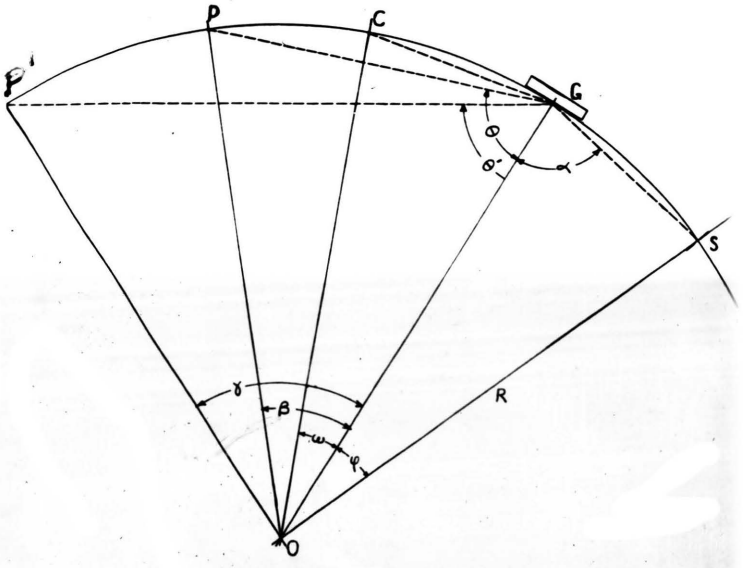


FIG. II
(See text)

preceding formulae are referred to FIG. II.
One of the primary advantages of a grazing incidence for illumination of the grating lies in the fact that most wave lengths are totally reflected from the grating surface when the angle of incidence is high. Sawyer [38] finds that for an

38. Sawyer, Op. Cit., p 292.

angle of incidence of 80° all wave lengths above 40 Å are totally reflected.

More detailed discussions of the theory of grating spectrographs are given in the various references quoted in the above paragraphs.

When the author took over the project the situation was as follows: The main chamber of the instrument, FIG. III, the film holder, FIG. IV, the pumping system, FIG. V, and a mount for the grating had been constructed and assembled and preliminary adjustments had been made. Still to be constructed were the slit mechanism and the light source, with its component power supply. Mr. R. G. Woodle, who has collaborated with the author on the present project, undertook the design and construction of the power supply

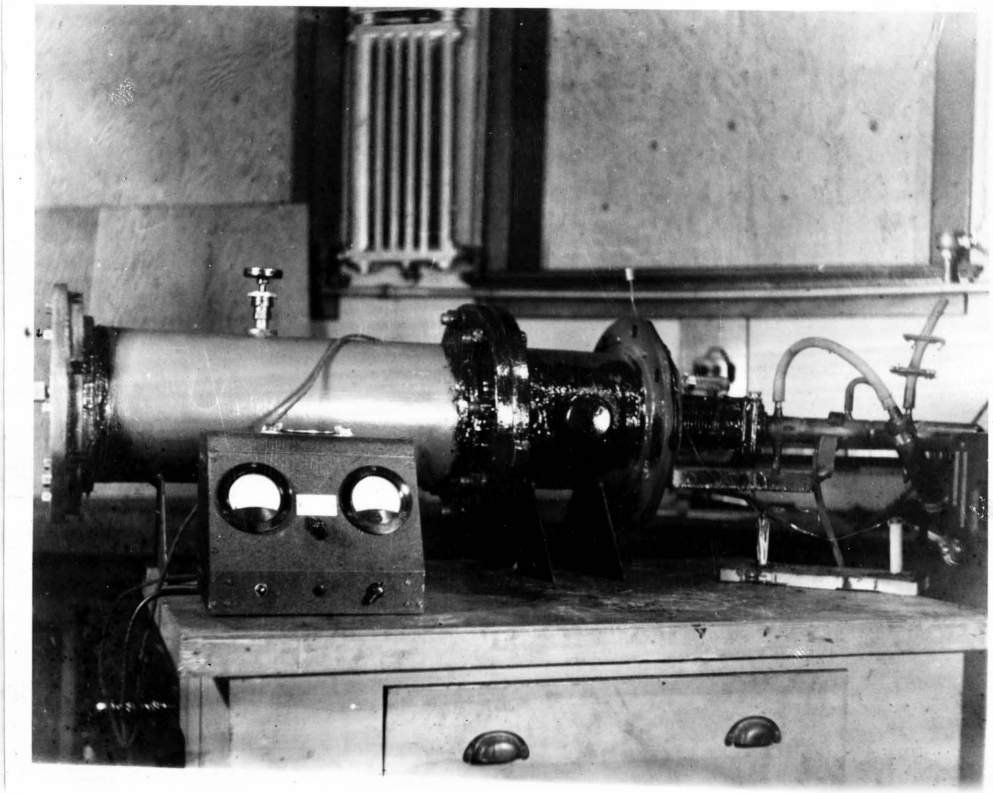


FIG. III
A Photograph Of The Assembled Spectrograph

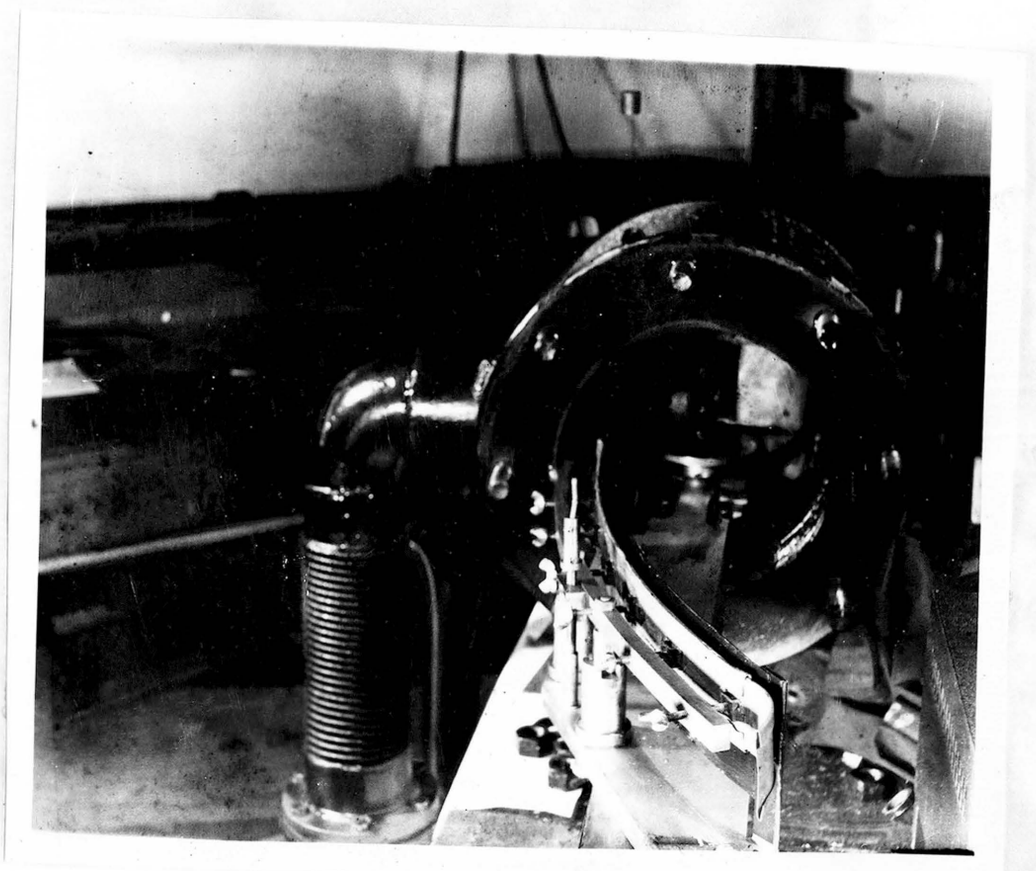


FIG. IV
The Film Holder In Position
(Note that the film must be
loaded into the holder from
the end toward the observer)

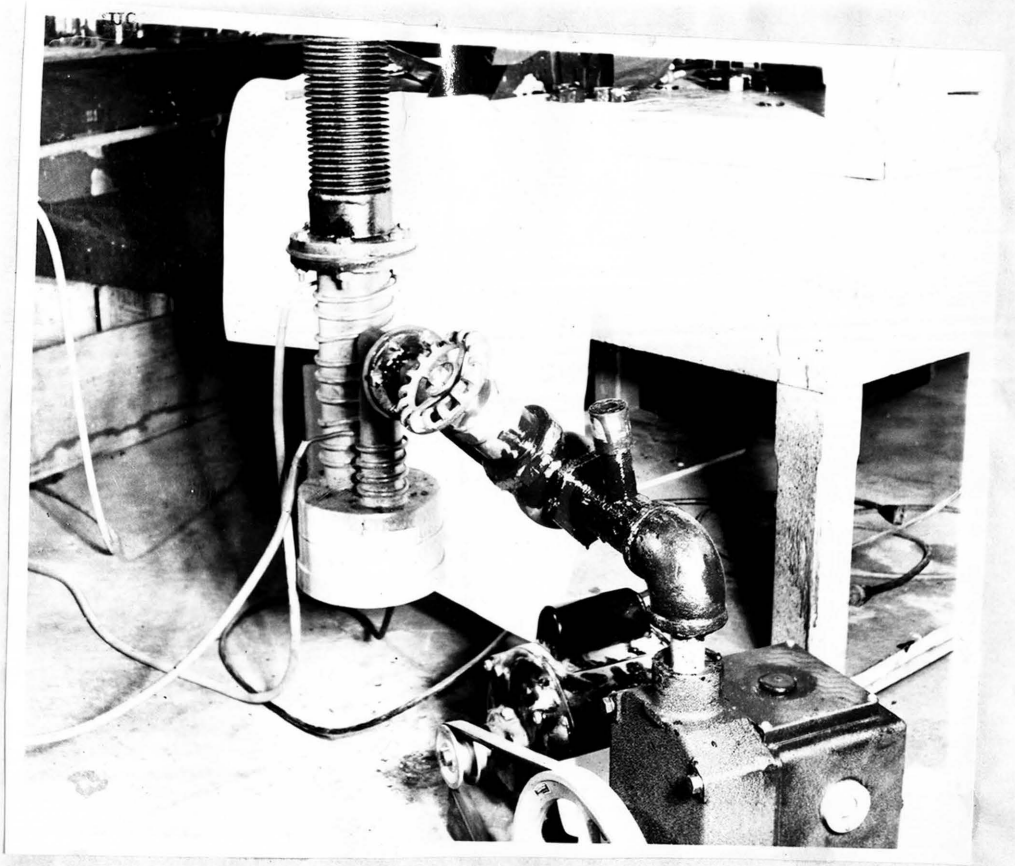


FIG. V
A View of the Diffusion Pump
And Its Companion Roughing Pump

and source tube mounting. For details concerning these items the reader is referred to the Masters' Thesis of Mr. Woodle.[39] The other problems involved

39. Woodle, R. G., Unpublished Masters' Thesis, Missouri School of Mines, 1951.

in the completion of the project will be discussed in detail below.

Slit Mechanism

The basic requirements for the slit mechanism for a grazing incidence spectrograph are as follows:

1. The slit must be precisely adjustable.
2. The slit jaws must be parallel opening, so that the center of the slit opening remains on the Rowland circle.
3. The slit jaws must be easily cleanable. This is especially important when a hot spark is used, since the resultant sputtering of the slit jaws makes frequent cleaning mandatory.

To these requirements must be added a fourth, peculiar to the vacuum ultraviolet.

4. The slit mechanism must be contained within

the vacuum chamber. After considering several slit designs,[40, 41] it was decided that a

40. Sears, J. E., A Symmetrically Opening Optical Slit, Journ. of Sci. Inst., Vol. 10, No. 12, pp. 376-377, 1933.

41. Elliott, A., A Symmetrically Opening Slit, Journ. of Sci. Inst., Vol. 10, No. 11, pp. 358, 359, 1933.

modification of a design by Strong[42] would serve

42. Strong, J., On An Optical Slit, Rev. of Sci. Inst., Vol. 12, No. 4, p. 213, 1941.

the purpose. In this design, the slit jaws, which in this case are made of Stellite,[43] are

43. Stellite, a remarkable alloy, may be vigorously cleaned in concentrated sulfuric or nitric acid.

mounted on small brass blocks. These blocks, in turn, are fastened at each end to the mechanism housing by small pieces of clock springs (see FIG. VI) in such a fashion that when the jaw blocks are pushed down by a screw mechanism they move apart in a pantagraph-like motion. The advantages of such a mechanism are:

1. The jaws, owing to the parallelogram type of construction, remain parallel.
2. The finest adjustment of the slit opening occurs when the opening is small. This is a feature found, so far, only in this type of mechanism.

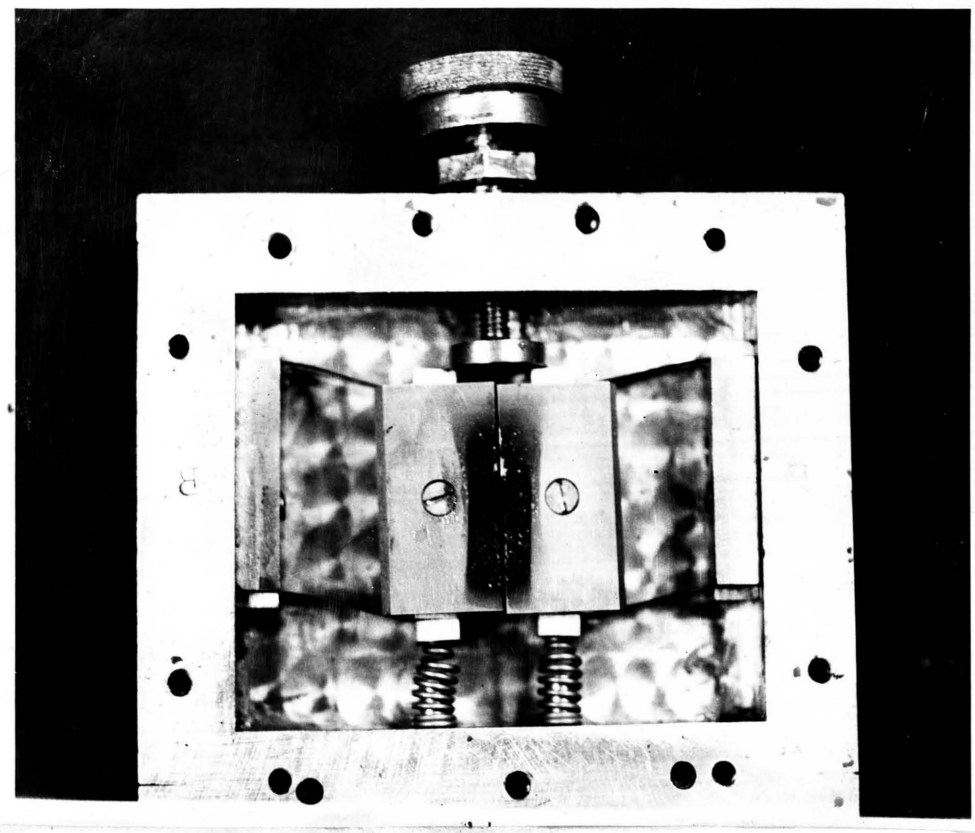


FIG. VI
A Parallel Opening Slit
(See text)

3. The slit can be completely closed without damage.
4. The mechanism is such that it could be fabricated to a fair precision with limited facilities.

The actual construction of the slit was accomplished by the author largely by hacksaw and file, but the operation of the slit appears to be quite satisfactory.

Shortly after the author started on the present project, it became apparent that a new mounting for the grating was mandatory. The mounting in service at that time had an intolerable amount of looseness and play, and there were no provisions for fine adjustments. Perhaps it would be well to remind the reader that a grating, for use in any type of spectrograph, must have three degrees of adjustable freedom, or freedom about the axes x, y, and z in FIG. VII. To replace the original part, the author has designed the grating holder shown in FIGS. VIII and IX. This grating holder is mounted on ball

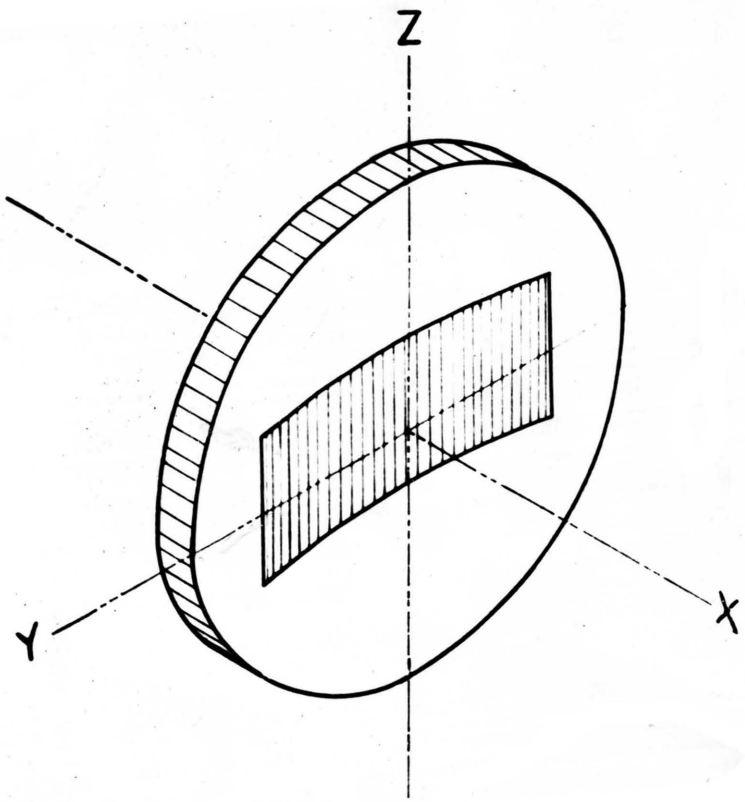


FIG. VII
The Three Axes of Rotation of a Grating
(See text)

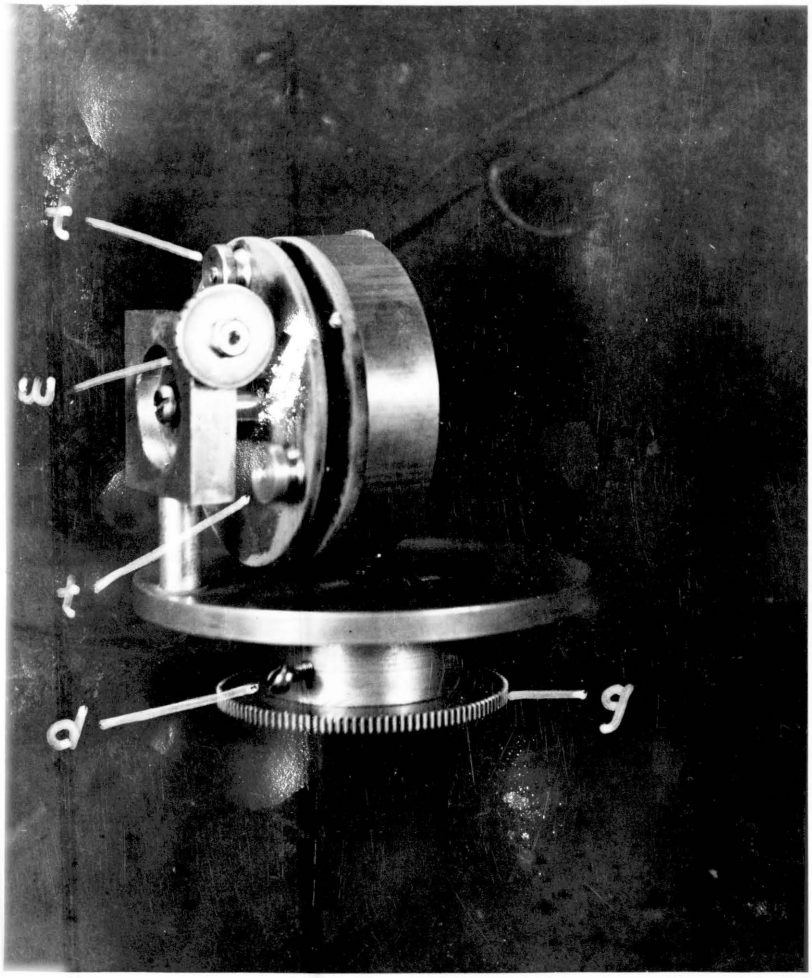


FIG. VIII
The Re-designed Grating Holder

d - screw tightened drag
g - gear for rotation about a vertical axis
w - worm and gear for rotation about the grating normal
t - thumb screws for fine adjustment of the grating

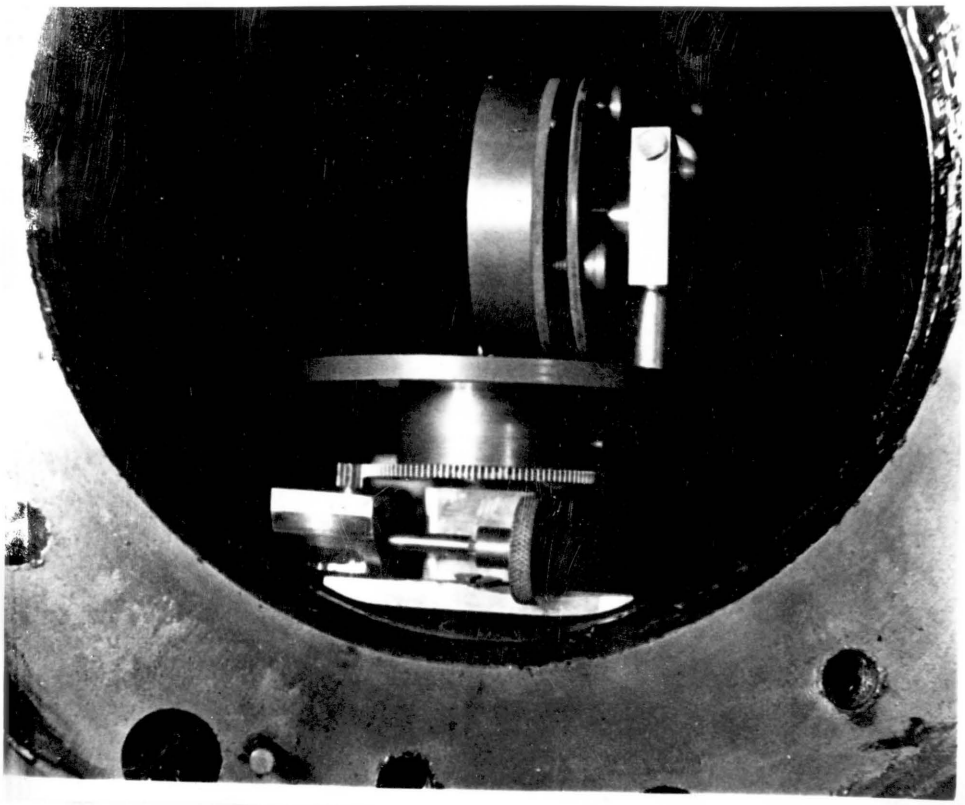


FIG. IX a
Grating Mount In Place In The Spectrograph

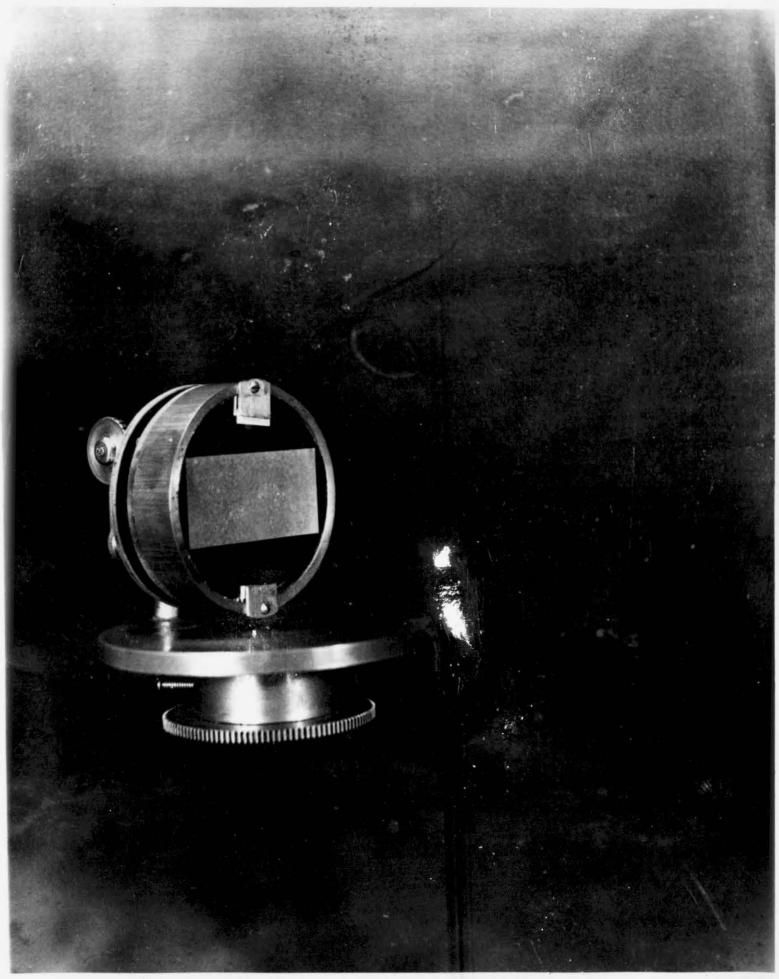


FIG. IX b
Another View of the Grating Mount

bearings on a fixed center post. A screw adjusted drag (d, FIG. VIII) to prevent free motion has been incorporated in the design. Rotation about the z axis of the grating is accomplished through a gear train which meshes with a gear fixed to the holder (g, FIG. VIII). A worm and gear, (w, FIG. VIII) is provided to allow rotation about the x axis while limited rotation about the y axis as well as some motion parallel to the x axis of the grating are obtained through adjustment of three thumb-screws (t, FIG. VIII). This redesigned grating holder works, but it is not entirely satisfactory. There is still a small amount of play in the mechanism and a person must be an amateur contortionist to make adjustments with the grating mounted in the spectrograph.

Further modifications of the design of the instrument that should be included at an early date include the placing of brass bumper plates and alignment pins between the slit mechanism and its collimator tube and between the slit-end cover plate and the spectrograph housing proper. These are essential if proper realignment with a minimum of effort is to be

obtained after disassembly of these parts.

Chapin, in his thesis,[44] and Rathenau and Peerklamp,[45] discuss the various adjustments of a grazing incidence spectrograph, but the author and his colleagues have developed a few special procedures that bear mentioning.

44. Chapin, Op. Cit., p. 39.

45. Rathenau and Peerklamp, Op. Cit.

To obtain the center of focus of the grating a parallax method is used. This consists of mounting a sharp pointed rod on an optical bench and observing its image from the grating through a telescope set for infinity. The rod was moved in and out along the axis of the grating until no parallax was to be seen between the telescope cross hairs and the image of the point. This procedure located the point within 1 mm of the center of focus of the grating.

To adjust the slit for parallelism with the grating rulings a high pressure mercury arc is focused on the slit. With the exception of two small portions at the ends, the slit was completely covered and the direct image and the third or fourth order mercury green

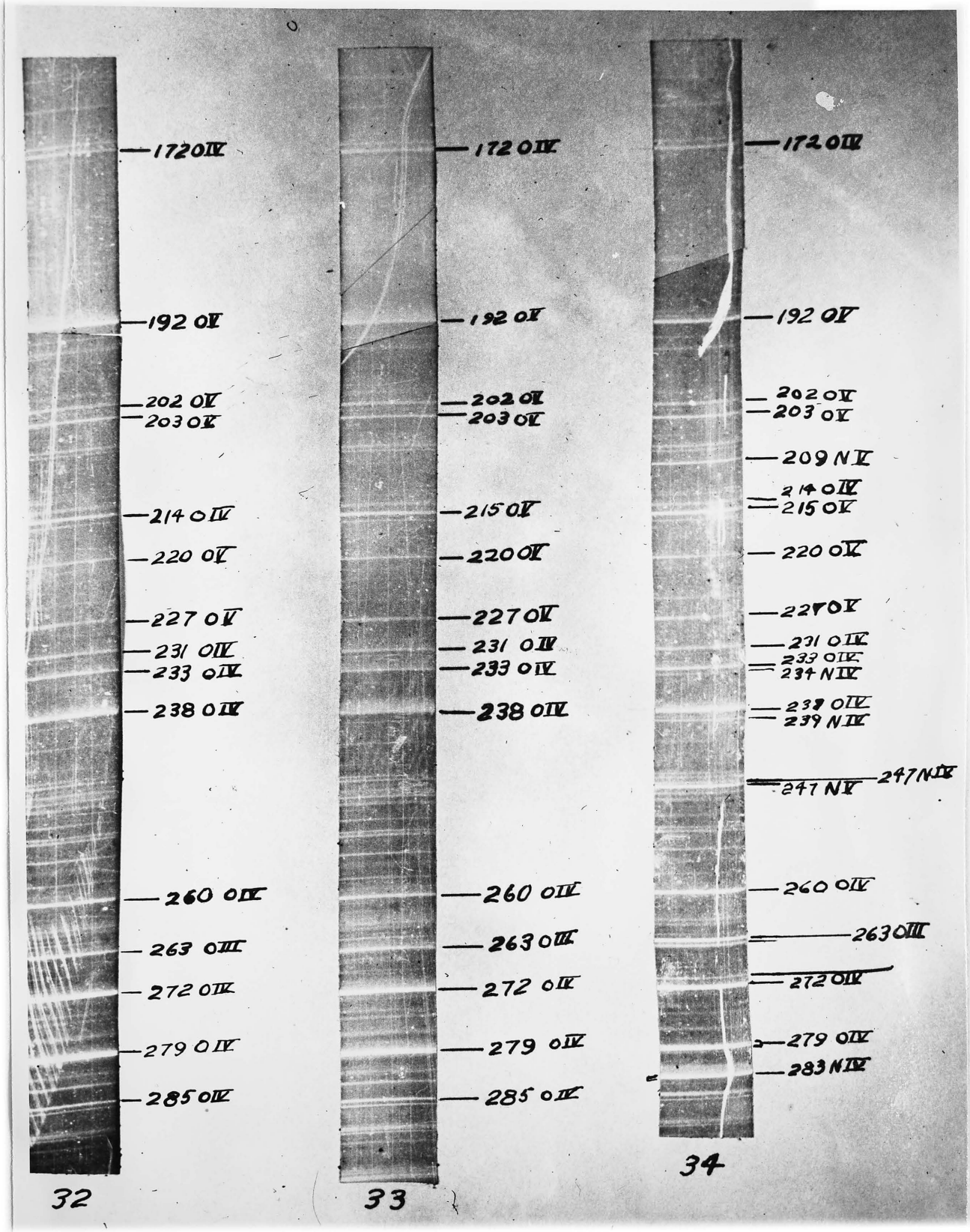
line were simultaneously observed through microscopes. If the slit was not parallel to the grating rulings two sharp lines would appear. As the slit was brought into parallelism with the rulings the two images merged together and finally coincided. It is felt that a fairly precise adjustment was made.

At the end of the first 39 exposures the grating had become covered with an oil film, and the slit jaws had been heavily sputtered with small bits of aluminum and covered with a good coating of carbon. The grating was cleaned quite satisfactorily by flushing the surface, first with acetone and immediately thereafter with distilled water. The grating has been ruled in speculum and aluminized and consequently it is quite susceptible to damage. The slit jaws are made of sterner stuff. Vigorous scrubbing of the flat surfaces with a glass rod and concentrated sulfuric acid failed to remove the carbon layer. As a last recourse the slit jaws were placed flat side down on a piece of plate glass covered with a very fine grade of carborundum (600 grit) and gently rubbed with

a circular motion. This method is effective and produced a clean looking finish on the jaws but its crude vigor should be avoided whenever possible.

Photographic Technique

At the time of this writing nearly 100 exposures have been made with the spectrograph. For the most part, these consist of adjustment photographs and have little value. However, one group of exposures, numbers 29 through 35, show typical line spectra of the types to be expected from such an instrument as the one under discussion. Exposures 32, 33, and 34 are shown in FIGS. X - XV, and will be discussed later. As was mentioned earlier, the spectrograph was designed to use Eastmans' new 35 mm Kodak SWR film. This film requires special handling techniques and it might be of help to future users of the instrument to describe those techniques developed by the author. The film may be safely handled in a darkroom under a Wratten Series 2 safelight. It comes from the manufacturer on plastic rolls, wrapped in aluminum foil, and sealed in a metal box and it was found


172 0 IV
192 0 V
202 0 V
203 0 V
214 0 IV
220 0 V
227 0 V
231 0 IV
233 0 IV
238 0 IV
260 0 IV
263 0 III
272 0 IV
279 0 IV
285 0 IV
32
172 0 IV
192 0 V
202 0 V
203 0 V
215 0 V
220 0 V
227 0 V
231 0 IV
233 0 IV
238 0 IV
260 0 IV
263 0 III
272 0 IV
279 0 IV
285 0 IV
33
172 0 IV
192 0 V
202 0 V
203 0 V
209 N V
214 0 IV
215 0 V
220 0 V
227 0 V
231 0 IV
233 0 V
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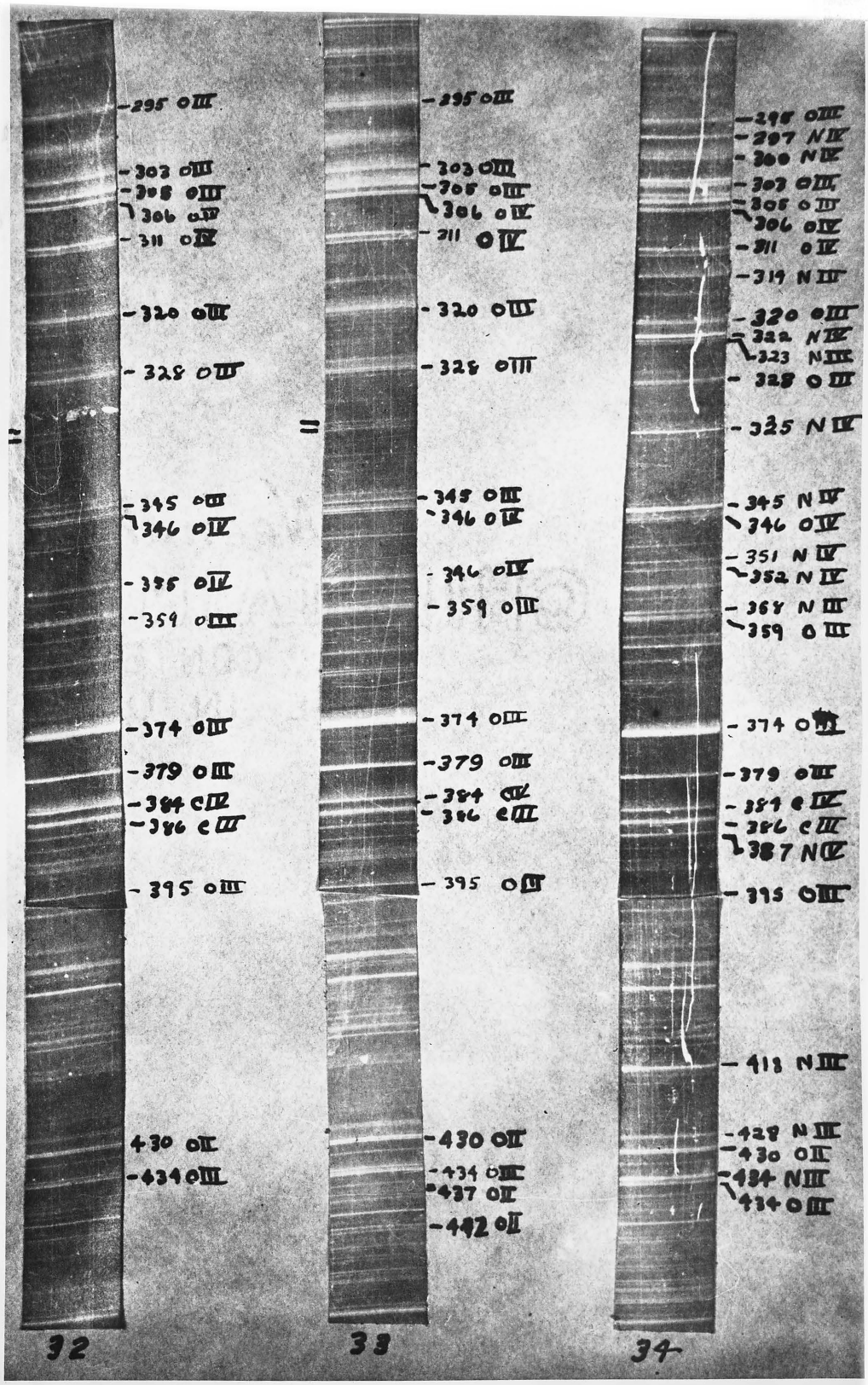
263 0 III
272 0 IV
279 0 IV
283 N IV
34

FIG. X


295 O III
303 O III
308 O III
306 O IV
311 O IV
320 O III
328 O III
345 O III
346 O IV
385 O IV
359 O III
374 O III
379 O III
384 C IV
386 C III
395 O III
430 O II
434 O III
32
295 O III
303 O III
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374 O III
379 O III
384 C IV
386 C III
395 O III
430 O II
434 O III
437 O II
442 O II
33
298 O III
297 N IV
300 N IV
307 O III
305 O III
306 O IV
311 O IV
319 N III
320 O III
322 N IV
323 N III
328 O III
325 N IV
345 N IV
346 O IV
351 N IV
352 N IV
368 N III
359 O III
374 O III
379 O III
384 C IV
386 C III
387 N IV
395 O III
418 N III
428 N III
430 O II
434 N III
434 O III
34

FIG. XI


485 OII
508 OIII
515 OII
525 OIII
554 OIV
597 OIII
599 OIII
608 OIV
609 OIV
617 OII
624 OIV
625 OIV
629 OI
32
485 OII
508 OIII
515 OII
518 OII
525 OIII
554 OIV
597 OIII
599 OIII
608 OIV
609 OIV
617 OII
624 OIV
625 OIV
629 OI
33
485 OII
415 N?
508 OIII
515 OII
525 OIII
554 OIV
?
597 OIII
598 OIII
?
608 OIV
609 OIV
617 OII
625 OIV
625 OII
629 OI
644 NII
34

FIG. XII

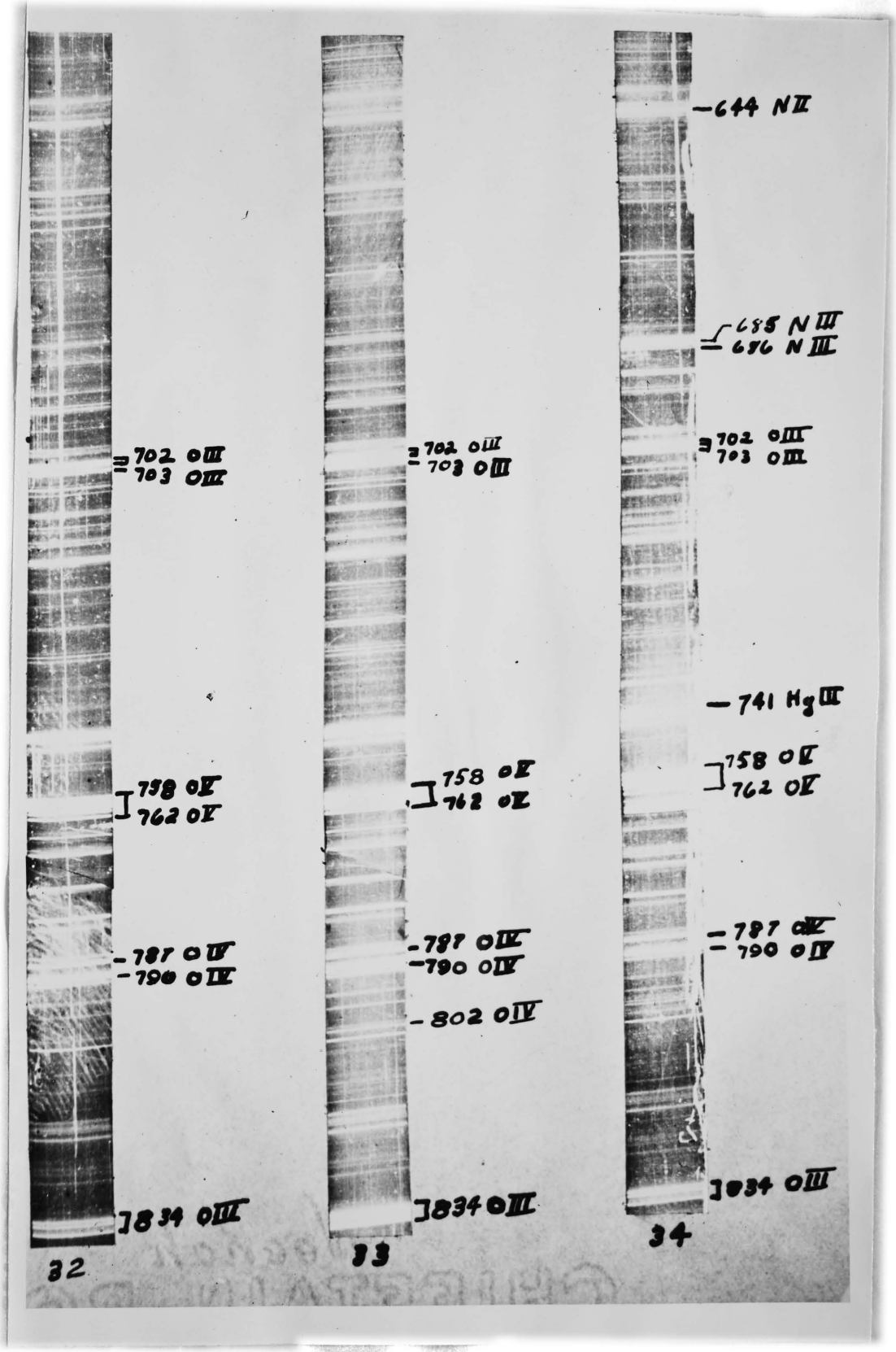
644 NII
685 NIII
686 NIII
702 OIII
703 OIII
741 HgII
758 OV
762 OV
787 OIV
790 OIV
802 OIV
834 OIII
32
33
34

FIG. XIII

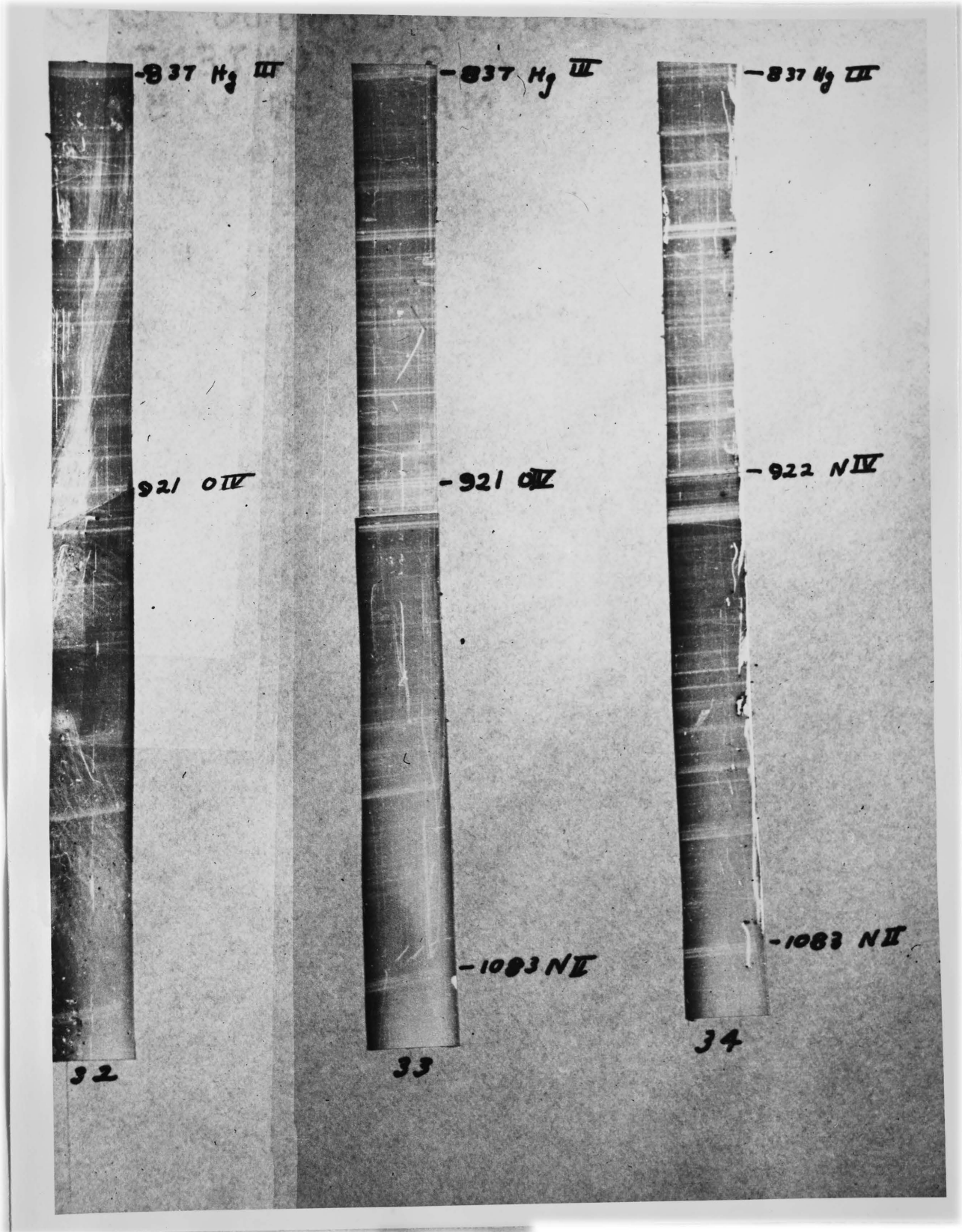
-837 Hg III
921 O IV
1083 N II
32
-837 Hg III
-921 O IV
-1083 N II
33
-837 Hg III
-922 N IV
-1083 N II
34

FIG. XIV

that after repeated usage the aluminum foil became cracked. It is recommended that a supplementary wrapping for the roll of film be provided.

In order to cut the film to the necessary 52 cm. length, the author taped the free end of the roll of film to a meter stick at the 52 cm. mark. (A stop facilitated dark room handling). The film was carefully unrolled and cut off at the end of the meter stick and the cut piece of film allowed to roll slowly back up on itself. A very small cut was made off the corners of one end of the film to allow it to slide easily into the spectrograph film holder.

An ordinary roll film tank has proved most convenient for development of the exposed film strips. Development in Kodak D-19 for four minutes, as recommended by Schoen and Hodge [46]

46. Schoen, A. L., and Hodge, E. S., Photographing Spectra in the Vacuum Ultraviolet, Jour. Op. Soc. Am., Vol. 40, No. 1, p. 23, 1950.

has produced the best results although a development for one minute in Kodak D-8 has produced good spectrograms. Some sort of wetting agent, preferably Kodak Photo-Flow should be used in a

preliminary washing before development and in the final rinse water. Under no circumstances should the film strips be wiped dry.

Because of the abrasion sensitivity of the Kodak S.W.R. film, some means of preserving the films must be developed. The author has successfully used coatings of thin spar varnish and of shellac. Of the two, the shellac seems most promising.

Identification of Spectrographic Lines

FIGS. X-XV compare the three exposures 32, 33 and 34. Exposure 32 was taken with hydrogen in the system, 33 had an oxygen atmosphere, and 34 was taken in air. Each exposure lasted for approximately three minutes at about one spark every two seconds. These exposures will be compared in detail later.

Because the author and his collaborators were not familiar with the prominent spectral lines, the identification of those lines presented no small problem. Only one English reference [47]

47. Boyce, J. C., and Robinson, H. A., Wavelength Identification Lists for the Extreme Ultraviolet, Jour. Opt. Soc. Am., Vol. 26, No. 4, p. 133, 1936.

was arranged in such a fashion as to be of much

use and the article by Edlen,[48] referred to time

48. Edlén, Bengt, Wellenlangen Und Termsystume zu den Atomspektren der Elemente Lithium, Beryllium, Bor, Kohlenstoff, Stickstoff und Sauerstoff. Nova Acta Regiae Societatis Scientiarum Upsaliensis, Ser. IV, Vol. 9,No.6, 1934.

and again by various authors, could not be located by the reference librarian.

After no little searching the author finally found a listing in the Library's Union Catalog, of the publication in which Edlen's article first appeared and it was obtained from the University of Missouri. It was no wonder that the other authors had so often referred to Edlen, for his article even contained pictures. Within an hour after first obtaining the reference a major portion of the lines on exposure 32, 33, and 34 had been identified. The more prominent of these lines are labeled in FIGS. X-XV. From equation (5) it has been determined that the angle of incidence, α, for the exposures 32-35 is 79.15°, and for exposure 90 it is 79.35°. The linear dispersions for various wave lengths for exposures 33 and 90 have been computed, using equation (3), and are tabulated in Table I.

TABLE I

	Exposure No. 33 $\frac{ds}{d\lambda}$		Exposure No. 90 $\frac{ds}{d\lambda}$	
λ	Computed	Measured	Computed	Measured
800 Å	0.321 mm/Å	0.344 mm/Å	0.323 mm/Å	0.306 mm/Å
520 Å	0.375 mm/Å	0.403 mm/Å	0.377 mm/Å	0.362 mm/Å
375 Å	0.418 mm/Å	0.452 mm/Å	0.421 mm/Å	0.407 mm/Å

These computed dispersions differ from the dispersion actually measured. This would indicate that the film holder does not actually lie on the Rowland circle.

After exposure 39 was completed, the spectrograph was completely dis-assembled for cleaning. The difference between the angles of incidence and between the linear dispersions for exposures 33 and 90 is caused by failure to realign the instrument in exactly the same position after re-assembly.

A cursory search of the exposures to date has already provided some interesting information. For comparison, FIGS. X-XIV show the three exposures 32,33, and 34 as previously mentioned. The most prominent and easily identified lines are those of oxygen and nitrogen. All three exposures show many lines of O II, O III, O IV, and OV in comparable intensities indicating that an unusually wide range of ionization has been obtained. Exclusion of oxygen from the system by the introduction of hydrogen (exposure 32) shows that a large portion of this oxygen excitation must occur in the glass and quartz of the source tube. Mercury, apparently from the Stokes gauge used to measure the source tube pressure is definitely present in some quantities as

evidenced by several lines. The most prominent of these is indicated in FIG.XIV.

Several lines are present which have not been identified. The most noticeable and the most interesting are shown in exposure 34, FIG. XII. One of these has a wave length of about 495 Å and has tentatively been marked as a nitrogen line because of its prominence in the exposure which used an air atmosphere in the source tube. A similar line occurs at approximately 567Å and is not even tentatively identified. No published table of lines, to the author's knowledge, mentions anything of such prominence as these two lines, and Edlén and Söderqvist, in their articles, show pictures which contain these lines but they make no effort to explain or identify them. Probably these lines are the second orders of nitrogen 247 and nitrogen 283.

Each of the exposures 32, 33, and 34 contain 600 or more distinct lines. Many of these lines are obviously multiplets of some sort and a refinement of technique will no doubt resolve some of them.

It had been hoped that a crystal might be mounted between the source and the slit in the manner

used by Skinner [49] for soft X-Ray studies. To this

49. Skinner, H. W. B., The Soft X-Ray Spectroscopy of the Solid State, Reports on Progress in Physics, Vol. V., Cambridge, Cambridge Press, pp. 257-282, 1939.

end a quartz crystal was fixed in place for exposures 35-42. Total absorption was obtained and the results were inconclusive but it is felt that other materials still hold promise. Three problems must be overcome if satisfactory crystal absorption spectra are to be obtained. First, a method for inserting crystals into the optical path without disturbing the settings of the instrument must be developed. Secondly, a procedure for obtaining very thin crystal sections will have to be perfected, and finally, some way to eliminate the heavy carbon deposit from the face of the crystal should be devised. This last problem is probably the most serious of the three. Careful elimination of carbon dioxide and carbon monoxide from the source tube atmosphere will probably prove to be most helpful.

When these problems have been overcome, there is a good possibility that important data will be obtained.

CONCLUSION

A vacuum ultraviolet grazing incidence spectrograph has been completed and placed into operation. It is felt that the instrument has very rewarding possibilities, but that to exploit these possibilities to a maximum some further modifications are necessary. These modifications include redesigning of the vacuum system, a better system for adjusting the grating, and the installatic of alignment guides and stops where needed.

The results so far obtained show that the instrument is fast, has a very sharp focus and a good depth of field, and, although the operating pressures are higher than those recommended by previous experimenters, that the absorption level is quite low because of the short optical path. In the hands of an experienced operator the spectrograph will produce good results.

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Mr. Chamberlain was in the Army for three and one half years, two years of which were spent in Europe. He was discharged from the Army in June of 1946, and re-entered Georgia Tech the same month.

He was graduated from Georgia Tech in 1948 and taught for a year and one half at the Southern Technical Institute. In June of 1950 he entered Missouri School of Mines for graduate work in Physics.

He married Miss Dorothy Lyle Jones in June of 1948, and they have one son, Langdon Andrew.