A SELF RECORDING SPECTROMETER

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The purpose of the research described in this paper was to develop a self-recording spectrometer for use with both emission and absorption spectra. While primarily intended for infrared investigations, its range was to comprise the entire spectral region accessible by either prisms or gratings.[1] An additional feature was to be the possibility of enclosing the whole instrument in an evacuated chamber so that the entire optical path of the radiation from emitting source to receiving thermopile would be in a high vacuum.

In this laboratory investigations to 20μ are being carried on continually with the high dispersion obtainable by means of spectrometers of the prism grating type.[2] Before starting such investigations, it is desirable to make preliminary surveys to learn the position, relative intensity and general character of the absorption bands of the substances under examination. The spectrometer with a thin prism of suitable material having a refracting angle of 30° or less, will serve effectively as a scouting instrument of low dispersion. Fitted with a prism train containing both a 60° and a 30° prism, or with an echelette grating, the spectrometer will also be capable of recording spectra with high dispersion through a very extended range of wave lengths. In addition to the prisms usually employed in infrared work, prisms of KCl, KBr and KI

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[1] Several self-recording prism spectrometers have already been constructed for use in the near infrared.

Langley, Ann. of Smiths. Obs. *1;* 1900.

Abbot and Fowle, Ann. of Smiths. Obs. *2;* 1908.

Ellis, Phys. Rev. Vol. 23, p. 48, 1924; J. O. S. A. *11*, 647; 1925.

Brackett-McAlister, Rev. Sci. Instr. *1*. 181; 1930.

[2] Trans. Faraday Soc. No. 103, *25*, Part 12, 913; 1929.

have been prepared from large single crystals grown in the laboratory as a part of this development, and with these there appears to be a very good prospect of extending the range of the instrument to 30μ or better. With coarse gratings replacing the prisms its range is unlimited, though it will then require some method, such as the introduction of properly chosen filters, for preventing the overlapping of spectra. In certain kinds of work a prism spectrometer of low dispersion could precede this recording instrument when fitted with a grating, thus forming a prism-grating outfit of maximum dispersive power and a range limited only by the prism material.

In a recording spectrometer, where it is necessary to use a thermopile receiver, a procedure similar to that used in the recording microphotometer may be employed, the spectrum being passed over a thermopile and the resulting galvanometer deflections being recorded photographically. The mechanical problem involved in automatic registration is to move a spot of light reflected from the galvanometer mirror, over the photographic paper (or move the paper under the spot) in a direction at right angles to that of the galvanometer deflections, in such a way that this motion will be exactly correlated with the angular positions of the dispersing prism. Also for successful recording it is necessary that the disturbing influences be removed as much as possible. One of the most important of these arises from diffused radiation, which may exceed by many times the infrared energy in the long wave-length region under examination. If, for any reason, there is some fluctuation in this diffused radiation, it will cause a galvanometer drift or deflection and seriously affect the character of the measurements which can be made on the spectral energy. Since this would be particularly annoying for a recording spectrometer, it is first of all required that variations in this radiation diffused from the walls and optical parts of the instrument be reduced to the minimum. To accomplish this the entire instrument must be very effectively insulated thermally from its surroundings.

Other disturbing effects are those due to stray electric or magnetic fields originating within or without the laboratory. These may be quite completely eliminated by enclosing the entire spectrometer and all external electrical instruments and connections in suitable metal sheathes. Mechanical vibrations, equally disturbing, are more difficult to obviate. Fortunately the 2nd and 3rd basements of the laboratory are relatively free from these disturbances, and for this and other reasons are especially adapted to this kind of work. Fluctuations in the radiating source are readily avoided and the effects of atmospheric absorption, particu-

larly CO_2 and H_2O are completely eliminated by having the entire op-
tical path from source to receiving thermocouple in a high vacuum.

Figs. 1 and 2 show the plan and section of the spectrometer. The in-
strument is of the Wadsworth-Littrow type, the radiation being turned
back through the prism by a plane mirror, the so-called Littrow mirror,
and focused by the collimating mirror upon the exit slit. Because the
returning beam cannot travel over the same path as the incident beam
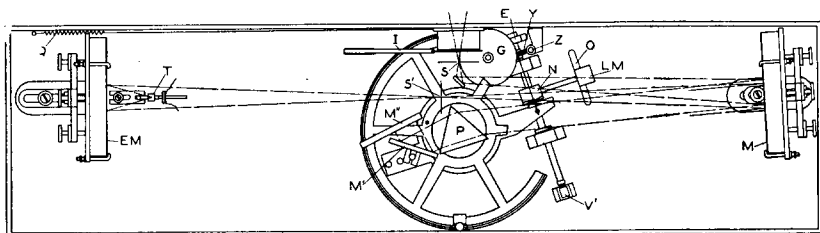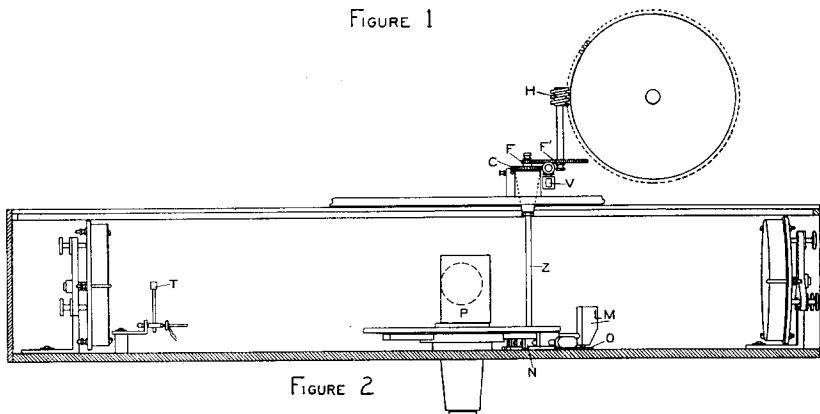and still come to focus on the exit slit, it is impossible strictly to fulfill

FIGURE 1

FIGURE 2

FIG. 1 AND 2. *Horizontal and vertical sections taken lengthwise of spectrometer.*

the condition that the radiation pass through the prism at minimum
deviation. The light enters the spectrometer through the entrance slit,
S, and is reflected by a small plane mirror to the collimating mirror, M,
which is 20 cms in diameter and has a focal length of $\frac{1}{2}$ meter. The paral-
lel light from this collimating mirror passes through the dispersing
prism approximately at minimum deviation and is reflected by the
Wadsworth mirror, M', so that it falls upon the Littrow mirror, M'',
at almost normal incidence. After reflection from M'', the light returns
to M' then passes through the prism again approximately at minimum
deviation. The collimating mirror brings it to a focus in a spectrum at
S'. This mirror, M, is a segment cut from a larger paraboloidal mirror

in such a manner that the axis of the paraboloid passes through the edge of the mirror, M. M is so adjusted that this axis passes midway between the slit S' and the virtual image of S. Since these are close together the aberration is reduced to a minimum. In order that the more essential features of the instrument may be seen readily, the supports which carry the slits S and S' are not shown in the figure. The exit slit here stops all the radiation except a narrow band of the spectrum which is focused by means of the elliptical mirror, EM, upon the receiving junctions of the thermopile. This thermopile is of the type recently developed and described by Firestone.[3] The advantages of the Wadsworth-Littrow optical system are generally recognized and have led to its use in many similar instruments.

The slits are bilateral and are separately adjustable. Their length is about 2.5 cm, which gives an image on the thermopile .5 cm long due to the fivefold reduction by the elliptical mirror. It is not advisable that the slits be longer than this because excessive curvature of the image must be avoided. All of these optical parts are mounted upon a heavy brass base through which passes the cone carrying the divided circle attached to the prism table, as seen in Fig. 2. This circle was made by Leiss and with a micrometer eyepiece permits reading the prism position accurately to seconds. The heavy base also carries a brass case completely enclosing the optical parts of the spectrograph, and is supported by three legs, the two at one end having fiber wheels, and the third at the rear ending in a conical point. These are evident in Fig. 3.

After the spectrometer has been put in optical adjustment it is rolled into a large rectangular box of steel with walls 1/2-inch thick. All joints of this box are welded. Along its bottom are two tracks T' and T'', one flat and the other with a V groove, which serve to guide the wheels at the forward end of the spectrometer. The conical point at the base of the third leg rests in a cone sunk in a fiber block F so placed that the spectrograph is in exactly the desired position in the steel box. At the open end of the box, through which the instrument is rolled, is a wide flange providing ample bearing for the end plate or door, the contact surfaces being accurately ground.

This method of supporting the spectrometer within the box prevents any disturbance of its adjustment by the movements which the sides of the steel box experience upon evacuation. Except for these three supporting points there are only two more connections between the outer steel case and the spectrometer proper. In each the contact is a non

[3] F. A. Firestone, Rev. Sci. Instr., *1*, 630; Nov. 1930.

rigid one formed by two ivory pins slipping into two receiving holes, and is capable of communicating a twist but not a thrust. It is used to transmit external rotation to certain parts of the spectrograph. The ivory points are poor conductors of heat and help to prevent disturbances arising from any temperature differences which may exist between the inside and outside of the steel box. .

The outsides of the brass case enclosing the spectrograph are highly polished, while the inside of the steel box is painted with aluminum
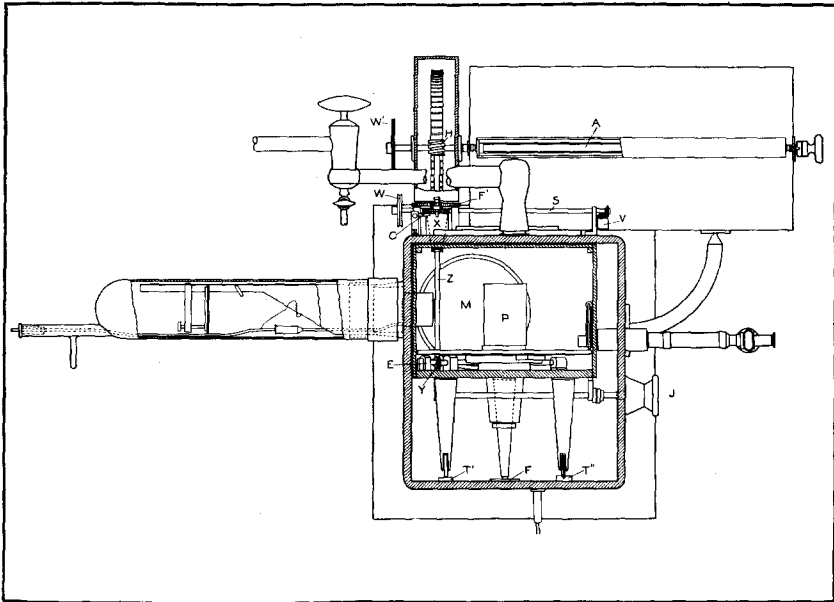

FIG. 3. *Vertical section taken crosswise of spectrometer.*

paint to reduce energy exchange by radiation. The outside of the steel box is heavily lagged with felt and when the entire system has been evacuated, the instrument itself with its enclosing brass case should be at a very uniform temperature and very free from localized temperature changes.

For several reasons it appeared advisable to place the source of radiation and the absorption cell outside the steel box containing the spectrograph. This was accomplished by welding a steel tube into a suitable aperture cut in the side of the box next to the entrance slit S. When absorption spectra are being recorded, the absorption cell is mounted in the inner end of this side tube and extends through an aperture in the brass case covering the spectrometer. The longer cells end just in front

of the entrance slit of the instrument. Fastened to the inner side of this same side tube and extending outwards 18 inches is the support for the radiating source and the mirror used to focus the radiation upon the spectrograph slit.

A heavy steel sleeve is mounted upon this side tube by means of an accurately ground joint. The glass tube surrounding the source and mirror slips over this sleeve and is made air tight by wax. The source is partially surrounded by a water cooled shield to prevent any of its radiation from reaching the spectrograph except that focused upon the slit by the mirror. Also a small glass tube is fused into the closed end of this large glass tube, through which the two small copper pipes used to fill the absorption cell pass, with an air tight wax seal. By melting off this wax the glass tube and the sleeve to which it is fastened may be removed at the ground joint, exposing the source, focusing mirror, and absorption cell for adjustment and exchange when necessary.

When it is not essential to have the entire optical path in vacuo all of the fittings just described may be removed. A tubular sleeve is then inserted into the side tube. The closed inner end of this sleeve has an aperture covered by a KBr plate to pass the radiation which will be focused upon the slit. The outer end of this sleeve has a flange which bears against the outer rim of the steel side tube. This joint is made air tight with wax. Under these conditions the source and absorption cells are outside the evacuated system, and can be varied as to kind and size in a manner not possible with the other arrangement.

The absorption cell is from five to twelve centimeters in length with windows of potassium bromide which are cemented on with deKhotinsky cement. Since the pressures within the cell range from zero to one atmosphere or more while outside there is a vacuum, it is necessary to clamp these windows in position in addition to cementing them. The cell may be evacuated, washed and filled to any desired pressure with the gas to be studied, through two 1/8 inch copper pipes, connecting it with a manometer and pump.

The recording system is as follows. Light from a tungsten lamp illuminates a small vertical slit in the end of a light tight box. An image of this slit is formed on the photographic recording paper after being reflected from the mirror of the recording galvanometer. The slit source and paper are the same distance from the galvanometer, about 12 feet. The photographic paper is wound around a drum in the camera so that it moves vertically under the image of the slit while a rotation of the galvanometer mirror causes a horizontal movement of the spot. The

drum is 80 cms in circumference and 50 cms long and its motion is exactly coordinated with the rotation of the prism so that, as the prism turns, a spectral energy curve may be traced out on the photographic paper. The light is focused upon the paper by means of two lenses, a 1/4 diopter spectacle lens mounted in front of the galvanometer mirror and a cylindrical lens of one inch focal length mounted immediately in front of the drum. This arrangement is similar to the optical system of the Moll recording microphotometer but larger, the cylindrical lens, A of Fig. 3, being 20 inches long. The focusing system gives an intense illumination of the spot which can be made so small and sharp that the resulting line traced in the paper is as fine as can be used.

Not only must the spot be sharply focused on the recording paper, but it must pass over the paper in such a way as to produce a proper photographic exposure. Because of its rectangular shape a more rapid motion is permitted in the horizontal direction than in the vertical direction for the same exposure. Fortunately the recording optical system was so adaptable that the illumination of the bromide paper could be varied to meet the various exposure times required. The necessity for proper exposure places a limit upon the speed of recording. Another limit also exists, for the spectrum must not be moved over the thermopile so rapidly that the galvanometer will fail to follow accurately the variations of energy density and so to trace out the true spectrum.

The mechanical system which correlates the rotation of the camera drum with prism position was carefully designed so that errors coming from this source might be as small as possible. Both the camera drum and prism are rotated by the same worm.

The motor used to drive the mechanism of the spectrometer is connected to the pulley, W, by means of a jointless cord belt. On the shaft with this pulley, immediately behind the gear C is the worm which operates the entire mechanism. It drives this gear C, which is mounted on top of the cone X. This cone is ground into a seat welded into the top of the steel box, and transmits the rotation through the steel case to the prism table within. Two ivory pins set in the bottom of the cone X extend into receiving holes in the cap of the vertical shaft Z, and communicate rotation but not thrusts to the spectrometer mechanism. The worm at the lower end of Z engages the gear Y, as shown in Fig. 1 and 3, and the horizontal shaft to which Y is attached drives the nut N, which is kept from rotating by the lever and weight, LM. This same shaft carries a veeder counter V'. As it turns, the nut, N presses against the arm of the spectrometer table thus rotating the prism P. The con-

tact between the traveling nut and the table arm is by means of two small round steel rods, the one on the nut being vertical and the one on the arm horizontal. As the nut, N, travels it carries with it the lever and mass, LM. On the under side of the latter is soldered a small steel ball which slides upon the flat polished plate, O. The spring, Q, is connected by a fine wire to the table arm by the aid of the wheel, G. The tension thus produced keeps the shaft firmly against the steel end plate, E, the shaft itself ending in a steel ball. In fact the spring Q is sufficiently stiff to prevent all lost motion between the moving parts of the spectrometer and its driving mechanism.

Above the gear C and on the same shaft with it is the small gear F which engages the large gear F' and thereby drives the drum by means of the worm and gear H. The shaft bearing the drum and the gear H, also carries the pulley W'. Wound around this pulley is a fine wire carrying a weight large enough to take up all the lost motion of the mechanism used to drive the drum. This weight and the spring Q together prevent all lost motion very completely.

By different motor speeds and the use of different pairs of gears, a wide range of speeds of rotation for prism and drum is obtained. The gears and worms are of the highest commercial quality and their errors of construction are all very small. The effects of such errors as do exist in them are entirely negligible, due to the great reductions in the speeds given to the prism and drum, and no observable effects of these imperfections appear in the final photographic records.

Altogether there are eight openings in the steel box. The door at the end, the steel side tube, and the ground joint for power transmission have been described. There is a second ground joint on top for the glass exhaust tube. This tube is of very large cross section and is provided with a stop cock having a bore of 2 cm. The box can be exhausted in one and a half hours so that a gauge at the mercury diffusion pumps will show pressures of 10^{-3} or 10^{-4} mm. If the box has stood over night evacuated not more than 30 minutes are necessary. Under these conditions there are no traces of H_2O or CO_2 absorption, and the thermopile becomes most sensitive.

Directly above the prism table is a 6-inch circular aperture, closed by a thick glass plate accurately ground to make an air tight joint. Besides serving as an observation window this opening is used to exchange prisms, to alter the slit widths, and for other purposes not requiring the withdrawal of the spectrometer from the box. The shutter which is shown at I is operated from without by means of the knob, J,

which, through a ground joint, can transmit a twist to a horizontal shaft operating the shutter. The connection between this ground joint and shaft is like that connecting the cone X with the shaft Z. The seventh aperture through the steel box is for the insertion of the micrometer miscroscope with which the spectrometer circle is read. Practice has shown that circle readings are unnecessary, since the veeder counter V mounted on the end of the shaft, S, Fig. 3 will give the prism position with the same accuracy as can be obtained by direct readings. Hence the micrometer is usually dispensed with and the hole closed. A small hole through the bottom of the box is used to pass the thermopile leads. This aperture is sealed with wax.

When the instrument was first adjusted simultaneous readings on the circle and Veeder Counter were made in order to reduce these Veeder readings to angles and, at the same time, to check the reliability of the mechanical connection between worm and circle. Successive readings of circle positions for the same Veeder readings indicated that uncertainties due to inaccuracy of the machanism were less than two seconds of arc when the settings were made immediately following one another.

With every thirty revolutions of the worm a circuit containing a lamp is closed. The cylindrical lens A focuses the light from this lamp in a sharp line across the photographic paper. The Veeder numbers at which these contacts occur are known, and, accordingly, the numbers corresponding to the lines upon the record. The spaces between successive lines correspond approximately to a rotation of the prism of 30'' of arc. Besides acting as landmarks on the energy curve from which corresponding wave lengths are determined, they make it impossible for shrinkage or deformation of the photographic paper to introduce appreciable errors in the determination of wave lengths. Micrometer measurements of the distance between these reference lines show that the maximum variation of any space from the mean is not more than would correspond to .4 sec of prism displacement.

There is every reason to believe that such small drifts as now occur occasionally in the recording galvanometer can be quite entirely eliminated with more experience. When there are no drifts it is possible to determine the percentage of absorption for any gas by comparing the energy curves obtained with the cell filled and empty, the current through the source being kept constant.

Up to this time accurate observations with this spectrograph have been limited to the measurements of a number of well-known emission lines and absorption bands by Professor Sleator and by Mr. Weber,

preliminary to further research. Among these are the absorption bands of C_2H_2, NH_3 and CH_3I and the emission lines of Hg from a quartz lamp. There are reproduced in Fig. 4 the energy curves obtained when the radiation from a platinum filament heated to a bright red color is passed through a cell of 11.5 cms length filled with NH_3 at various pressures, using a KCl prism of 30° dispersing angle. This prism had its second face silvered thus reversing the radiation directly without the use of the Wadsworth-Lithrow mirror system. The slit widths were .2 mm.
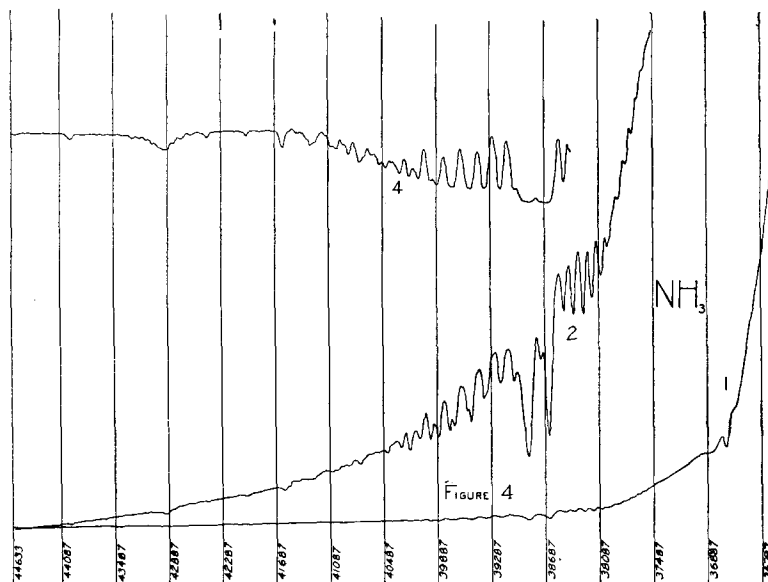

FIG. 4. *Curves showing the absorption bands of NH_3 at various pressures and with different degrees of amplification.*

These curves have been drawn on tracing cloth directly from the original curves as obtained on the photographic paper. In the reproductions only every twentieth one of the reference lines has been drawn. On the original record the lines reproduced here are 2 inches apart so that the reference lines on the photographic record are one tenth of an inch apart. This distance corresponds to thirty veeder numbers; hence the reference lines in the figure are six hundred veeder numbers apart, and also 600 seconds of arc. The original records have not been reproduced since it was quite certain that many parts of the photographic tracings would be too fine to be seen in the reduced cuts. Also occasionally curves overlapped in a way quite likely to cause confusion when

shown on a greatly reduced scale. For this latter reason Curve No. 3 which ran closely parallel with No. 2 is omitted in Fig. 4.

Curve No. 1 was obtained with NH_3 at a pressure of 11 cms of mercury. The thermopile was connected directly to the recording galvanometer which is a high sensitivity instrument. The band under the figure 1 consists of a positive and negative branch together with a well marked zero branch whose veeder number is approximately 36,677. This is the 6.2μ band of NH_3. The bands which show two well defined zero branches at 38,642 and 38,863 are those at 10.3μ and 10.7μ. No other absorption regions are noticed in this record which was obtained without using methods for amplifying the galvanometer deflections. The sharp falling off in energy in curves 1 and 2 is due to the decrease in energy of the emitting source with increasing wave length, combined with the effect of increasing dispersion of the prism.

In Curve No. 2 conditions are identical with those in No. 1 with the single exception that the galvanometer deflections have been amplified fifteen or twenty times by means of a Moll relay. This amplification has made it impossible to record the 6.2μ band since the energy in this part of the spectrum is now sufficient to give deflections off the paper. The two bands at 10.3μ and 10.7μ are shown well resolved. A comparison of the results here shown with those of Barker[4] indicate that nearly the same resolution has been obtained by the double use of a 30° KCl prism as had hitherto been possible by gratings, and suggests that if a prism train composed of a 60° prism and a 30° prism used twice were employed the resolution might very well equal or surpass that of the grating spectrometer. It should be said, however, that materially higher resolution is now being obtained in this region with gratings than was possible when Dr. Barker measured these bands. Whether or not these prism records can be made to show resolutions comparable with those of spectra produced by gratings, it is evident that this instrument is not a simple scouting spectrometer. It is capable of doing much more, as this 10μ NH_3 band shows.

The higher sensitivity used in Curve No. 2 has also brought to light a band at veeder number 42887. This band, which was first observed by Robertson and Fox[5] as a simple peak in the neighborhood of 15μ, is shown more fully developed in Curve No. 4 where the experimental conditions differ from those of Curve 2 in the single respect that the absorption cell now contains NH_3 at a pressure of 61 cms. This higher

[4] Barker, Phys. Rev., *33*, 684; 1929.

[5] Robertson and Fox, Proc. Roy. Soc. A., *120*, 161; 1928.

pressure while bringing out the details of the longer band, has suppressed those of Curve No. 2. That the band at 42887 needs more gas to bring out its details, has just been demonstrated by Mr. Weber, who has shown that it is remarkably developed when a cell 3 meters long is used.

In Fig. 5 are reproduced the photographic records obtained with CH_3I, at a pressure of 20 cms. The absorption cell is the same as used with NH_3. Curve C_1, shows three absorption regions. The one of shortest wave length, at about 36011 veeder number, represents three bands not separated, i.e. those at 3.25, 3.37 and 3.52μ belonging to the E,F and G series of Meyer and Bennett. The band at 37397 is a superposition of bands at 7 and 8μ belonging to the C and D series. At 39197 one sees slight indications of a band with evident structure. This is the one at 11.3μ belonging to the B series. The break in the curve is due to an adjustment of the recording galvanometer made to keep the spot of light on the paper.

In Curve C_3 the conditions are identical with those of Curve C_1, except that the galvanometer deflections have been increased about 15 times by means of the Moll relay. As with NH_3 the spectral region of short wave lengths can no longer be registered on account of the relatively large amount of energy here. The dispersion of the prism is not sufficient to show additional structure in the band at 37397, but at 39197 or at 11.3μ this additional structure becomes very evident due to the coarseness of the band spacing and to the increased dispersion of the prism in this region. An examination will show that every third line is stronger than the intervening two as the work of Meyer and Bennett[6] shows so beautifully.

The curves in Figs. 4 and 5 show some of the striking results already obtained with this instrument. They are among the first records and do not, in the opinion of their author, represent even approximately the best to be expected from the instrument. So far the prisms available have been much smaller than will ultimately be used.

It is hoped that larger prisms may be provided, which will mean more energy. Better control of temperature and other disturbing influences, will permit greater amplification also. With more available energy and greater amplification it will be possible to use much finer slits. Narrow slits in connection with the prism trains which will be available later would give much greater resolution. This, in addition to the improved technique resulting from longer experience, will mean results much superior to those shown here.

    [6] Bennett and Meyer, Phys. Rev., *32*, No. 6, 888; Dec. 1928.

Any one of the curves of Figs. 4 or 5 required for recording about one hour and a quarter. Allowing the time necessary for preliminary evacuation, for the various adjustments which must be made before a record may be taken, for changing the absorbing gases, etc., it is possible to obtain four or five complete records on one or more sheets of photographic paper in a single day. The calibration of the instrument is obtained by plotting veeder numbers as abscissae against known wave
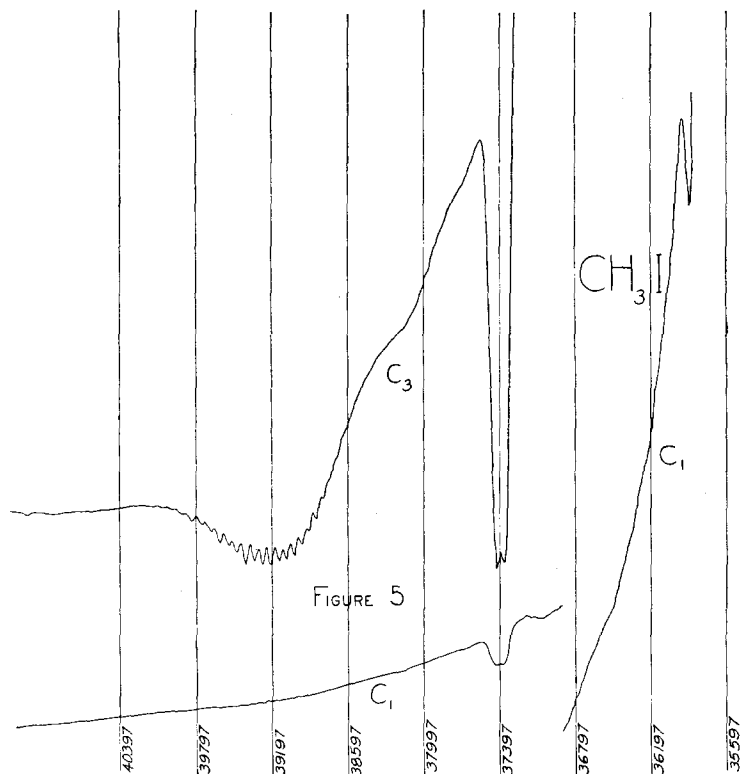

FIG. 5. *Curves showing the absorption bands of CH₃I at various pressures and with different degrees of amplification.*

lengths as ordinates on as large a scale as is justified by the present number of lines which serve as standards. The positions of the lines in such absorption spectra as are shown here usually can be estimated by eye with an accuracy of three veeder numbers, which is all that our present calibration justifies. The time required for determining from our calibration curve the wave lengths of all the lines shown on a record containing four or five curves is perhaps another half day. If the percentages of absorption corresponding to the various lines of an absorption

band are required, then very appreciably more time must be spent in obtaining this information from the curves.

The new prism materials now available, KCl, KBr, and KI make it possible by using them in the prism grating spectrometers to extend the range of accurate measurements much beyond the point possible when only rock salt could be obtained. Already, in fact, by replacing the salt prism by one of KBr the measurements on some lines in the neighborhood of 19μ have been made with an accuracy justifying the use of five significant figures in expressing their wave lengths. When a sufficient number of sharp lines are known to serve as standard lines in a calibration to 25μ and beyond, similar accuracy may be approached in that region with this spectrometer. Such precision requires that the positions of the lines with respect to the reference lines be obtained by micrometer measurement and the labor of interpolating the results of a photographically recorded curve is then similar to that of measuring the usual spectrogram.

Mechanically the spectrometer appears to function very perfectly. Thus while it is possible to have a set of reference lines for each curve, in practice it has been found satisfactory most often to make a single set at the time the first curve on a given paper is traced. This is justified since a second set of reference lines has been found to lie directly upon the first set, whether the drum has been turned backward to begin a new curve, or continues to revolve and record the long wave length end of the spectrum on a second revolution. When the records shown in the figures were obtained, the distance between adjacent reference lines, which are a tenth of an inch or 2.5 mm apart on the photographic paper, corresponded to thirty veeder numbers, or to 30 seconds of arc. It is possible by exchanging gears to make this distance between reference lines either more or less. Thus Mr. Weber has had occasion to increase the spacing corresponding to thirty veeder numbers by a factor of three, i.e., to 7.5 mm. Sharp lines recorded on different papers on different days can be checked to two veeder numbers or to the same number of seconds on the prism circle. The limit to the precision attainable will apparently depend ultimately upon the accuracy of the relation to be established between wave length and veeder numbers for a given prism, and not upon the spectrometer mechanism.

To date Mr. Weber, who is now using the instrument, has apparently well established lines of band spectra out as far as 26μ. The wave-length limit attainable will be determined by the transparencies of the KBr and KI prisms.

In this spectrometer is embodied the extensive experience of those members of the staff interested in infrared spectroscopy and the writers wish to express their deep appreciation for this cooperation, which in a very large degree contributed to the success of the instrument. To Professor Firestone particularly much of the excellence of the design is due, while Mr. Hermann Roemer and his associates in the instrument shop are responsible for the perfect working of the entire equipment which is a clear evidence of very superior workmanship. Finally to Professor Sleator acknowledgments are due for permission to use his data for the Figs. 4 and 5.

Magnetic Phenomena. S. R. Williams. Pages xxii+230. McGraw-Hill Book Company. New York, 1931. Price, $3.00.

The author states the purpose of this book as follows: "The goal of this book then is to stimulate in upper classmen in college the spirit of research, and possibly enlist the interest of those who have just finished their graduate work and are casting about for a field of investigation which may be inaugurated on their own initiative." The book is scarcely a text book, but rather a reference book which the teacher may cite to his students who have shown ability and interest in physics. For such a purpose this book will be a welcome one to a great many teachers.

The first part of the book is an introduction into the current notions concerning magnetism and an account of some of the methods of measurement. In consideration of the type of student to whom the book is directed, it is rather unfortunate that the author did not employ more rigorous treatments in certain places.

The latter part of the book is divided into chapters whose headings are, magneto-mechanics, magneto-acoustics, magneto-electrics, magneto-thermics, magneto-optics, cosmical magnetism, and magnetic theories and experimental facts. In these chapters the author has given brief accounts of practically all the various "effects" which have been reported by investigators. The book will serve as an introduction to the subject and the many references will enable the reader to widen his knowledge.

J. R. COLLINS