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RADIOMETRIC MEASUREMENTS OF ULTRAVIOLET SOLAR INTENSITIES IN THE STRATOSPHERE

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ABSTRACT

A description is given of a photoelectric cell and filter type of ultraviolet-intensity meter [1][1] which is combined with an audio-frequency generator and radio transmitter and transported aloft by means of unmanned balloons.

The radio-frequency wave is modulated by the response of the photoelectric cell, the response being proportional to the intensity of the incident ultraviolet rays. The height of the balloons is indicated by a radio barograph. The radio signals giving the altitude of the apparatus and the ultraviolet intensities are received and recorded graphically at a ground station.

Six balloon ascensions were made during the latter part of June and the early part of July 1937. Altitudes up to about 80,000 ft (24 km) were attained, but owing to the weakness of the signal and the consequent interference by noise strictly quantitative data were obtained only to about 64,000 ft (19 km).

Below 14 km the transmissions of ultraviolet through the filters remain fairly constant, indicating but little change in the spectral quality of the shortest wave lengths. At a height of about 14 km the transmissions of the filters begin to decrease, indicating a selective increase in intensity of ultraviolet of the shortest wave lengths, as a result of a decrease in the amount of ozone above the apparatus.

Between 14 and 19 km the filters show an unmistakable decrease in transmission, indicating that the apparatus had passed through an appreciable portion of the ozone layer, variously estimated at 15 to 30 percent of the superposed ozone, the lower value being in good agreement with previous explorations (in 1934), taking into consideration the latitude and the season of the year.

At the highest altitudes attained the intensity of the ultraviolet radiation in the band of wave lengths shorter than 3132 A was about 3 times the value observed at sea level. This spectral band includes, of course, also wave lengths not observed at sea level.

CONTENTS

[1] Numbers in brackets refer to references and notes at the end of this paper,

I. INTRODUCTION

For some years the writers have made measurements of ultraviolet solar radiation, using a photoelectric cell and filter radiometer [1, 2]. By means of this device a measurement is obtained of the spectral quality (the spectral-energy distribution) and the total intensity of the radiation in the band of wave lengths shorter than 3132 A, which is recognized as having a therapeutic effect, at least in healing rickets.

It is well known that the spectral quality and total intensity of the ultraviolet solar radiation that comes to the earth's surface are determined largely by the amount and distribution of ozone in the stratosphere. This information has been obtained almost entirely by means of spectrophotography. While the results so obtained appear to be authentic, nevertheless, the photographic method has several shortcomings, the most noteworthy being that no strictly quantitative measurement is obtained of the intensity of the incident radiation at different heights above the earth's surface.

In a previous paper [4] there was given an outline of a proposed method of determining the spectral quality and the total intensity of the ultraviolet of short wave lengths in solar radiation at various heights above the earth's surface. The proposed device consists of a photoelectric cell, filter radiometer [2], and auxiliary apparatus for transmitting radio signals. It is transported aloft by means of sounding balloons. While the photoelectric cell and filter radiometer cannot compete with a spectroradiometer in recording fine details in spectral-energy distribution, it has proved adequate for the purpose for which it was designed [2, 3]; and, because of its light weight, it is easily adapted for transportation into the stratosphere by means of sounding balloons [23].

In this connection, it is interesting to note that within the past few years radio-wave transmitting and receiving instruments (like many other physical devices) have become a very useful auxiliary means of recording data obtained in remote or otherwise inaccessible places. In earlier researches, in which the measuring apparatus (thermometer, barograph, pyrheliometer, etc.) was transported in sounding balloons, the uncertainty of subsequently securing the data depended upon the additional hazard of recovering the balloons. Nowadays, the measurements of temperature, barometric pressure, humidity, and in the present instance, ultraviolet solar intensity, are transmitted from aloft by means of radio waves, which are received and recorded in a central station on the ground coincidently with the time of observation. No lives are hazarded and the observations are on record, even if the balloons and measuring instruments are not recovered.

In this respect the writers have been singularly fortunate. Using three sets of instruments, six flights were made, and, to date, only one instrument remains unrecovered. This particular instrument had made two previously successful flights, and each time it was recovered undamaged.

One unit remained hidden for more than a month between two large trees in an infrequently visited forest before it was recovered, undamaged. The recovery of this unit was especially important, because the photoelectric cell had ceased to function after attaining a height of 21,500 ft (6.5 km; the barometer signal indicated an ascent to 78,000 ft; 23.8 km), and on recovery it was ascertained that it was the photoelectric cell and not the resistors that had become defective.

It is of course to be recognized that the herein-described radiometric procedure is still in an experimental stage of development. However, when we consider the fact that in this preliminary trial the apparatus was assembled from stock laboratory equipment which had many shortcomings (the photoelectric cells were not the most sensitive that can be made; the radio-wave transmitter was weak; and the radio-wave receiver was not the most sensitive obtainable), we regard the method feasible and highly promising for studying ultraviolet solar intensities in the stratosphere.

Aside from the scientific value of the data so obtained, from a purely utilitarian standpoint, the investigation of this problem is of importance because of the need of information on the spectral-energy distribution in the extreme ultraviolet of solar radiation used in heliotherapy.

Some experimenters have attempted to evaluate the ultraviolet in solar radiation by calculation, on the assumption that the spectral-energy distribution in the extreme ultraviolet of the sun, outside the earth's atmosphere, is similar to that of a black body at 6,000° K.

In a previous communication [4] attention was called to spectroradiometric measurements by Pettit [6] and to photoelectric cell and filter measurements by the writers [3] showing that the solar spectral intensity, in the extreme ultraviolet, has an abrupt and continuous drop with decrease in wave length; and that the slope of this spectral-energy distribution outside the earth's atmosphere is closely represented by that of a black body at 4,000° K, or perhaps even lower.

The object of the present paper is to present the results of a preliminary attempt to determine radiometrically the spectral quality and total intensity of the ultraviolet solar radiation of short wave lengths, in the stratosphere, and thereby obtain a check on the spectrographic determinations of the distribution of ozone (made by Dobson, Goetz, Regener, and others), which are somewhat in disagreement in that in Regener's [8] balloon ascents a considerable portion of the ozone appeared to be diffused to somewhat lower elevations than recorded in the two ascents reported upon by O'Brien [11] and by Mohler [10]. As will be shown presently, both sets of observations may be correct. For example, in our flight 3, as the apparatus rose above the earth's surface there was an increase in the values of the filter transmissions with but little change in the total intensity, just as though the bulk of the ozone was increasing in amount during the flight and was situated at a much higher elevation than was attained by our apparatus on that date. Again, on two of our subsequent flights (4 and 5) there appeared to be a definite change in spectral quality and a rapid increase in total intensity, beginning at a much lower elevation than in flight 3, indicating a considerable penetration into the layer of ozone which seemed to extend to a much lower elevation on these dates.

Since the information in flights 3 and 5 was obtained with the same instrument, the differences in intensity of ultraviolet solar radiation at the same elevation, observed on widely different dates, may perhaps be ascribable to differences in formation or diffusion of ozone into the lower levels of the stratosphere, rather than to differences in instrumental equipment. However, as noted in section VI, until confirmatory data can be secured, the unexpected results obtained in flight 3 are ascribed to unexplained changes in the instruments rather than to an increase in ozone during the flight, although varying meteorological conditions suggest such a possibility.

In this connection, reference is made to a discussion of atmospheric ozone and meteorology by Dobson and Meetham [13, 16], in which it is shown that the total amount of ozone varies with the latitude and the season, being a maximum in the local spring and a minimum in the local autumn; also that (in Europe) marked daily variations in ozone occur with varying meteorological conditions, the maximum amounts of ozone being generally observed in areas of low barometric pressure ("cyclonic regions") and the smallest amounts in areas of high barometric pressure ("anticyclonic regions") [16]. However, the association of this rise in ozone value with polar air currents, in the troposphere, does not seem to be the result of a simple transportation of ozone by air currents [19].

From the foregoing citations it appears that the position of the ozone layer, which is situated on the average at a height of 22 [9] to 24 km [8], is not stationary [16]. In fact, in addition to slow seasonal changes reported by others, there are irregularly occurring variations of short duration. For example, in the ultraviolet-intensity measurements made by one of the writers (W. W. C., in 1934) at Flagstaff, Ariz. (elevation 7,300 ft.; 2.2 km), on several days the filter transmission measurements indicated a conspicuously higher transparency (a lower ozone concentration) than the average value for the same season, the same air mass, and the same visual clearness of the atmosphere [2].

The data obtained in these preliminary explorations of ultraviolet solar intensities in the stratosphere are too meagre to warrant more than a brief consideration in connection with the relation that is known to exist between the variations in the ozone content and meteorological conditions. They are very suggestive, nevertheless, in indicating a quick method of exploring the extent and location of the maximum concentration of the ozone layer as a function of the season, barometric pressure, circulation of polar air currents, etc. [12, 13, 16].

II. DESCRIPTION OF THE ULTRAVIOLET-INTENSITY METER AND AUXILIARY APPARATUS

In the photoelectric cell and filter radiometer [1], as used by the writers on the earth's surface, the ultraviolet intensity is measured in terms of the scale reading of a microammeter. The intensity can be obtained also with a graphically recording meter.

For measuring the ultraviolet intensity in the stratosphere, it was necessary to introduce a very radical change in the design of this apparatus in order to reduce the weight. Instead of the balanced amplifier and microammeter, the photoelectric cell controls an audio-frequency generator which feeds into an amplifier.

For tests in the laboratory, the auxiliary apparatus used with this type of ultraviolet meter consists of telephone receivers (also a standard audio-frequency generator [17] for use in determining the audio frequency emitted by the ultraviolet meter) or a suitable electronic frequency meter.

For measurements in the stratosphere, the auxiliary apparatus used with our photoelectric ultraviolet meter [1, 4] is based on the radio-meteorograph method [7] developed by Diamond, Hinman,

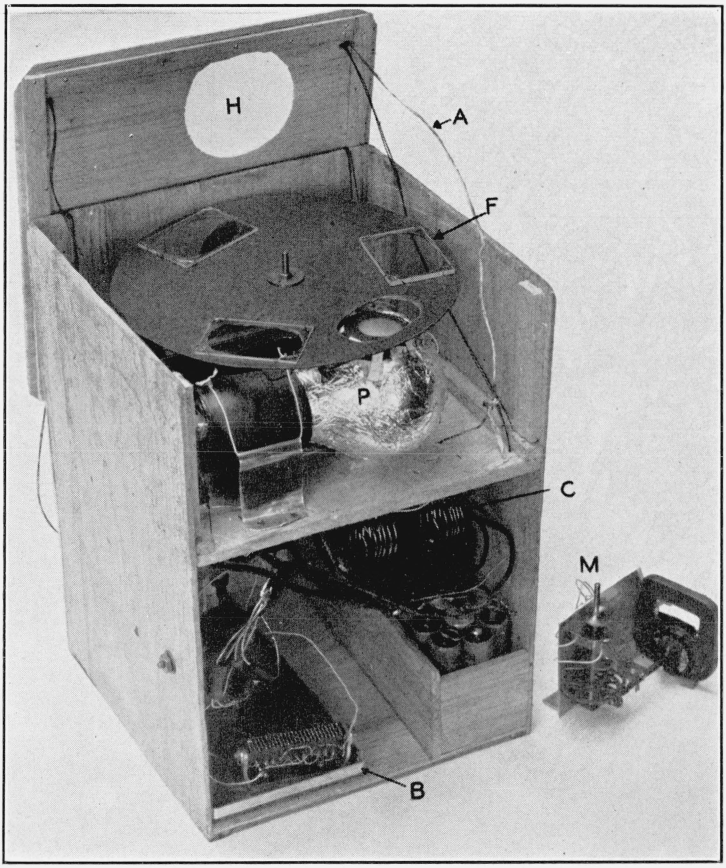

FIGURE 1.—*Assembled stratosphere ultraviolet meter, housed in balsa-wood box, open at the top and front, showing the photoelectric cell, P; glass filters, F; radio barograph, B; radio-frequency oscillator, C; antenna, A; sample motor, M; hole, H; and other accessories.*

and Dunmore of the radio section of this Bureau. It comprises (a) a radio transmitter, which, combined with the ultraviolet meter, is transported in the unmanned balloon; and (b) a ground-station receiving and graphically recording apparatus, consisting of a super-regenerative receiving set, an electronic frequency meter, an amplifier and electrical filter unit, and a recorder. The radio section made available to us a sample radio-meteorograph transmitter and a complete receiving setup, and assisted us in modifying, to meet our needs, the ingenious barometric-pressure element of the radio meteorograph [7] used for the purpose of indicating the altitude of the balloons.

An essential part of this barograph,[2] *B*, shown in the lower part of figure 1, consists of a number (about one-third the number used in

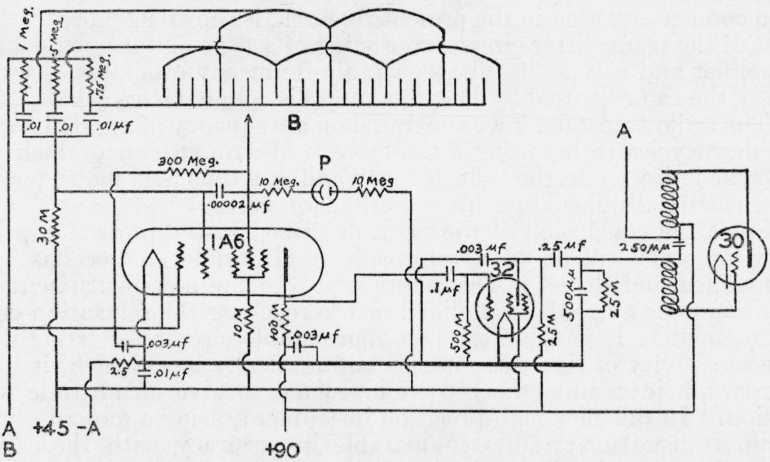

FIGURE 2.—*Electric-circuit arrangement of the photoelectrically controlled, P, audio-frequency generator, and, upper part, the radio barograph circuit, B.*

the radio meteorograph [7]) of thin electric-conducting strips, separated by thicker insulating strips. A contact point on a movable arm, operated by the pressure diaphragm of the barometer, closes an electric circuit as it crosses these metal strips; and, depending upon the resistance and capacitance connected in the grid circuit, a predetermined modulation frequency is produced, characteristic of a particular segment. By suitable connection of the segments, in groups of one and three (as shown at *B*, in fig. 2) having the same modulation frequency, identification is obtained of the height attained by the balloons. This barometric apparatus was calibrated for pressure (in absolute scale) by the aeronautic instruments section of this Bureau.

It should be noted (fig. 2) that the grid circuit of the relaxation oscillator contains a resistance of many megohms and an extremely small charging condenser in order to secure sufficient sensitivity for the type of photoelectric cell used. In order to reduce the effects of the capacitance of the electrodes, a high resistance (10 megohms) is connected on each side of the photoelectric cell. The circuit is essentially voltage-controlled.

[2] Manufactured by Julien P. Friez & Sons, Inc., Baltimore, Md. [7]. One of the modifications consisted in cutting the contact arm near its end and connecting it (suitably insulated) directly to the control grid in order to reduce its capacitance

It is to be noted also that the photoelectric cell functions by an emission of electrons, on exposure to ultraviolet radiation, and not as a variation in resistance [7] as the oscillating circuit is commonly used. Upon irradiation of the photoelectric cell, the liberated electron current changes the potential of the control grid, thus changing the frequency of the audio oscillation. It is necessary to keep a potential of some 45 v on the negative electrode (the photosensitive surface) in order to properly operate the photoelectric cell. It is, therefore, difficult to build a stable oscillator, directly controlled by a relatively insensitive photoelectric cell. The circuit arrangement described in the previous paper [4], represented a first step in the evolution of a suitable photoelectrically controlled audio oscillator. The audio oscillator, consisting of a type 1A6 radio tube with suitable resistances and condensers, used in the present research, is shown in figure 2. The rest of the transmitter circuit, consisting of a type 32 tube as an audio amplifier and a type 30 tube as a radio-frequency oscillator, is essentially the same as used by Diamond and his collaborators [7].

The radio transmitter was operated on a frequency of approximately 50 megacycles (6 m) using a single vertical-wire antenna, which was attached directly to the "shock cord" and was thus held under tension and electrically insulated from the balloon cords.

Since the conclusion of the work described in the present paper, a new precision model of a stratosphere ultraviolet meter has been assembled and tested in the laboratory. In the new instrument the photoelectric current is amplified before reaching the relaxation oscillator, making it possible to use a more stable circuit. Furthermore, the sensitivity of the entire unit is automatically tested each time the barograph interrupts the ultraviolet signal to give an altitude indication. In this new high-precision instrument, using a more powerful radio transmitter, results comparable in accuracy with those at a ground station should be obtainable.

III. DESCRIPTION OF THE ASSEMBLED APPARATUS

In figure 1 is shown the ultraviolet meter. This consists of a photoelectric cell and filters and a photoelectrically controlled audio-frequency generator; also the auxiliary radio-transmitting apparatus, assembled in its housing of balsa wood, temporarily open at the top and front for purposes of exposition [23]. The dimensions of the box are 16 by 16 by 22 cm.

When all adjustments have been made, the apparatus is completely inclosed, except the hole, *H*, in the top to admit sunlight to the photoelectric cell. The sides and bottom are then wrapped with cotton batting and covered with a black cloth. The total weight is about 1.6 kg (3.5 lb).

Referring to figure 1, and beginning the description at the top, an essential part of the apparatus is a cardboard disk (boiled in ceresin wax to exclude moisture) with four elliptical openings (25 by 37 mm), three of which are covered with glass filters, *F*, having the spectral transmissions shown in figure 3. This disk is rotated by a small electric motor, *M* (shown at the lower right of fig. 1), operated on 0.009 amp from two small flashlight batteries.

The speed of rotation of this disk ranged from 1 revolution in about 40 sec (about 60 sec in fig. 4) to 2 min in the different flights. In the slower rotations the momentary shadows cast on the photoelectric cell by the suspension threads, as the instrument rotated about its axis, are clearly indicated by indentations in the graphical record (fig. 4).

The cadmium photoelectric cell, *P*, is a General Electric type FJ–135, spherical bulb, with the base removed and the glass covered with aluminum foil to exclude stray light and to remove possible electrostatic charges. This type of cell, which responds to radiation of wave lengths extending from 2600 to 3250 A, is eminently adapted to this type of ultraviolet measurement. The top of the cell is covered with a diffusing window of Corex *A* glass (40 mm in diameter and 2 mm thick) molded to fit the spherical bulb, and fine ground on both faces. Over this window, which is highly transparent to 2500 A in the ultraviolet, is placed a black-paper cover with an opening 17 mm in diameter, as shown in figure 1. This combination is secured to the photoelectric cell by means of adhesive tape.

The spectral response for an equal-energy stimulus (fig. 3), and the sensitivity for different angles of incidence (fig. 5), were determined for each combination of photoelectric cell and Corex *A* diffusing window before mounting, as shown in figure 1. As will be noted on a subsequent page, before making a flight the complete unit (photoelectric ultraviolet meter and its radio transmitter) was calibrated against a standard of ultraviolet radiation [5].

In the lower part of the box is shown the barometric switching unit (*B*, to the left), some of the dry batteries, and *C*, the radio-frequency oscillator coils.

The box containing this apparatus is suspended from its corners by strong (waxed) linen threads and a stranded copper-wire antenna, *A*, 1.5 m in length. Above this is a "shock cord" about 3 m in length, consisting of six strands of rubber ribbon, each 3 mm in width.

Some of the earlier ascensions were made with three balloons in a cluster, and later ascensions were made with four balloons tethered at different lengths (5 to 20 m) from a common meeting point, from which the box of apparatus was suspended (on a cotton cord) at a total distance of about 25 m below the balloons, which was sufficient to prevent possible shadowing by the balloons when fully expanded. The ascensions were made in relatively still air, and there was practically no drifting of the box of instruments which hung vertically below the balloons as they ascended.

The balloons were sufficiently inflated with hydrogen to exert a pull of 1¾ to 2¼ lb (800 to 950 g) each, as determined by a small spring balance. One balloon was inflated more than the others in order to have it burst before the others, which acted as parachutes to retard the descent and prevent injury to the instruments.

In order to secure a radiometric record of the ultraviolet intensity near the earth's surface, when there was no strong wind, the balloons were released by means of a cord drawn through a metal ring attached above the rubber "shock cord," by means of which the whole device could be held in leash, thus permitting the instrument box to swing freely some 5 m above the ground.

When all was in readiness, and the recorder was working properly, one end of this launching cord was released, the pull of the balloons caused the cord to slip through the ring without difficulty, and the ascension of the apparatus proceeded without further interruption. Six exploratory flights were made in this manner.

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The ascensions of the apparatus were made at the Bureau's radio field station at Meadows, Md., some 25 km from Washington. In the preliminary part of the work we had the valuable experience and assistance of W. S. Hinman, Jr., and, later on, E. G. Lapham, both from the radio section of this Bureau.

Several ascensions were made through cloudy skies. Judging from the cleanness of the filters after recovery of the apparatus, if any moisture was condensed on the filters while passing through the clouds its effect was only temporary. There are some indications that the temperature of the disk rose to 55° C, or perhaps higher, during the flight.

A notice was attached to the instrument box stating that a reward would be paid for the return of the instruments, intact as found; and the finder was requested to write us, describing the recovery—how many balloons had burst, etc. These descriptions of recovery of the apparatus proved interesting and instructive. In one instance, the balloons and apparatus must have traveled some 500 km; and, at 5 o'clock on the morning following the flight, two balloons, carrying the instrument box about 10 m above the ground, were discovered floating above a cornfield, some 50 km south of Raleigh, N. C.—a distance of some 450 km in direct line from their starting point. The apparatus ("camera") was returned unbroken and made two subsequent flights. In another instance the instruments (motor still running) and two unexploded balloons descended, and were recovered unharmed during a rain and lightning storm near Allentown, Pa., a distance of some 200 km. Aside from the interest in the monetary reward, the finders seemed interested and cooperative in returning the apparatus.

1. DESCRIPTION OF THE ELECTRIC MOTOR

One of the preliminary problems in the development of the stratosphere ultraviolet meter was a means of temporarily placing the glass filters, in succession, over the window of the photoelectric cell. A small electric motor was decided upon as best adapted for this purpose. But since no commercial motors having the proper power and weight were available, it was necessary to construct a suitable unit to rotate a disk supporting three filters. After a few trials a model (see fig. 1) was constructed which operated on about 9 ma at a potential of 3 v, and yet had sufficient power to rotate the disk. This motor with the reduction gearing (800 to 1) weighed only 3 oz.

The field poles are constructed of tool steel and measure over-all approximately 1¾ by 1¾ by 3/16 in. The armature, which is ⅞ in. in diameter and 3/16 in. in thickness, is wound with four coils (about 3,500 turns) through eight slots (0.2 in. diameter) near the circumference of the armature.

The silver commutator and brushes, and the reduction gears were obtained from d-c watthour meters,[3] and were remodeled to give a desired speed of rotation of the filter disk, which was about 1 rpm (revolution per minute).

Since the relaxation oscillator was operating in an extremely sensitive manner it was necessary to locate the motor relative to the transmitter coils, photoelectric cell, and relaxation oscillator circuits,

[3] The commutators and gearing from a number of replaced d-c watthour meters were kindly supplied to us by the Potomac Electric Power Co., of this city.

so that the electromagnetic effect of the rotation of the armature of the motor was a minimum. In this position, the field through the motor was at right angles to that through the radio-frequency oscillator coils.

In the first flights, motor troubles were encountered because the small dry cells (type *Z*) which were used did not have sufficient capacity to maintain the proper voltage to operate the motor at the low temperatures encountered. In one case, there was evidence of a breakdown in the motor winding, resulting in excessive battery drain. For the later flights, large cells (standard flashlight type) were employed and gave practically uniform motor speed throughout the records (see fig. 4).

2. DATA ON THE FILTERS AND PHOTOELECTRIC CELLS

Supplementing the foregoing general information on the radiometric equipment, it is relevant to include the following details regarding the spectral transmissions of the filters and the spectral responses of the photoelectric cells depicted in figure 3.

The three glass filters (fig. 3) were selected to have suitable transmissions in order to give three bands of radiation of approximately the same increments of intensity and to secure a good tracing on the recorder sheet. The samples of Helioglass (*H*) and barium-flint (*Ba-1*) were ground and polished to a suitable thickness. The sample of lantern-slide glass (*LS*) was selected to meet our filter-transmission requirements. Sufficient material of each kind of glass was provided in order to have a reserve for a number of ultraviolet meters, thus saving work in determining the transmissions and simplifying the calculations in the reduction of the data.

Since completion of this preliminary exploration, it appears that the Helioglass (*H*) filter is too transparent (fig. 7) to suppress the incidental errors of observation and to show the expected change in transmission with altitude. Hence, in the future, a more opaque filter will be used.

The spectral responses of the Cd photoelectric cells, covered with the Corex *A* diffusing glass, are depicted in figure 3. They are practically insensitive to wave lengths longer than about 3250 A and have a maximum response in the region of 2850 A. Hence, they are well adapted for measuring the slight increase in intensity in the ultraviolet at 2880 to 2900 A, which becomes perceptible at high altitudes.

The spectral range of the photoelectric response coincides closely with the numerous important absorption lines of ozone in the region of 3227 A and shorter wave lengths [14].

While this narrow spectral response makes the measurement more nearly in terms of homogenous radiation, nevertheless, it would have been desirable to use a cell with a wider spectral response in order to secure a more powerful action in the radio transmitter and thus furnish a more stable sending device. However, with the new instrument proposed for future work, the stability of the relaxation oscillator and transmitter are independent of the sensitivity of the photoelectric cell.

From the data thus far obtained, it appears that when more is known about ultraviolet intensities in the stratosphere it may be possible to dispense with the filters as a means of determining the spectral quality of the incident radiation. This will reduce the weight, and will make it possible to attain higher altitudes with the equipment now used. Furthermore, a larger part of the photoelectric cell can then be exposed and intensities at lower solar altitudes can be measured. By suitable standardization [5] before the ascent, it may be possible to explore the ozone layer from day to day without these filters to determine the spectral quality.

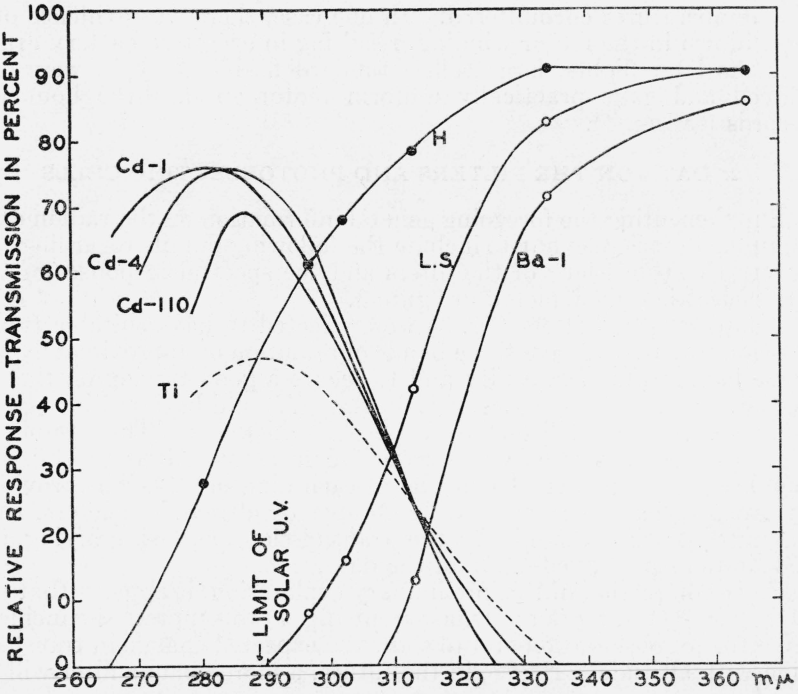

FIGURE 3.—*Graphs showing the spectral response of the various cadmium photoelectric cells; also the spectral-transmission curves of the filters*

IV. DESCRIPTION OF A BALLOON FLIGHT

As already mentioned, the ground-station receiving and recording equipment was a duplicate of the apparatus described and illustrated in figure 10 of the paper published by Diamond, Hinman, and Dunmore [7]. The recorder and its auxiliary amplifier failed to depict frequencies proportional to the change in intensities of ultraviolet radiation.[4] The recorder was therefore used merely as an indicator of the time scale and for identification of the altitude signals. The values of the audio frequencies, emitted by the transmitter, were therefore read directly on the dial of the electronic-frequency meter and written in pencil on the corresponding graphical record. This saves time in subsequent calculations.

In figure 4 are shown two parts of a graphic record of an exploratory flight (4) made with our apparatus on July 2, 1937.

Referring to figure 1, it may be noted that, as the disk rotates, the two opaque spaces between the glass filters, *F*, act as a shutter to

[4] The cause of this defect was subsequently located in the auxiliary amplifier.

exclude radiation from the photoelectric cell, and the lowest audio frequencies recorded (along the lower horizontal line marked 1.0, fig. 4), are reference frequencies, analogous to a graphic laboratory record of the zero scale reading of a galvanometer.

When the oblong open space in the disk is over the window of the photoelectric cell, as shown in figure 1, the maximum audio-frequency

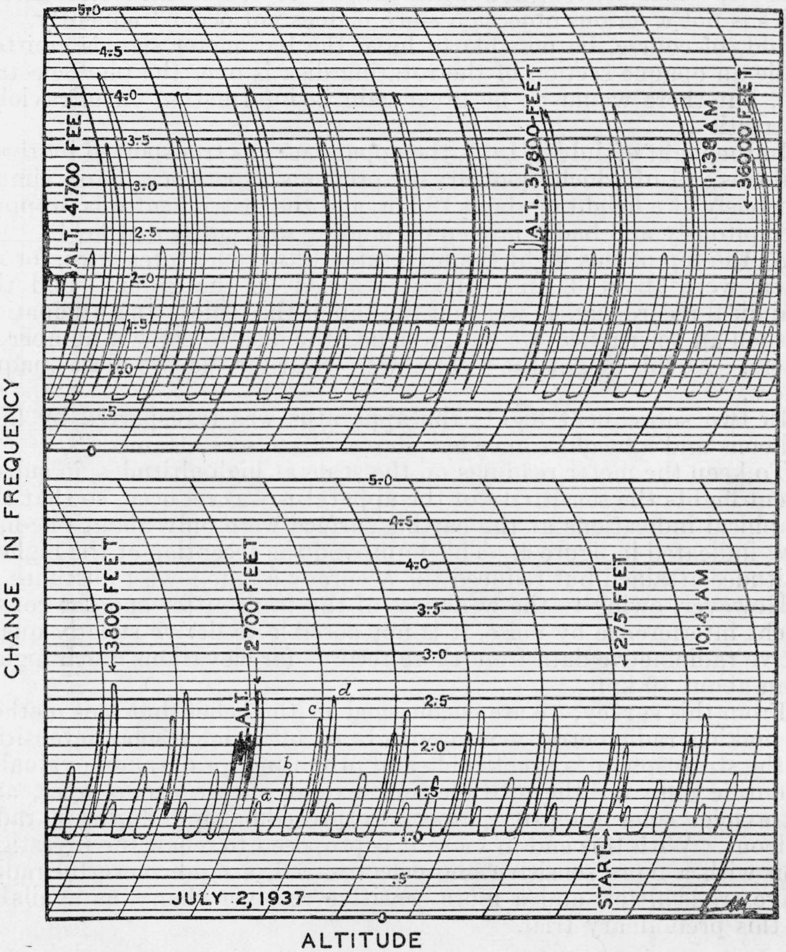

FIGURE 4.—*Reproduction of two parts of a graphic record of the ascension of a stratosphere ultraviolet solar intensity meter, showing the change in frequency (ordinates) with change in intensity of ultraviolet radiation transmitted through the filters* (a, b, c) *as a result of change in altitude; also audio-frequency signals, ALT, of the radio barograph.*

note is emitted, the maximum deflection is read on the dial of the electronic frequency meter, and the maximum deflection of the recorder arm is inscribed on the graphical record, as shown in figure 4.

As the disk continues to rotate, the three filters, *F*, which are arranged in order of decreasing transparency to ultraviolet radiation, pass in succession over the window of the photoelectric cell; and correspondingly smaller deflections are successively read on the frequency meter and are traced on the graphical record.

With change in elevation of the apparatus, the movable arm of the barometric-pressure apparatus crosses the metal contacts on the pressure switching element (*B*, in figs. 1 and 2) and an entirely different audio-frequency note is emitted, as indicated at the points *ALT*, figure 4. This interruption in the graphic record of ultraviolet intensities is not a serious objection since it does not occur frequently. It would, of course, be possible to have the barometer signals emitted while an opaque section of the rotating disk is over the photoelectric cell, but there would be no great gain in information on ultraviolet intensities.

In the flight of July 2, 1937, the apparatus was transported by three balloons, all of which, contrary to previous experience, burst simultaneously at a height of about 18 km, and the instrument was dropped precipitously and badly broken on landing in a cultivated field.

At the top of this flight the integrated ultraviolet intensities, for no filter, were about 3 times those recorded on the ground, and the graphical record (fig. 4) went off the top of the scale. In anticipation of such an occurrence, we had designed the disk to carry a number of filters. At this height the records were clear for the two most opaque filters.

In two subsequent flights the apparatus was transported by four balloons and a height somewhat above 23 km was attained.

To keep the meter readings on the scale at high altitudes, in subsequent flights the sensitivity of the apparatus was reduced, so that the graphical indications at the earth's surface were only about one-half that indicated in figure 4. This improved the reception at the highest altitudes attained but reduced the accuracy at the lowest altitudes.

However, owing to the weakness of the transmitter and the consequent interference by noise, it is not possible to derive strictly quantative radiometric data from these records for elevations much higher than about 19 km.

From this survey, we are encouraged in the belief that this method of making radiometric measurements of ultraviolet solar intensities in the stratosphere is practicable and promising for obtaining valuable scientific data on the altitude and extent of the ozone layer, and ultraviolet solar intensity, especially preceding and during a radio fadeout. With this end in view, it is proposed to renew the investigation with a more sensitive photoelectric cell, a more powerful radio-wave transmitter, and a more sensitive receiver than was available in this preliminary trial.

1. NOTES ON THE SIX FLIGHTS

In view of the interest these observations may have in other fields of research, as they already have in the case of radio-wave fadeouts, a few details are given regarding each flight. In all the flights latex balloons, model 350, made by the Dewey and Almy Chemical Co. were used.

Flight 1.—Cd-1 photoelectric cell and auxiliary apparatus transported aloft by means of three balloons joined in a cluster. Strong NNW wind; a few fleeting fractocumulus clouds but none near the apparatus.

Ascent started at 11:22 a. m., EST, on June 22, 1937. Ultraviolet record terminated at 12:14 p. m. at an elevation of 33,500 ft (10 km), when the motor ceased rotating the filters, leaving the photoelectric cell covered with the opaque-filter mounting. On recovery it was observed that the heat of the sun had melted the ceresin wax in the filter mounting, showing a rise in temperature to 55° C. Total height attained was 69,000 ft (21 km). Apparatus recovered in good condition on June 25 at Bishop's Head, Md.

For comparative purposes, simultaneous observations of ultraviolet solar intensities were made with NBS standard ultraviolet meter and *Ti-1* photoelectric cell [1] from 10:40 a. m. to 1:40 p. m.; sky free from dust after several rainy days.

Good radio intensity reported by the radio section of this Bureau.

Flight 2.—*Cd-110* apparatus transported by three balloons in a cluster. Sky thick, hazy; no wind; balloons released with cord through ring, which method permitted observations near the earth.

Ascent started at 11:06 a. m. on June 24. Ultraviolet record terminated 11:59 a. m., at an altitude of 29,900 ft (9 km) when the motor stopped, leaving the *LS* filter over photoelectric cell, which furnished observations of ultraviolet intensities to 38,000 ft (11.5 km), where noise interfered. A maximum height of 60,000 ft (18 km) was attained.

At the start this unit drifted E, then ENE at 11:10 a. m. and disappeared from sight. Later the signals became stronger, indicating that the instruments were again near by (probably drifting in a southerly direction). They were found at 5 a. m. the following morning floating over a cornfield at Angier, N. C., a distance of some 260 miles (435 km) south of the starting point.

Poor radio record and a possible radio fade-out was reported by the radio section of this Bureau.

Flight 3.—*Cd-110* apparatus, for second time, transported by three balloons in a cluster. Sky was thick and partly covered with fractocumulus clouds. Balloons disappeared between clouds at 3,000 ft; were again visible at 5,000 ft and disappeared at 6,000 ft. The ultraviolet intensity increased between 6,000 and 10,000 ft (3 km.), indicating exposure of the photoelectric cell to solar radiation. At 12,000 ft the apparatus entered a second cloud layer from which it emerged quite rapidly at an elevation of 13,000 ft (4 km).

This ascent was made on June 30 and the signaling period extended from 11:08 a. m. to 1:15 p.m., when noise interfered. A maximum altitude of 52,250 ft (16 km) was attained at 12:07 p.m. In this flight the motor interfered somewhat with the radio signal.

This apparatus descended, uninjured, during a thunderstorm, near Allentown, Pa., and was recovered, motor still running, about 2:30 p.m., soon after the radio signal was lost.

Good radio intensity reported by the radio section.

Flight 4.—*Cd-1* apparatus transported aloft for second time by means of three balloons in a cluster. The sky was clear except for a few scattered fractocumulus clouds. Light W breeze; balloons released by means of ring and cord. No drift of apparatus behind ballons.

Ascent started at 10:42 a.m., on July 2 and continued until 12:34 p. m., when all three balloons burst simultaneously at an altitude of 60,500 ft (18 km). During the descent the barograph signals were received in rapid succession, indicating a rate of fall of 100 mph (miles per hour) at the start to 85 mph in the lower atmosphere. The box containing the instruments landed squarely on its bottom (under the barograph) in a cornfield near Chestertown, Pa., where it was recovered on July 15. Aside from breakage of the radio tubes and one glass filter and injury to the barograph and photoelectric cell, the rest of the apparatus was salvaged intact. In order to avoid the possibility of one bursting balloon affecting the others (which may have been the cause of the simultaneous bursting of these three balloons), in subsequent ascents the balloons were leashed at different heights from the apparatus.

In this flight an excellent graphical record (fig. 4) was obtained, except above 50,000 ft (15 km), where noise interfered with the recording of the full ultraviolet intensity (I_0) when no filter intervened.

The radio section reported more absorption in the radio signal (less ozone). This is also indicated by higher ultraviolet intensities, figure 9.

Flight 5.—*Cd-110* apparatus used for third time, transported by four balloons, staggered and less highly inflated than in preceding trials in order to attain a higher altitude. Sky relatively clear at start. Balloons passed through clouds at an elevation of about 2,000 ft. Light W breeze. In rising, the balloons drifted slowly ENE, then NE, then possibly S, after reaching an altitude of 8,000 to 10,000 ft (radio signal alternately faded, indicating the apparatus was almost directly overhead).

Ascent started at 10:37 a. m. on July 7, and the ultraviolet record continued until 12:46 p. m. The maximum altitude of 64,000 ft (19.4 km) was attained at 12:27 p. m., after which an interesting barograph record was obtained of the first part of the descent (also ultraviolet, except for noise).

The radio section observed a large radio fade-out beginning at 1:47 p. m. and lasting 15 min. Unfortunately, our ultraviolet record ceased at 12:46 p. m. Judged from flights 4 and 5 (see fig. 9), the ultraviolet intensity preceding the fade-out was lower (in flight 5) than in flight 4. Of the three sets of instruments used in the six flights, only this one remains unrecovered.

Flight 6.—Cd-1 apparatus transported aloft by four staggered balloons. Sky overcast, no direct sunlight below 3,000 ft. Strong breeze and windy, but no lag of apparatus behind the balloons.

Ascent started at 10:36 a. m. on July 12, and the ultraviolet record continued until 11:12 a. m., at 21,600 ft, when the photoelectric cell ceased to function. The instruments attained an altitude of 78,000 ft (23.6 km) and landed in an infrequently visited woods near Hollywood, Md. (some 30 miles (50 km) from the starting point), where the apparatus was found, uninjured, over a month later. It was then found, as surmised at the time of the ascent, that the photoelectric cell and not the resistors in that part of the circuit had failed.

V. EVALUATION OF THE ULTRAVIOLET-INTENSITY MEASUREMENTS

Since the spectral-response curves of the photoelectric cells and the transmissions of the filters used in this work are similar to those employed in our previous investigations, the procedure used in evaluating the measurements of ultraviolet solar radiation of wave lengths shorter than 3132 A in the stratosphere is the same as that employed in calculating the data secured with our standard photoelectric intensity meter at a ground station [3].

In these calculations use is made of the spectral response data of the photoelectric cell (covered with the diffusing window of Corex *A* glass) for an equal energy spectrum; also the data on the spectral transmissions of the glass filters. Furthermore, since, in the stratosphere flights, the angle of incidence of the rays on the photoelectric cell varies with the solar height it is necessary to determine also the sensitivity (the response) for different angles of incidence of radiation upon the window of the photoelectric cell. Since, as will be shown presently, this factor is small, the errors resulting from a change in angle of incidence with rotation of the ultraviolet meter around the suspension cord as an axis and with the slow (conical pendulum) swaying of the apparatus during the flight (the latter is indicated by periodic variations in the audio-frequency signals, see fig. 5) seem to be outweighed by other larger, also unavoidable, instrumental errors that enter into the measurements.

These errors would be most effective in determining the absolute value of the full intensity (I_0) at a given height. This is different from the determination of the percentage transmission of the filters in which a knowledge of the full intensity I_0 is unnecessary; the chief requirement being that there is no marked change in intensity while securing the two intensity measurements (filter and no filter, I_g, and I_0, respectively).

The rotation of the filters is so rapid that the change in intensity on the photoelectric cell with a slow (conical pendulum) swaying of the apparatus, while passing from one filter to an adjoining filter, is of secondary importance. Hence, the variation in the percentage transmission of a filter as a result of swaying of the apparatus container would be largest for the filter opposite to the uncovered opening in the disk and could be detected and corrected by comparing the relative transmissions of two adjoining filters, or the percentage transmissions of the two filters adjoining the unobstructed opening (I_0) in the disk. This is evident in the sequence of rotations *A*, *B*, *C*, *D*, in figure 5, where all the points lie on the average curve (*A* and *C*) or some points do not fall on the average curve (in *B* and *D*).

In this survey no corrections of this type are undertaken, partly because the ascensions were made in relatively still air, and there was practically no swaying of the apparatus, at least while it remained in sight. Furthermore, there are no marked indentations in the records

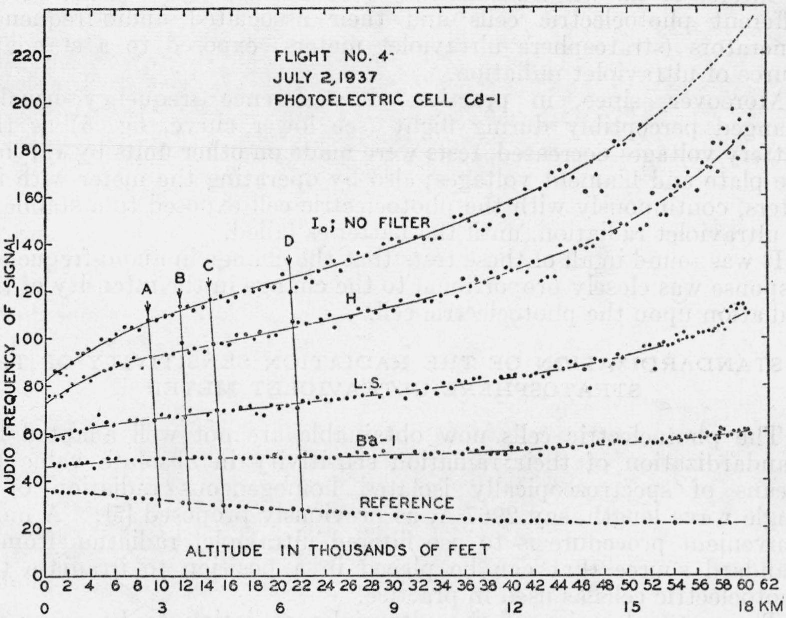

FIGURE 5.—*Variation in ultraviolet intensity (audio-frequency signal) with altitudes as observed through the three glass filters.*

Data taken from the complete graph, of which figure 4 is a part.

of ultraviolet intensities caused by shadowing of the radiometer window as the result of marked swaying of the apparatus in the stratosphere where the measurements are of the greatest importance. The momentary shadowing of the window of the photoelectric cell by the antenna (and to a lesser extent, by the suspending threads) during rotation of the instrument container produces a sharp indentation in the tracing of the stylograph pen (fig. 4). However, the errors resulting from this interruption in the record seem negligible.

1. STANDARDIZATION OF THE AUDIO-FREQUENCY RESPONSE

In the operation of the ultraviolet meter, it is important to know the relation between the audio-frequency response and the intensity of radiation upon the photoelectric cell.

It is to be noted that in this instrument a frequency of 40 to 60 cycles (the lowest depression in fig. 4 and the lowest line in fig. 5) is generated when the photoelectric cell is not illuminated. This "reference frequency" is determined primarily by the values of the high resistance (300 megohms) and the small capacitance (0.00002 μf) in the control grid circuit of the type 1A6 relaxation oscillator tube (see fig. 2). The sensitivity of the meter is likewise determined by these units.

Upon exposure of the photoelectric cell to ultraviolet radiation, the control grid becomes more and more positive as the radiation is increased, resulting in an increased frequency of audio oscillation.

The proportionality of this increase in audio frequency with increase in intensity of ultraviolet radiation was tested by means of a group of filters, of known transmission, used in connection with several different photoelectric cells and their associated audio-frequency generators (stratosphere ultraviolet meters) exposed to a standard source of ultraviolet radiation.

Moreover, since, in practice, the reference frequency usually changed perceptibly during flight (see lower curve, fig. 5) as the battery voltages decreased, tests were made on other units by varying the plate and filament voltages; also by operating the meter with its filters, continuously with the photoelectric cell exposed to a standard of ultraviolet radiation, until the batteries failed.

It was found in all of these tests that the change in audio-frequency response was closely proportional to the change in the intensity of the radiation upon the photoelectric cell.

2. STANDARDIZATION OF THE RADIATION SENSITIVITY OF THE STRATOSPHERE ULTRAVIOLET METER

The photoelectric cells now obtainable are not well adapted for standardization of their radiation sensitivity in absolute value by means of spectroscopically isolated homogeneous radiation of a single wave length, say 2967 A, as previously proposed [5]. A more convenient procedure is to use filtered ultraviolet radiation from a standard source that can be placed in a position to irradiate the photoelectric cells as used in practice.

The spectral range of the ultraviolet radiation to be measured extends from about 2900 to 3250 A—that is, from the short wave-length limit of the solar spectrum to the long wave-length limit of the response of the photoelectric cells used in this research. Hence, it is important to obtain calibration factors only for this spectral band.

By means of a screen of Corex *D* glass (see table 1, col. 4), which is opaque to wave lengths shorter than about 2800 A, the radiation from the standard quartz mercury-arc lamp [5], effective on the photoelectric cell, is confined practically to the strong emission lines at 2967, 3024, and 3132 A. This is found to be a convenient and reliable source for standardizing the radiation sensitivity of the photoelectric ultraviolet meter, including the audio-frequency generator, in absolute units. However, since the 60-cycle fluctuations in light intensity of the new type of alternating-current quartz mercury-arc lamp (having Wehnelt electrodes) caused interference in the audio-frequency generator circuit, the first described [5] form of direct-current quartz mercury-arc lamp was used to standardize the stratosphere ultraviolet-intensity meter. This source irradiates the interior of the photoelectric cell closely in the same manner as when it is exposed to solar radiation. This eliminates small corrections for variation in sensitivity of different parts of the photosensitive surface of the cell.

Since the photoelectric cell is selective in its spectral response it is necessary to incorporate in the calibration of the ultraviolet meter two radiation sensitivity constants, or factors.

One of these factors, designated factor *P*, associates the absolute spectral intensities of the standard of ultraviolet radiation with the relative spectral response of the photoelectric cell and the total response of the ultraviolet meter (the audio frequency generated) when the cell is exposed to this standard.

The other factor, *G*, associates the relative spectral emission of the source measured (in this case the sun) with the same relative spectral response of the photoelectric cell as used in calculating the factor *P*. The method used in obtaining these two factors is outlined in the two following captions:

(a) DETERMINATION OF FACTOR P

The procedure used in calculating the factor *P*, is practically the same as previously described [3]. If the standard of radiation [5] has been used extensively, the relative spectral intensities of the mercury emission lines between 2537 and 3342 A are redetermined by means of an achromatic quartz-fluorite spectroradiometer, calibrated for spectral transmission [15]. The total intensity of this band of radiation, at a given distance (say 1 m) from the lamp, is determined by means of a balanced thermopile and filters, as previously described [15]. From these two sets of measurements the absolute intensity of each spectral line is calculated. These data are given in column 2 of table 1. In this same table, column 4, is given the energy (in $\mu w/cm^2$) transmitted through the Corex *D* filter used in standardizing the photoelectric cells. This procedure is simpler and appears to be more reliable than to determine the absolute intensity of each spectral line, at a given distance from the lamp, as measured at the exit slit of a spectroradiometer [3, 18].

In column 5 of the same table, the relative spectral response of photoelectric cell *Cd-1* for different wave lengths is tabulated. These data were obtained by placing the cell (covered with the Corex *A*

TABLE 1.—*Standard mercury lamp calibration of the stratosphere-ultraviolet meter used for flight 4*

[Determination of the factor *P* for evaluating the observed data.]
On exposure of the stratosphere-ultraviolet meter (*Cd-1*, flight 4) to the standard of ultraviolet radiation, the observed audio-frequency meter scale reading was 895. The factor *P* is 198.7÷895=0.222 for flight 4.

1	2	3	4	5	6
Wave length	Energy of Hg arc lamp	Transmission, Corex *D* screen	Energy through Corex *D*	Relative response, *Cd-1*	Energy times relative response
A	$\mu w/cm^2$		$\mu w/cm^2$		
3132	408.0	0.790	322	0.250	80.5
3024	17.1	.686	117	.495	57.9
2967	85.5	.585	50	.610	30.5
2890	37.6	.425	16	.720	11.5
2804	65.3	.245	16	.760	12.2
2750	21.4	.140	3	.750	2.3
2700	27.0	.075	2	.710	1.4
2650	125.0	.032	4	.600	2.4
Total			530		198.7

diffusing glass window as used in sunlight) at the exit slit of a spectrometer and comparing the photoelectric responses with those of a thermopile. Each wave length is diffused over the surface of the cell in much the same manner, so that any effect of unequal surface sensitivity should be minimized.

From the products of the relative responses of the photoelectric cell (col. 5 of table 1) and the spectral distribution of energy of the quartz mercury-arc lamp, radiated through the Corex *D* glass screen (col. 4) a calculated total response index (198.7) is obtained for the photoelectric cell *Cd-1* when exposed to the standard of ultraviolet radiation (see col. 6, table 1).

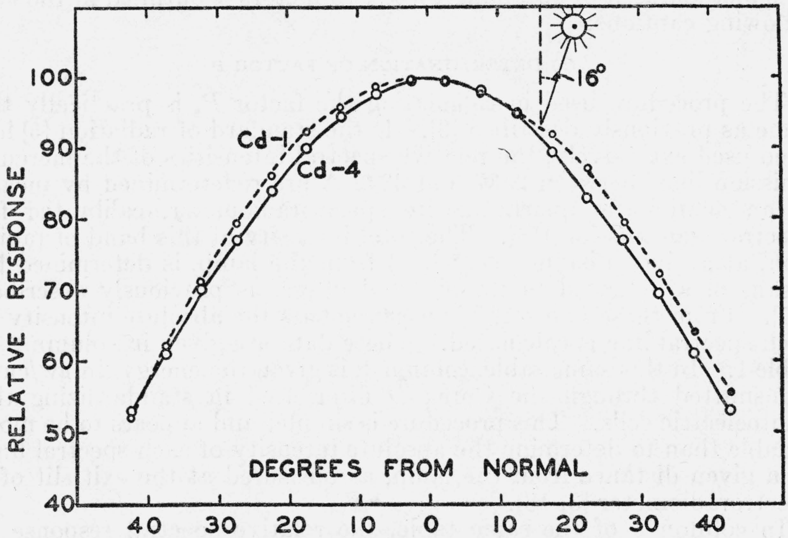

FIGURE 6.—*Variation in sensitivity of the photoelectric cell with variation in angle of incidence of radiation on the diffusing window*

The photoelectric cell is now placed in the audio-frequency ultraviolet meter and, upon exposure to the standard of ultraviolet radiation, the resulting change in audio frequency is recorded. For example, using cell *Cd-1* in the instrument outfit of flight 4, a change of 895 in the scale reading of the frequency meter was obtained. (It is to be noted that in the tables the frequency meter scale reading, which is 5 times the actual audio frequency has been used throughout for convenience.) The ratio of the two values ($198.7 \div 895 = 0.222$) is known as the factor *P* for photoelectric cell *Cd-1* in its associated ultraviolet meter. This factor, $P=0.222$, was used in evaluating the intensity of ultraviolet radiation of sunlight during flight 4.

The factor *P* depends, of course, on the kind of photoelectric cell and the constants of the relaxation oscillator circuit. For example, in flight 1, using the same photoelectric cell, *Cd-1*, the numerical value of this factor was $P=0.191$.

In practice, the latter part of this calibration (namely, the standardization of the change in audio frequency upon exposure to the standard mercury arc lamp) is made when the apparatus is completely assembled and adjusted, shortly before launching.

(b) DETERMINATION OF FACTOR G

In order to determine the factor *G* used in evaluating the ultraviolet solar radiation of wave lengths shorter than 3132 A (relative to the total range of wave lengths intercepted by the photoelectric cell), a knowledge of the relative spectral intensities in this spectral range is required.

The method used in determining the spectral-energy distribution by the photoelectric cell and filter method is described in detail in a previous publication [3].

Briefly stated, the first requisite is a series of ultraviolet-filter transmissions observed for various solar altitudes (air masses); or, in this case, for various elevations of the ultraviolet meter. These are obtained from the audio-frequency values observed at any altitude.

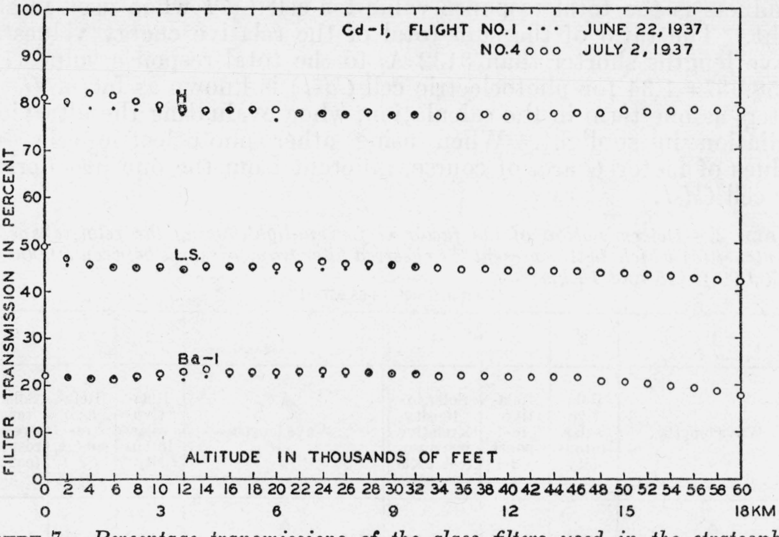

FIGURE 7.—*Percentage transmissions of the glass filters used in the stratosphere ultraviolet meter*

Data calculated from the curves of observations depicted along the lines *A*, *B*, *C*, *D*, etc. of figure 6.

For example, referring to line *A*, figure 5, at an elevation of 10,000 feet (3 km) the percentage transmission of the *Ba-1* filter is the height of the ordinate of *Ba-1* above the reference frequency divided by the height of the ordinate I_0, similarly above the reference frequency.

In this manner, the percentage transmissions of the three filters are calculated for the various flights. The calculations of the transmissions for flight 4 are depicted in figure 7, from which it may be noted that at an elevation of 10,000 ft. (3 km) these filters, when used with photoelectric cell *Cd-1*, had a transmission of 22, 45, and 79 percent, respectively.

In this connection, it is to be emphasized that, using smooth curves drawn through the observations, as indicated in figure 5, the calculations of two persons, working independently, were in agreement within 1 percent. Hence, no attempt was made to calculate each observation independently.

As may be noted in figure 7, there is but little change in the transmissions of these filters (i. e., the spectral-energy distribution) in ascending from 10,000 to 60,000 ft (3 to 18 km). Hence, within the limits of experimental errors, the factor *G* is calculated for a single spectral-energy curve that best represents the filter measurements at the highest altitudes. The data for this spectral-energy distribution are given in column 2 of table 2.

Referring to table 2, in the calculations involving the spectral energy, a wave-length interval of 10 A is used. The wave length (col. 1) associated with each band, is at the center of this 10 A interval.

In column 3, the photoelectric response data are given for cell *Cd-1* as read from the smooth curve in figure 3. In column 4 is tabulated the product of the relative solar energy and the relative photoelectric response for the different wave-length intervals. The sum of these products is the total response value for cell *Cd-1* when used in sunlight. The ratio of the sum total of the relative energy values for wave lengths shorter than 3132 A, to the total response value ($79.1 \div 58.957 = 1.34$ for photoelectric cell *Cd-1*) is known as factor *G*. It enters as one term in the calculation, when evaluating the ultraviolet radiation in sunlight. When using other photoelectric cells, the values of factor *G* are, of course, different from the one just derived for cell *Cd-1*.

TABLE 2.—*Determination of the factor G for sunlight, using the relative spectral intensities which best represent the observed filter transmissions between 50,000 and 60,000 ft (15 and 18 km)*

[Factor $G=79.1\div58.957=1.34$]

1	2	3	4	1	2	3	4
Wave length	Relative solar intensity	Relative response, *Cd-1*	Solar intensity ×relative response, (col. 2×3)	Wave length	Relative solar intensity	Relative response, *Cd-1*	Solar intensity ×relative response, (col. 2×3)
A				A			
2935	0.25	0.665	0.166	3135	10.0	.235	2.350
2945	.45	.650	.293	3145	11.1	.215	2.386
2955	.70	.630	.441	3155	12.3	.190	2.337
2965	.95	.615	.584	3165	13.6	.175	2.380
2975	1.20	.600	.720	3175	14.9	.160	2.384
2985	1.50	.580	.870	3185	16.3	.140	2.282
2995	1.75	.560	.980	3195	17.8	.125	2.225
3005	2.20	.540	1.188	3205	19.2	.110	2.112
3015	2.6	.515	1.339	3215	21	.095	1.995
3025	3.0	.495	1.485	3225	22	.085	1.870
3035	3.7	.470	1.739	3235	24	.070	1.680
3045	4.3	.450	1.935	3245	26	.055	1.430
3055	4.8	.425	2.040	3255	27	.045	1.215
3065	5.4	.405	2.187	3265	29	.035	1.015
3075	6.0	.380	2.280	3275	31	.025	.775
3085	6.6	.355	2.343	3285	33	.015	.495
3095	6.9	.330	2.277	3295	35	.005	.175
3105	7.4	.310	2.294				
3115	8.3	.280	2.324	Total			58.957
3125	9.1	.260	2.366	Total shorter than 3132 A	79.1		

3. CORRECTION FOR VARIATION OF THE PHOTOELECTRIC RESPONSE WITH THE ANGLE OF INCIDENCE OF RADIATION

In view of the fact that the sun is never directly overhead in this latitude and varies in altitude with the time of the day and of the year, it is necessary to have a knowledge of the variation of photoelectric response with the angle of incidence of solar radiation upon the Corex A diffusing window (fig. 1).

In figure 6 data are given on this variation of response with variation in incidence of radiation, through an angle of 40° from the normal, for cells *Cd-1* and *Cd-4*. In this illustration each curve is the average of data taken by rotating the cell in two different planes

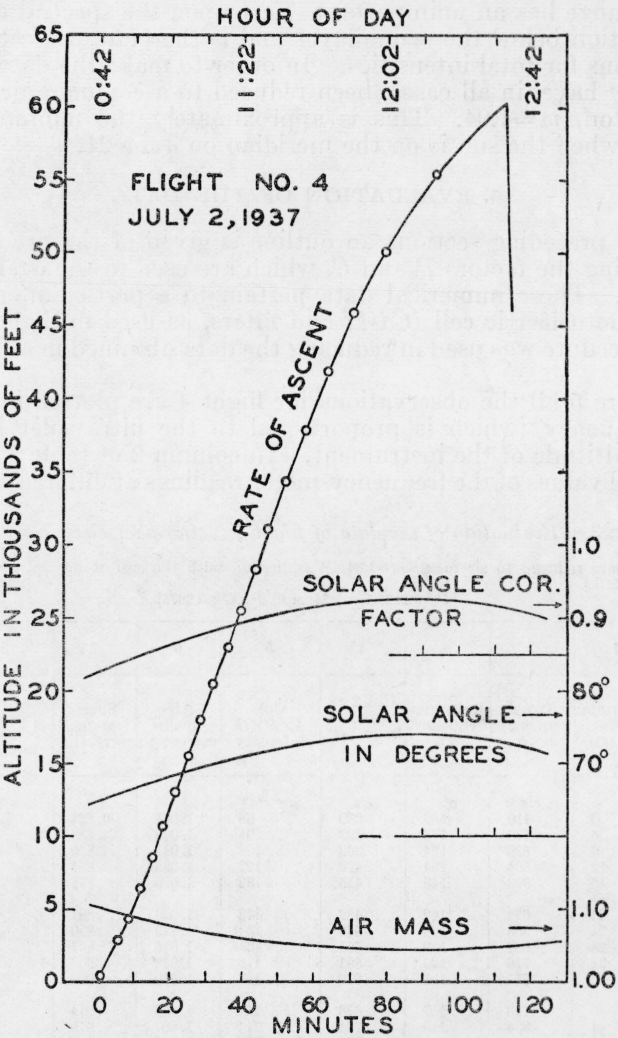

FIGURE 8.—*Graph showing rate of ascent, solar-angle, and air-mass data used in the calculations described in the text for flight 4.*

at right angles to each other and observing the response at intervals of 5° in the four directions from the normal position.

It is to be noted that within an angle of 20° (which includes the solar angle during most of the stratosphere flights) the correction is relatively small. Nevertheless, a correction is made in the evaluation of the data for the slightly reduced response resulting from the angular deviation of the incident radiation from normal (see fig. 8) on the cell.

Associated with the (angular) change in the height of the sun during the measurements is the change in air mass (see the lower curve in fig. 8) which occurs as the result of the solar rays coming through the atmosphere at varying angles during the different times of the day. This is not to be confused with another change in air mass as the result of increasing altitude of the balloons and apparatus, which change has an unimportant effect upon the spectral quality of the radiation below the ozone layer and is therefore neglected in the calculations for total intensities. In order to make the data comparable, they have, in all cases, been reduced to a common air mass for Washington, $m=1.04$. This is approximately the minimum value attained when the sun is on the meridian on June 21.

4. EVALUATION OF THE DATA

In two preceding sections an outline is given of the procedure for determining the factors P and G, which are used in the evaluation of the data. These numerical data pertain to a particular ultraviolet meter, photoelectric cell (*Cd-1*) and filters, as used in flight 4. The same procedure was used in reducing the data obtained in all the other flights.

In figure 5 all the observations for flight 4 are plotted in terms of audiofrequency (which is proportional to the ultraviolet intensity) and the altitude of the instrument. In column 2 of table 3 are given numerical values of the frequency-meter readings at different altitudes.

TABLE 3.—*Evaluation of the data of flight 4, using photoelectric cell, Cd-1*

[Intensities are reduced to air mass, $m=1.04$, Washington, with the sun at normal incidence to the photoelectric cell.]

[$P=0.222$; $G=1.34$; and $P\times G=0.2975$]

1	2	3	4	5	6	7	8
Altitude in feet ÷1,000	Signal frequency, ×5	Reference frequency, ×5	Col. 2−3 corrected frequency, ×5	Col. 4×P×G intensity	Air-mass correction	Solar-angle correction	Col. 5×6÷7 corrected intensity
	c/s	c/s	c/s	μw/cm²			μw/cm²
0	410	180	230	68	1.061	0.823	88
4	478	173	305	91	1.049	.838	114
8	526	164	362	108	1.041	.850	132
12	564	154	410	122	1.035	.861	147
16	593	148	445	132	1.029	.871	156
20	624	142	482	143	1.023	.881	166
24	653	134	519	154	1.019	.890	176
28	681	130	551	164	1.015	.897	185
32	716	125	591	176	1.012	.903	197
36	751	121	630	187	1.010	.909	208
40	793	117	676	201	1.008	.914	222
44	834	113	721	214	1.007	.919	235
48	890	111	779	232	1.005	.922	253
52	959	109	850	253	1.005	.923	275
56	1,047	110	933	278	1.006	.922	303
60	1,163	110	1,053	313	1.007	.921	342

As noted elsewhere, the vertical lines A, B, C, and D, in figure 5 indicate the sequence of the frequency-meter readings, in succession, as the different filters rotated over the window of the photoelectric cell.

From these frequency-meter readings is deducted the reference frequency (zero of the scale, col. 3) giving the corrected frequency (col. 4). The product of these values and the factors *P* and *G* gives the intensity of the ultraviolet radiation (col. 5) of wave lengths less than 3132 A incident upon the photoelectric cell, at various elevations.

Since during any flight (for example, flight 4; see fig. 8) there is a variation in solar altitude and consequently a change in air mass through which the rays reach the earth, a correction is made for variation of air mass from $m=1.04$ (when the sun is on the meridian, June 21). These corrections which are given in col. 6 of table 3, are small since all the flights were made near the noon hour and near the summer solstice.

Moreover, since during any flight the angle of incidence of the solar rays upon the window of the photoelectric cell varies with the altitude of the sun (the hour angle from the meridian, as differing from small variations, as a result of swaying of the instrument container, which require special consideration) a correction (see fig. 8) must be made also for variation in sensitivity with angle of incidence (see fig. 6) of the solar rays upon the photoelectric cell. These corrections to the data obtained in flight 4, are given in column 7 of table 3; and, of course, similar corrections are applied to the observations obtained on the other flights.

The variations in the observations (fig. 5) are caused by an irregular swinging (circular or elliptical pendulum motion) of the apparatus relative to the balloons as a result of irregular air currents during the ascent. Hence, referring to figure 6, it can be seen that some of the points will be too high while others will be too low. A study of figures 5 and 6 indicates that the magnitude of the swing never exceeded about 5° from normal, otherwise a larger variation in the observations should have resulted. An average curve is, therefore, drawn through the data, giving a slight preference to higher values to compensate for the obviously defective data caused by the shadowing of the photoelectric cell by the suspension cords and antenna at the corners of the instrument as it rotates.

As noted on a preceding page, the instruments hung directly beneath the balloons, even in the strongest wind encountered (15 to 20 mph) and did not lag behind. This is to be expected, since the air stream surrounding the instrument has approximately the same velocity as that at the balloons.

The corrected intensity of ultraviolet solar radiation is obtained as the product of columns 5 and 6 divided by column 7. (See col. 8, table 3.) In this manner the data for total intensity of radiation of wave lengths shorter than 3132 A for the six flights have been reduced to a common basis of normal incidence and air mass 1.04, Washington. These data are plotted in figure 9.

Based upon observations made with a receiver of small angular opening at Washington and at Flagstaff and upon measurements of scattered radiation by Pettit [6] and the authors, an estimated curve (dotted curve in fig. 9) for direct sunlight has been plotted basing the higher altitude values upon those of flight 5.

In table 4, meteorological data as observed by the United States Weather Bureau are tabulated for 11:00 a. m. on the days on which the six flights were made. These data may prove of interest in show-

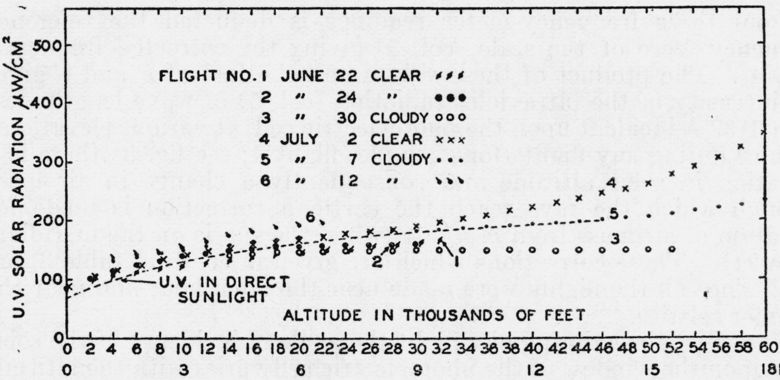

FIGURE 9.—*Ultraviolet solar and sky radiation at various altitudes above the earth's surfacc*

ing a possible relation between movements of cold masses of air and intensity of ultraviolet radiation as affected by an increase in ozone.

TABLE 4.—*Meteorological data on the days of the six stratosphere flights as reported by U. S. Weather Bureau*

Date (1937)	Radiation (g cal/cm²/day)		Temperature	Wind		Sunshine	Indicated air mass
	Actual	Normal		Direction	Velocity		
			°F		mph		
June 22	736	496	78	NW	14	Clear	NPC
24	790	501	80	WNW	7	do	NPC
30	322	520	78	SW	5	Cloudy	NPC+NPA.
July 2	770	512	73	WSW	5	Clear	NPC
7	598	502	86	NW	6	Cloudy	TA, possibly NP
12	660	493	87	NW	10	do	TA

VI. DISCUSSION OF THE DATA

In taking an inventory of the results obtained in this investigation of ultraviolet solar intensities in the stratosphere it is to be noted that, unfortunately, our observations cease at an elevation of about 19 km, above which the information sought promises to be the most interesting.

As already noted, the results obtained are too meagre to attempt an extensive calculation of the two main factors that reduce the ultraviolet intensities of short wave lengths in the directly incident beam. These factors are: (a) molecular (Rayleigh) scattering by the air, which theoretically should vary inversely as the 4th power of the wave length, and (b) selective absorption by ozone, which, beginning at about 3200 A, increases rapidly in absorption with decrease in wave length, attaining a maximum in the region of 2500 A [21, 22]. Below elevations of about 7,000 ft the intensity of ultraviolet solar radiation is further reduced by absorption and scattering by smoke and dust, especially in the vicinity of cities.

From our measurements at Flagstaff, Ariz. (elevation 7,300 ft, 2.2 km) the effect of sky radiation was found to be extremely small; averaging about 0.3 percent of the total ultraviolet intercepted through an angular opening of 23° [2]. In the present investigation the angular opening to the interior of the photoelectric cells was about 68°, from which the calculated sky radiation entering this type of radiometer, at an elevation of 7,000 to 10,000 ft (2.1 to 3 km) amounts to 3 or 4 percent of the total. This appears to be negligible in comparison with other far greater errors that enter into the present measurements.

In the relatively narrow band of wave lengths intercepted by the photoelectric cell, the selective increase in intensity of ultraviolet solar radiation, of the shortest wave lengths relative to the longer wave lengths, as the result of Rayleigh scattering at high altitudes, is small [11]. Hence, the effect upon the filter transmissions is of a second order in determining the spectral quality of the directly incident ultraviolet solar radiation. Incidentally, this effect would produce a less rapid decrease in the filter transmission (a less rapid decrease in the apparent amount of ozone overhead) than the true value.

Since the spectral range of the response of the photoelectric cell is so narrow (less than 250 A) but little change in transmission of the filters with altitude is to be expected, unless there is a marked change in the amount of superimposed ozone. For this reason in future ascents a filter that is considerably more opaque to the ultraviolet than *H*, in figure 7, is to be used.

It is desirable to obtain data on different dates, using the same apparatus. In this manner operating conditions will be the same, and any marked variations in the observations may be ascribed presumably to differences in meteorological conditions.

In this connection, the data on ultraviolet intensities (fig. 9) and filter transmissions obtained on flights 2, 3, and 5 are of especial interest, because they were obtained on widely different dates, using the same photoelectric cell, *Cd-110*, and the same filters.

The observations obtained on flight 3 are inconsistent in that there was a continuous increase in the values of the transmissions of the filters with altitude, up to the highest altitudes (16 km) attained. Coincidently, there was practically no increase in the total intensity (I_0) with increase in altitude (fig. 9). On this date meteorological conditions were so unsteady that, until confirmatory data can be obtained showing that during an ascension the apparatus can drift under or into an increasing mass of cold air (see table 4) containing a larger mass of ozone [13, 16], this inconsistency is to be ascribed to an unexplained temporary defect in the instruments.

On the other hand, in flight 5, using the same instruments, the measurements are consistent with similar data obtained in flight 4 (using another instrument, see figs. 7 and 9), and they are consistent with expectations based upon known physical conditions of the atmosphere, showing a gradual increase in total intensity (I_0) and a decrease in the transmissions of the filters, with increase in altitude.

Using the data obtained in flights 4 and 5, it is of interest to obtain a rough estimate of the ozone layer traversed in these two ascents. In order to eliminate the effect of dust and smoke, in the present calculations the lowest elevation taken into consideration is 30,000 ft (9 km), although, as shown in figure 7, there is but little change in the filter transmissions between 10,000 ft (3 km) and this elevation.

At a height of about 14 km the transmissions of the filters begin to decrease, indicating a decrease in ozone. This is in good agreement with the results reported by O'Brien [11] and by Mohler [10] who, on two ascensions in manned balloons (in 1934 and 1935), found but little ozone below the 15-km level.

For elevations above 14 to 19 km (46,000 to 64,000 ft), where our quantitative measurements cease, the two filters, *Ba-1* and *LS*, show a gradual decrease in transmission (the high-transmission filter, *H*, ordinarily varies but little in transmission [3]), indicating a spectrally selective increase in intensity in ultraviolet of the shortest wave lengths, relative to the longer wave lengths intercepted, as the result of an appreciable decrease in the amount of ozone above the apparatus.

This is in good agreement with the results reported by Mohler [10], in which the amount of ozone above the exploring balloon changed appreciably in rising from a height of 16 to 22 km (53,000 to 72,000 ft), indicating a decrease of over 20 percent in the superposed ozone. This variation in ozone concentration with height was more abrupt than that found by the Regeners [8] and by Goetz, Dobson, and Meetham [9].

1. CALCULATIONS OF THE AMOUNT OF OZONE TRAVERSED

As already mentioned, in passing through the upper regions of the earth's atmosphere ultraviolet solar radiation is reduced in intensity (a) by molecular scattering and (b) by ozone absorption.

In order to obtain an estimate of the amount of ozone traversed, it is necessary to eliminate the effect of molecular (Rayleigh) scattering, which varies as the inverse 4th power of the wave length.

Data on the reduction in intensity (based upon the optical density of 1 atmosphere) at given wave lengths by Rayleigh scattering are taken from a paper by O'Brien [11]. To simplify our calculations, these data are transformed into transmissions for tenths of atmospheres and plotted in figure 10.

From these spectral transmissions and the calculated spectral values of solar intensity times the relative response of the photoelectric cell (see col. 4, table 2) and the spectral transmission of filter *Ba-1* (see fig. 3) is calculated the change in transmission of the filter as a function of altitude. This change (scattering correction) is given in figure 11. The difference between the observed filter transmissions and the correction for Rayleigh scattering ($A-B$) gives the change in transmission associated with the amount of ozone penetrated (curve *C*, fig. 11).

In order to translate this change in filter transmission into depth of the ozone layer penetrated, a knowledge of the spectral transmission of ozone is essential. From the published data of Fabry and Buisson [21] the spectral transmissions of hundredths of a centimeter of ozone (ntp) have been calculated and plotted in figure 10.

The effect of change in ozone thickness upon the filter (*Ba-1*) transmission is calculated in the same manner as outlined above for scattering. The spectral values in each of the transmission curves for hundredths of a centimeter of ozone are multiplied by the product of the photoelectric-cell response and the relative spectral solar intensities (see col. 4, table 2). This gives a total calculated response value for the photoelectric cell for different thicknesses of ozone in intervals of 0.01 cm. The maximum of this response corresponds to a wave length of approximately 3125 A. Next, a product is obtained

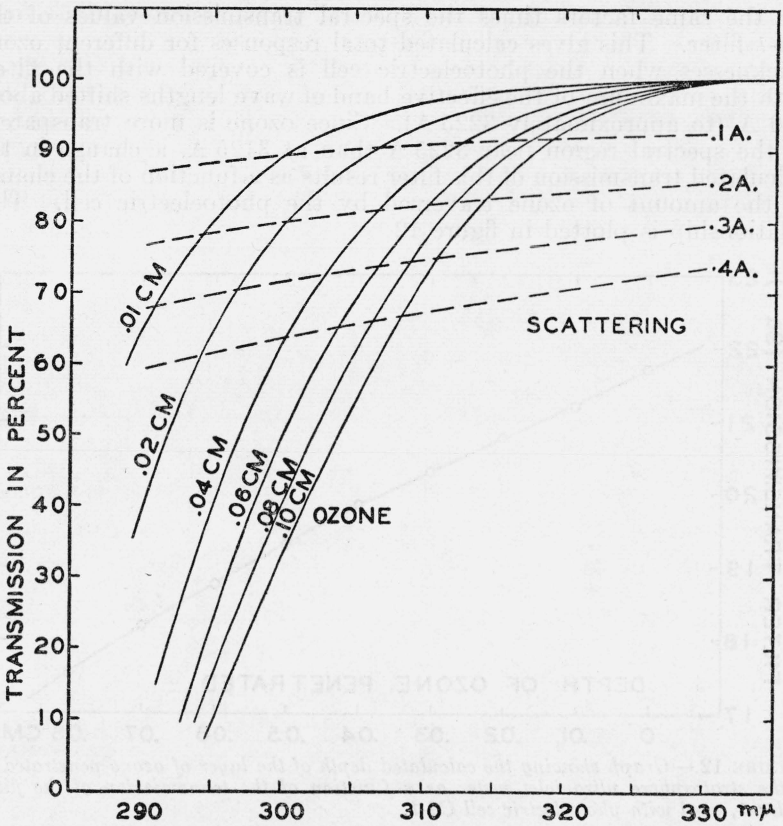

FIGURE 10.—*Graphs showing the spectral transmission of the air as affected by molecular (Rayleigh) scattering and by ozone absorption.*

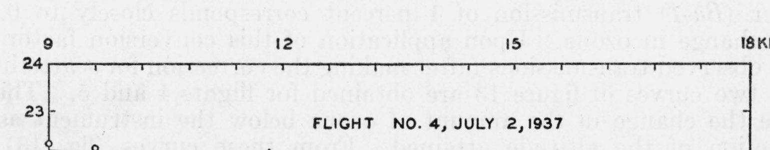

FIGURE 11.—*Graphs showing the observed transmissions of the filter* Ba-1 *at various altitudes (curve A) and the corrected transmissions (curve C) after correction for molecular (Rayleigh) scattering (curve B).*

for the same factors times the spectral transmission values of the *Ba-1* filter. This gives calculated total responses for different ozone thicknesses when the photoelectric cell is covered with the filter, with the maximum of the effective band of wave lengths shifted about 100 A (to approximately 3225 A). Since ozone is more transparent in the spectral region near 3225 A than at 3125 A, a change in the calculated transmission of this filter results as a function of the change in the amount of ozone traversed by the photoelectric cell. This relationship is plotted in figure 12.

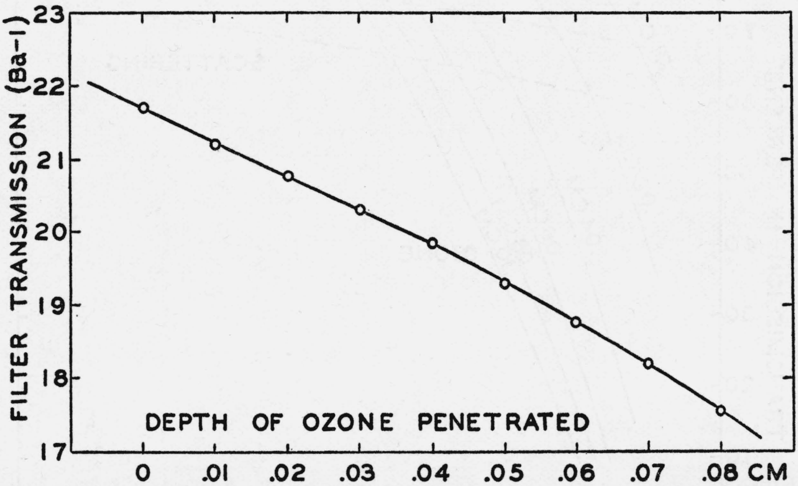

FIGURE 12.—*Graph showing the calculated depth of the layer of ozone penetrated by the stratosphere ultraviolet meter as a function of the transmission of the filter, Ba-1, used with photoelectric cell Cd-1.*

For a change in thickness of about 0.1 cm (ntp) in the layer of ozone, this curve approximates a straight line, for which a change in filter (*Ba-1*) transmission of 1 percent corresponds closely to 0.02 cm change in ozone. Upon application of this conversion factor to the observed transmissions (after making the correction for scattering) the two curves of figure 13 are obtained for flights 4 and 5. These give the change in the amount of ozone below the instrument as a function of the altitude attained. From these curves (fig. 13) it appears that in ascending to a height of 18 km (60,000 ft) in flight 4, the apparatus passed through 0.08 cm of ozone (ntp) and in flight 5, through 0.04 cm, or a penetration of approximately 30 percent and 15 percent, respectively, of the ozone present at this latitude at this time of the year. For flight 4 this is a decidedly greater penetration than previously observed at an elevation of 18 km [10, 11]. The data obtained in flight 5 are in good agreement with those obtained in the manned balloon ascension of 1934 [11].

It is to be emphasized that these values are based upon preliminary data and that future measurements with better equipment may modify the values obtained. The data are presented mainly for the purpose of illustrating a new method of determining the distribution of ozone at high altitudes.

In connection with the foregoing calculations on the extent of the ozone layer penetrated in our balloon ascensions, it is of interest to attempt to estimate this value by another method.

Using the data given in figure 7, of a previous paper [2], which shows the change in filter transmission with the seasonal variation in ozone, it is deduced that a decrease in ozone amounting to 0.013 cm (ntp) produces a change of about 1 percent in the value of the filter transmission. On this basis, the observed decrease of 4 percent in the filter transmission (*Ba-1*, in fig. 7), in ascending from an altitude of 14 to 19 km, represents a decrease in ozone amounting to about 0.05 cm (ntp) above the apparatus in flight 4 and about 0.025 cm in flight 5, or a penetration of 20 percent and 10 percent, respectively, of the ozone present in this latitude in June to July [13, 20].

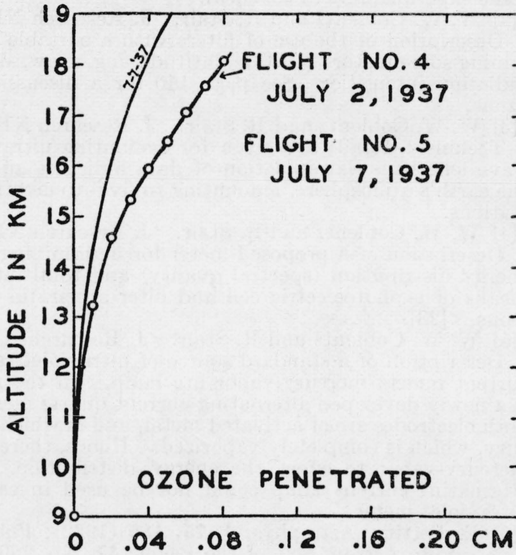

FIGURE 13.—*Graphs showing the depth of the ozone layer penetrated by the stratosphere ultraviolet meter in flights 4 and 5.*

While no great accuracy can be claimed for such data, they are interesting and instructive in being in agreement with information obtained by various other methods of attack, showing that the ozone in the atmosphere is present in the form of a definite layer, presumably having an appreciably higher concentration in the center than at the top and the bottom, and situated at a height easily attainable by sounding balloons.

In concluding this discussion it may be noted that the foregoing method of reducing the observations may be applied to data obtained at land stations in determining the variation of ozone with time of the day or year. Thus it should be possible with a single photoelectric cell and filter to follow the ozone cycle through the year and from year to year through the sunspot cycle. It is important, however, to use a number of cells (at least two or three) which are calibrated and intercompared frequently to insure against change in their spectral or total photoelectric response.

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VII. REFERENCES AND NOTES

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