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EVALUATION OF ULTRAVIOLET SOLAR RADIATION OF SHORT WAVE LENGTHS

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ABSTRACT

Technical details are given for evaluating ultraviolet solar radiation by two closely agreeing methods: (a) by means of a balanced thermopile and filter radiometer, calibrated against a standard of thermal radiation, and (b) by means of a photoelectric ultraviolet meter calibrated against a standard of ultraviolet radiation. A photoelectric cell and filter method for determining the solar ultraviolet spectral-energy distribution is described. Data are given on ultraviolet solar radiation intensities observed at Washington, D. C., San Juan, P. R., and Flagstaff, Ariz. The intensity of ultraviolet solar radiation of wave lengths shorter than and including 3132 A, in the clearest, midsummer, midday sunlight at Washington is about 75 μw/cm^2 decreasing to one-tenth this value (8 μw/cm^2) during the clearest, midwinter, midday sunshine. Extrapolation of the data observed at the three stations (Washington, San Juan, and Flagstaff) indicates an ultraviolet intensity of about 600 μw/cm,^{2} outside the earth's atmosphere—a fivefold to eightfold increase as compared with a 20 to 30 percent increase in total intensity of all wave lengths.

CONTENTS

I. INTRODUCTION

The evaluation, in absolute units, of the energy in the short-wave-length ultraviolet region of the solar spectrum has been attempted by several methods. The most common procedure is to integrate the energy curve, observed throughout the whole solar spectrum, and calculate the fractional part that is contained in the band of wave lengths (for example, between 2900 to 3100 A) under investigation. Then, from a determination of the total radiant flux (the solar intensity Q, in gram-calories, as usually observed) the part in the short wave lengths is calculated. The objection to this method is the lack of accurate data on the spectral-energy distribution, particularly in the ultraviolet.

A proposed variation in this method is to calculate the spectral-energy distribution on the assumption that the radiation from the sun is comparable with that of a black body at 6,000° K. However, in view of the fact that the effective radiating surface of the sun emits selectively, this assumption is obviously untenable. In addition to this fact is the uncertainty of the atmospheric-transmission coefficients which are constantly changing. Hence, the method would be useful only in a very general way.

The most promising method of evaluation of the short-wave-length ultraviolet in solar radiation is by means of filters placed over either a selective (photoelectric) or a nonselective (thermopile) radiometer. This procedure requires a determination of the spectral-energy distribution and the radiant flux (the total intensity) within and adjacent to the band of wave lengths under investigation.

This Bureau's interest in the evaluation of the ultraviolet of short wave lengths in solar radiation began about 8 years ago, when, in connection with the widespread interest in light sources and window materials for therapeutic purposes [1],[1] it was urgent to obtain an estimate (having some degree of reliability) of the amount of ultraviolet in sunlight that has a therapeutic value, at least in healing rickets.

The earliest investigations [1, 2], using a thermocouple and filters of window glass, led to an estimate of the upper limit in intensities that might be expected in ultraviolet solar radiation, useful for therapeutic purposes.

From these crude beginnings, as the demand for more exact data increased, improvements were made in the filter methods of radiometry; and data were obtained on ultraviolet solar-radiation intensities at sea level and at high elevations [3]. For this purpose the best available ultraviolet spectral-energy measurements were used in calculating the amount of ultraviolet, of wave lengths 3132 A and shorter, in sunlight.

Since the ultraviolet intensities in the shortest wave lengths were extremely low, the investigation was undertaken anew, using a ("differential") balanced thermocouple and filter method, which greatly increased the accuracy of the measurements [3, 4].

However, there was an outstanding uncertainty in the ultraviolet solar-radiation measurements, which evidently was owing to the lack of knowledge of the spectral-energy distribution. This conclusion seemed to follow from the good agreement obtained on artificial

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

sources, in which the radiation in a spectral band was integrated by spectroradiometric and filter methods [4], and it was further substantiated in a subsequent interlaboratory comparison of lamps [5], in which good agreement was obtained in the spectral-energy measurements.

Subsequent tests of the balanced thermocouple and filter radiometer as a standard ultraviolet dosage intensity meter [6] on artificial sources justify the belief that the device is reliable, provided the ultraviolet spectral-energy distribution of the source is known with sufficient accuracy. In the case of the sun it was evident that the spectral-energy distribution, in the extreme ultraviolet, is not known with sufficient accuracy, and that it should be determined at the time of the physiological or biological application of the radiation stimulus.

In view of the fact that the thermopile is not sufficiently sensitive to measure accurately, by means of filters, the spectral-energy distribution of solar radiation in the region of 2900 to 3200 A, the writers have devised a portable ultraviolet meter, consisting of a balanced amplifier, photoelectric cell, and microammeter [7], which is eminently adapted to determine the spectral quality of ultraviolet solar radiation, practically simultaneously with any biological tests that may be in progress.

Moreover, recent improvements in methods of calibrating the photoelectric ultraviolet meter against a standard of ultraviolet radiation [8] make it possible to use this instrument to determine (a) the spectral quality and (b) the total intensity (the latter in absolute value) thus greatly reducing the equipment, work, and expense in conducting field measurements of solar ultraviolet radiation.

There was recently published a preliminary outline [9, 10] of the procedure for determining the spectral-energy distribution in the extreme ultraviolet of the solar spectrum by means of a titanium photoelectric cell and filters [7]. It was shown [9] that: (a) because the ultraviolet solar spectral-energy curve is not known with sufficient accuracy (particularly in the region of the H and K lines; 3700 to 4000 A), and (b) because there are no suitable filters to place over a thermopile in order to confine its response to wave lengths shorter than about 3300 A (in which we are chiefly interested) a photoelectric cell which is insensitive to wave lengths longer than about 3300 A is especially adapted for determining the spectral-energy distribution in the band of wave lengths extending from 2900 to 3300 A, by the filter method.

The object of the present paper is to present technical details to serve as a guide in evaluating the ultraviolet of short wave lengths in solar radiation, by two closely agreeing methods: (a) by means of a balanced thermopile and filter radiometer which is calibrated against a standard of thermal radiation [11]; and (b) by means of a titanium photoelectric ultraviolet intensity meter [7], calibrated in absolute value against a standard of ultraviolet radiation [8].

At the outset, it is to be noted that, for small air masses, the previously published values of ultraviolet intensities remain practically unchanged; but, for large air masses, where the spectral-energy distribution was practically unknown prior to the adoption of the present method of spectral-energy evaluation, the ultraviolet intensities are appreciably lower than previously reported.

II. DETERMINATION OF THE DISTRIBUTION OF ENERGY IN THE EXTREME ULTRAVIOLET OF THE SOLAR SPECTRUM

A knowledge of the distribution of intensities in the spectrum, in relative units, is essential in order to evaluate the energy in a given band of wave lengths.

As shown in figure 2 of a previous paper [10], owing to the presence of the Fraunhofer absorption lines, caused by vapors of various elements in the solar atmosphere, and the absorption lines caused by ozone in the terrestrial atmosphere, the solar spectrum appears discontinuous when photographed under a sufficiently high dispersion. On the other hand, as ordinarily observed radiometrically, with a low dispersion, the ultraviolet spectral-energy curve is relatively smooth and free from indentations [12].

As indicated in the previous paper [10], by means of the titanium photoelectric cell and a group of four glass filters, the spectral band of ultraviolet, extending from 2900 A to about 3500 A, is separated into five parts. This procedure requires only a few minutes, thus securing the information desired without the necessity of making corrections for change in air mass.

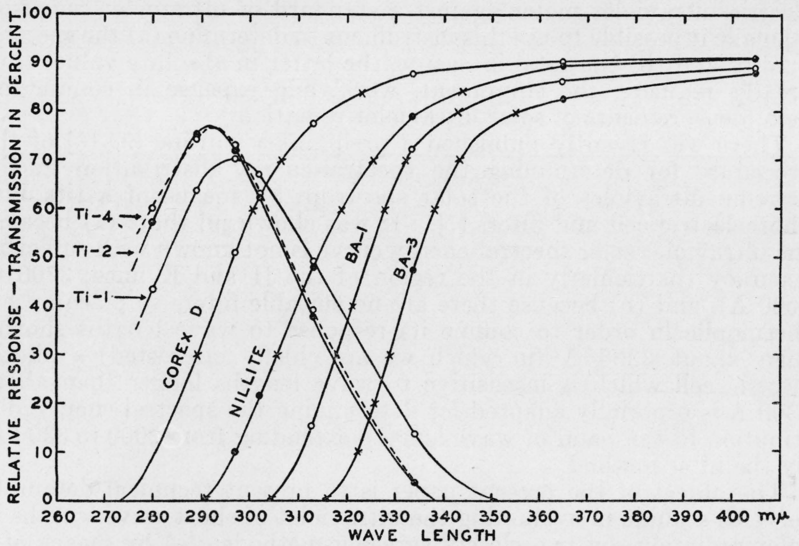

FIGURE 1.—*Relative response curves of titanium photoelectric cells* Ti–*1*, Ti–*2*, *and* Ti–*4 to an equal-energy spectrum; also spectral transmission of glass filters used* (*Corex* D, *Nillite; both trade names*); *and barium-flint glass* (Ba–*1 and* Ba–*3*; *thickness 1 mm and 3* mm, *respectively*).

Wave length 400 mμ=4000 A.

From a detailed study of the shape of the spectral-energy curve required to give calculated transmissions in agreement with the observed photoelectrically integrated filter transmissions, it appears that a relatively smooth curve with but slight indentations, as observed by Pettit [12], answers the purpose of evaluating the ultraviolet for use in medicine.

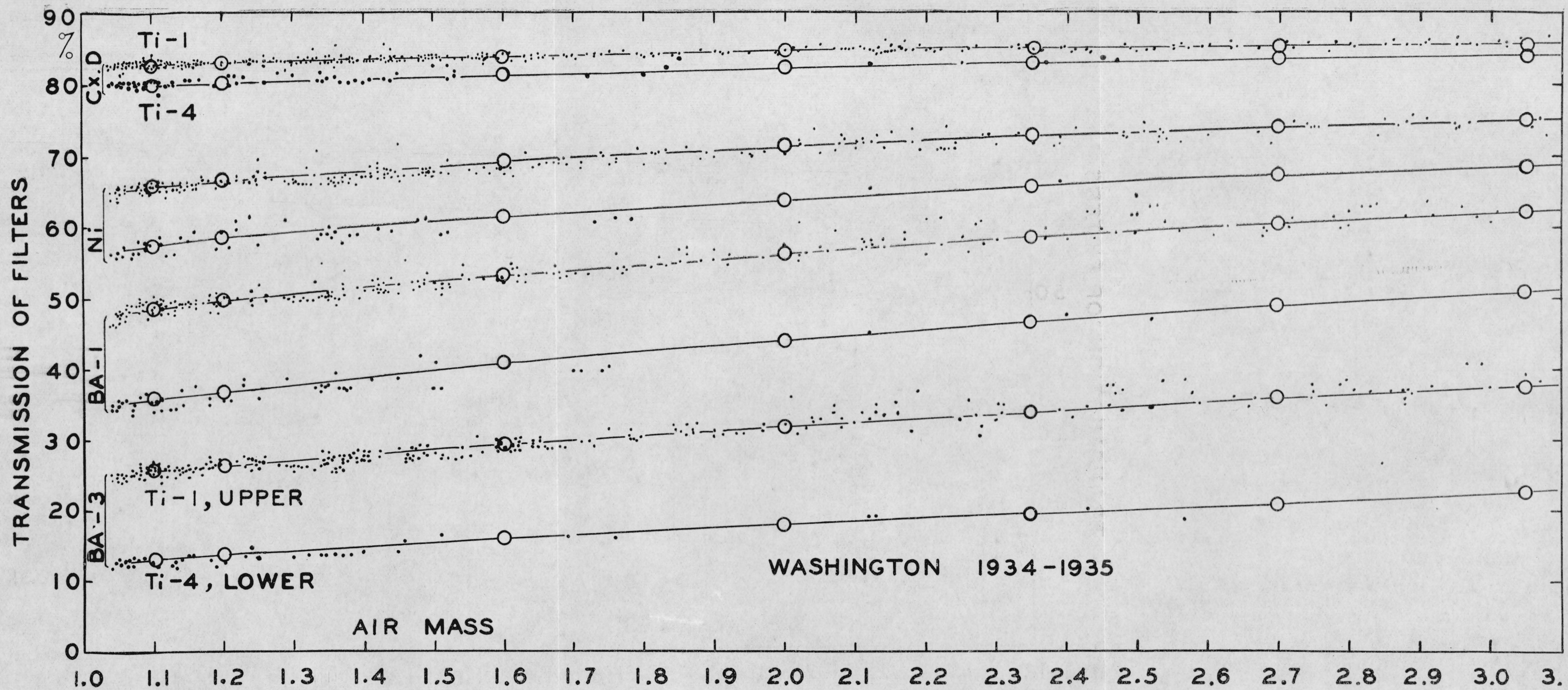

FIGURE 2.—*Diurnal variation in transmission of ultraviolet solar radiation through standard filters (see figure 1) observed at Washington*

The large circles are the calculated transmissions for ultraviolet spectral-energy curves identified with the corresponding air masses, see figure 9. The black dots represent observed values.

The experimental procedure is to observe the percentage transmission of the ultraviolet solar radiation in the band extending from the extreme wave lengths that penetrate the atmosphere (about 2900 A) to the limit of response of the particular photoelectric cell used (3300 to 3500 A). This is observed through a set of four glass filters; Corex D, Nillite (both trade names), and two samples of barium-flint glass (abbreviated Cx. D; Ni.; Ba–1; and Ba–3, respectively), having the spectral-transmission curves illustrated in figure 1. High accuracy in transmission is required only between 2900 and 3500 A.

In this same illustration are given also the spectral response (the spectral liberation of electrons; the electron emission) curves of two titanium photoelectric cells Ti–1 and Ti–4, selected because of the marked difference in their spectral sensitivity. As a consequence, there is a corresponding difference in the apparent percentage transmission of integrated ultraviolet solar radiation through the same filter when used with these two photoelectric cells.

As shown in the previous paper [10] with the high precision attained in recent measurements it is necessary to group the observations of filter transmission according to the season, in order to take into consideration the variation in atmospheric ozone. This reduces the spread in the values of the filter transmissions for the same air mass.

In figure 2 are shown graphs of typical observations of integrated filter transmissions for various solar altitudes (air masses, m) on the clearest days in Washington, D. C. Similar data, observed at Flagstaff, Ariz. (elevation 7,300 ft; also at 10,500 ft) are illustrated in figures 4 and 5 of the previous paper [10].

Provided with observations of the type depicted in figure 2, the first step in the evaluation of the ultraviolet radiation in the spectral band of wave lengths shorter than and including 3132 A, is to determine, by calculation, the shape of the spectral-energy curve of wave lengths shorter than about 3500 A required to give the observed transmissions, using the above-mentioned four filters and two photoelectric cells. This gives eight conditions for establishing the shape of the spectral-energy curve for any given air mass traversed by the solar rays.

The first calculations of the shape of the spectral-energy curve were made while observations were in progress at the Lowell Observatory, Flagstaff, Ariz. (elevation, 7,300 ft), in May 1934. For this purpose, the average ultraviolet solar spectral-energy curve observed by Pettit [12] at Tucson, Ariz. (elevation about 2,500 ft), in May 1931, was used as a starting point. The product of this spectral-energy curve (shown dotted in fig. 3) and the spectral-response (the electron emission) curve of the photoelectric cell (fig. 1), gives the solar spectral-energy distribution as it affects the particular photoelectric cell employed in making the measurements. In other words, it is the solar spectral-energy distribution as it would be observed with a spectroradiometer in which the nonselective radiometer is replaced by a selective (photoelectric) radiometer. For the eye it is the "luminosity curve."

For example, curve Ti–1 is the spectral response of photoelectric cell Ti–1, when exposed directly to solar radiation whose spectral-energy distribution is shown by the dotted curve in figure 3. The product, at each wave length, of this photoelectric appraisal of the spectral energy by the corresponding percentage transmission of the filter (fig. 1) gives, in each case, the spectral-energy distribution as transmitted through the filters marked Cx. D.; Ni.; Ba–1; and Ba–3 in figure 3. The ratio of the area under each of these curves to the area under the curve Ti–1 gives, in each case, the fraction of the incident ultraviolet that is transmitted by the filter. Similar curves were obtained for the titanium photoelectric cell Ti–4.

As was to be expected, owing to the difference in altitude of the two observing stations (Tucson and Flagstaff), there were systematic deviations of the calculated from the observed photoelectrically integrated filter transmissions; these deviations being in agreement for both photoelectric cells. The spectral intensities taken from Pettit's

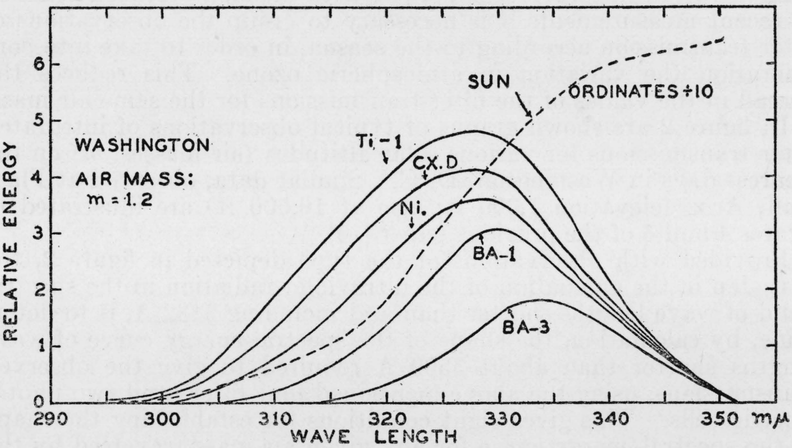

FIGURE 3.—*Spectral-energy curve of the sun as it would be observed with a non-selective radiometer and with a selective photoelectric radiometer,* Ti–*1, without a filter, and through the standard filters* Ba–*3, etc.*

Wave length 350 mμ=3500 A.

energy curve, in the region of 2950 to 3050 A were slightly too high, and the intensities at 3250 to 3550 A were appreciably too low (as was to be expected) to fit the observations at the higher elevation (7,300 ft) at Flagstaff, Ariz. By making slight changes in the assumed energy curve, in these two spectral regions, after one or two further trial adjustments and calculations, a set of calculated filter transmissions was obtained, for the two photoelectric cells and the four filters, which, within the experimental errors in the observations, was in good agreement with the transmissions observed in May and June at Flagstaff for an air mass, m=1.35, and with the transmissions observed at Washington, for m=1.20, in October and the first part of November 1934. This spectral-energy curve was, therefore, identified with the air mass m=1.20 at Washington and m=1.35 at Flagstaff.

Subsequently a prolonged investigation was made of the spectral transmissions of the filters and of thin samples (to determine the end points), by radiometric and photographic means; and a redetermination was made of the spectral photoelectric response curves of the photoelectric cells. In figure 1 the radiometric transmissions are indicated by dots and circles. The intervening parts of the curves (×××) were established by photographic means.

This investigation introduced slight changes in the spectral-transmission curves and in the spectral photoelectric response curves which, in turn, required a slight change in the assumed spectral-energy curve (fig. 3)—mainly increasing the indentation at 3250 A. As a result of this more exact determination of the spectral transmissions of the filters there was even better agreement than previously found between the observed and the calculated percentage transmissions of the integrated ultraviolet solar radiation through all the filters, except, perhaps, the filter of Nillite glass, which was a piece of special window glass that did not have a high optical polish and, hence, should not be given the same weight as the others.

The agreement attained between the calculated and the observed values is closer than required, because of the inevitable variations in the observed values caused by ever-changing atmospheric conditions.

In table 1 is given an example of the procedure in calculating the transmission of the photoelectrically integrated ultraviolet solar radiation through the various filters. In this table columns 2 and 3 give the spectral response (the spectral liberation of electrons), respectively, of the two photoelectric cells (Ti–1 and Ti–4), produced by an equal-energy spectrum.

Column 4 is the ultraviolet spectral-energy distribution (intensities are relative values) which is found to give the observed filter transmissions for an air mass $m=1.20$, at Washington. (See fig. 3.)

Columns 5 and 6 give the products of the ultraviolet solar intensities (column 4) and the spectral photoelectric responses (columns 2 and 3, respectively). The solar spectral-energy curve as it would be observed with titanium photoelectric cell Ti–1, attached to a spectroheliometer is illustrated in figure 3 (Ti–1). In other words, these two columns give the spectral distribution of the photoelectric response to the given solar radiation.

Columns 7, 8, 9, and 10 are the spectral transmissions, respectively, of filters Cx. D; Ni.; Ba–1; and Ba–3.

Columns 11, 12, 13, and 14 are the products of column 5 (solar energy times relative photoelectric response for Ti–1) and the spectral transmissions of the filters (columns 7, 8, 9, and 10, respectively). This gives the spectral distribution of the photoelectric response with titanium photoelectric cell Ti–1 observed through the various filters. (See fig. 3.)

Columns 15, 16, 17, and 18 give the spectral-energy distribution (photoelectric response) as observed with titanium photoelectric cell Ti–4, using the above-mentioned filters Cx. D; Ni.; Ba–1; and Ba–3.

The calculated transmissions of the photoelectrically integrated ultraviolet solar radiation, for air mass $m=1.20$, for the various filters, are obtained by taking the ratio of the areas under the curves (for example, the area under the curve Ba–3 to the area under the curve Ti–1, in fig. 3); or by taking the ratio of the summation of

TABLE 1.—*Example of the procedure followed in calculating the transmission coefficients of the filters, for a given distribution of energy (column 4), which were subsequently identified with the observed transmissions for air mass m=1.20, at Washington*

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Wave lengths (angstroms)	Relative spectral response		Relative solar energy (m=120)	Relative solar energy × relative response		Transmission of filter				Transmission of filters × solar energy × relative response (Ti–1)				Transmission of filters × solar energy × relative response (Ti–4)			
	Ti–1	Ti–4		Ti–1	Ti–4	Cx. D	Ni.	Ba–1	Ba–3	Cx. D	Ni.	Ba–1	Ba–3	Cx. D	Ni	Ba–1	Ba–3
2950	0.70	0.75	0.005	0.004	0.004	0.46	0.067	-------	-------	0.002	0.001	-------	-------	0.002	0.001	-------	-------
2975	.70	.71	.200	.140	.142	.54	.110	-------	-------	.076	.015	-------	-------	.077	.016	-------	-------
3000	.69	.665	.465	.321	.309	.595	.155	-------	-------	.191	.050	-------	-------	.180	.048	-------	-------
3025	.68	.62	.817	.555	.507	.645	.205	-------	-------	.358	.114	-------	-------	.327	.104	-------	-------
3050	.64	.56	1.225	.784	.686	.687	.265	-------	-------	.539	.208	-------	-------	.471	.182	-------	-------
3075	.59	.50	1.76	1.038	.880	.722	.33	0.034	-------	.750	.343	0.035	-------	.635	.290	0.030	-------
3100	.54	.45	2.30	1.242	1.035	.750	.39	.08	-------	.931	.484	.099	-------	.776	.404	.083	-------
3125	.50	.39	2.79	1.395	1.088	.772	.455	.14	-------	1.077	.634	.195	-------	.840	.639	.152	-------
3150	.455	.35	3.51	1.597	1.228	.792	.52	.215	0.013	1.264	.830	.343	0.021	.973	.639	.264	0.016
3175	.41	.30	4.41	1.808	1.323	.807	.58	.30	.043	1.459	1.048	.542	.078	1.068	.767	.397	.057
3200	.37	.25	5.75	2.128	1.438	.822	.635	.39	.08	1.749	1.351	.830	.170	1.182	.913	.561	.115
3225	.32	.20	8.01	2.563	1.602	.833	.68	.47	.125	2.135	1.743	1.205	.320	1.334	1.089	.753	.200
3250	.28	.16	10.4	2.912	1.664	.845	.728	.545	.195	2.461	2.120	1.587	.568	1.406	1.211	.907	.324
3275	.24	.12	12.1	2.904	1.452	.853	.745	.61	.27	2.477	2.163	1.771	.784	1.239	1.082	.886	.392
3300	.20	.085	14.0	2.800	1.190	.861	.768	.665	.35	2.411	2.150	1.862	.980	1.025	.914	.791	.417
3325	.155	.055	15.6	2.418	.858	.868	.790	.704	.435	2.099	1.910	1.702	1.052	.745	.678	.604	.373
3350	.12	.025	17.5	2.100	.437	.872	.807	.734	.52	1.831	1.695	1.541	1.092	.381	.353	.321	.227
3375	.095	.01	18.9	1.795	.189	.878	.823	.76	.59	1.577	1.477	1.364	1.059	.166	.156	.144	.112
3400	.07	.00	20.0	1.400	-------	.882	.833	.78	.645	1.235	1.166	1.092	.903	-------	-------	-------	-------
3425	.05	-------	20.5	1.025	-------	.885	.843	.795	.685	.907	.864	.815	.702	-------	-------	-------	-------
3450	.03	-------	21.0	.630	-------	.888	.853	.81	.72	.559	.537	.510	.454	-------	-------	-------	-------
3475	.015	-------	21.3	.320	-------	.890	.859	.821	.745	.285	.275	.262	.238	-------	-------	-------	-------
Total	-------	-------	-------	31.879	16.032	-------	-------	-------	-------	26.373	21.178	15.755	8.421	12.827	9.342	5.893	2.233
Total transmissions, in percent (for comparison with the observed transmissions)										82.7	66.5	49.4	26.4	80.1	58.2	36.8	13.9

columns 14 and 5 (or 18 and 6 for Ti–4) in table 1, to obtain the transmission through the filter Ba–3; and a similar procedure is followed for the other filters.

The last line in table 1 gives, for the assumed spectral energy distribution, the calculated percentage transmissions of the four filters, Cx. D; Ni.; Ba–1; and Ba–3, as used with photoelectric cells Ti–1 and Ti–4.

Using the spectral-energy curve for air mass $m=1.20$, and factors based upon Pettit's [12] atmospheric transmission coefficients, other spectral-energy curves were calculated. Proceeding as indicated above (see fig. 1), on multiplying, point by point, these spectral-energy curves by the spectral-response curves of the two photoelectric cells and by the spectral transmissions of the respective filters, calculated photoelectrically-integrated ultraviolet transmissions were obtained for the four filters, using the two photoelectric cells (eight determinations), which (after several minor adjustments of these spectral-energy curves) were in close agreement with the observed filter transmissions for air masses $m=1.10$, 1.20, 1.60, etc. (see table 2), at Washington, and correspondingly equivalent air masses (lower solar altitudes) at Flagstaff.

TABLE 2.—*Ultraviolet solar spectral-energy distribution (relative intensities; unrelated for different air masses) corresponding with the observed filter transmissions (four filters with two* Ti *photoelectric cells) at the various air masses, at Washington*

Wave lengths (angstroms)	Air mass; *m*										
	1.10	1.20	1.60	2.00	2.35	2.70	3.05	3.40	3.70	4.00	4.35
2950	0.05	0.005	0.001	------	------	------	------	------	------	------	------
2975	.28	.20	.019	0.005	0.002	0.001	------	------	------	------	------
3000	.60	.465	.164	.056	.018	.007	0.002	------	------	------	------
3025	1.00	.817	.326	.122	.049	.018	.004	0.002	0.001	------	------
3050	1.50	1.225	.546	.230	.100	.041	.018	.006	.003	0.001	------
3075	2.05	1.76	.830	.404	.180	.083	.040	.016	.008	.004	0.0015
3100	2.7	2.30	1.16	.585	.304	.148	.071	.033	.017	.009	.004
3125	3.3	2.79	1.57	.838	.463	.240	.119	.066	.034	.018	.009
3150	4.0	3.51	2.01	1.20	.700	.370	.195	.113	.060	.036	.017
3175	4.8	4.41	2.74	1.62	.989	.564	.317	.186	.109	.064	.033
3200	6.4	5.75	3.73	2.30	1.46	.866	.507	.306	.191	.160	.063
3225	8.9	8.01	5.41	3.48	2.30	1.40	.854	.547	.352	.224	.126
3250	11.5	10.4	7.11	4.67	3.15	1.99	1.23	.799	.522	.340	.195
3275	13.3	12.1	8.58	5.78	4.02	2.60	1.66	1.105	.743	.497	.293
3300	15.1	14.0	10.18	7.07	5.02	3.35	2.20	1.50	1.04	.715	.438
3325	16.9	15.6	11.63	8.17	5.91	3.98	2.66	1.84	1.29	8.96	.552
3350	18.8	17.5	13.05	9.30	6.82	4.65	3.15	2.21	1.57	1.112	.695
3375	20.3	18.9	14.30	10.35	7.67	5.31	3.64	2.59	1.87	1.336	.847
3400	21.3	20.0	15.30	11.20	8.40	5.90	4.10	2.95	2.15	1.560	1.000

In table 2 are given the spectral-energy distributions (relative intensities) found to correspond with the observed filter transmissions for the air masses indicated at the top of the table.

In figure 2 the large circles show the agreement between the calculated and the observed transmissions at different solar heights (air masses), using titanium photoelectric cells Ti–1 and Ti–4, and the four filters Cx. D, Ni.; Ba–1; and Ba–3.

Having proved the trustworthiness of the method, and having established the shape of the spectral-energy curve, it should suffice in actual practice to determine the shape of the spectral-energy curve with one or two filters at the time of making the observations; and from this information, the reduction factor for evaluating the ultraviolet can be taken from previously tabulated data that apply to the particular photoelectric cell used. In fact, during the clearest days, it probably will be unnecessary to determine the spectral quality by making filter measurements.

It is to be noted that these spectral-intensity curves give the average energy distribution in the solar spectrum; whereas, using a large dispersion, spectroradiometric measurements of the radiation between the absorption lines (see fig. 2 of the previous paper [10]) would give an energy curve filled with indentations. However, the slope of the envelope drawn through the intensities measured between the absorption lines would decrease with the wave length as observed spectroradiometrically [12] and as indicated by the filters.

As pointed out in previous papers, owing to the highly selective spectral response of the photoelectric cells, the effect of the low-intensity radiation at 2900 to 2950 A is greatly magnified in the transmission measurements. However, after correcting for this selective magnification, the spectral-energy curves, as determined by the photoelectric cell and filter method, appear to be in good agreement with the few spectroradiometric data that are avaliable for comparison. Another check on the accuracy of this method will be obtained by calculation of the atmospheric-transmission coefficients.

In concluding this discussion it is to be emphasized that heretofore, owing to the almost complete lack of solar spectral-energy data, of wave lengths shorter than about 3100 A, at low elevations (Washington), the data used in evaluating the ultraviolet in sunlight at low altitudes were little more than extrapolations of measurements made at high altitudes.

Since the calculated spectral-energy curve that gives the observed filter transmissions fits the observed spectral-energy curve at high altitudes (due allowance being made for the difference in altitude of the two stations, Tucson and Flagstaff, Ariz.); and since there is no good reason for doubting (see, however, section V–2) that at low elevations, for the equivalent air mass (higher atmospheric pressure but shorter column traversed by the solar rays), the same relative spectral-energy distribution obtains as observed at high altitudes, there is ample justification in using the ultraviolet spectral-energy curves, derived by the above-described filter method, in evaluating the ultraviolet in sunlight at stations of low elevation.

III. EVALUATION OF ULTRAVIOLET SOLAR RADIATION WITH A BALANCED THERMOCOUPLE AND FILTER RADIOMETER

In view of the uncertainty of the solar spectral-energy curve in the region of 3800 to 4100 A, it is necessary to limit the spectral range to the narrowest band of wave lengths readily obtainable, in order to attain the high accuracy desired in the most recent evaluation of the ultraviolet (in absolute units). For this purpose the balanced thermocouple is covered with an especially selected sample of optically polished red-purple Corex A glass (no. 986), which was found to have the same homogeneity (the same percentage transmission) through the two widely separated areas that cover the openings leading to the two receivers of the balanced thermocouple. The sample of red-purple glass used in previous measurements [4] was not so perfect optically.

In figure 4 is shown the spectral transmission of the red-purple Corex A glass (no. 986, thickness 3.1 mm), which is practically opaque to wave lengths longer than 425 mμ (4250 A). Used in connection with the cell of water, 1 cm in thickness, the transparency of this glass in the infrared is practically eliminated, and the thermopile response is confined principally to the violet and ultraviolet, as obtains in a titanium photoelectric cell. The small amount of infrared transmitted by the combined filters is determined by inserting, temporarily, a filter of Noviol A glass, which shuts out the ultraviolet (fig. 4). The transmission curves of the Ba-flint exclusion filter and the Corex A compensating filter are also given in figure 4.

1. CALIBRATION OF THE GALVANOMETER-SCALE READING

The first step in the evaluation of ultraviolet radiation by means of a balanced thermoelectric radiometer is to calibrate the thermopile-

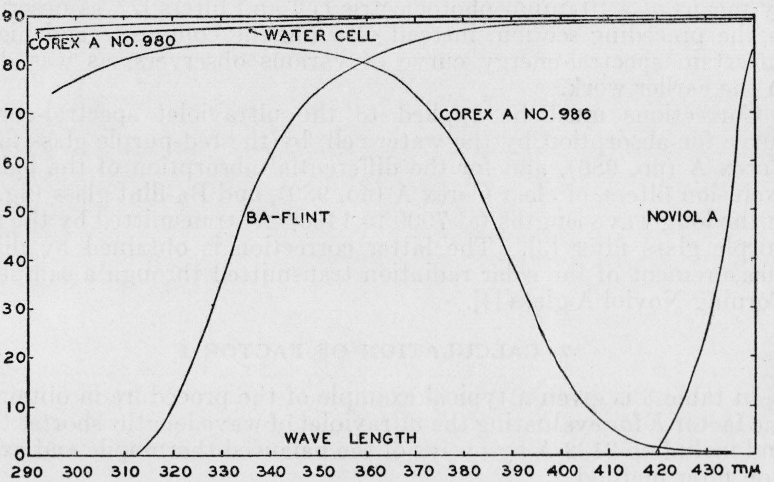

FIGURE 4.—*Transmission of filters used in the balanced-thermopile and exclusion-filter method of evaluation of ultraviolet.*

Wave length 420 mμ=4200 A.

galvanometer deflection, in absolute value, against a standard of radiation [11]. For this purpose the water cell and the red-purple Corex A filters are removed, and the receivers (first the one, then the other) are exposed to the standard lamp as described on page 731 of a previous paper [4]. If these filters were kept in place the calibration would have to be made by the method used with photoelectric cells (see section IV–1).

Since the galvanometer sensitivity is subject to variations, a standard sensitivity (with a means of testing it, as described in previous papers) is adopted; and all the ultraviolet solar-radiation measurements (for example, column 3 of table 4) are reduced to this sensitivity.

The radiation sensitivity of the thermopile (no. 254),[2] determined at various times during the past three years, has remained constant within the errors of observation; the average value of the scale reading being 1 cm=44.55 μw/cm^2, see column 7 of table 4.

The next procedure is to make a series of measurements of ultraviolet solar radiation by means of the barium-flint glass exclusion filter and the compensating filter of clear Corex A glass (no. 980), as described on page 731 of the previous paper [4]; and at closely the same time measurements are made of the spectral quality of the sunlight, as described in section II.

For, as already stated, a knowledge of the ultraviolet spectral-energy curve, in relative units, is necessary in order to determine the factor *F*, required to evaluate the fractional part of wave lengths shorter than and including 3132 A, relative to the total ultraviolet excluded by the filter.

The present experimental procedure differs from that previously employed [3, 4] in that the spectral-energy curve, in the region of 2900 to 3550 A, is determined directly at the time of the energy evaluation, by means of a titanium photoelectric cell and filters [7], as described in the preceding section, instead of using the composite and highly uncertain spectral-energy curve of various observers, as was done in the earlier work.

Corrections must be applied to the ultraviolet spectral-energy curve for absorption by the water cell, by the red-purple glass filter, Corex A (no. 986), and for the differential absorption of the pair of exclusion filters, of clear Corex A (no. 980), and Ba-flint glass (fig. 4), in the long wave lengths (at 7000 to 14000 A) transmitted by the red-purple glass filter [3]. The latter correction is obtained by direct measurement of the solar radiation transmitted through a sample of Corning Noviol A glass [4].

2. CALCULATION OF FACTOR *F*

In table 3 is given a typical example of the procedure in obtaining the factor *F* for evaluating the ultraviolet of wave lengths shorter than and including 3132 A by means of the balanced thermopile and exclusion filter method.

[2] Balanced thermopile no. 254 consists of two complete linear thermopiles of Bi-Ag, joined in opposition. Each thermopile consists of 4 couples, with individual receivers, 1.2 by 2.2 mm, mounted on a small fiber support, 25 mm in diameter, depicted in figure 1, of BS Sci. Pap. **17**, 188 (1921) S413. By removing the circular part, along the common edge of the two mountings, the combination fits in a box 4.5 cm in diameter. The linear receivers facilitate adjustment of the two thermopiles to the same radiation sensitivity.

TABLE 3.—*Typical example of the calculation of the factor F for evaluating ultraviolet solar radiation of wave lengths shorter than and including 3132* A, *by means of the balanced thermopile and exclusion-filter radiometer*

[The solar spectral energy is for air mass m=1.20 at Washington]

1	2	3	4	5	6	7	8	9	10
Wave lengths (angstroms)	Transmission; Corex A, no. 980 (2.08 mm)	Transmission; Ba-flint (3.12 mm)	Col. 2−3	Correction; fluorite window (2.40 mm)	Transmission H_2O cell (1 cm)	Transmission; Corex, no. 986 (3.10 mm)	Products of col. 4×5×6×7	Relative solar energy (m=1.20)	Col. 8×9. Calculated spectral energy excluded
2950	0.875	0.000	0.875	0.961	0.864	0.740	0.537	0.005	0.003
3000	.877	.000	.877	.963	.866	.768	.562	.465	.26
3050	.880	.000	.880	.966	.868	.792	.585	1.225	.72
3100	.883	.000	.883	.968	.869	.810	.602	2.30	1.38
3150	.884	.025	.859	.970	.870	.823	.597	3.51	2.10
3200	.885	.10	.785	.972	.871	.830	.551	5.75	3.17
3250	.887	.22	.667	.973	.871	.834	.471	10.4	4.90
3300	.888	.35	.538	.974	.872	.835	.381	14.0	5.34
3350	.888	.51	.378	.975	.872	.835	.268	17.5	4.69
3400	.889	.61	.279	.977	.873	.834	.1985	20.0	3.97
3450	.891	.69	.201	.978	.874	.832	.143	21.0	3.00
3500	.893	.745	.148	.979	.875	.828	.105	21.7	2.28
3550	.895	.78	.115	.980	.876	.817	.0807	24.5	1.98
3600	.896	.81	.086	.980	.877	.802	.0593	28.3	1.68
3650	.898	.83	.068	.981	.877	.783	.0458	30.7	1.41
3700	.899	.846	.053	.981	.878	.745	.0340	33.3	1.13
3750	.899	.86	.039	.982	.879	.685	.0231	34.6	.80
3800	.900	.87	.030	.982	.880	.605	.0157	36.2	.57
3850	.900	.875	.025	.983	.880	.500	.0108	40.3	.44
3900	.900	.88	.020	.983	.881	.380	.0066	48.3	.32
3950	.901	.882	.019	.983	.882	.270	.00445	57.5	.26
4000	.901	.883	.018	.983	.883	.170	.0027	68.7	.19
4050	.901	.884	.017	.983	.884	.102	.0015	71.0	.11
4100	.901	.884	.017	.984	.885	.055	.0008	73.5	.06
4150	.901	.884	.017	.984	.886	.030	.0004	76.0	.03
4200	.901	.884	.017	.984	.887	.011	.00016	79.0	.01
4250	.901	.884	.017	.984	.888	.006	.00009	82.0	.01
4300	.901	.884	.017	.984	.889	.004	.00006	85.0	.00
4350	.901	.884	.017	.985	.890	.002	.00003	87.0	.00
Total energy measured									40.82
Total energy of wave lengths less than 3132 A								4.36	

The factor F=4.36÷40.82=0.107, for m=1.20

In table 3, columns 2 and 3 give the spectral transmissions, respectively, of the balancing filter of Corex A glass (no. 980) and the exclusion filter of barium-flint glass. The difference in transmission of these two filters is given in column 4.

Column 5 gives the correction for the fluorite window, which is a fixed part of the balanced thermopile and consequently present when the thermopile is calibrated by means of a standard of radiation. The fluorite window decreases uniformly in transmission from 0.916 in the near infrared to 0.903 at 4350 A and 0.880 at 2950 A.

Column 8 is the product of columns 4, 5, 6, and 7 and is a constant of the instrument. The product of column 8 and the solar spectral energy for an air mass, m=1.20 (column 9), gives the solar spectral energy (column 10) excluded by the Ba-flint glass filter.

The ratio of the area (4.36) under the spectral-energy curve, of wave lengths shorter than and including 3132 A, to the total area (40,823) is F=0.107, for m=1.20, Washington.

Using the data given in column 8 of table 3 and the spectral-energy data for different air masses (table 2), additional factors are calculated. This forms the graph of reduction factors F in figure 5, for determining the amount of ultraviolet radiation of wave lengths shorter than and including 3132 A, relative to the total measured.

These factors are somewhat smaller than the values previously used [4]. This is owing to changes in the assumed spectral-energy curve, especially for large air masses, where the previous curves resulted from uncertain extrapolations in the short wave lengths.

An example of the reduction of the observed data, which procedure is relatively simple, is given in table 4. Column 3 gives the observed average galvanometer deflection on insertion of the Ba-flint glass exclusion filter and the balancing filter of clear Corex A (no. 980) glass.

TABLE 4.—*Reduction of data observed on May 18, 1935, using a balanced thermopile with filters of* Ba-*flint and Corex* A (*no. 980*), *in conjunction with a red-purple filter, Corex* A (*no. 986*), *and a water cell*

1	2	3	4	5	6	7	8
Time	Air mass	Observed galvanometer deflection	Correction for infrared effect	Differences of col. 3−4	Factor F	Thermopile-galvanometer sensitivity (1 cm)	Total ultraviolet of wave lengths shorter than and including 3132 A; col. 5×6×7
a. m.		cm	cm	cm		μw/cm^2	μw/cm^2
9:16	1.33	10.29	0.35	9.94	0.094	44.55	41.6
9:55	1.21	11.32	.22	11.10	.105	44.55	51.9
10:36	1.13	12.22	.44	11.78	.114	44.55	59.8
11:30	1.06	12.89	.62	12.27	.122	44.55	66.7
11:50	1.06	13.04	.40	12.64	.122	44.55	68.7
p. m.							
12:31	1.06	12.93	.38	12.55	.122	44.55	68.2
12:50	1.08	12.85	.55	12.30	.120	44.55	65.8
1:36	1.13	11.85	.35	11.50	.114	44.55	58.4
1:55	1.16	11.65	.57	11.08	.111	44.55	54.8
2:39	1.27	10.03	.38	9.65	.099	44.55	42.5
3:00	1.35	9.71	.40	9.31	.092	44.55	38.1

Column 4 gives the galvanometer deflection on insertion of the Ba-flint and Corex A filters (noted in the preceding paragraph) when the thermopile is covered with a filter of Noviol A glass which shuts out the ultraviolet. The transmission of this filter (82 percent) is determined as explained in the previous paper [4]. The values in column 4 are the observed galvanometer deflections divided by the transmission of this filter. This (infrared) correction is relatively small. Column 5 gives the total ultraviolet, of wave lengths shorter than about 4000 A, shut out by the Ba-flint glass filter.

Column 6 gives the factor F (read from fig. 5 for the air mass at the time of making the measurements) which serves to deduce, from the total ultraviolet measured (column 5), the amount that is of wave lengths shorter than and including 3132 A.

Column 7 is the radiation sensitivity of the thermopile, in microwatts per square centimeter (μw/cm^2), for 1-cm deflection of the galvanometer, observed by exposure to the standard of radiation [11].

Column 8, which is the product of columns 5, 6, and 7, is the total flux of ultraviolet solar radiation, in microwatts per square centimeter, of wave lengths shorter than and including 3132 A, incident at Washington, on May 18, 1935, which was a very clear day, with a

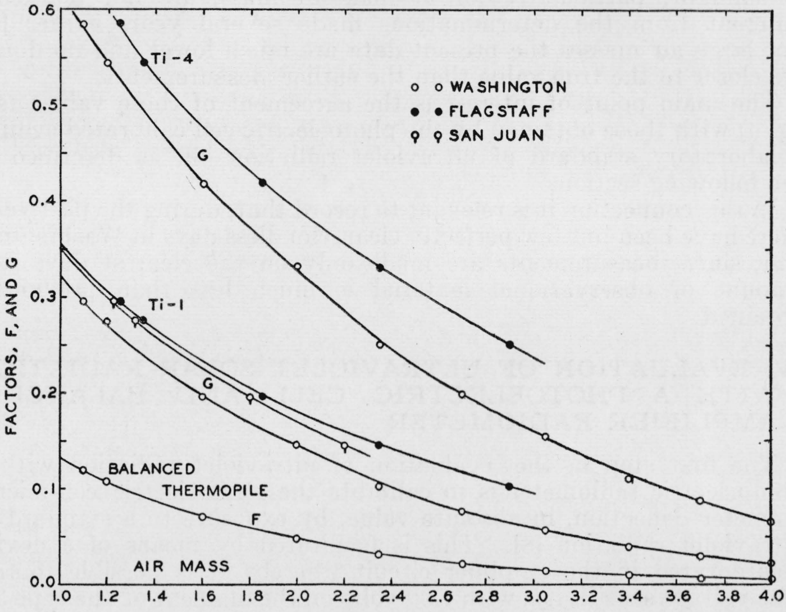

FIGURE 5.—*Reduction factors used in determining the amount of ultraviolet solar radiation of wave lengths shorter than and including 3132* A, *relative to the total radiation measured when using a balanced thermopile and exclusion-filter radiometer,* F, *and when using a photoelectric cell,* G.

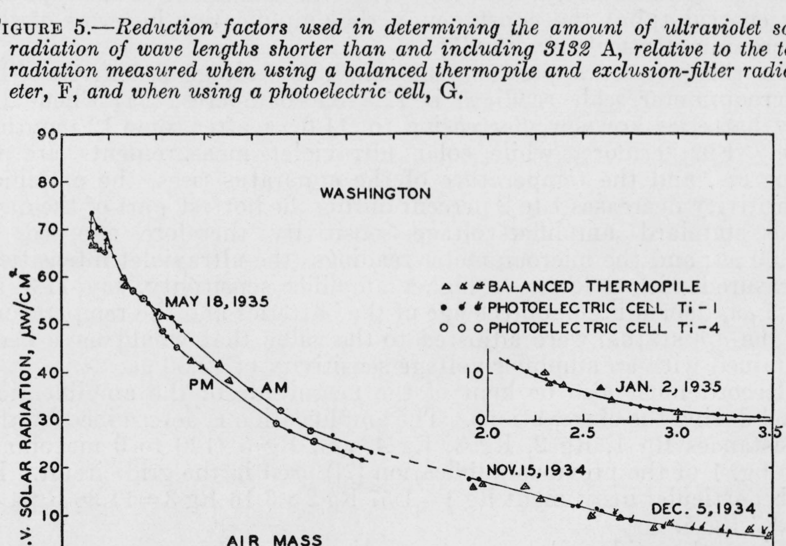

FIGURE 6.—*Measurements of ultraviolet solar-radiation intensities at Washington, showing the agreement in the results obtained by two methods of evaluation: (1) by means of a balanced thermopile and filter radiometer, calibrated against a standard of thermal radiation, and (2) by means of a photoelectric ultraviolet meter, calibrated against a standard of ultraviolet radiation.*

cloudless sky, small corona, and light west wind; but with somewhat lower intensities in the afternoon. (See fig. 6.)

Considering the changes made in the ultraviolet solar spectral-energy curve in the meantime, the present values of the ultraviolet in sunlight, particularly for a small air mass, are not markedly different from the determinations made several years earlier [4]. For large air masses the present data are much lower and no doubt are closer to the true value than the earlier measurements.

The main point of interest is the agreement of these values (see fig. 6) with those obtained by the photoelectric cell calibrated against a laboratory standard of ultraviolet radiation [8], as described in the following section.

In this connection it is relevant to record that, during the past year, there have been but few perfectly clear, cloudless days in Washington; and, since measurements are made only on the clearest days, the amount of observational material is much less than previously obtained.

IV. EVALUATION OF ULTRAVIOLET SOLAR RADIATION WITH A PHOTOELECTRIC CELL AND BALANCED-AMPLIFIER RADIOMETER

The first step in the evaluation of ultraviolet radiation with a photoelectric radiometer is to calibrate the photoelectric cell-microammeter deflection, in absolute value, by exposure to a standard of ultraviolet radiation [8]. This is facilitated by means of a device incorporated in the amplifier circuit whereby it is possible to test (the voltage sensitivity, with 1.90 volts on the filament of the type 32, screen-grid tube) the constancy of the amplification in terms of the microammeter-scale reading [7].

In the present apparatus the amplifier voltage sensitivity (the microammeter scale reading) is 12.5 microamperes (μa) when the dry batteries are new, decreasing to 11.0 μa after some 12 months' use. Furthermore, while solar ultraviolet measurements are in progress, and the temperature of the apparatus rises, the amplifier sensitivity decreases 1 to 2 percent during the hottest part of the day. The standard amplifier-voltage sensitivity therefore adopted is 12.00 μa; and the microammeter readings (the ultraviolet intensities, measured with a lower or higher amplifier sensitivity, say 11.3 to 12.5 μa, depending upon the age of the batteries and the temperature of the apparatus) were adjusted to the value that would have been obtained with an amplifier voltage sensitivity of 12.00 μa.

Record must also be kept of the magnitude of the amplification used during the observations. The amplification is determined by the resistances Rg 1, Rg 2, Rg 3, Rg 4, and Rg 5 (120 to 0 megohms; see fig. 1 of the previous publication [7]) used in the grid circuit. In this particular instrument Rg 1=1.57 Rg 2=3.16 Rg 3=11.86 Rg 4=39.87 Rg 5.

Since the grid resistance commonly used in the measurements in Washington is Rg 3, the radiation sensitivity of the microammeter-scale reading, for the two photoelectric cells Ti–1 and Ti–4, exposed to the standard of ultraviolet radiation [8], was determined for the grid resistance Rg 3 and an amplifier sensitivity of 12.00 μa.

1. CALIBRATION OF MICROAMMETER-SCALE READING

The following is an example of the determination of the radiation sensitivity of the microammeter for the grid resistance Rg 3 and an amplifier sensitivity of 12.00 μa, when used with titanium cells Ti–1 and Ti–4, respectively.

The ultraviolet radiant flux from the Uviarc lamp (covered with a filter of Corex D glass, to eliminate wave lengths less than 2804 A) of wave lengths shorter than and including 3132 A, determined with the balanced thermopile and filters, was 81.0 μw/cm^2. This is used in table 5.

At the same distance from the lamp the microammeter readings for the two photoelectric cells Ti–1 and Ti–4 were 5.250 and 4.840 μa, respectively. These values are used in table 5.

TABLE 5.—*Example of the procedure followed in calibrating the balanced photoelectric amplifier, using a standard Uviarc lamp with a Corex* D *filter*

[Data obtained on December 11, 1935]

1	2	3	4	5	6	7	8	9	10	11
Wave length (angstroms)	Relative energy through Corex D	Absolute energy through Corex D	Relative response of titanium cells		Energy×relative response		μa value for each wave length		Factor P	
			Ti-1	Ti-4	Col. 3×4 Ti-1	Col. 3×5 Ti-4	Ti-1	Ti-4	Col. 6 / Col. 8 (Ti-1)	Col. 7 / Col. 9 (Ti-4)
		μw/cm^2					μa	μa		
3342	13.2	6.6	0.134	0.035	0.884	0.231	0.101	0.029	--------	--------
3132	106.6	53.2	.49	.39	26.068	20.748	2.989	2.569	8.72	8.08
3024	37.0	18.5	.68	.62	12.580	11.470	1.443	1.420	8.72	8.08
2967	14.0	7.0	.70	.72	4.900	5.040	.562	.624	8.72	8.08
2890	3.6	1.8	.64	.73	1.152	1.314	.132	.163	8.72	8.07
2804	1.0	.5	.43	.57	.215	.285	.025	.035	--------	--------
Total	[1] 162.2	[1] 81.0	--------	--------	45.799	39.088	[2] 5.250	[2] 4.840	[3] 8.72	[3] 8.08

[1] Totals for 3132 A and shorter wave lengths. The value observed with balanced thermocouple and filter radiometer is 81.0 μw/cm^2.
[2] Observed photoelectric-microammeter readings.
[3] Mean values of the factor P: for Ti–1=8.72; Ti–4=8.08, for Rg. 3.

The relative spectral intensities of the radiation from the Uviarc lamp, through the above-mentioned filter of Corex D glass, as measured with a spectroradiometer, are given in column 2 of table 5. Column 3 gives, for each line, the intensity in absolute value derived from column 2 and the total intensity (81.0 μw/cm^2) as measured with the balanced thermopile and filters [8].

Column 6, which is the product of columns 3 and 4, gives the spectral intensities in terms of the spectral response (the electron emission) of photoelectric cell Ti–1. The sum of these photoelectrically (weighted) appraised spectral values is 45.799.[3]

This produced a microammeter-scale reading of 5.25 μa. From this it follows that the radiation sensitivity factor P, when using Ti–1 is (45.799÷5.25=8.72. This sensitivity factor P is a constant of the instrument when used with photoelectric cell Ti–1, and together with the factor G (see sec. III–2), it is used to evaluate the incident radiation in absolute units (microwatts per square centimeter).

[3] This is the spectral photoelectrically weighted value in microwatts per square centimeter. If the photoelectrical response (the electrons liberated per unit incident radiation) were the same at each wave length, then the integrated value would be 81.0 μw/cm^2—the same as would be used in calibrating a nonselective radiometer. The factor G restores the photoelectrically appraised solar radiation to the true value.

Similarly, column 7, which is the product of columns 3 and 5, gives the evaluation of the lamp with the photoelectric cell Ti–4, the sum of the photoelectrically (weighted) appraised spectral values being 31.310. This produced a microammeter reading of 4.84 μa. Hence, the sensitivity factor P, when using Ti–4, is (39.088÷4.840=)8.08. This factor P is a constant of the instrument when used with Ti–4, and, together with the factor G (pertaining to Ti–4), it is used to evaluate the incident radiation (the microammeter-scale reading) in absolute units.

In view of the attempt made to calibrate the microammeter-scale reading, in absolute value, by means of homogeneous radiation of wave length 2967 A [8], columns 8, 9, 10, and 11, of table 5 are included to show how the values of factor P, for the photoelectric cells Ti–1 and Ti–4, may be derived from the use of single wave lengths, even when not isolated spectroscopically. For example, columns 8 and 9 show how the observed microammeter readings, 5.25 and 4.84 μa, respectively, may be apportioned according to the relative intensities of the various spectral lines given in columns 6 and 7, respectively. The factor P, as calculated for each spectral line, is in agreement with the value derived from the integrated heterogeneous radiation, and it is believed that the same value would have been obtained with spectroscopically isolated radiation, for example, of wave length 3024 A.

The foregoing values of the radiation-sensitivity factor $P=8.72$ and 8.08 [weighted μw/cm^2], respectively, for the photoelectric cells Ti–1 and Ti–4 (noted in a previous paper [8]) are determinations made on a single date. The average values of four calibrations, made between January 22 and December 16, 1935, are $P=9.06$ and 8.20 [weighted μw/cm^2,] respectively. These values (given in column 7 of table 7) are used in evaluating the measurements (the microammeter readings) with these two photoelectric cells, given under a subsequent section.

2. CALCULATION OF FACTOR *G*

The ultraviolet solar-radiation intensities, I_0, for evaluation in absolute units, are obtained in connection with the measurements of the filter transmissions $I_f \div I_0$, used in determining the spectral-energy curve (sec. II). This spectral-energy distribution is necessary in order to deduce the factor G, required to calculate the fractional part (of wave lengths shorter than and including 3132 A) of the total measured by the particular photoelectric cell used.

In table 6 is given a typical example of the procedure in obtaining the factor G, for evaluating the ultraviolet of wave lengths shorter than and including 3132 A from the total measured. In this table column 2 gives the solar spectral-energy for air mass $m=1.20$. (See tables 2 and 3.)

Column 3 gives the spectral response of photoelectric cell Ti–1 for an equal-energy spectrum. Column 4 (the products of the data in columns 2 and 3) gives the solar spectral-energy distribution as it would be measured with the photoelectric cell Ti–1. (See curve Ti–1 in fig. 3.)

The ratio of the area under the solar spectral-energy curve, column 2, of wave lengths shorter than and including 3132 A,[4] relative to the

[4] By taking this area from column 2, instead of column 4, the correction is applied for reducing the measurements to what would be observed with a nonselective radiometer.

total area under the spectral-energy curve as observed with the photoelectric cell, column 4, gives the factor G (8.72÷31.879=0.274) for evaluating the ultraviolet radiation of short wave lengths, when measured with the titanium photoelectric cell Ti–1.

A similar calculation (column 6) gives the factor G (8.72÷16.032=0.544) for evaluating the ultraviolet solar radiation of wave lengths shorter than and including 3132 A, when measured with titanium photoelectric cell Ti–4.

TABLE 6.—*Typical example of the calculation of the factor G, for evaluating ultraviolet solar radiation of wave lengths shorter than and including 3132* A, *by means of a photoelectric radiometer, consisting of titanium photoelectric cells Ti–1 and Ti–4, and a balanced amplifier*

[The solar spectral energy is for air mass m=1.20 at Washington]

1	2	3	4	5	6
Wave lengths (angstroms)	Relative solar energy (m=1.20)	Relative spectral response (Ti-1)	Product of column 2×3	Relative spectral response (Ti-4)	Product of column 2×5
2950	0.005	0.70	0.004	0.75	0.004
2975	.20	.70	.140	.71	.142
3000	.465	.69	.321	.665	.309
3025	.817	.68	.555	.62	.507
3050	1.225	.64	.784	.56	.686
3075	1.76	.59	1.038	.50	.880
3100	2.30	.54	1.242	.45	1.035
3125	2.79	.50	1.395	.39	1.088
3150	3.51	.455	1.597	.35	1.228
3175	4.41	.41	1.808	.30	1.323
3200	5.75	.37	2.128	.25	1.438
3225	8.01	.32	2.563	.20	1.602
3250	10.4	.28	2.912	.16	1.664
3275	12.1	.24	2.904	.12	1.452
3300	14.0	.20	2.800	.085	1.190
3325	15.6	.155	2.418	.055	.858
3350	17.5	.12	2.100	.025	.437
3375	18.9	.095	1.795	.01	.189
3400	20.0	.07	1.400		
3425	20.5	.05	1.025		
3450	21.0	.03	.630		
3475	21.3	.015	.320		
Total			31.879		16.032

Total less than 3132 A=8.72 (column 2).

The factor G=8.72÷31.879=0.274 for Ti–1; and 8.72÷16.032=0.544 for Ti–4.

Using the spectral response data of the two photoelectric cells Ti–1 and Ti–4, given in columns 3 and 5, respectively, of table 6, and the ultraviolet solar spectral energy data for different air masses (table 2), additional factors are calculated. In this manner are obtained the graphs of reduction factors G, for determining the amount of ultraviolet solar radiation of wave lengths shorter than and including 3132 A, illustrated in figure 5.

3. CALCULATION OF ULTRAVIOLET RADIANT FLUX

Supplied with the foregoing data, the evaluation of the ultraviolet solar intensities, as measured with the photoelectric cells, is relatively simple. An example of the calculations involved is given in table 7, which is similar to table 4.

TABLE 7.—*Reduction of data observed on May 18, 1935, using titanium photo electric cells* Ti-1 *and* Ti-4 *and the balanced amplifier*

1	2	3	4	5	6	7	8
Time	Air mass	Photo-electric cell used	Observed deflection	Correction for reducing observed value to sensitivity 12.0 μa	Factor *G*	Radiation sensitivity of photo-electric cell amplifier radiometer (factor *P*)	Total ultra-violet of wave lengths shorter than 3132 A (Col. 4×5×6×7)
a. m.			μa				μw/cm²
8:16	1.65	Ti-1	13.54	0.999	0.189	9.06	23.2
8:39	1.52	Ti-4	7.62	1.003	.441	8.20	27.6
9:30	1.27	Ti-1	12.68	1.005	.253	14.55	46.9
10:12	1.17	Ti-4	12.00	1.015	.553	8.20	55.2
10:49	1.10	Ti-1	7.65	1.011	.299	28.72	66.4
11:01	1.09	Ti-4	13.36	1.012	.584	8.20	64.7
p. m.							
12:02	1.06	Ti-4	13.73	1.017	.596	8.20	68.2
12:13	1.06	Ti-1	15.89	1.012	.313	14.55	73.2
12:59	1.08	Ti-1	15.48	1.014	.306	14.55	69.9
2:07	1.18	Ti-1	13.48	1.017	.275	14.55	54.8
2:22	1.21	Ti-4	10.77	1.017	.540	8.20	48.5
3:23	1.45	Ti-4	15.17	1.023	.460	4.08	29.1
3:43	1.57	Ti-1	13.12	1.023	.200	9.06	24.3
3:51	1.63	Ti-1	12.30	1.023	.191	9.06	21.8

In column 4, table 7, are given the observed microammeter readings, after the usual corrections for errors in the scale calibration, and for the shunt used in the amplifier circuit. This shunt (about 1,100 ohms) is connected in parallel with the microammeter to introduce critical damping.

Column 5 gives the corrections of the voltage sensitivity of the amplifier, which was practically 12.00 μa at the start but decreased to 11.73 μa in the afternoon. The factor *G* is given in column 6 (see fig. 5 from which the data were obtained).

In column 7 is given the radiation sensitivity factor *P* (in microwatts per square centimeter) of the microammeter for the particular photoelectric cell used; Ti-1=9.06 for Rg 3, and Ti-4=8.20 for Rg 3, when used as calibrated.

In some cases the microammeter deflection was reduced by means of a resistance in series (see fig. 1 of the previous paper [7]). This increased the factor to 14.55 (column 7). Late in the afternoon the amplifying resistance Rg 2 was used. Since in this instrument, Rg 3÷Rg 2=2.01, the sensitivity factor *P*, with Ti-4, is reduced from 8.20 to 4.08.

Column 8, table 7, gives the total flux of ultraviolet solar radiation of wave lengths shorter than and including 3132 A, in microwatts per square centimeter, as observed with the two photoelectric cells Ti-1 and Ti-4 on May 18, 1935. These data are in agreement with the observations with the balanced thermocouple and filter radiometer (table 4).

The ultraviolet solar-radiation intensities as measured by these two photoelectric cells (standardized as just described), and as measured with a balanced thermopile (described in section IV-2) are depicted in figure 6. The agreement in the observations appears to be closest for large air masses. This is perhaps to be expected, in view of the fact that the photoelectric cells magnify the intensities in the shortest wave lengths, and this would be most apparent for small air masses. In view of the impracticability of making simultaneous measurements by means of these three radiometers (two photoelectric cells and one thermopile) the agreement in the results is satisfactory. Similar variations in the observations were recorded in previous intercomparisons of methods of evaluating ultraviolet solar radiation [4].

4. SUMMARIZING COMMENTS

Probably the most outstanding result of these studies of various methods of evaluating the short-wave-length ultraviolet in sunlight is the repeated observation of a radiant flux (intensity) almost twice as large as the value calculated on the basis of early observations of the ultraviolet spectral-energy curve.

Unable to find serious errors in their work, and unable to make their results agree with the older ideas of much lower values of ultraviolet solar intensities than they were obtaining, the writers have tried various methods of attack, including the determination of the ultraviolet solar spectral energy.

All methods seem to be in agreement in indicating that the ultraviolet radiant flux, of wave lengths shorter than and including 3132 A, in the clearest midsummer, midday sunlight, in Washington, is about 75 μw/cm^2. In arriving at this conclusion the following three distinctly different methods of evaluation were used:

(1) The radiometer was a single thermocouple receiver [3], covered permanently with a cell of water to absorb the infrared rays, and with a filter of Corning red-purple glass, Corex A, no. 986, to isolate the ultraviolet rays of wave lengths shorter than about 4000 A. This combination reduces the intensity to about 8 percent of the total incident upon the receiver. The apparatus was used also without this filter, thus admitting about 75 percent of the full intensity (the part transmitted by the water cell) upon the thermocouple receiver.

Two exclusion filters of Ba-flint glass were used (singly and in combination) to eliminate some of the uncertainty of the assumed ultraviolet spectral-energy distribution (of wave lengths shorter than 3132 A), which was based upon the few, highly discordant measurements available. The radiant flux of ultraviolet of wave lengths shorter than and including 3132 A was determined in absolute value, in terms of the total incident solar-radiation intensity Q, measured with a pyrheliometer [3].

(2) A balanced thermocouple and filter radiometer were used [4], either with or without the red-purple filter of Corex A glass (no. 986). A single-exclusion filter of Ba-flint glass (and a balancing filter of clear Corex A glass no. 980) were used to isolate the ultraviolet of short wave lengths.

This method requires a knowledge of the spectral-energy curve in only the ultraviolet of short wave lengths, instead of the whole spectrum as used in the preceding method. Nevertheless, a direct comparison of these two widely different methods of evaluating ultraviolet solar radiation gave concordant results [4]; the uncertainty of the magnitude of the absolute values being ascribable to the uncertainty of the spectral-energy curve employed in reducing the observations.

(3) The third method (described in this paper) consists in evaluating the ultraviolet of short wave lengths by means of a titanium photoelectric cell calibrated, in absolute value, against a standard of ultraviolet radiation [8].

This method differs also from the two preceding methods in that the solar spectral-energy distribution, in the extreme ultraviolet, is determined directly by means of a titanium photoelectric cell and filters, at the time of the ultraviolet radiation measurements, instead of using the highly uncertain extrapolations, previously employed.

Comparative measurements of ultraviolet solar intensities were made also with the balanced thermocouple and exclusion filter of Ba-flint glass, as described in method (2), but employing the directly observed ultraviolet spectral-energy curve in reducing the data. The balanced thermocouple and filter method, therefore served as a means of comparing the three methods of evaluating the ultraviolet in sunlight.

The ultraviolet solar intensities, measured by the herein described photoelectric and thermoelectric radiometers, using the ultraviolet spectral-energy distributions as observed with the herein described photoelectric-cell and filter method, are in good agreement.

The fact that the absolute values, particularly for large air masses, are somewhat lower than previously observed [4], is ascribable to changes in the ultraviolet spectral-energy curves, which are somewhat lower in the extreme ultraviolet than previously used. There is also a possibility that the recently observed values of ultraviolet intensities may be lower, owing to a lower solar emission of ultraviolet of short wave lengths.

From a comparison of the data obtained by these three widely different methods of evaluation it appears that the average intensity of the solar ultraviolet, of wave lengths shorter than and including 3132 A, during the clearest midsummer weather, at midday, in Washington, is about 75 $\mu w/cm^2$, decreasing to about 8 $\mu w/cm^2$ at noon in midwinter.

V. ULTRAVIOLET SOLAR-RADIATION DATA

In a preceding paper various factors affecting ultraviolet solar radiation were discussed [10], but no numerical data of radiation intensities were given. In the present caption measurements are given of ultraviolet intensities at Washington, D. C., San Juan, P. R., and Flagstaff, Ariz.

1. OBSERVATIONS AT WASHINGTON, D. C

The average values of the filter transmissions of ultraviolet solar radiation, observed with the titanium photoelectric radiometer [7] in 1935, seem to be somewhat lower than similar measurements made in 1934. Furthermore, the total ultraviolet intensities appear to be somewhat higher in 1935 than observed in 1934 (see fig. 7). Both methods of appraisal seem to indicate that the stratosphere was somewhat clearer of ozone in 1935. As a consequence the ultraviolet spectral-energy curves that give calculated transmissions in agreement with the observed transmissions for 1935, should probably be identified with air masses that are a trifle larger than mentioned in the preliminary announcements, namely, $m=1.23$, instead of $m=1.20$ [9, 10]. In the present calculations the spectral-energy curve identified with the average transmissions for air mass $m=1.20$ is used.

The ultraviolet solar intensities (of wave lengths shorter than and including 3132 A) observed at Washington in 1934 and 1935, are depicted in figure 7. It is to be noted that the recent measurements were made only on the clearest, cloudless days and, hence, there is not such a wide range of intensities, for the same air mass, as was recorded in previous papers [3, 4]. However, as already mentioned, even on the clearest days (for example, May 18, 1935, fig. 6) the ultraviolet solar radiation is subject to relatively large changes in intensity.

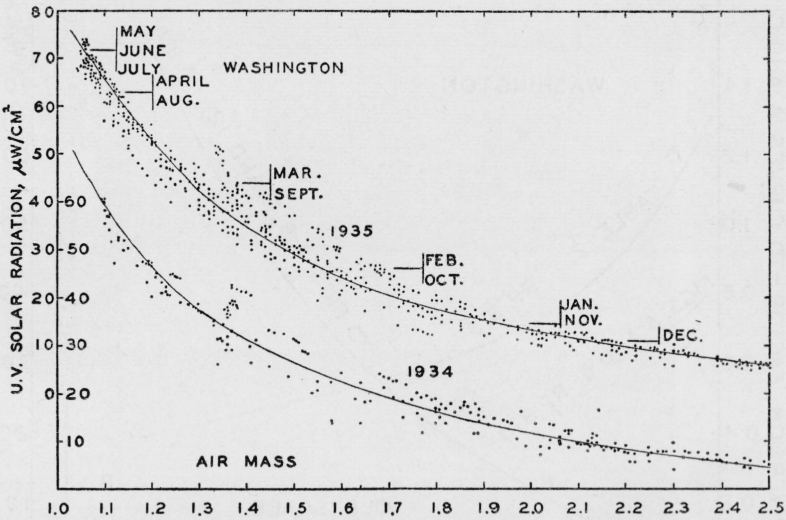

FIGURE 7.—*Measurements of ultraviolet solar-radiation intensities, of wave lengths shorter than and including 3132* A, *during some of the clearest days at Washington.* (See fig. 6.)

From the data depicted in figures 6 and 7 it appears that the intensity of ultraviolet solar radiation, of wave lengths shorter than and including 3132 A, during the clearest weather, at a midlatitude sea-level station (Washington) at the noon-hour ranges from about 75 μw/cm^2 in midsummer, to 0.1 this value (about 8 μw/cm^2) in midwinter. In figure 7 the noon-hour intensities, at the middle of each month (Feb., Oct.), are indicated at the intersection of short horizontal and vertical lines.

(a) CORRECTIONS TO THE WASHINGTON OBSERVATIONS OF SEPTEMBER 1929 TO JUNE 1931

In a supplemental note to the paper describing the ultraviolet solar measurements, made with a single thermocouple receiver and a pair of barium-flint exclusion filters (p. 976 of reference [3]), attention was called to the fact that the ultraviolet intensities required a correction (an increase in value) of 10 to 20 percent.

The intensities observed in Washington from September 1929 to January 1931, can be corrected by means of factors taken from graphs A or B in figure 8, which were worked out from the average data given in figure 7 of the previous publication [3] and from figures 6 and 7 of the present paper.

From graph A it can be seen that for air mass $m=1.05$ the ultraviolet intensities must be increased to $(1.25\times 56=)$ 70 $\mu w/cm^2$, and for $m=3$ they must be decreased to $(0.4\times 3.8=)$ 1.5 $\mu w/cm^2$. For $m=1.25$ the values remain unchanged. Graph B, figure 8, converts the old microwatt scale to the new. For example, 56 $\mu w/cm^2=$ 70 $\mu w/cm^2$, new scale.

The foregoing survey shows that, for low air masses, the previously estimated increase (of 10 to 20 percent) in the values of the solar

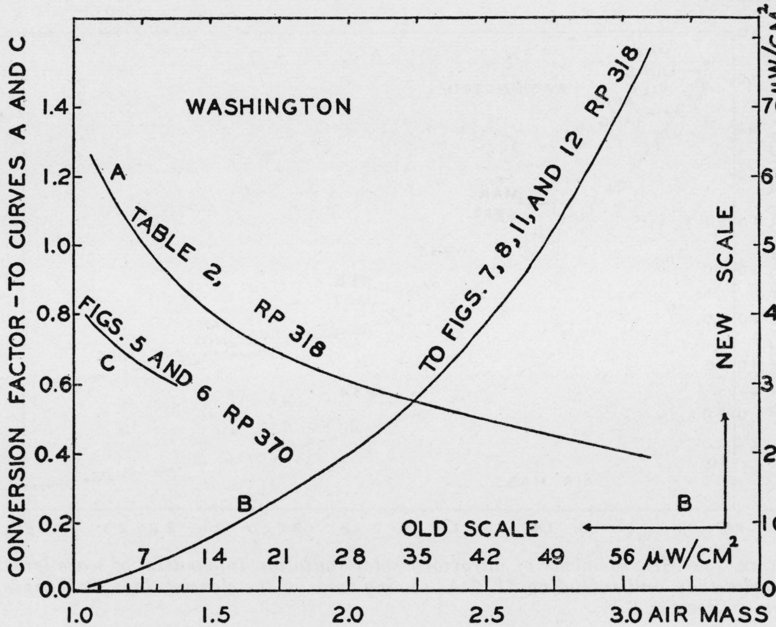

FIGURE 8.—*Factors for correcting the ultraviolet solar-radiation intensities observed at Washington in 1929 and 1931.*

Graph B relates the old microwatt scale to the new scale of intensities.

intensities was close to the herein recorded factors. But for large air masses the values must be decreased. These high intensities, for large air masses, resulted from the use of erroneous spectral-energy curves, which, in the entire absence of observational data, were uncertain extrapolations.

It is of course possible that in 1929–30 the ultraviolet intensities were lower than average, as appears to be the case for the observations made in 1934 (fig. 7); but owing to the errors of observations, and to the diverse atmospheric conditions under which these earlier measurements were made, it is impracticable to attempt a closer evaluation. They served their purpose at the time they were obtained, and with the development of more refined methods of measurement, these data are chiefly of climatological interest, showing the wide difference in intensities observed on clear and on hazy days.

The observations made in June 1931 with the balanced thermocouple and exclusion-filter radiometer, depicted in figures 5 and 6 of an earlier paper [4], may be corrected by means of graph C in figure 8. The data are comparative, obtained under similar conditions, for several types of radiometers. The same solar spectral-energy curves were used, and the good agreement in the observations, made with the various instruments, is not affected by applying the corrections taken from graph C in figure 8.

The practical significance of this correction is that in the physiological (erythemal) tests the total ultraviolet solar energy required to produce a minimum perceptible erythema is probably 10 to 15 percent lower than previously published [4, 6]. However, since, for the same person, skin sensibility is subject to a variation of 2 to 3 fold, this correction is of minor importance. If such a correction is made the agreement between the observed and the calculated erythemogenic efficiency is even closer than previously recorded [6].

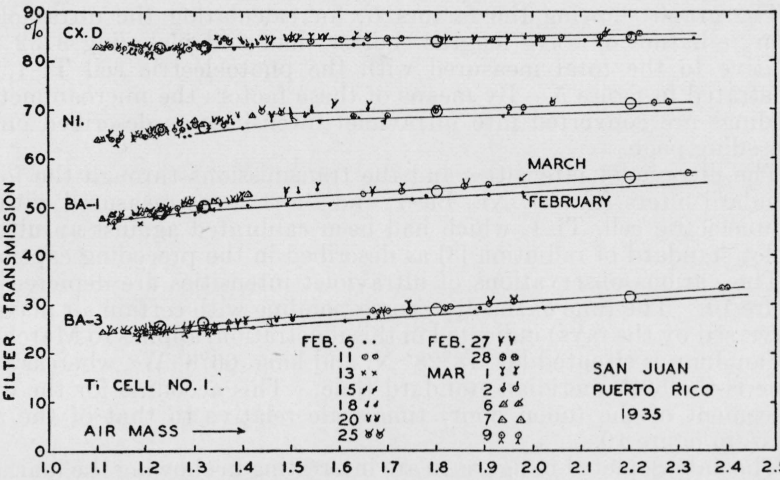

FIGURE 9.—*Diurnal variation in transmission of ultraviolet solar radiation through standard filters, see figure 1, observed at San Juan, P. R.*

The large circles are the calculated transmissions for ultraviolet spectral-energy curves identified with the corresponding air masses, see figure 2.

2. OBSERVATIONS AT SAN JUAN, P. R.

The measurements of ultraviolet solar intensities at San Juan, Puerto Rico, were made during February and the first half of March 1935.

A brief description of climatic conditions was given in a previous paper [10]. It will, therefore, suffice to state that during the forenoon the measurements were often interrupted by alternate cloudiness (rapidly moving fracto-cumulus clouds) and sunshine. By noon, and often continuing throughout the entire afternoon, the whole sky was cloudless, except over the inland mountains to the south and southwest, where the morning clouds (now cumulus and strato-cumulus) had been blown by the prevailing north and northeast winds. Judged by the filter transmissions the air seemed to be the quietest and clearest (transmissions lowest) a short time after the sun had passed the meridian (see fig. 9).

The ultraviolet transmissions through the filters for various solar altitudes are depicted in figure 9. As mentioned in the earlier paper [10] owing to an apparent increase in ozone there was a marked increase in the transmissions after February 6. The general trend of the transmission curves for San Juan, figure 9, seems somewhat different from that of similar observations in Washington, figure 2. Moreover, for the same solar altitude, the percentage transmission is somewhat lower in the tropics, as previously noted [10]. As a result the assumed spectral-energy curves that give calculated transmissions in agreement with the observations at Washington, for air masses $m=1.10$, 1.20, 1.6, 2.0, etc. (see heavy circles, fig. 2), are in good agreement with the San Juan observations for larger air masses, respectively, $m=1.23$ 1.32, 1.80, 2.20, etc. (see large-size circles, fig. 9). It is to be noted that there is no regularity in the differences in the corresponding air masses, giving the same filter transmissions, at these two stations. However, owing to the paucity of the observations, this is probably to be expected.

The graph showing the factors G, for calculating the ultraviolet solar radiation of wave lengths shorter than and including 3132 A, relative to the total measured with the photoelectric cell Ti–1, is illustrated in figure 5. By means of these factors the microammeter readings are converted into ultraviolet intensities as described on a preceding page.

The ultraviolet intensities and the transmissions through the four standard filters (Cx. D, Ni., Ba–1, and Ba–3) were measured with a photoelectric cell, Ti–1, which had been calibrated against an ultraviolet standard of radiation [8] as described in the preceding caption.

The various observations of ultraviolet intensities are depicted in figure 10. The time of the day (corresponding with certain air masses traversed by the rays) indicated in this illustration, applies to March 1.

San Juan is situated lat. 18°28′ N. and long. 66°6′ W., whereas the time is the 60th meridian standard time. This accounts for the displacement of the (noon hour) time-scale relative to that of the air mass, in figure 10.

The data depicted in figure 10 are interesting in showing the marked difference in the solar intensities on days when the sky was very clear (VC) and on a very hazy day (VH), which occurred on February 25, 1935. During the forenoon measurements of March 7, the sky changed from very clear to very hazy, which condition is shown in the short graph (between 10 and 11 a. m.) in figure 10.

The smallest air mass through which measurements were made was $m=1.10$, the ultraviolet intensity being about 85 $\mu w/cm^2$ (March 7, 1935). This may be compared with similar measurements on a very clear day in Washington, May 18, 1935 (fig. 6) when the ultraviolet intensity was 67 $\mu w/cm^2$ for $m=1.10$. This difference in intensity, amounting to 21 percent is, no doubt, to be attributed to differences in the ozone content of the stratosphere, as noted in a previous paper [10].

From the data in figure 10, it appears that for an air mass $m=1.00$ to 1.01, which occurs during the noon hour for about 4 months in San Juan [10], the ultraviolet intensity, of wave lengths shorter than and including 3132 A, is 95 to 98 $\mu w/cm^2$, or about 20 percent higher than is ever attained in Washington (u.v. $Q=75$ $\mu w/cm^2$ for $m=1.05$). In this connection reference is made to a discussion of this subject in an earlier paper [10].

In concluding the discussion of the foregoing measurements, it is to be noted that the calculated and the observed filter transmissions for the four filters (fig. 9) do not coincide so nicely as obtains in the

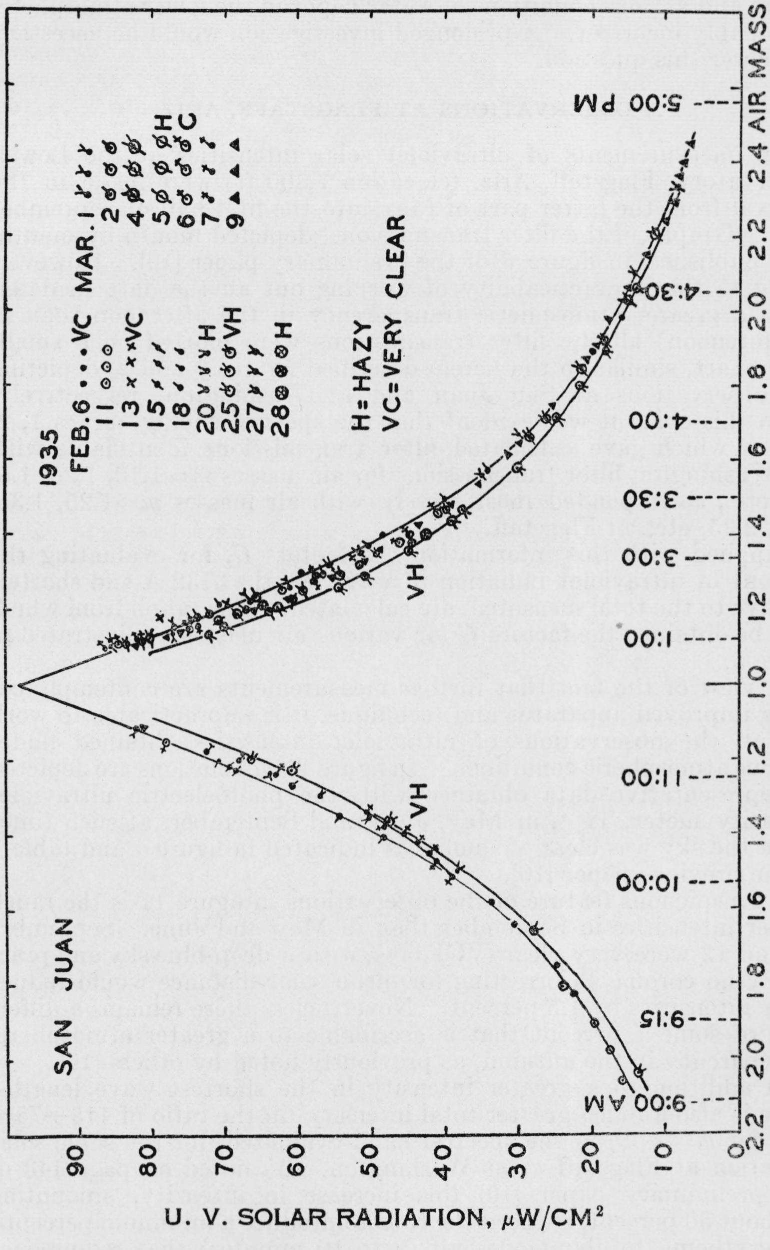

FIGURE 10.—*Measurements of ultraviolet solar-radiation intensities of wave lengths shorter than and including 3132 A at San Juan, P. R. in 1935.*

Washington observations (fig. 2). With rapidly changing local atmospheric conditions (cloudy a. m., clear p. m.) and with a lower ozone content in the stratosphere, it is probable that the ultraviolet spectral-energy curves, for different air masses traversed by the rays, are slightly different from the ones used in the calculations. That is to say, the assumption of reciprocity of density and length of air path traversed, for a heterogeneous combination of ozone in the stratosphere and various conditions of water vapor in the lower atmosphere, is probably incorrect. A prolonged investigation would be necessary to answer this question.

3. OBSERVATIONS AT FLAGSTAFF, ARIZ.

The measurements of ultraviolet solar intensities at the Lowell Observatory, Flagstaff, Ariz. (elevation 7,300 ft) were made in the interval from the latter part of May into the first half of September 1934. Graphs of the filter transmissions, depicted month by month, were published in figure 5 of the preliminary paper [10]. However, owing to the impracticability of working out all the data in detail (with a greater atmospheric transparency in the afternoon than in the forenoon) all the filter transmissions were plotted on a small-scale chart, similar to the herein-described figures 9 and 2, depicting the observations at San Juan and at Washington, respectively. From this chart it was evident that the spectral-energy curves 1, 2, 3, etc., which gave calculated filter transmissions identifiable with the Washington filter transmissions for air masses $m=1.10$, 1.20, 1.6, 2.9, etc., corresponded most closely with air masses $m=1.25$, 1.35, 1.85, 2.35, etc., at Flagstaff.

Supplied with this information the factors G, for evaluating the amount of ultraviolet radiation of wave lengths 3132 A and shorter, relative to the total measured, are calculated. The graph from which may be obtained the factors G for various air masses is illustrated in figure 5.

In view of the fact that further measurements are contemplated, using improved apparatus and technique, it is impracticable to work out all the observations of ultraviolet intensities obtained under various atmospheric conditions. In figure 11 calculations are depicted of representative data obtained with the photoelectric ultraviolet intensity meter, Ti–4, in May, June, and September, at such times when the sky was clear of smoke, as indicated in figure 4 and table 1 of the previous paper [10].

A conspicuous feature of the observations in figure 11 is the much higher intensities in September than in May and June. September 11 and 12 were very clear (VC) days, with a deep-blue sky and practically no corona. Correcting for mean solar distance would reduce these intensities by 4.5 percent. Nevertheless there remains a difference of some 7 percent that is ascribable to a greater atmospheric transparency in the autumn, as previously noted by others [10].

In addition to a greater intensity in the shortest wave lengths, there is also a much greater total intensity (in the ratio of $115\div 75=1.53$ for $m=1.05$) in the spectral band evaluated, for the same solar elevation at Flagstaff as at Washington. As noted on page 143 of the preliminary paper [10] this increase in intensity, amounting to about 50 percent, reduced the time to produce a minimum perceptible erythema to about one-half (9 to 10 minutes) that required at Washington. This lack of correlation of energy and time to produce a minimum perceptible erythema, at these two stations, is owing to a change in spectral quality of the ultraviolet at the higher elevation, where there is a rapid increase in spectral intensity in the region of 2900 to 2950 A, which is in the region of the maximum of the spectral erythemic reaction at about 2967 A.

On page 146 of the preliminary paper [10] attention was called to two sets of measurements that were obtained on the San Francisco Peaks (Fremont Saddle, elevation 10,500 ft) under fairly clear atmospheric conditions. The total ultraviolet intensities, measured with the two titanium cells Ti–1 and Ti–4, at the noon hour on June 12

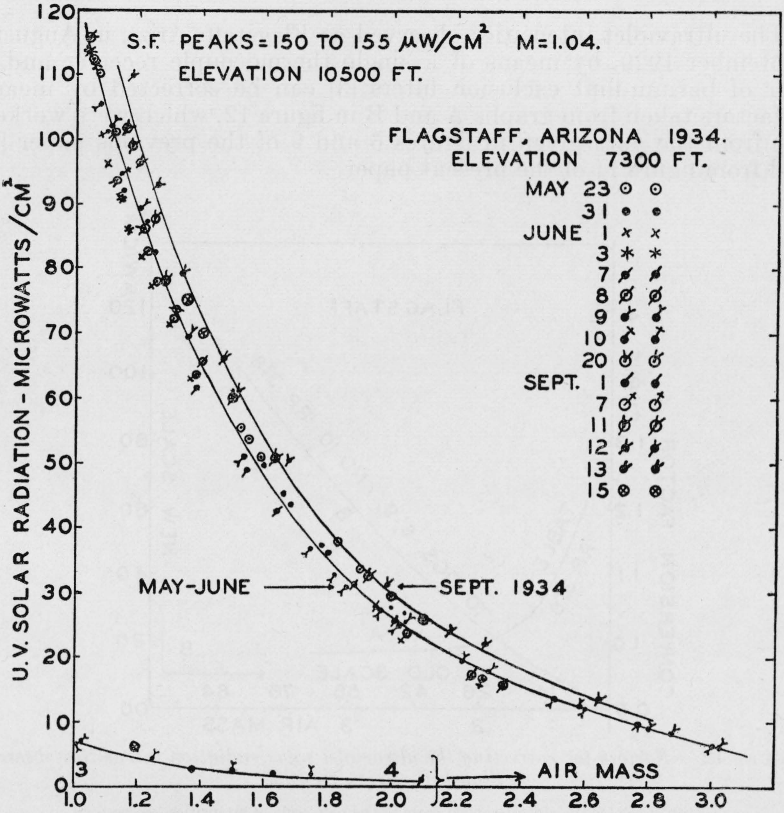

FIGURE 11.—*Measurements of ultraviolet solar radiation intensities of wave lengths shorter than and including 3132 A, during some of the clearest days at Flagstaff, Ariz., in 1934.*

and July 5, 1934, were in close agreement, the intensity values being about 155 μw/cm² for m=1.04 and about 150 μw/cm² for m=1.08. These values are about (155÷115=1.35) 35 percent higher than the maximum intensities observed during the clearest noon hours at Lowell Observatory station (elevation 7,300 ft). The smaller difference (12 to 15 percent) in intensities, mentioned in the preliminary report [10], is owing to the fact that no allowance was made for a difference in the factors G, for these two stations.

No controlled erythema tests were obtained. Such a test, undertaken on June 12, was interrupted by smoke from a forest fire on Crater Hill, some 6 miles to the west of the observatory. However, from the sunburn resulting from exposure of the face and hands, at this high altitude, it may be expected that a minimum perceptible erythema will be produced on the untanned skin in a proportionately shorter time (6 to 7 minutes) than that observed (9 to 10 minutes) at the Flagstaff station.

(a) CORRECTIONS TO THE FLAGSTAFF OBSERVATIONS OF AUGUST–SEPTEMBER 1929

The ultraviolet intensities observed at Flagstaff, Ariz., in August–September 1929, by means of a single thermocouple receiver and a pair of barium-flint exclusion filters [3] can be corrected by means of factors taken from graphs A and B in figure 12, which were worked out from the data given in figures 6 and 9 of the previous paper [3] and from figure 11 of the present paper.

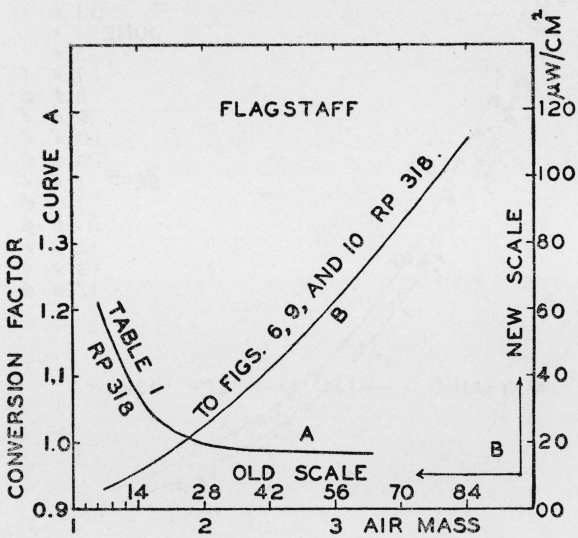

FIGURE 12.—*Factors for correcting the ultraviolet solar radiation intensities observed at Flagstaff, Ariz., in 1929.*

Graph B relates the old microwatt scale to the new scale of intensities, see figure 8.

From figure 12 it can be seen that for air masses $m=2$ to $m=3$, the earlier data remain practically unchanged; but for smaller air masses there is a gradual increase in the numerical values 42 μw/cm^2 (old)=42 μw/cm^2 (new scale); 56 μw/cm^2 (old)=63 μw/cm^2 (new scale); 70 μw/cm^2 (old)=86 μw/cm^2 (new scale).

In concluding the presentation of the data on ultraviolet solar-radiation intensities (of wave lengths shorter than and including 3132 A) at these three stations (Washington, San Juan, and Flagstaff), it is of interest to obtain an approximate estimate of the intensity outside of the terrestrial atmosphere.

Following the procedure commonly employed in meteorology, this estimate is obtained by plotting the observed intensities on a logarithmic scale (ordinates in fig. 13) against the corresponding air masses, as abscissas, and extrapolating the graphs to zero air mass.

Figure 13 is a small-scale reproduction of the graphical determination of the extraterrestrial ultraviolet solar intensity by this method. Graph A represents the average curve drawn through the observations, at Washington, taken from figure 7 for the year 1934. Similarly graph B depicts the data observed in 1935. These curves, when extrapolated to zero air mass, intersect at the same point (at 560 μw/cm^2), as they should if the atmospheric (ozone) absorption which was higher in 1934 is eliminated. It is to be noted that all these graphs are slightly curved in the larger air masses, which is probably to be expected, since the radiation is not homogeneous.

Graph C represents the intensities observed at San Juan when it was very clear (VC). It is taken from the upper curve in figure 10, and on the logarithmic scale it appears to be approximately a straight

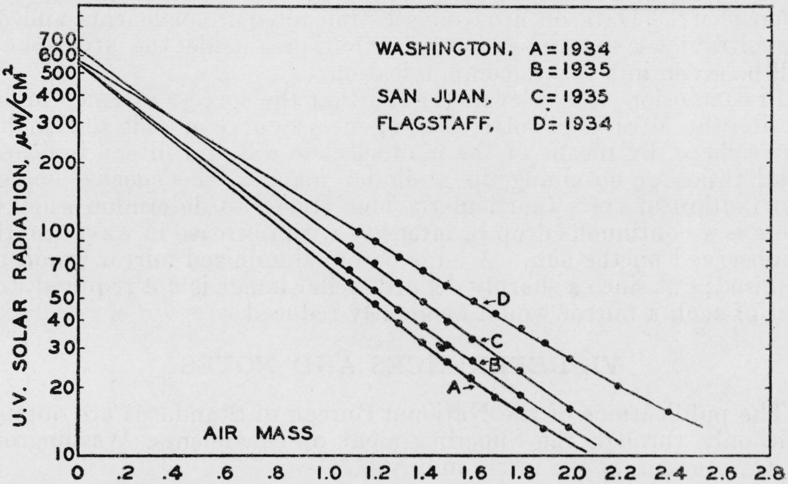

FIGURE 13.—*Ultraviolet solar intensities plotted on a logarithmic scale and extrapolated to zero air mass in order to obtain an estimate of the intensity outside the earth's atmosphere.*

line. When extrapolated to zero air mass an ultraviolet intensity of 650 μw/cm^2 is indicated.

Graph D represents the intensities observed at Flagstaff in 1934. It is the average curve taken from figure 11, and on the logarithmic scale it appears to be slightly curved for large air masses. When extrapolated to zero air mass an ultraviolet intensity of 590 μw/cm^2 is indicated.

The average value of the ultraviolet solar intensity for zero air mass, determined by extrapolation of these four graphs, is 590 μw/cm^2. The close agreement in the extrapolated values is probably to be considered fortuitous [13].

It is to be noted that this estimated value of about 600 μw/cm^2 represents the intensity of the radiation comprised in the spectral band of wave lengths shorter than 3132 A, and does not include appreciable radiant flux, of wave lengths shorter than 2900 A, that may be present outside the terrestrial atmosphere. This is a five- to eight fold increase as compared with a 20 to 30 percent increase in the total intensity of all wave lengths.

Whether there is appreciable radiation of wave lengths shorter than about 2900 A outside the earth's atmosphere is an interesting question. In a recent communication Pettit [12] calls attention to his observations which show that, even after presumably completely eliminating the absorption by ozone, there is an abrupt and continuous drop in the solar spectral-energy curve, of wave lengths shorter than 3000 A, outside the earth's atmosphere—a well-known phenomenon for all known terrestrial sources, and probably to be expected of the complex radiation emanating from different depths of the solar surface.

The spectral intensities of the above-described energy curves for different air masses, when extrapolated to zero air mass, show a continuous drop with decrease in wave length, in good agreement with Pettit's [12] average solar spectral-energy curve outside the earth's atmosphere. Data on atmospheric transmission coefficients and on the ultraviolet spectral-energy distribution outside the atmosphere will be given in a future communication.

In conclusion, it is relevant to add that the success attained in depicting the ultraviolet solar spectral-energy curve outside the earth's atmosphere, by means of the photoelectric cell and filters, indicates possibilities of obtaining, in a similar manner, the spectral-energy distribution of stars (particularly blue stars), to determine whether there is a continuous drop in intensity with decrease in wave length, as observed on the sun. A large chrom-aluminized mirror would be required; but since a sharply defined stellar image is not required, the cost of such a mirror would be greatly reduced.

VI. REFERENCES AND NOTES

The publications of the National Bureau of Standards are obtainable only through the Superintendent of Documents, Washington, D. C., prepaid, at the prices indicated.

[1] W. W. Coblentz, Trans. Illum. Eng. Soc. **23,** 287 (1928).

[2] W. W. Coblentz and R. Stair, BS J. Research **3,** 629 (1929) RP113 (15¢).

Data on spectral characteristics of light sources and window material. From four methods of attack the conclusion arrived at (page 642) was that, at the most, less than 0.3 percent of the total incident solar radiation (and more likely only 0.1 of this value) at sea-level stations has a therapeutic effect in healing rickets.

[3] W. W. Coblentz and R. Stair, BS J. Research **6,** 951 (1931) RP318 (10¢).

A description is given of quantitative measurements (at Washington, D. C. and Flagstaff, Ariz.) of extreme ultraviolet solar radiation, of wave lengths less than 3130 A, using a nonselective thermocouple receiver and two filters of barium-flint glass. A preliminary statement is given of the performance of a balanced ("differential") thermocouple and filter method.

[4] W. W. Coblentz, R. Stair, and J. M. Hogue, BS J. Research **7,** 723 (1931) RP370 (10¢).

A complete description is given of the construction, calibration, and operation of a balanced ("differential") thermocouple and exclusion-filter radiometer. A comparison of solar ultraviolet intensities, measured with the balanced thermocouple and filter method and with the previously used single thermocouple and exclusion filter; also physiological (erythemal) tests using measured intensities of ultraviolet of the sun and of artificial sources; and tests of the integration of ultraviolet radiation by spectroradiometric and by filter methods.

[5] Report of the Illum. Eng. Soc. Subcommittee on Measurement and Evaluation of Ultraviolet Radiation, Trans. Illum. Eng. Soc. **28,** 684 (1933).

[6] W. W. Coblentz, R. Stair, and J. M. Hogue, BS J. Research **8,** 759 (1932) RP450 (10¢).

Description of the evaluation of ultraviolet in different commercial sources by means of a balanced thermocouple and filter radiometer used as a dosage intensity meter. On page 769 are enumerated the advantages in using homogeneous radiation of wave length 2967 A as a standard source for correlating the physiologic (erythemal) reaction with the radiation stimulus.

[7] W. W. Coblentz and R. Stair, BS J. Research, **12,** 231 (1934) RP647 (5¢).

Description of the construction and performance of a portable ultraviolet intensity meter consisting of a photoelectric cell of titanium, a balanced amplifier circuit, and a microammeter

[8] W. W. Coblentz and R. Stair, J. Research NBS **16,** 83 (1936) RP858 (5¢).

The advantages and disadvantages of sources emitting either a continuous or a discontinuous spectrum are considered in connection with the use of such lamps as a standard of ultraviolet radiation. A description is given of a commercial vertical quartz-mercury arc for use as a standard source of ultraviolet for calibrating photoelectric ultraviolet intensity meters, in absolute units.

[9] W. W. Coblentz, Puerto Rico J. Public Health and Tropical Medicine **11,** 1 (1935).

The problem of evaluating ultraviolet radiation for use in medicine is discussed. An outline is given of the procedure in determining the solar ultraviolet spectral-energy distribution by means of a photoelectric cell and filters [7].

[10] W. W. Coblentz and R. Stair, J. Research NBS **15,** 123 (1935) RP816 (5¢).

Various factors that affect ultraviolet solar-radiation intensities are discussed. The photoelectric cell and filter method of determining the spectral quality is outlined. Data are given on the variation of ozone with altitude and latitude.

[11] W. W. Coblentz and R. Stair, BS J. Research **11,** 79 (1933) RP578 (5¢).

Verification of standards of radiation maintained by the National Bureau of Standards for calibrating nonselective radiometers in absolute value.

[12] E. Pettit, Astrophys. J. **75,** 185 (1932); Publ. Astronom. Soc. of the Pacific, 47, No. 280, December 1935.

A spectroradiometric determination of the distribution of energy in the ultraviolet end of the solar spectrum.

[13] Using a prolonged series of measurements, this method of reducing the data should prove useful in studying the variability of the ultraviolet radiation of the sun.

WASHINGTON, February 12, 1936.