edge of the spectral energy distribution of the source, in relative magnitude.

In the case of the sun the relative spectral intensities are constantly changing with variation in air mass, (solar altitude) clouds, smoke, etc. Moreover for the same air mass the atmosphere may be more transparent in the afternoon than in the forenoon; also more transparent in the fall than in the spring—as the result of variation in atmospheric ozone. In addition to these factors is the variation in the intensity of the ultraviolet transmitted, depending upon sun spots.

Hence, there appears to be no standard spectral energy curve for a particular solar altitude, or air mass. It is therefore desirable to determine, by some simple means, the relative spectral intensities, at least in the spectral band of wave lengths shorter than about 3300A, simultaneous with their biological use.

For this purpose the thermopile and filter radiometer method of evaluating ultraviolet solar radiation is at a disadvantage owing to the fact that the filter does not have a sharp cutoff (the absorption begins at about 5000A), requiring a knowledge of the spectral energy curve throughout the whole range of the ultraviolet of wave lengths shorter than 5000A. Hence, since this spectral energy curve is not accurately known, the greater the spectral range encompassed by the filter the greater the errors in the radiometric evaluation.

In this respect a photoelectric cell of titanium or cadmium, which responds to only a very small range of the ultraviolet (wave lengths shorter than about λ3300A, to the limit of the solar spectrum at about λ2900A) is more suitable than the thermopile, provided the spectral response of the photoelectric cell is determined accurately and remains constant. In fact from an investigation now in progress, it appears that the titanium photoelectric cell and a group of filters is applicable not only for determining the short wave length ultraviolet solar spectral energy curve to a high degree of accuracy; but calibration, in absolute value, against a standard source of ultraviolet radiation, is also a reliable means of evaluating the ultraviolet in the spectral band of wave lengths shorter than λ3130 A.

Contrary to earlier notions (remaining partly from the unsatisfactory performance of early forms of gas filled photoelectric cells, in which there was great fatigue; and in which the response depended upon the applied voltage and was not proportional to the intensity) the selective spectral response of the modern, highly evacuated titanium or cadmium protoelectric cell, in contrast with the nonselective spectral response of the thermopile, appears to be an advantage instead of a hindrance, at least in the evaluation of the short wave length ultraviolet solar radiation, to which this type of photoelectric cell is especially sensitive.

The main inconvenience arises in calibrating the photoelectric cell in absolute units, against a standard source of ultraviolet radiation, which (in contrast with the calibration of the thermopile against a standard of radiation) requires additional calculations, based upon the relative spectral energy distribution of the standard source of ultraviolet radiation, and the relative spectral response of the photoelectric cell. This information is required in order to determine the (much larger) scale reading of the auxiliary microammeter that would have been obtained if the spectral response of the photoelectric cell had been nonselective.

The determination of the solar spectral energy curve, in the ultraviolet of short wave lengths, by means of a photoeletcric cell and filters is very simple and can be accomplished in a few minutes, whereas the energy measurements with a spectroradiometer is complicated, slow and tedious. In both methods wide bands of the spectrum are measured. Hence, owing to the small dispersion that can be used, the observed solar spectral energy curve, in the region of 2900A to 3200A, appears to be relatively smooth and free from indentations(14), whereas, using a high dispersion, photographs show the spectrum deeply indented with the Fraunhofer absorption lines of the sun and with the absorption lines of ozone in the terrestrial atmosphere.

Hence, for the purposes of the present work, the evaluation of the spectral energy curve that fits the observed filter transmissions is probably as accurate as the spectral energy curve determined spectroradiometrically. In fact, from the highly selective response of the photoelectric cell in the region of λ2900A to λ3000A, slight variations in ultraviolet intensity in this spectral region (in which we are especially interested) are more easily and more accurately determined by the integrated measurements, with the filters, than with a spectroradiometer, because of the accompanying losses in intensity by absorption in the optical system and in the auxiliary reflecting apparatus.

The experimental procedure of the investigation now in progress consists in observing the variation in spectral quality and total intensity of the ultraviolet of wave lengths λ2900A to about λ3500A in sunlight, throughout the day and throughout the year, by means of titanium photoelectric cells having the spectral response curves illustrated in Fig. 1; and by means of a set of four glass filters, (designated Corex D, Nillite, Ba-flint 1, and Ba-flint 3) having the transmission curves illustrated in Fig. 1.

Data of this type are illustrated in Fig. 2 which depicts the observations made at the Lowell Observatory, Flagstaff, Arizona (elevation 7300 feet) during the summer of 1934.

The next step is to determine by calculation, the shape of the spectral energy curve required to give the observed filter transmissions. For this purpose, in the first trial calculation, use was made of the average ultraviolet solar spectral energy curve observed by Pettit(14) at Tucson, Arizona (elevation about 2500 ft.) in May, 1931. The product of this spectral energy curve and the spectral response curve of the photoelectric cell (Fig. 1) gives the solar spectral energy curve as it affects the particular photoelectric cell employed in making the measurements. Fig. 3.

For example curve "Ti. No. 1" in Fig. 3 is the shape of the solar spectral energy curve as it would be observed by the titanium photoelectric cell No. 1. The product, at each wave length, of this spectral energy by the corresponding spectral transmission of the filter, (Fig. 1) gives the spectral energy curves Cx, Ni, Ba-1, and Ba-3 in Fig. 3. The ratios of the areas under these curves to the area under the curve, Ti. No. 1, give the calculated per cent transmissions of the filters. Similar curves were obtained for the titanium photoelectric cell No. 4.

From the deviations of the calculated from the observed filter transmissions, which were in agreement for both photoelectric cells, it was apparent that the intensities of Pettit's energy curve in the region of λ2950A to λ3050A were slightly to high, and the values at λ3250A to λ3550A were appreciably

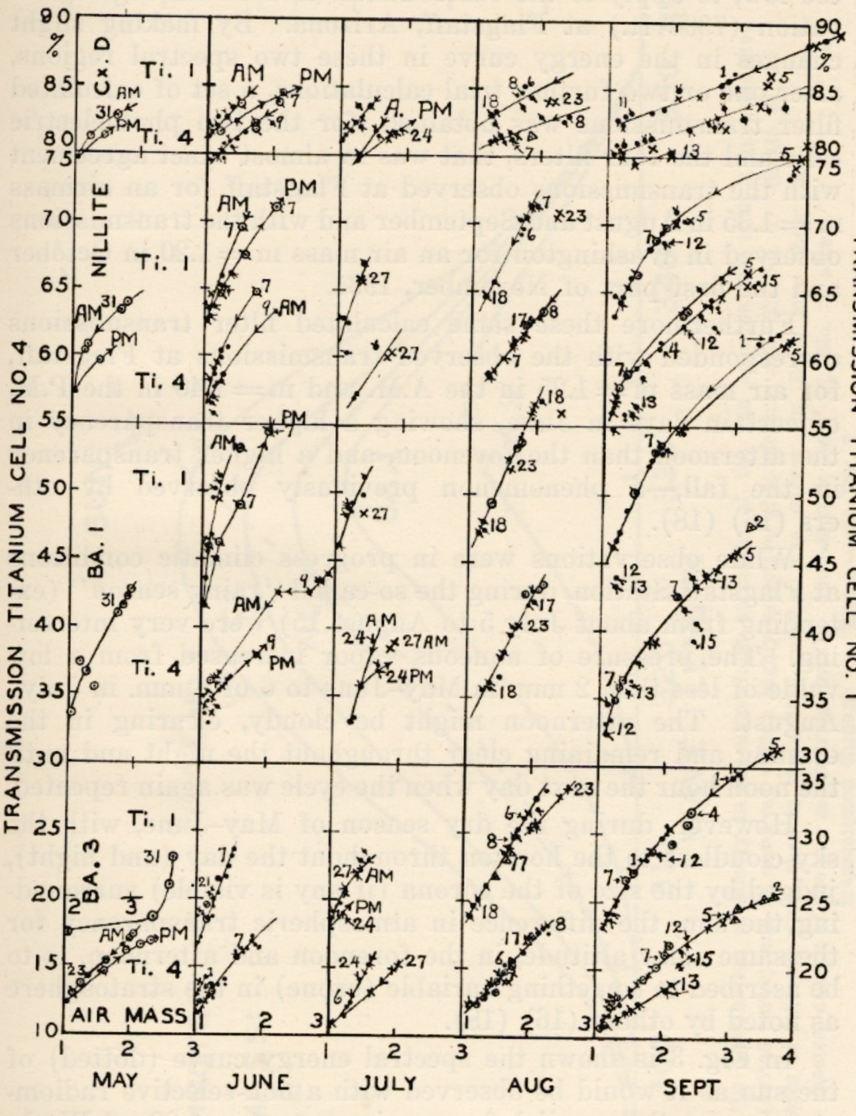

Fig. 2,

Fig. 2.—Showing the diurnal and seasonal variation in the ultraviolet solar radiation transmitted through four filters (Ba-3, Ba-1, Nillite and Cx; see Fig. 1) observed at the Lowell Observatory, Flagstaff, Arizona, elevation 7300 ft., using titanium photoelectric cells No. 1 and No. 4. The small numbers (''2'', ''7'', ''27'', etc.) indicate the day of the month on which the observations were made.

too low, to apply to the observations of 1934 the higher elevation (7300 ft.) at Flagstaff, Arizona. By making slight changes in the energy curve in these two spectral regions, after one or two further trial calculations, a set of calculated filter transmissions was obtained, for the two photoelectric cells and the four filters, that was in almost exact agreement with the transmissions observed at Flagstaff for an airmass $m = 1.35$ in August and September and with the transmissions observed in Washington for an air mass $m = 1.20$ in October and the first part of November, 1934.

Furthermore these same calculated filter transmissions corresponded with the observed transmissions at Flagstaff, for air mass $m = 1.25$ in the A.M. and $m = 1.40$ in the P.M. of certain days in June, showing a higher transparency in the afternoon than the forenoon, and a higher transparency in the fall,—a phenomenon previously observed by others (16) (18).

While observations were in progress climatic conditions at Flagstaff Station, during the so-called "rainy season" (extending from about July 5 to August 15) were very interesting. The pressure of aqueous vapor increased from a low value of less than 2 mm. in May–June to 6 or 8 mm. in July–August. The afternoon might be cloudy, clearing in the evening and remaining clear throughout the night and until the noon hour the next day when the cycle was again repeated.

However, during the dry season of May–June, with the sky cloudless to the horizon throughout the day (and night), judged by the size of the corona (if any is visible) surrounding the sun, the difference in atmospheric transparency for the same solar altitude, in the forenoon and afternoon, is to be ascribed to something variable (ozone) in the stratosphere as noted by others (16) (18).

In Fig. 3 is shown the spectral energy curve (dotted) of the sun as it would be observed with a non-selective radiometer (e.g., a thermopile) for an air mass $m = 1.20$, at Washington. The scale of ordinates is different from that of the energy curve as it is observed with the photoelectric cell, and with the filters. By means of this spectral energy curve and Pettit's(14) atmospheric transmission coefficients other spectral energy curves were calculated.

On multiplying, point by point, these spectral energy

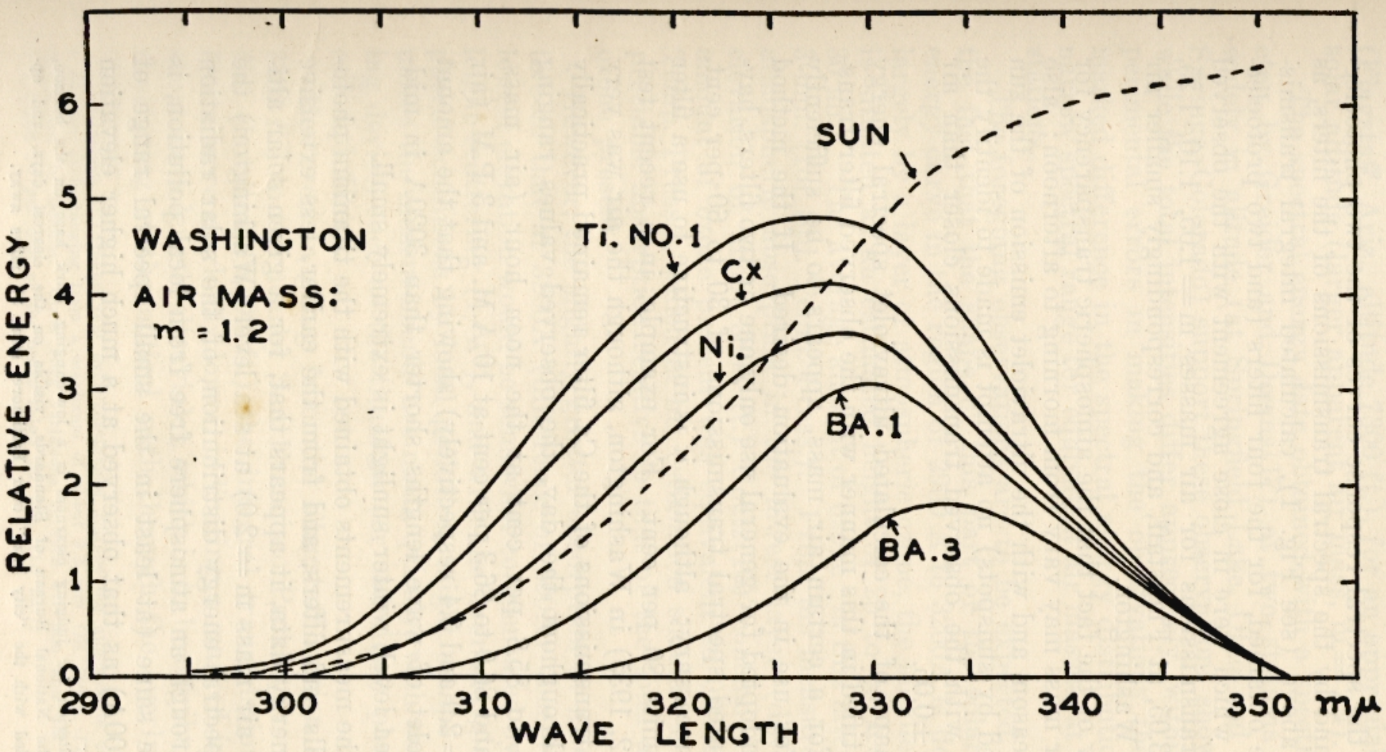

Fig. 3.—Showing the distribution of energy in the ultraviolet spectrum of the sun as observed with a non-selective radiometer (dotted curve) and as observed with a highly selective photoelectric cell, Ti. No. 1. (Scale of ordinates is different from that of the dotted curve.) The curves Cx, Ba-3, etc., show the spectral energy of the sun as observed by the photoelectric cell, Ti. No. 1 after transmission through the filters — see Fig. 1.

curves by the spectral response curves of the two photoelectric cells and by the spectral transmissions of the filters, as indicated above (see Fig. 1), calculated integral transmissions were obtained, for the four filters (and two protoelectric cells) which were in close agreement with the observed integral transmissions for air masses m = 1.05, 1.10, 1.25, 2.20, and 3.05, at Flagstaff, and correspondingly smaller air masses in Washington.

In view of the fact that the atmospheric transparency for a given air mass may vary from morning to afternoon; also with the season, and with the ultraviolet emission of the sun (as affected by sunspots) no attempt is made to identify the calculated with the observed transmissions closer than air mass m = ±0.05.

The shape of the calculated ultraviolet spectral energy curve identified in this manner with the observed filter transmissions for a certain air mass, appears to be sufficiently accurate for use in the evaluation desired. If the method should be adopted for general use only one or two filters, having integrated spectral transmissions of 30 to 60 per cent, would be necessary; although it is instructive to use a filter that transmits 80 per cent. For example, in a recent test (January 2, 1935) in Washington, although the air was very clear,[1] the transmissions of the Cx filter remained practically constant throughout the day, the observed values ranging from 85.5 to 85.8 per cent at the noon hour (air mass, m = 2.1) and 86.0 to 86.3 per cent at 10 A.M. and 3 P.M. (air mass, m = 2.9 and 3.4 respectively) showing that the amount of ultraviolet of wave lengths shorter than 3020A in mid-latitude, sea level, winter sunlight is extremely small.

From the measurements obtained with the titanium photoelectric cells and filters, and from the earlier, less extensive spectral energy data, it appears that, for a given solar altitude, (say air mass m = 2.0) at sea level (Washington) the relative spectral energy distribution, of the solar radiation shining through an atmosphere free from local pollution, is closely the same (at least in the small spectral range of 2900 to 3300A) as that observed at a much higher elevation

(1) One criteriŏn for judging clearness is a low-hanging, dark haze on the horizon, N., N. E. of the National Bureau of Standards, visible on the clearest days, and apparently identified with the "city haze" over Baltimore, some 30 miles away.

(Flagstaff, Ariz., altitude 7300 ft.), for an appreciably lower solar altitude (larger apparent air mass, m.= 2.4).

The spectral energy data obtained with a spectroradiometer, by Greider and Downs(17) at two stations differing widely in alitude (at Springfield Lake, Ohio and Colorado Springs, Colorado) support these observations showing that, while the total intensities differ appreciably, within the experimental errors in making the observations there is no marked difference in the spectral energy distribution in this narrow spectral range for equivalent air masses, at these two stations.

The foregoing observations are to be expected, owing to the fact that the shape of this part of the solar spectral energy curve in the region of 2900 A to 3200A is determined largely by a layer of atmospheric ozone, the middle of which is situated at an estimated height of 25 to 50 Km. (15 to 30 mi.). The average amount of ozone [2] in this later is about 3 mm. (for Std. Temp. Press.). From his measurements of atmospheric absorption in the lowest layer (difference in elevation of about 3800 ft.) Goetz(16) concluded that the amount of ozone present was equivalent to 0.03 mm (Std. Temp. Press.), which in his estimation should exert an appreciable absorption relative to that of the total amount of ozone present.

However, the slightly greater absorption at λ2900A relative to that at 3200A (difference of 300A) observed at the lowest elevation would be somewhat compensated by the Rayleight seattering ($1/\lambda^4$), and with the over-charging atmospheric conditions by local pollution, might escape detection, unless the measurements are made quickly, with an integrating device, such as the titanium (or cadmium) photoelectric cell and filters.

However, in going from the Flagstaff station (elevation 7300 ft.) to the nearby San Francisco Peaks (Fremont Saddle, elevation 10,500 ft.) the integral transmissions of the filters were markedly lower, indicating a marked increase in short wave length ultraviolet, which is to be attributed to the shortening of the optical path through the overlying layer

(2) Dobson (18) found that over continental Europe the atmospheric ozone varies in a seasonal cycle ranging from a maximum of about 3.3 mm (St. Temp. Press.) in April to 2.3 mm in October. Goetz cites variations between 1.7 mm and 4.2 mm. Regener (19) found 70 per cent of the ozone below 30 Km. (18 mi.).

of ozone and consequent greater transparency to ultraviolet radiation.

In concluding this discussion it is relevant to note that, owing to the difficulty and uncertainty of the accuracy in determining the ultraviolet solar spectral energy curve, the thermopile and filter method of evaluating ultraviolet solar radiation is subject to errors that do not occur in the evaluation of ultraviolet in artificial sources (12).

Summary.—In the foregoing pages is outlined a method of evaluation of ultraviolet solar radiation that appears to overcome the above-mentioned difficulties. Based upon extensive experimental data, to be published later, the procedure proposed is to determine the ultraviolet solar spectral energy curve by means of a photoelectric cell (of titanium or cadmium, which responds to only a narrow spectral region) and one or two filters, simultaneous with the biological test.

To obtain the intensity in absolute units the photoelectric cell and auxiliary electric current meter (microammeter and amplifier)(13), are calibrated against a standard of ultraviolet radiation (a 110-volt quartz mercury arc lamp), which has been standardized by means of the thermopile and filter(12). So long as the spectral photoelectric response remains unchanged, the evaluation of ultraviolet solar radiation of wave lengths shorter than and including λ3130A, by means of a photoelectric cell, appears to be just as reliable as a direct measurement with a thermopile and filter.

The description of the details of such a procedure will be published in a future paper. It will, therefore, suffice to add that differences in transmission through the above-mentioned filters were easily observed with photoelectric cells Ti. No. 4 and Ti. No. 2, which differed but slightly in spectral photoelectric response as indicated in Fig. 1. After extensive use the spectrophotoelectrical response curves of the cells employed in the present research showed no variations comparable to the difference in the spectral response curves of cells No. 4 and No. 2, recorded in Fig. 1. It is therefore believed that the observed seasonal changes in the transmission of ultraviolet solar radiation through the filters are owing to variations in atmospheric transparency, and are not owing to changes in the spectral response curves of the photoelectric cells.

SUPPLEMENTAL NOTE ON EXPERIMENTATION IN ULTRAVIOLET SOLAR INTENSITIES IN SAN JUAN P. R.

When the foregoing lecture was presented (February 7, 1935) the writer was unable to reply to the question of comparative ultraviolet solar intensities in the tropics and in higher latitudes. Subsequently he obtained interesting measurements *, some of which have a direct bearing on this subject. It is therefore relevant to discuss this question in this paper.

In this lecture it was emphasized that the amount of ultraviolet that reaches the earth's surface is determined by the ozone in the stratosphere; also that the amount of atmospheric ozone is somewhat lower in the tropics than in midlatitude. Consequently the ultraviolet intensities in the tropics should be somewhat higher than in midlatitude, for the same solar altitude.

The subsequent, direct, measurements were in agreement with expectations. It was found that, for the same solar altitude (air mass traversed by the rays) the ultraviolet solar intensities in the tropics (at San Juan) were somewhat higher than at a midlatitude, sea-level station (Washington) that is free from local air pollution.

However, this small difference in intensity, for the same solar altitude, does not appear to be sufficient to produce marked differences in biological effects. If differences in biological effects are observable, that are ascribable exclusively to differences in ultraviolet intensities, they are probably owing to the fact that throughout the year, at the noon hour, in the tropics the sun shines through a smaller air mass than in higher latitudes.

For example, in midlatitude (Washington) only during two months of the year (May 15 to July 15) does the sun shine through an atmosphere of air mass $m = 1.04$ to $m = 1.05$ (never less than $m = 1.04$) whereas in the tropics (San Juan) during almost six months, at the noon-hour, the sun shines through an airmass of $m = 1.05$ or smaller. Twice,

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* SUMMARY OF SET-UP USED IN COMPLETION OF CALIBRATION OF THE WESTINGHOUSE U. V. METER:

Four photoelectric cells (3 of Ti. and 1 of Th.), in connection with suitable condensers, have been calibrated to indicate the ultraviolet solar radiation of wave lengths shorter than 3130A, in ergs per cm.^{2}, effective in producing 1 impulse (1 "click") on the recorder, and, hence, by inference available for biophysical, physiological and climatological investigations.

during this interval (about May 12 and about August 1, at San Juan) the sun is in the zenith, $m = 1.00$; and during an interval of about four months (April 20 to August 20) at the noon-hour, the sun shines through an airmass of $m = 1.00$ to 1.01. Consequently, during a period of about four months, the shortest, biologically most effective, wave lengths (at 2900A to 3000A) are very greatly increased in intensity, and the average intensity of the whole spectral band at 2900 to 3130A; (recognized as having a specific biological action, at least in curing rickets) is about 20 per cent higher in the tropics than is ever attained in midlatitude (Washington),—a phenomenon that can occur only at a sea-level station in the tropics.

Moreover, during the five winter months when the short-wave-length ultraviolet in sunlight is most needed in preventing rickets, at midlatitude stations the shortest, biologically most effective wavelengths are almost completely absorbed, and the intensity of the less effective wavelengths is reduced to less than one-sixth the value that obtains in the tropics.

In addition to the greater intensity of the ultraviolet there usually is also a greater number of hours of sunshine in the tropics during the five winter months; ranging from a total of about 200 hours in London and Stockholm, 300 to 350 hours in Berlin and Paris, 800 hours in New York and Colon, and 1100 hours in San Juan.

Other factors to be considered are differences in temperature, air movement, humidity and the amount of clothing worn,—all of which no doubt have an effect upon rickets, which is practically unknown in the tropics.

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