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OBSERVATIONS ON RADIATION FROM THE SKY

AND

AN ATTEMPT TO DETERMINE THE ATMOSPHERIC CONSTANT OF RADIATION

BY

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OBSERVATIONS ON RADIATION FROM THE SKY

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ATTEMPT TO DETERMINE THE ATMOSPHERIC CONSTANT OF RADIATION.

§1. Radiation from the Sky.

For more than a year observations on the radiation from the sky have been made at Benson, the results of which are given in the following tables. Up to May 1920 the instrument used was the Differential Ether Radiometer, a description of which appears in the *Q.J.R. Met. Soc.*, Vol. XLVI., No. 196. This instrument gave satisfactory observations for radiation from the zenith, but owing to the large vertical angle of the cone of radiation it deals with, it was found unsuitable for separating the radiation at different zenith distances.

From May to August an instrument, kindly lent me by Mr. L. F Richardson, was used. This was made by Mr. Richardson while he was at Eskdalemuir, but he could not find time to fit it up. It was a thermopile with copper-eureka junctions alternately blackened and polished, placed at the end of a thick walled copper tube. This gave quite satisfactory results, excepting that it's zero position was liable to change. The semi-vertical angle of its cone of radiation was $\tan^{-1} 1/5$, or 11° 18′.

In August a more permanent instrument was erected at Benson, which is described somewhat briefly in the *Meteorological Magazine* for October 1920. In this instrument the semi-vertical angle of the cone of radiation is $\tan^{-1} 1/10$, or 5° 42′, and the change of zero is so slow that it does not affect a set of observations taking only a few minutes to make. Since August observations have been made almost daily, and on some days, when there seemed to be features of especial interest, observations have been made at about two-hour intervals. An observation consists of the following details. The whole radiation from the sky at the following altitudes: 7° 30′, 22° 30′, 37° 30′, 52° 30′, 67° 30′, and 82° 30′, and also from the surface of a grass field. These are defined as zones 6, 5, 4, 3, 2, 1, and 7. Also from the same zones such radiation as will pass through a glass screen, which means diffuse solar radiation, since there is never any measurable quantity between sunset and sunrise, but always some between sunrise and sunset.

The radiation is expressed in gramme calories per square cm. per day. It is the radiation from a hemisphere falling on one square cm. perpendicular to the rays, not, save for the zenith, that falling on a horizontal surface. Of course, radiation from a hemisphere cannot fall perpendicularly upon any one plane, but we can form a convenient measure on the supposition that the radiation is coming from a solid angle as large as a hemisphere of which the small cone dealt with presents a sample of

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average intensity. Gramme calories per day seem the most convenient unit, as the radiation so expressed is readily transferred into the amount of ice melted or water evaporated in the natural meteorological unit of a day. It may be put into milliwatts by dividing by 20·8, or into g.cal. per minute by dividing by 1440.

It should be added that the three instruments have been compared by simultaneous observations on the sky and found to agree well. In each case the primary calibration gives the equivalent radiative temperature. The instruments are calibrated by being exposed to radiation from a black body at a known temperature, and the results are put into gramme calories by a table which depends, of course, on the value assigned to Stefan's constant. The instrument now in use is calibrated about once a fortnight, but its constants are not found to vary beyond two or three per cent.

The figures in Table I. give the equivalent radiative temperature of the sky near the zenith on sundry dates during the past year. The earlier observations were mostly, but not exclusively, taken on clear evenings a little after sunset. The later observations also refer to the time of sunset, but not so largely to clear nights.

TABLE I.—EQUIVALENT SKY TEMPERATURES IN °F.

	Dec. 1919.	Jan. 1920.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1 ..				6			33	45		14	10	0	−8
2 ..		−11					25	28		54	1		42
3 ..		−18		−32						40			−7
4 ..							7			14	46	−4	36
5 ..			−10	7		−1	13	51	19	59	25	41	35
6 ..	−6		−46					46	18	16	12	−6	−15
7 ..			−39			9				15	52	44	34
8 ..	−21			−41			11	22		52	23	38	−16
9 ..	−39							22	19	48	20	37	1
10 ..							19		23		14	47	−19
11 ..	3			−29		47			27	3	7	−1	11
12 ..	9				2			39	62	12	9	3	−32
13 ..					5	2		25	30	13	12	−2	−39
14 ..			−21			10			41		14	17	18
15 ..								41	33	46	46	35	−29
16 ..	−32				−18			61		4	48	−7	−24
17 ..			5					22	21	50	1	−11	27
18 ..				−24				22		3	−10	−1	35
19 ..	−45		15	−27				18	12	4	3	5	33
20 ..				−30		14		62	6	3		36	10
21 ..						6					43	−25	−7
22 ..					21		23		18	7	7	−13	−15
23 ..			−31		−17		36	69			1	−19	14
24 ..			−36		−15	28			19		2	4	52
25 ..			−24			38	52				−11	2	13
26 ..									12	14	−8	36	3
27 ..						44		28	55	14	38	44	1
28 ..									3	17	−6		2
29 ..						56	27			16	−5	41	51
30 ..						25			3	53	−9	42	−1
31 ..									9		44		50

The equivalent radiative temperatures, as may be seen from the table, range frequently over some 60° F. in the winter, and some 40° F. in the summer; the highest temperatures, which are always found with a dense layer of low clouds, are in general a degree or two below that of the air at the time; the lowest temperatures which prevail on clear, but not necessarily on calm, nights are far below the corresponding minima in the screen or on the grass. It should be remembered that these equivalent radiation temperatures do not represent the mean temperature of the air or of any special layer of it, but are such that if a body were exposed to radiation from the sky near the zenith, and could neither gain nor lose heat by other means, its temperature would continually approximate towards the given value.

TABLE II.—MEANS FOR THE MONTH.

Zones	1.	2.	3.	4.	5.	6.	7.
Dec. 1919 ..	425	—	—	—	—	—	—
Jan. 1920 ..	428	—	—	—	—	—	—
Feb. ,, ..	416	—	—	—	—	—	—
Mar. ,, ..	430	—	—	—	—	—	—
April ,, ..	446	—	—	—	—	—	—
May ,, ..	500	505	520	544	576	645	—
June ,, ..	513	515	524	545	580	649	—
July ,, ..	543	548	559	577	621	699	—
Aug. ..	535	537	548	576	629	740	—
Sept. ,, ..	527	528	538	560	595	696	716
Oct. ,, ..	494	499	516	537	565	678	690
Nov. ,, ..	436	440	449	469	503	605	650
Dec. ,, ..	411	415	425	446	478	595	630

In Table II. the monthly means of the radiation from various zones, as already defined, are given, the sky being free from clouds and the time about sunset. Each value depends on the average of some ten observations. The radiation is expressed in gramme calories per cm. per day, and it falls perpendicularly on the face of the thermopile. It must not be confused with the net radiation, which is the difference between that which the surface receives and that which it gives out. The values given depend on the value assigned to Stefan's constant, but assigning a different value to the constant would alter them all in the same proportion. The point to be noticed is the small difference in the radiation from zone 1 and zones 2 or 3. From zone 3 the mass of air radiating is 25 per cent. more than for zone 1, but the increase in the radiation is only three per cent. The difficulty of reconciling these values will be shown later. But there seems no doubt about the figures; not only are they consistent for the various months, but they are consistent for every single observation taken with a clear sky. Neither can they be due to faulty calibration of the instrument, because that would alter the magnitudes, but not their ratios. There might be a systematic error due to change of zero in the instrument, but the change is too slow, and, moreover, this chance of error has been avoided by taking the observations on alternate occasions in reverse order.

Table III. gives the radiation from the various zones of a cloudy sky. The first row refers to a fully overcast sky, but not to clouds of any special density: the second row gives the same values as percentages of the value for zone 7. The third and fourth rows give similar values for densely overcast skies and for thick fog. The cloud sheets have been formed of low cloud so thick as to cause noticeable darkness, and the fogs so thick that it could not be seen if there were clouds above. Thick low cloud and fog have the same effect upon the radiation, and have been classed together. The figures are the means of about 20 observations each for October and November; they are daylight values, because otherwise the character of the clouds could not be ascertained, but the diffuse solar radiation always present in the daytime has been subtracted. The actual values for the dense cloud and fog are lower, because the fogs were associated with frost.

TABLE III.—RADIATION FROM A CLOUDY SKY.

Zone 1.	2.	3.	4.	5.	6.	7.
		Overcast.				
676	674	678	678	682	699	704
95·7	95·7	96·4	96·4	96·8	99·3	100
		Very thick cloud or dense fog.				
670	670	670	670	670	672	676
99·2	99·2	99·2	99·2	99·2	99·5	100

The results with regard to fogs are particularly interesting. The intensity of radiation from a thick fog is within a few per cent. of that from a full radiator at the same temperature. On several occasions when at Benson a fog has given such radiation; the weather has been clear and sunny on the Chiltern Hills a few miles off, so that the fog at Benson can only have been a few hundred feet thick, and would not have contained more water than a layer ·01 in. in thickness. An equal layer of clear air, even in winter, would contain more water, and the radiation would certainly be some 200 g.cal. less. It follows that water in the liquid form must radiate much better than the same amount of water in the form of vapour, unless, indeed, a fog reflects a fair proportion of the earth's radiation which clear air allows to pass.

Table IV. gives the average change in value on clear days between about 14h. and 18h., and gives as a sample the series of observations taken on November 23, which was clear throughout. The printed figures stand exactly as they are taken from the rough observation book. When there are two rows, the upper row gives the scale reading of the instrument when it is exposed to the unimpeded radiation from the corresponding zone of the sky; the lower row is the difference between the radiation which will come through and from a window glass screen and that from the same glass screen backed by a piece of metal. Thus, if a piece of glass backed by metal is placed across the pencil of radiation, the radiation falling on the face of the thermo-electric pile is that coming from the glass. If on removing the metal the scale value of the galvanometer reading rises, it must be due to radiant energy which can get through the glass, but not through the metal. Since at night no change of value following the removal of the metal can ever be detected and by day a rise invariably follows, the inference is that the rise of value is due to diffuse solar radiation, and that the quantity is measured by the extent of the rise. These values are shown in the second of the two rows, and, subtracting them from the figures just above, the result gives the true radiation from the sky.

TABLE IV.—OBSERVATIONS FROM NOTE BOOK TAKEN ON NOVEMBER 23RD.

Time.	1.	2.	3.	4.	5.	6.	7.
10h.	452 23	461 26	482 24	510 45	560 61	678 70	671 32
12h.	462 20	470 20	482 22	500 26	548 33	675 42	680 13
15h.	430 18	433 19	444 12	463 14	502 20	620 23	649 2
16h. 30m. ..	398	408	419	433	462	578	601
17h. 30m. ..	408	411	422	440	468	576	612
20h.	402	406	412	431	460	587	600
MEAN VALUE OF CHANGE FROM 14H. TO 18H.							
October ..	19	21	25	26	34	57	77
November ..	12	13	15	21	22	37	58
December ..	14	13	14	14	22	34	48

This sky radiation is least in the early morning; in October and November it reaches a maximum about 14h. and falls in the afternoon and evening, but the fall after sunset is slow. As might be expected, the fall is least for the zenith and increases with the zenith angle. The differences with different zenith angles are of interest, because, as far as we know, the daily change of temperature is confined to the lowest stratum, and the differences should give some clue to the proportion of the radiation which comes from that stratum. About ten days in October and November and six in December were available for the means; the lower values for November are perhaps casual. What is apparent is that about 14h. in the autumn the zenith sky radiates some 15 g.cal. more than it does in the evening after sunset, and that the difference from the sky near the horizon is from two to three times as much.

§2. DIFFUSE SOLAR RADIATION.

The diffuse solar radiation has also been studied, but the amounts received depend upon so many variables that it must suffice to give such general results as are quite clear. They are as follows:—

1. The amount coming from the neighbourhood of the zenith on a clear day in gramme calories per cm.² per day is approximately equal to the number expressing the altitude of the sun in degrees.

2. The amount increases to a maximum as the zenith angle increases to a value of about 60°, at which angle the maximum occurs.

3. A grass field reflects about one-third of the diffuse solar radiation from the sky that falls upon it.

4. Broken clouds, showing much white, reflect the most radiation; in the midday hours in September the amount may reach 300 g.cal. It does not seem to matter if the clouds are high or low; fog, with the sun just breaking through, will show a large value. As with clear skies, the amount increases with the zenith distance, but the values from any definite direction are subject to rapid changes.

5. Especially dense and heavy cloud sheets supply about the same diffuse solar radiation as a clear sky does. A dense fog supplies about as much as a sheet of Cirro Cumulus.

6. On cloudless days low haze adds to the diffuse solar radiation.

7. The direction of the sun has very considerable effect on clear days. The radiation from parts of the sky near the sun is the greater, but the observations do not suffice to lay down any fixed rule.

The following figures give the means for all the observations in October that were taken within four hours of midday in November within three hours, and in December within 2½ hours :—

	1.	2.	3.	4.	5.	6.	7.
October	57	60	70	75	78	66	35
November	51	50	55	56	57	40	22
December	41	41	46	47	52	40	17

The observations made by Anders Ångström (Some problems relating to the Scattered Radiation from the Sky. A. Ångström, *Monthly Weather Review*, No. 47, pp. 797–798, Nov. 1919) as to the effect of clouds on the radiation have been confirmed at Benson. Cirrus cloud has been found to have a very trifling effect upon the net radiation from the earth; whereas a thick layer of low cloud may cut it off entirely.

§3. Theoretical Considerations.

The figures given in the tables represent certain observational facts; it remains to be seen if we can calculate the radiation for each zone, and then adjust the method of calculation and the numerical values of the constants so as to make the observed and calculated values agree. But the constants so found—if, indeed, they can be found—will refer to ordinary air such as exists over England under average conditions, not to theoretically dry air.

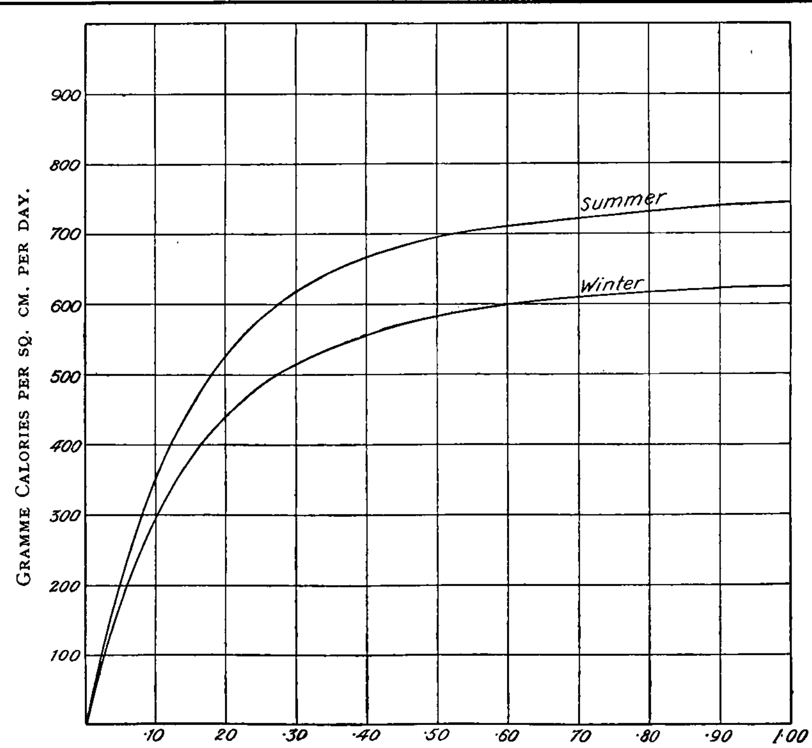
It is assumed that the radiative properties of the air are the same at all heights, an assumption which is probably incorrect, but which can be partially allowed for later when a suitable mean value for the radiative power of the air has been obtained.

In a paper published in the *Q.J.R. Met. Soc.* for April, 1920, Vol. XXVI., No. 194, a method of calculating the radiation from the sky suggested by Mr. L. F. Richardson is set out. This method employs the constant η, where η is defined as the percentage of long-wave radiation that will be absorbed by a layer of air 100 mb. thick when the radiation passes perpendicularly through the layer. Or it may be defined thus:— If the layer of air radiated as a full radiator it would give out σT^4 on each side, but it actually gives out $\eta\sigma T^4$. Hence η is a fraction lying between 0 and 1.

The first process is to prepare a table by Mr. Richardson's method, giving the calculated radiation from the sky near the zenith for all values of η. The results are set out in Table V. and graphically in Fig. 1. The curves were obtained by calculating directly some 20 values, and then drawing smoothed curves through the points so determined, and the tables have been deduced from the curves by inspection. The arithmetic has been done by a slide rule, and, admitting the assumptions are right, the values should be correct within about ·5 per cent.

TABLE V.—VALUES OF THE RADIATION, *R*, FROM THE ZENITH FOR VARIOUS VALUES OF η IN SUMMER AND WINTER.

η	·05	·10	·15	·20	·30	·40	·50	·60	·70	·80	·90	1·00
R. Summer ..	204	345	452	524	616	666	692	709	721	730	737	742
R. Winter ..	177	291	379	437	516	558	581	599	610	619	622	624



VALUES OF η.

FIG. 1—CURVES SHOWING RADIATION FROM THE SKY IN TERMS OF η.

The next process is to calculate the radiation that should be found coming from the various zones. The first step in this process is, knowing the value of η for a perpendicular path through a layer to find the value for an inclined path. The formula is $(1-\eta_z)=(1-\eta)^{\sec z}$ where η_z is the value corresponding to a zenith angle z.

Using a slide rule, a table of logarithms, and a table of cosines, Table VI. has been formed in this way.

TABLE VI.—EMISSIVITY OF STRATUM 100 MB. THICK AT VARIOUS ZENITH ANGLES.

Zenith Angle.												
0° ..	·010	·050	·10	·20	·30	·40	·50	·60	·70	·80	·90	1·00
7°·30′ (Zone 1)	·010	·050	·10	·20	·30	·40	·50	·60	·70	·80	·90	1·00
15° ..	·010	·052	·10	·21	·31	·41	·51	·61	·71	·81	·91	1·00
22°·30′ (Zone 2)	·011	·054	·11	·22	·32	·43	·53	·63	·73	·82	·92	1·00
30° ..	·012	·057	·11	·22	·34	·45	·55	·65	·75	·84	·93	1·00
37°·30′ (Zone 3)	·013	·062	·12	·24	·36	·48	·59	·69	·78	·87	·93	1·00
45° ..	·014	·070	·14	·27	·39	·51	·62	·73	·83	·90	·96	1·00
52°·30′ (Zone 4)	·017	·081	·16	·31	·44	·57	·68	·78	·86	·93	·98	1·00
60° ..	·020	·097	·19	·36	·51	·64	·75	·84	·93	·97	·99	1·00
67°·30′ (Zone 5)	·026	·125	·24	·44	·62	·73	·84	·90	·96	·98	1·00	1·00
75° ..	·038	·163	·32	·58	·75	·86	·93	·97	·99	·99	1·00	1·00
82°·0′ (Zone 6)	·050	·324	·55	·82	·93	·98	·99	1·00	1·00	1·00	1·00	1·00
Horizon ..	1·000	1·000	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00

The next step is to prepare Table VII., which gives the theoretical amount of the radiation from each zone in terms of η. It is more convenient, however, to express these amounts as percentages rather than as actual values in gramme calories. The standard, 100, denotes the full black body radiation from the bottom layer of the atmosphere, and is taken as 742 g.cal. for the summer and 624 for the winter. The figures are obtained thus :—Take $\eta = \cdot 30$, then by Table V the radiation from the zenith or zone 1 is for the summer 616 ; 616 is 83 per cent. of 742 ; hence 83 is entered in the table for $\eta = \cdot 30$ and the zenith sky. Next from Table VI., where η as defined above equals ·30, the equivalent value for zone 2 is ·32. From the Table or Curve (Fig. 1) the theoretical radiation for $\eta = \cdot 32$ is 626, which is 85 per cent. of 742, so 85 is entered in the table for $\eta = \cdot 30$ and zone 2. And so on. Table VII. is for the summer ; it is unnecessary to prepare another table for the winter, because owing to the similarity of the winter and summer curves of radiation (Fig. 1,) the winter radiation expressed as a percentage of 624 is almost identical with the summer radiation expressed as a percentage of 742. There are differences here and there of one per cent., but the figures make no pretence of being accurate within less than one per cent.

TABLE VII.—THEORETICAL AND OBSERVED PERCENTAGES FROM EACH ZONE.

η	·01	·05	·10	·20	·30	·40	·50	·60	·80	·90	Calculated Percentages. (A)	Observed Percentages.		
												Clear Sky.	Cloudy Skies.	Densely Cloudy Skies.
Zone														
1 ..	6	28	47	72	83	90	94	96	98	99	72	72·2	95·9	99·2
2 ..	7	29	51	74	85	91	94	96	99	99	72	72·6	95·7	99·2
3 ..	8	33	54	77	88	93	95	97	99	100	74	74·2	96·4	99·2
4 ..	9	41	63	84	92	95	97	98	100	100	78	77·0	96·4	99·2
5 ..	15	55	77	92	96	98	99	99	100	100	84	82·6	96·8	99·2
6 ..	28	85	95	99	100	100	100	100	100	100	95	94·3	99·3	99·5

On the right of the table are placed for reference the percentages, referred to the same standard, of the observed summer radiation on clear days. Also the theoretical radiation (A) computed on the supposition that the emissivity of the air is selective and that one-third of the energy has a value ·05 and two-thirds a value ·50, and the observed percentages for ordinarily and for densely clouded skies.

We can now compare the theoretical and the observed values of the radiation, and see which value of η gives the best fit.

For cloudy skies the result is quite simple. For a general average and for all six zones of the atmosphere the sky radiation from a cloudy sky is given closely by $\eta = \cdot 60$, and for a densely clouded sky or thick fog by $\eta = \cdot 80$ or $\cdot 90$. Neither does it matter in this case that η has been assumed to be the same in each layer, because with so high a value of η it is only the lower layers that matter ; the theoretical values would hardly be altered if we completely ignored the upper half of the atmosphere. That only the lower layers matter is shown in the observations by the fact that the equivalent radiative temperature of a cloudy sky is very little below the surface temperature at the time.

The case is different for clear skies. For the zenith sky the mean for the summer is 530 g.cal. (72%); for the winter (November and December) it is 423 g.cal. (67%). These correspond to $\eta = \cdot 205$ and $\cdot 188$, but for zone 6 the value $\eta = \cdot 10$ makes the observed and calculated figures fit. It might be expected that zone 6 would give the higher value of η, because it would refer to the lower air which contains the water vapour, but the reverse is the case.

An explanation may be sought in the selective radiation of the air. If one-third of the whole energy of the long-wave radiation has wave-lengths for which $\eta = \cdot 05$ and the remaining two-thirds follow the rule $\eta = \cdot 50$, the theoretical values (A) given on the right of Table VII. are obtained. These give quite a good fit with the observed values. The value $\eta = \cdot 50$ need only hold for the lower strata, and it is possible that $\eta = \cdot 05$ may hold for dry air throughout, the higher value being due to the selective action of water vapour. The whole evidence tends to show that the radiation of the atmosphere on clear days comes from the very lowest stratum, for it is very closely correlated with the surface temperature, it has a considerable diurnal range (*see* Table IV.), and, so far as we know, diurnal changes in temperature are confined to the lower strata.

It does not seem from the results obtained at Benson, in so far as they have as yet been examined, that the relative humidity at the time makes much appreciable difference in the radiation from the sky ; it is the temperature that is all important. Being given the surface temperature and a cloudless sky, the radiation can be estimated within about four per cent. with comparative certainty. If 220 g.cal. per sq. cm. per day be subtracted from the full radiation at the screen-reading temperature, it will give a close approximation to the radiation from the zenith sky.

The following statistical data for clear skies may be of interest :—

The Standard Deviation of the sky radiation at Benson in the winter is about 40 g.cal. per sq. cm. per day.

The Standard Deviation of the full radiation at the surface temperature in the screen is about 40 g.cal.

The Standard Deviation of the net or effective radiation is about 20 g.cal.

The correlation between the sky radiation and the surface temperature is about $\cdot 90$.

The correlation is not significant between the sky radiation and the relative humidity, or between the effective radiation and the surface temperature.

A further point must be mentioned. The radiation falling on the face of the thermo-electric pile, which will not pass through glass, has been called radiation from the sky, but there is no means of knowing how much of it is scattered and dispersed radiation which has come from the earth and been scattered by the air, and how much is true radiation emitted by the air. Some 40 per cent. of the solar radiation is supposed to be reflected back to space, and it is reasonable to suppose that some portion of the earth's radiation is reflected back by the sky. If an appreciable portion is so reflected a lower value must be assigned to η.

§4. Sky Radiation to a Horizontal Surface.

It remains to determine the radiation from the sky received on a horizontal surface at ground level.

Each zone supplies its own quota which depends on the three factors: its intrinsic radiation, the solid angle it subtends at the receiving surface, and the value of the vertical component. The last two factors combined give $\kappa\int_\alpha^\beta \sin 2\theta\, d\theta$ as the vertical component from a uniform sky for the zone lying between altitudes α and β. For the six zones this gives the following percentages of the whole, assuming the sky uniform :—

6·6	18·3	25·0	25·0	18·3	6·6

To find the intrinsic radiation from each zone the figures of Table II. are available, but the values for zones 2 to 6 are missing before May. For the year 1920 the mean for the zenith is 473, and it has been assumed that the rate of increase with increasing zenith distance is the same for the year as for the eight months where figures are available. This gives for a clear sky about the time of sunset the following values :—

1.	2.	3.	4.	5.	6.
473	477	489	511	547	642

Multiplying by the proportionate amounts the following values for the radiation received per day upon a horizontal square centimetre from each zone are given :—

32	82	122	128	100	42

The last two numbers are somewhat too large because the bulk of the radiation comes from the upper half of the zones, since the vertical components are greater, whereas the numbers 547 and 642 refer to the middle of the zone; but the error is not serious.

The total is 506—say 500 for the reason just given—and represents the average daily supply of heat from the atmosphere throughout the year falling on one sq. cm. in the South of England on clear days, and it corresponds to a zenith distance of some 50° or altitude of 40°. For fully clouded skies the value would be about 700, and the general mean for all days must be in the neighbourhood of 600. For a mean temperature of 50° F. or 10° C. the outward radiation from the earth is 711 g.cal., so that the net or effective radiation for a clear sky is rather over 200 g.cal. This is some 25 per cent. less than the values usually given, but Benson is nearly at sea-level (186 ft. above M.S.L.), and the observations giving higher values have mostly been made at much greater altitudes.