On the Scattering of the Sun's Ray in the High Atmosphere (III)

By T. Sato

Nagasaki University

(Manuscript received 18 August 1966, in revised form 6 June 1967)

Abstract

The flux of primary scattered radiation received by the horizontal plane of 1 cm^2 at 75 levels placed at intervals of 500 m from 1 km to 38 km are computed for solar altitudes 30° , 60° and 90° and the results summarized in the following four points are obtained;

- (1) The flux decreases with increase of q for given h and λ_i'
- (2) the flux increases with increase of h for given q and λ_i'
- (3) the wavelength in which the flux is maximum decreases with increase of q for given h
- (4) the wavelength mentioned in (3) decreases with increases of h for each q

1. Introduction

As the altitude becomes higher and higher in the atmosphere, the blue sky becomes darker and darker. The problem of Rayleigh scattering of light, which has an essential relation to this fact, has not yet been fully solved in spite of its major importance in all problems relating to the radiational effects in the atmosphere.

The author has studied the problems related to this in a paper (Sato, 1962) and in a series of papers titled: On the Scattering of the Sun's Ray in the High Atmosphere.

In the first paper of this study (Sato, 1955) the author computed the intensity of scattered light at 5 km level in four wavelength ranges, each of which has the energy equal to $\frac{1}{4}$ of the total solar energy at the upper boundary of the earth's atmosphere. In the second paper (Sato, 1964) he did the same computation for 75 levels placed at intervals of 500 m from 1 km to 38 km. Moreover the total solar energy is divided into 12 wavelength ranges, each of which has the energy equal to $1/12$ of the total energy. The study is restricted only to the primary scattered light in the vertical plane normal to the vertical plane passing through the center of the sun in the sky dome. In this (third) paper, he computed the flux of primary scat-

tered radiation received by the horizontal plane of 1 cm^2 at the above mentioned 75 levels for solar altitudes 30° , 60° and 90° and obtained the results summarized in four points given in Section 6.

2. The method of computation

Let O and O' be the earth's centre and a point on its surface. Take 75 points $E_1E_2\cdots E_q\cdots E_{75}$ on the prolonged line of OO' , i.e. the vertical line at O' . The elevation of E_1 is 1 km, and two adjacent points E_q and E_{q+1} are apart from each other by 500 m. Hence, $O'E_q = 1/2(q+1)$ km. Consider a horizontal plane of 1 cm^2 area on E_q point, which is vertical to OE_q . It is named E_q plane. This plane can receive the primary scattered radiation generated by the atmosphere in the sky dome bounded by a horizontal plane at E_q and the atmospheric upper limit. In the following we compute the flux of primary scattered radiation received by the upper side of E_q plane. Now we divide the total energy of the Sun outside the earth's atmosphere into twelve domains. Let p_i , λ_i , λ_i' , k_i and $I_0(\lambda_i')$ be respectively the mean transmission coefficient of each domain, the upper limit of wavelength of the domain, the wavelength corresponding to p_i , extinction coefficient corresponding to p_i and the Sun's energy out-

Table 1. The values of $p_i \lambda_i \lambda_i' I_0(\lambda_i') k_i$

i	1	2	3	4	5	6
p_i	0.600	0.795	0.867	0.912	0.941	0.961
λ_i	0.409	0.466	0.519	0.577	0.638	0.708
λ_i'	0.3572	0.4364	0.4910	0.5445	0.6088	0.6763
$I_0(\lambda_i')$	1655	2806	3109	2799	2643	2321
k_i	$0,4924 \cdot 10^{-3}$	$0,2210 \cdot 10^{-3}$	$0,1380 \cdot 10^{-3}$	$0,8915 \cdot 10^{-4}$	$0,5836 \cdot 10^{-4}$	$0,3832 \cdot 10^{-4}$

i	7	8	9	10	11	12
p_i	0.973	0.985	0.991	0.995	0.998	1.000
λ_i	0.793	0.905	1.058	1.282	1.738	∞
λ_i'	0.7456	0.8567	0.9850	1.1396	1.4960	2.5356
$I_0(\lambda_i)'$	1923	1405	1065	457	352	74
k_i	$0,2595 \cdot 10^{-4}$	$0,1482 \cdot 10^{-4}$	$0,8519 \cdot 10^{-5}$	$0,4753 \cdot 10^{-5}$	$0,1601 \cdot 10^{-5}$	$0,1940 \cdot 10^{-6}$

side the earth's atmosphere. We have the following table (Sato, 1955). (Table 1).

$I_0(\lambda_i')$ is obtained from Abbot's research and Linke's Table. The unit and wavelength width are $(\text{cal}/\text{cm}^2 \cdot \text{min}) \cdot 10^{-6}$ and 0.001μ .

Let θ_1 be the angle between a line passing through E_q and OE_q line, which is hereafter denoted by θ_1 line. Let A be the azimuth of the vertical plane containing θ_1 line relative to the Sun's azimuth. Take the following values of θ_1 and A : $\theta_1=95+5n$ ($n=0 \sim 5$), 150, 180 in degree, $A=0, \pi/2, \pi, 3\pi/2$.

In this case the atmospheric model is the same as in Part I (Sato, 1955) and its upper limit is 40 km. Let $0''$ be the intersecting point of θ_1 line by the atmospheric upper limit, and now let T_r be a point on θ_1 line which is apart from E_q by the distance of r . The amount of primary scattered intensity dp_1 received at E_q from a region of spherical shell of 1 m width with its center at T_r bounded by a cone of one steradian with its axis in $(\theta_1 A)$ direction and its vertex at E_q is expressed in the unit of intensity of incident solar radiation as follows

$$dp_1 = \frac{3k_i \rho(T_r)}{16\pi} (1 + \cos^2 \varphi) p_i^{\Sigma(T_r)} \quad (1)$$

$$\cos \varphi = \sin \theta_1 \cos A \cos h - \cos \theta_1 \sinh, \quad (2)$$

where h is the solar elevation, $\rho(T_r)$ the atmospheric mass in 1 m^3 at T_r , and $\Sigma(T_r)$ is the sum of two traversed masses, one of which is the mass between the upper atmospheric limit and T_r and the other is that between

T_r and E_q in the unit of whole atmospheric mass penetrated by the vertical cylinder at $0'$ (Sato, 1964).

Now put

$$\rho(T_r) p_i^{\Sigma(T_r)} = S'(i q \theta_1 A r h) \quad (3)$$

then

$$dp_1 = \frac{3k_i}{16\pi} (1 + \cos^2 \varphi) S'(i q \theta_1 A r h) \quad (4)$$

Let us denote

$$dH_{ps} = dP_1 \sin(\theta_1 - 90^\circ) \quad (5)$$

Then we have only to carry out multiple integration to $dH_{ps} \cos(\theta_1 - 90^\circ)$ with respect to r from E_q to $0''$ along θ_1 line and θ_1 from $\theta_1 = \pi/2$ to π and A from $A=0$ to $A=2\pi$ to find the flux of primary scattered radiation received by the horizontal plane $H_{ps}(i q h)$ at E_q , i.e.

$$H_{ps}(i q h) = \int_0^{2\pi} dA \int_{\frac{\pi}{2}}^{\pi} d\theta_1 \int_{E_q}^{0''} dr \cdot dH_{ps} \cos(\theta_1 - 90^\circ) \quad (6)$$

The integrant in (6) is

$$\begin{aligned} & \frac{3k_i}{16\pi} (1 + \cos^2 \varphi) S'(i q \theta_1 A r h) \sin\left(\theta_1 - \frac{\pi}{2}\right) \\ & \times \cos\left(\theta_1 - \frac{\pi}{2}\right) \end{aligned} \quad (7)$$

Hence

$$\begin{aligned} H_{ps}(i q h) = & \frac{3k_i}{16\pi} \int_0^{2\pi} dA \int_{\frac{\pi}{2}}^{\pi} d\theta_1 (1 + \cos^2 \varphi) \\ & \times \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \int_{E_q}^{0''} dr \cdot S'(i q \theta_1 A r h) \end{aligned} \quad (8)$$

To the calculation of (8) we will depend on the numerical integration.

Let T_1 , T_2 and T_3 be three points on the line section $E_q 0''$ which divide $E_q 0''$ into four equal parts and $T_0 = E_q$, $T_4 = 0''$, and the value of $S'(i q \theta_1 A r h)$ at $T_n (n=0 \sim 4)$ be denoted by $S'(n)$ and set for brevity

$$S(i q \theta_1 A h) = S'(0) + 4S'(1) + 2S'(2) + 4S'(3) + S'(4) \quad (9)$$

Then we can calculate as follows by Simpson's formula

$$\int_{E_q}^{0''} S'(i q \theta_1 A r h) dr = \frac{1}{3} \cdot \frac{1}{4} \cdot E_q 0'' \cdot S(i q \theta_1 A h) \quad (10)$$

For the following particular combination of q and λ'_i , the precise calculation is indispensable to expect satisfactory result:

$$q=1 \sim 30, \lambda'_1; q=1 \sim 19, \lambda'_2; q=1 \sim 15, \lambda'_3; \\ q=1 \sim 4, \lambda'_4; q=1 \sim 2, \lambda'_5; \text{ for } \theta_1 = 95^\circ$$

and

$$q=1 \sim 20, \lambda'_1; q=1 \sim 7, \lambda'_2; q=1 \sim 7, \lambda'_3; \\ \text{for } \theta_1 = 100.$$

For this purpose we must make three auxiliary points T_a , T_b and T_c which divide the section $T_0 T_1$ into four equal parts. In this case, let us put

$$\left. \begin{aligned} f_1 &= S'(0) + 4S'(a) + 2S'(b) + 4S'(c) + S'(1) \\ f_2 &= S'(1) + 3S'(2) + 3S'(3) + S'(4) \end{aligned} \right\} \quad (11)$$

where $S'(a)$, $S'(b)$ and $S'(c)$ are respectively the value of $S'(i q \theta_1 A r h)$ at T_a , T_b and T_c . So we have only to calculate (12) instead of (9)

$$S(i q \theta_1 A h) = \frac{1}{4} f_1 + \frac{9}{8} f_2 \quad (12)$$

Now put

$$E_q 0'' \cdot S(i q \theta_1 A h) = C''(i q \theta_1 A h) \quad (13)$$

Substitute (13) and (10) in (8), we get

$$H_{ps}(i q h) = \frac{3k_i}{16\pi} \int_0^{2\pi} dA \int_{\frac{\pi}{2}}^{\pi} d\theta_1 (1 + \cos^2 \varphi) \\ \times \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \cdot \frac{1}{12} C''(i q \theta_1 A h) \quad (14)$$

Moreover let us put

$$(1 + \cos^2 \varphi) C''(i q \theta_1 A h) = C'(i q \theta_1 A h) \quad (15)$$

In the preceding calculation, $E_q 0''$ are expressed in the unit of the earth's radius 6370 km. Hereafter we will use C.G.S. unit As $1 \text{ m}^3 = 10^6 \text{ cm}^3$, $1 \text{ km} = 10^5 \text{ cm}$, and

$$\frac{3k_i}{16\pi} \cdot \frac{1}{3} \cdot \frac{1}{4} \cdot 6370 \cdot 10^5 \cdot 10^{-6} = 3.16816 k_i \quad (16)$$

$$S_1(i q \theta_1 A h) = 3.16816 k_i C'(i q \theta_1 A h) \quad (17)$$

is the amount of primary scattered intensity received at E_q point from a cone of one steradian with its axis in $(\theta_1 A)$ direction and vertex at E_q . We calculated S_1 for all combinations of i , q , θ_1 , A , h .

Then we have

$$H_{ps}(i q h) = \int_0^{2\pi} dA \int_{\frac{\pi}{2}}^{\pi} d\theta_1 \cdot S_1(i q \theta_1 A h) \\ \times \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \quad (18)$$

Strictly speaking, $\Sigma(T_r)$ is dependent on A , because the mass traversed by the direct solar ray is evidently dependent on A , although that traversed by the scattered ray is never dependent. But when the Sun's altitude $h \geq 30^\circ$ we can recognize $\Sigma(T_r)$ to be independent of A with negligible error in this research, then $1 + \cos^2 \varphi$ is the only one existing expression in (17) that is dependent on A . Let us define $F(i q \theta_1 A h)$ by (19)

$$F(i q \theta_1 A h) = S_1(i q \theta_1 A h) \\ \times \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \quad (19)$$

To calculate that flux of scattered radiation received by the horizontal plane we must use the following procedure: we will at first integrate F with respect to θ_1 and then with respect to A . This procedure demands us a lot of work. But we can fortunately utilize the fact that the only existing expression $(1 + \cos^2 \varphi)$ in (19) is dependent on A which is clear from the above explanation. This utilization enables us to save some extent of the labour.

As $S(i q \theta_1 A h)$ is independent of A in this

case we can put $S(i q \theta_1 h)$ instead of $S(i q \theta_1 A h)$. From (17) we get

$$\begin{aligned} & S_1(i q \theta_1 A h) \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \\ &= 3.16816 k_i (1 + \cos^2 \varphi) \cdot E_q 0'' \cdot S(i q \theta_1 h) \\ & \quad \times \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \end{aligned} \quad (20)$$

Putting

$$E_q 0'' \cdot S(i q \theta_1 h) = S_2(i q \theta_1 h) \quad (21)$$

becomes

$$\begin{aligned} & S_1(i q \theta_1 A h) \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \\ &= 3.16816 k_i (1 + \cos^2 \varphi) \sin\left(\theta_1 - \frac{\pi}{2}\right) \\ & \quad \times \cos\left(\theta_1 - \frac{\pi}{2}\right) S_2(i q \theta_1 h) \end{aligned} \quad (22)$$

Let us put

$$3.16816 k_i (1 + \cos^2 \varphi) = f(i q \theta_1 A h) \quad (23)$$

Then

$$\begin{aligned} H_{ps}(i q h) &= \int_0^{2\pi} dA \int_{\frac{\pi}{2}}^{\pi} d\theta_1 \cdot F(i q \theta_1 A h) \\ &= \int_0^{2\pi} dA \int_{\frac{\pi}{2}}^{\pi} d\theta_1 \cdot f(i q \theta_1 A h) S_2(i q \theta_1 h) \\ & \quad \times \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right). \end{aligned} \quad (24)$$

It is clear that

$$\begin{aligned} \int_0^{2\pi} f(i q \theta_1 A h) dA &= \frac{\pi}{2} \left\{ f(i q \theta_1 0 h) + f\left(i q \theta_1 \frac{\pi}{2} h\right) \right. \\ & \quad \left. + f(i q \theta_1 \pi h) + f\left(i q \theta_1 \frac{3}{2} \pi h\right) \right\} \end{aligned} \quad (25)$$

Denote the bracket of the right hand side of (25) by $f'(i q \theta_1 h)$. Then

$$\begin{aligned} H_{ps}(i q h) &= \frac{\pi}{2} \int_{\frac{\pi}{2}}^{\pi} d\theta_1 \cdot f'(i q \theta_1 h) S_2(i q \theta_1 h) \\ & \quad \times \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \end{aligned} \quad (26)$$

Putting

$$f''(i q \theta_1 h) = f'(i q \theta_1 h) \sin\left(\theta_1 - \frac{\pi}{2}\right) \cos\left(\theta_1 - \frac{\pi}{2}\right) \quad (27)$$

then

$$H_{ps}(i q h) = \frac{\pi}{2} \int_{\frac{\pi}{2}}^{\pi} d\theta_1 \cdot f''(i q \theta_1 h) S_2(i q \theta_1 h) \quad (28)$$

By putting

$$f''(i q \theta_1 h) S_2(i q \theta_1 h) = S_3(i q \theta_1 h) \quad (29)$$

$$H_{ps}(i q h) = \frac{\pi}{2} \int_{\frac{\pi}{2}}^{\pi} d\theta_1 \cdot S_3(i q \theta_1 h) \quad (30)$$

We calculated $S_3(i q \theta_1 h)$ for the above mentioned values of i , q , θ_1 and h . We replaced the integration of $S_3(i q \theta_1 h)$ with respect to θ_1 by two Simpson's formulae, the one is bounded by $\theta_1 = 90^\circ \sim 120^\circ$, and the other by $\theta_1 = 120^\circ \sim 180^\circ$. Hence the numerical formula of H_{ps} will be

$$\begin{aligned} H_{ps}(i q h) &= \frac{\pi}{2} \left[\frac{\pi}{3} \cdot \frac{5}{180} \left\{ 4 \left\{ S_3(i q, 95^\circ, h) \right. \right. \right. \\ & \quad \left. \left. + S_3(i q, 105^\circ, h) + S_3(i q, 115^\circ, h) \right\} \right. \\ & \quad \left. + 2 \left\{ S_3(i q, 100^\circ, h) + S_3(i q, 110^\circ, h) \right\} \right. \\ & \quad \left. + S_3(i q, 120^\circ, h) \right] + \frac{\pi}{3} \cdot \frac{30}{180} \left\{ S_3(i q, 120^\circ, h) \right. \\ & \quad \left. + 4 S_3(i q, 150^\circ, h) \right\} \end{aligned} \quad (31)$$

3. The result of computation

H_{ps} is the flux of primary scattered radiation received by E_q plane in each wavelength domain in $(1/12) I_0$ unit. Sum up these 12 values of each domain and divide by 12, *i.e.* $\Sigma H_{ps}/12$, then we can get the value for the total wavelength in I_0 unit which is denoted by T in Table 2. These values are given in Table 2. Multiplication of H_{ps} and $I_0(\lambda_i')$ is the flux of primary scattered radiation received by E_q plane in 0.001μ width of wavelength with its centre at λ_i' in the unit of $\text{cal/cm}^2 \cdot \text{min}$, and $\Sigma H_{ps}/12$ multiplied by $I_0 = 1.94$ is the value for total wavelength domain in $\text{cal/cm}^2 \cdot \text{min}$ unit.

4. How to use Table 2

The table shows the values of H_{ps} for $h=60^\circ$ and is expressed in the unit of $(1/12) I_0 10^{-n}$ for each wavelength domain denoted by D and $I_0 10^{-n}$ for T . The calculated values for $h 30^\circ$ and 90° are not given in this paper. In Table 2, $q=0$ in the column of q means the earth's surface, $q=1$ and q means the level of 1 km height and $(q+1)/2$ km, so that

Table 2. Spectral and total flux of primary scattered radiation received by the horizontal plane at various altitudes denoted by q .
The values are expressed in $(1/12)I_010^{-n}$ for each wavelength domain denoted by D and in I_010^{-n} for total wavelength domain.

D	1	2	3	4	5	6	7	8	9	10	11	12	T
$\frac{n}{q}$	4	5	5	5	5	5	5	6	6	6	7	7	5
0	1101	7530	5413	3831	2653	1809	1255	7325	4186	2397	8118	986	2915
1	1054	6922	4907	3434	2366	1609	1113	6482	3767	2116	7168	870	2684
3	999	6319	4424	3068	2105	1424	983	5712	3316	1861	6299	764	2456
5	937	5728	3965	2719	1862	1256	865	5017	2908	1631	5518	670	2232
7	874	5173	3542	2413	1643	1105	759	4392	2544	1426	4830	585	2022
9	809	4652	3150	2132	1445	969	665	3843	2225	1246	4211	511	1823
11	746	4171	2798	1888	1271	850	582	3360	1942	1088	3674	446	1642
13	683	3724	2477	1661	1105	744	509	2932	1693	948	3201	388	1470
15	621	3309	2184	1458	975	649	443	2553	1474	825	2783	337	1312
17	562	2931	1918	1276	850	565	386	2218	1279	716	2415	293	1166
19	504	2579	1676	1110	738	490	334	1919	1106	618	2085	253	1030
21	448	2250	1457	962	638	423	288	1653	952	532	1797	218	902
23	394	1952	1256	827	548	363	247	1415	815	456	1536	186	785
25	345	1684	1080	709	469	310	211	1208	696	389	1312	158	680
27	301	1453	929	608	401	265	180	1031	594	332	1119	135	588
29	261	1251	796	520	343	227	154	879	507	283	955	116	506
31	227	1076	682	445	293	194	131	752	433	241	814	9858*	437
33	197	922	584	380	250	165	112	641	369	206	689	8341	376
35	170	790	499	325	214	141	9544*	547	314	175	592	7157	323
37	145	675	425	276	182	120	8117	464	267	149	502	6076	275
39	125	577	363	236	155	102	6918	395	227	127	428	5176	236
41	107	492	309	201	132	8680*	5886	336	193	108	364	4400	201
43	9138*	418	263	171	112	7360	4989	285	164	9153*	308	3730	171
45	7761	356	223	145	9491*	6237	4225	242	139	7754	261	3159	146
47	6601	301	189	122	8034	5283	3579	205	118	6566	221	2674	124
49	5577	255	159	103	6760	4439	3012	172	9893*	5520	186	2248	104
51	4714	214	134	8673*	5687	3752	2542	145	8343	4655	157	1899	8793*
53	3976	180	113	7306	4787	3144	2131	122	6995	3903	131	1592	7407
55	3324	150	9412	6093	3996	2626	1780	102	5843	3260	110	1330	6187
57	2770	125	7833	5063	3319	2180	1476	1220	4848	2705	9109*	1103	5151
59	2289	104	6476	4191	2744	1802	1220	6970	4007	2236	7527	912	4257
61	1880	847*	5293	3427	2245	1474	999	5704	3279	1831	6166	747	3488
63	1523	687	4287	2775	1818	1194	809	4619	2657	1482	4993	604	2826
65	1220	549	3432	2219	1453	954	646	3691	2121	1183	3986	483	2261
67	958	431	2689	1739	1138	748	506	2893	1663	928	3125	378	1774
69	734	330	2061	1332	872	573	388	2215	1273	710	2392	290	1360
71	539	242	1511	976	639	420	284	1623	933	520	1753	212	983
73	373	167	1045	674	442	290	197	1122	645	360	1212	147	689
75	229	103	642	415	272	178	121	690	396	221	745	90	424
$\frac{n}{q}$	6	6	7	7	7	7	7	8	8	8	9	9	7

the value for the level of 500 m height is not calculated. The attached mark * indicates the change of common unit. Let us denote Q as the value of q at which the values changes a unit. It should be noticed that the

value of n in the array of the upper side is applied to the range from $q=0$ to $Q-1$. However, n in the array of the lower side is applied to that from Q to 75.

The flux for $q=0$ has been already given

Table 3. Ratio of H_{ps} for $q=0$ given in the paper (Sato 1962) to that given in this paper.

h	1	2	3	4	5	6	7	8	9	10	11	12	T
30	1.002	1.067	1.096	1.133	1.153	1.161	1.172	1.174	1.224	1.191	1.194	1.185	1.083
60	1.005	1.050	1.074	1.099	1.110	1.124	1.131	1.145	1.131	1.142	1.143	1.147	1.056
90	0.996	0.960	0.941	0.923	0.912	0.906	0.898	0.893	0.884	0.854	0.873	0.896	0.972

in Table 11(b) in the previous paper (Sato, 1962). This is slightly different from that of Table 1 in this paper. The ratio of the value in the paper (Sato, 1962) to that in Table in this paper is given in Table 2. This difference is attributed to the condition that we have only used $\theta=30, 60, 90$ these values being corresponding to $\theta_1=120^\circ, 150^\circ$ and 180° in this paper, and therefore the value in the paper (Sato, 1962) is inferior to that in this paper in precision. But the value of the ratio is interesting in the meaning that it has regular change: it decreases with increasing h .

5. Explanation of figure

The result of calculation are not only expressed in Table above mentioned but also given in three figures to facilitate the synoptical understanding.

Figs. 1 to 3 give the spectral distribution of the flux of primary scattered radiation

Fig. 1. Spectral distribution of the flux of primary scattered radiation received by the horizontal plane at various altitudes for solar elevation 30° . The numbers attached to curves denote q .

Fig. 2. Spectral distribution of the flux of primary scattered radiation received by the horizontal plane at various altitudes for solar elevation 60° . The numbers attached to curves denote q .

Fig. 3. Spectral distribution of the flux of primary scattered radiation received by the horizontal plane at various altitudes for solar elevation 90° . The numbers attached to curves denote q .

received by the horizontal plane for each h by taking λ_i' in 0.1μ unit as abscissa and the value as ordinate in $(\text{cal}/\text{cm}^2 \cdot \text{min}) 10^{-5}$ unit, the number attached to the curve being q .

6. Some results

We can derive the following laws from the Tables and figures as far as the primary scattering is concerned;

- (1) The flux decreases with increasing q for each h and each λ_i'
- (2) the flux increases with increasing h for each q and each λ_i'
- (3) the wavelength in which the flux becomes maximum decreases with increasing q for each h
- (4) the wavelength mentioned in 3 decreases with increasing h for each q

Acknowledgments

The author expresses his sincere thanks to

Dr. M. Kano of the Meteorological Research Institute for his earnest and helpful discussions. The expense of this work was defrayed by the Special Fund for Sciences of Educational ministry of Japan.

References

- Sato, T., 1955: On the scattering of the sun's ray in the high atmosphere (1). *J. meteor. Soc. Japan*, **33**, 194-204.
- , 1962: The Intensity of Scattered Light for Each Wavelength in a Rayleigh Atmosphere Composed of Spherical Shells. *Ibid.*, **40**, 148-161.
- , 1964: On the scattering of the sun's ray in the high atmosphere (2). *Ibid.*, **42**, 163-172.

上空における散乱光 (III)

佐 藤 隆 夫

長崎大学

地上を No. 0 とし、上空 1 km を No. 1, 500 m 上昇するごとに No. を一つずつ増し、38 km 上空を No. 75 とする。この各高さに水平面を考え、この上面に当る第一次散乱光強度を計算した結果、次の四つの法則のあることが判明した。

1. 強度は太陽の高度に関係なく、各波長について高さが増すに従って減少する。
2. 強度は各高さ及び各波長につき、太陽高度が増すに従い増加する。
3. 強度が極大となる波長の値は各太陽高度につき、高さが増すに従い減少する。
4. 強度が極大となる波長の値は各高さにつき、太陽高度が増すに従い減少する。