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Determination of Extra-terrestrial Constant for the Dobson's Ozone Spectrophotometer

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ABSTRACT. In this paper some known techniques for the determination of Extra-terrestrial Constant, which figures prominently in the calculation of total amount of ozone have been presented with suggestions to reduce the subjective and other errors to a minimum.

1. From the measurements of Dobson's spectrophotometer using a specified wavelength pair, the total amount of ozone, x, is given by the following expression —

$$L=L_0-(\alpha-\alpha')\mu x-(\beta-\beta')m-(\delta-\delta')\sec z \quad (1)$$

The notation is conventional in accordance with the Observer's Handbook for the instrument. The constants $(\alpha-\alpha')$, the difference in the absorption coefficient of ozone for the two wavelengths and $(\beta-\beta')$ the difference in the respective atmospheric coefficients are known. L is obtained from measurements for each set of (μ, m). Under haze-free conditions the last term containing $(\delta-\delta')$ can be neglected, so that

$$L+(\beta-\beta')m = L_0-(\alpha-\alpha')\mu x \quad (2)$$

Thus once L_0, the extra-terrestrial constant, which is a characteristic of the spectrophotometer in use, has been fixed, the total amount of ozone can be calculated for each set of observations. L_0 is usually determined by taking observations at close intervals on an occasion when the amounts of ozone are expected to be fairly constant. Then the graph obtained by plotting the values of $[L+(\beta-\beta')m]$ against μ is a straight line, which on extrapolation to $\mu_0=0$ gives L_0, the extra-terrestrial constant.

2.1. For some places haze-free conditions are extremely rare and when ozone amounts also vary, even though slightly, the points given by the expression (2) above do not lie exactly on a straight line with the result that the attempt to fit a straight line and then carry out an extensive extrapolation to $\mu=0$, may easily introduce a large subjective error of the order of 10 per cent or more in the value of L_0. The scattering factor $(\delta-\delta')$ due to haze can, however, be eliminated by using two pairs of wavelengths. Rewriting expression (1) for the two pairs of wavelengths, say, A and D, we have

$$L_A = L_{0A}-(\alpha-\alpha')_A\,\mu x-(\beta-\beta')_A\,m-(\delta-\delta')_A\sec z \quad (3)$$

$$L_D = L_{0D}-(\alpha-\alpha')_D\,\mu x-(\beta-\beta')_D\,m-(\delta-\delta')_D\sec z \quad (4)$$

Since μ, m and $\sec z$ have nearly the same value and $(\delta-\delta')_A$ is nearly equal to $(\delta-\delta')_D$, we get by substituting the accepted numerical values of $(\alpha-\alpha')_A$, $(\alpha-\alpha')_D$, $(\beta-\beta')_A$ and $(\beta-\beta')_D$

$$x_{AD} = \frac{(L_{0A}-L_{0D})-(L_A-L_D)}{1\cdot388\,\mu} - \cdot009 \quad (5)$$

and similar expressions for other sets of wavelength pairs (Dobson 1957). When the observations are taken simultaneously for the wavelength pairs A and D, the differences $(L_{0A}-L_{0D})$ of the respective extra-terrestrial constants enter directly into calculation. Therefore, L_{0A} and L_{0D} need not be determined individually.

TABLE 1

25 October 1963 (Forenoon)

μ	2·201	1·804	1·616	1·473	1·404	1·326
$1/\mu$	·4543	·5543	·6188	·6789	·7123	·7541
$L=(L_A-L_D)$	—·7919	—·6298	—·5562	—·4990	—·4605	—·4334
$(L+\cdot 0125\ \mu)$	—·7644	—·6072	—·5369	—·4806	—·4429	—·4168
(a) L^*_0	·0500	·0500	·0500	·0500	·0500	·0500
P^*	·3825	·3768	·3751	·3727	·3636	·3645
(b) L^*_0	·1500	·1500	·1500	·1500	·1500	·1500
P^*	·4279	·4322	·4370	·4406	·4349	·4399
(c) L^*_0	·2000	·2000	·2000	·2000	·2000	·2000
P^*	·4507	·4599	·4718	·4745	·4704	·4777
(d) L/μ	—·3598	—·3491	—·3442	—·3388	—·3280	—·3268

Putting $L_0=L_{0A}-L_{0D}$ and $L=L_A-L_D$ in expression (5), we get

$$(L+\cdot 0125\mu)=L_0-1\cdot 388\mu x \qquad (6)$$

which is similar to expression (2) and gives the value of L_0 when the straight line represented by the plot of $(L+\cdot 0125\mu)$: μ is extrapolated to $\mu=0$, as before.

2.2. Measurements for three successive days taken from the records of New Delhi Ozone Laboratory and calculations are given in Tables 1—4. The technique already described is illustrated in Fig. 1 which shows that even after eliminating the effect of haze the points do not lie on a straight line, obviously due to normal experimental variations and slight variations in the value of the total amount of ozone. Under these circumstances, this technique can give rise to large subjective errors.

TABLE 2

26 October 1963 (Forenoon)

μ	2·094	1·676	1·410	1·314
$1/\mu$	·4775	·5967	·7092	·7610
$L=(L_A-L_D)$	—·7417	·5705	·4754	—·4316
$(L+\cdot 0125\mu)$	—·7155	·5495	·4578	·4152
(a) L^*_0	·0500	·0500	·0500	·0500
P^*	·3780	·3702	·3726	·3665
(b) L^*_0	·1500	·1500	·1500	·1500
P^*	·4258	·4299	·4435	·4426
(c) L^*_0	·2000	·2000	·2000	·2000
P^*	·4496	·4597	·4789	·4806
(d) L/μ	—·3542	—·3404	—·3371	—·3284

TABLE 3

27 October 1963 (Forenoon)

μ	2·414	1·945	1·730	1·591	1·434	1·326
$1/\mu$	·4143	·5141	·5780	·6285	·6973	·7541
$L=(L_A-L_D)$	—·9077	—·7108	—·6188	—·5586	—·4975	—·4559
$(L+\cdot 0125\mu)$	—·8775	—·6855	—·5952	—·5387	—·4796	—·4393
(a) L^*_0	·0500	·0500	·0500	·0500	·0500	·0500
P^*	·3968	·3911	·3854	·3825	·3818	·3815
(b) L^*_0	·1500	·1500	·1500	·1500	·1500	·1500
P^*	·4382	·4425	·4432	·4453	·4515	·4570
(c) L^*_0	·2000	·2000	·2000	·2000	·2000	·2000
P^*	·4587	·4673	·4721	·4767	·4863	·4946
(d) L/μ	—·3761	—·3654	—·3565	—·3511	—·3469	—·3438

TABLE 4

Mean values for 25, 26 and 27 October 1963

	$1/\mu$	·50	·55	·60	·65	·70	·75
(a)	P^*	·383	·380	·377	·376	·374	·371
(b)	P^*	·433	·435	·437	·441	·444	·446
(c)	P^*	·457	·462	·468	·474	·479	·484
(d)	L/μ	·358	·352	·347	·344	·339	·334

3.1. To avoid the long extrapolation, Dobson and Normand (1958) have suggested the following method which reduces the subjective error considerably.

When x, the total amount of ozone is constant, we have from expression (6),

$$(L_0-L)/\mu = \text{constant} \qquad (7)$$

An approximate value of L_0 is first obtained, say, by the method of extrapolation, and a nearly equal value L^*_0 is assumed, so that the difference $L^*_0-L_0=S$ (say) is a small quantity.

Again, let $P^*=(L^*_0-L)/\mu$ (8)

Substituting the value of L^*_0 in (8) we get

$$P^* = S/\mu + (L_0-L)/\mu$$
$$= S/\mu + \text{constant} \qquad (9)$$

The plot of $P^*:1/\mu$ is a straight line having the slope S, which is derived from the graph. Thus the true value of L_0 is obtained by subtracting S from the assumed value L^*_0, having due regard to the signs.

3.2. Except for stations at low latitudes the ideal conditions are rarely obtained, and the above graph for a day is rarely a straight line (Fig. 2a, b or c). The process has to be repeated for a number of successive days, when the total amount of ozone is expected to be fairly constant. The points given by mean P^* : $1/\mu$ graph for a number of days provide a better fit on a straight line as seen from the Fig. 3a, b or c.

3.3 The straight line given by the plot of mean P^* : $1/\mu$ can also be extrapolated to $1/\mu$ =0 to give the value of $(L_0-L)/\mu$ from which the value of L_0 can be deduced, but less accurately.

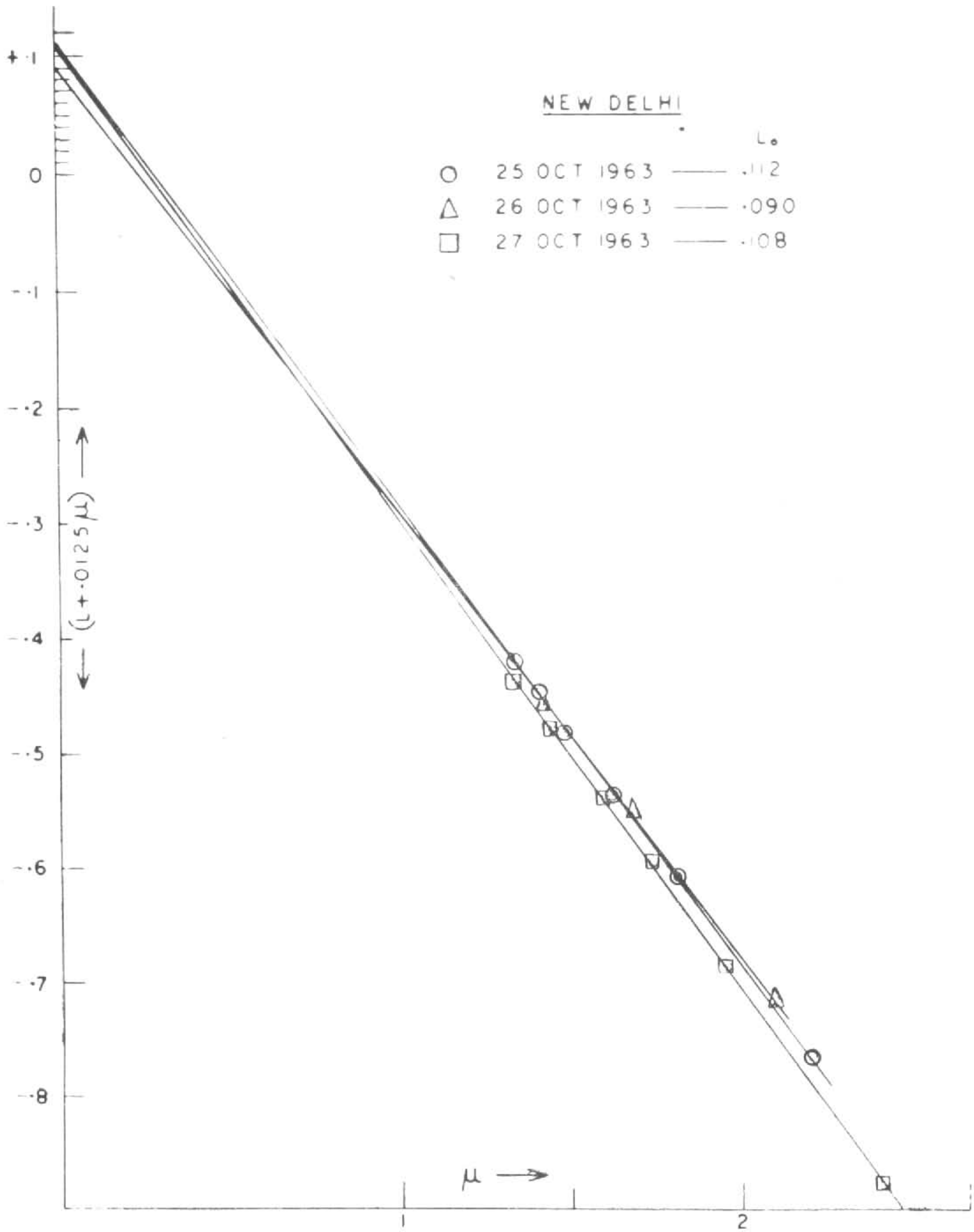

Fig. 1. Plot of $(L+\cdot 0125\mu):\mu$

The extra-terrestrial constant L_0 is obtained by extrapolation to $\mu=0$. The lowest and highest values of L_0 obtained by this method differ by about 20 per cent for the three days

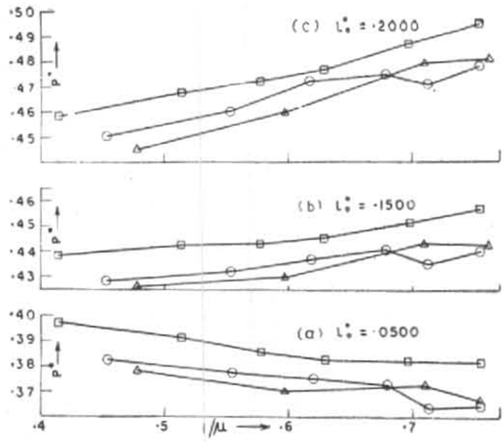

Fig. 2. Plot of P^*:$1/\mu$ with three sets of assumed values of L^*_0 = (a) ·0500, (b) ·1500, (c) ·2000

In each set, the circles, triangles and squares represent the points for 25, 26 and 27 October 1963 respectively. None of the graphs corresponding to any of the dates is found to be a straight line

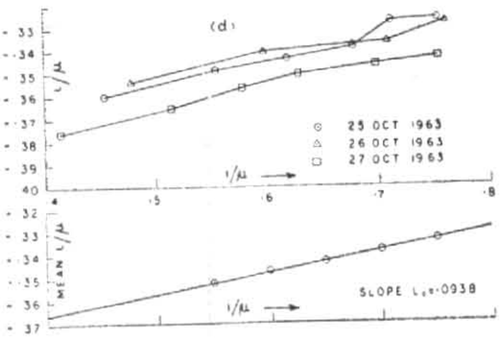

Fig. 4. Plot of (L/μ):$(1/\mu)$ for individual days is given in the upper figure (d) from which mean L/μ is obtained and plotted against $1/\mu$ in the lower figure. The slope gives the value of L_0 directly

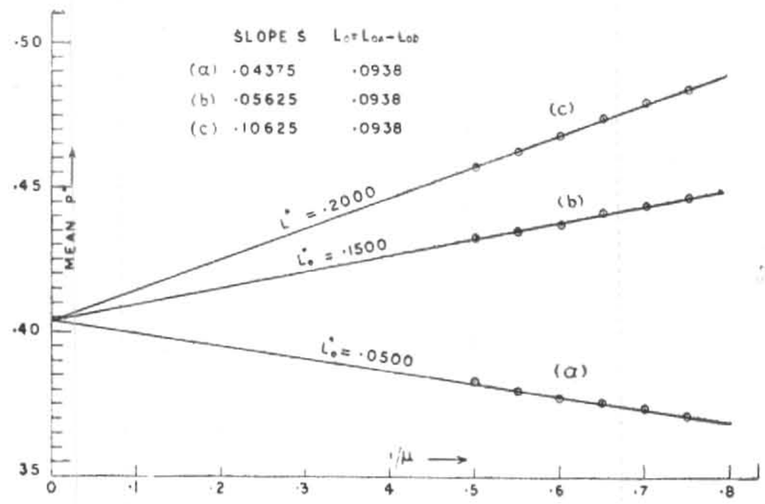

Fig. 3. Mean P^* obtained from each of the three sets (a), (b) and (c) of Fig. 2 has been plotted against $1/\mu$ (vide Table 4)

The graph mean P^* : $1/\mu$ is a straight line for the corresponding set and all the three straight lines meet on the P^* axis at ·408. The slope determined for each of the sets is indicated. The resulting L_0 is the same for all the three sets (a), (b) and (c).

TABLE 5

Extra-terrestrial Constant L_0

	Obtained from plot of	Date	L_0
(i)	$(L + \cdot 0125\mu) : \mu$	25 October 1963	·112
(ii)	Do	26 October 1963	·090
(iii)	Do	27 October 1963	·108
(iv)	$P^* : 1/\mu$ with $L^*_0 = \cdot 0500$	Mean of 25,26 and 27 October 1963	·0938
(v)	$P^* : 1/\mu$ with $L^*_0 = \cdot 1500$	Do	·0938
(vi)	$P^* : 1/\mu$ with $L^*_0 = \cdot 2000$	Do	·0938
(vii)	$L/\mu : 1/\mu$	Do	·0938

4. The graph resulting from a plot of mean $P^* : 1/\mu$ poses a problem when the points do not lie on a straight line, as subjective error is difficult to avoid. The solution lies in repeating the whole process for the same set of observations, with at least 3 different assumed values of L^*_0 and drawing the three mean $P^* : 1/\mu$ lines for the corresponding L^*_0 values.

Since $P^* = S/\mu + (L_0 - L)/\mu$, the intercept of the straight line given by the plot of $P^*:1/\mu$ on the P^* axis is $(L_0 - L)/\mu$, a constant. Therefore, all the lines given by this graph, will meet at the same point on the P^* axis whatever the assumed value of L^*_0. This feature enables us to position the lines correctly, so that each line gives the same value of L_0. Only under difficult atmospheric conditions and with varying amounts of ozone, the points will be too scattered to make the method a success. Therefore in using this method the days when large changes in ozone occur or days with considerable haziness should be omitted.

4.1. An example, with the same set of observations given in the tables and using three assumed values of L^*_0, *viz.*, ·0500, ·1500, ·2000 is illustrated in Fig. 3. The error in the determination of L_0 in this manner is expected to be less than 1 per cent.

5. In the techniques described in paras 3 and 4, a rough idea of the extra-terrestrial constant is necessary for the assumption of a value for L^*_0. We can dispense with the assumption of L^*_0 altogether, thereby doing away with much of the calculations in the following manner.

5.1. Rewriting expression (7), we get

$$L/\mu = L_0/\mu - \text{constant} \qquad (10)$$

Here the slope obtained from the plot of $L/\mu : 1/\mu$ gives the extra-terrestrial constant directly. But as explained earlier, the determination is to be carried out with the plot of mean $(L/\mu) : (1/\mu)$ for a number of successive days to arrive at an accurate value. The result is illustrated in Fig. 4.

6. Comparative values of $L_0 = L_{0A} - L_{0D}$ obtained with the use of different techniques described in this paper are given in Table 5.

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