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EFFECT OF DUST AND HAZE ON MEASUREMENTS OF ATMOSPHERIC OZONE MADE WITH DOBSON'S SPECTROPHOTOMETER*

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SUMMARY

To obtain the amounts of atmospheric ozone from measurements with Dobson's photo-electric spectrophotometer, allowance has to be made for the extinction of light by scattering due to molecules and large particles. Dobson has proposed two slightly different formulae which lead to appreciably differing values on hazy days. The assumptions involved in the formulae are examined and Dobson's equation is generalized, assuming the particle scattering to vary as λ^{-n}. The expression for the ozone amount is split up into two terms, the first main term being that obtained on the assumption of a pure atmosphere and the second correction term denoting the haze-scattering. On calculating the ozone amounts with different values of n, it is found that these show much greater consistency if n has a value intermediate between those assumed in Dobson's two formulae and somewhere near zero.

On hazy days in winter, it is observed that $(\delta' - \delta'')$, the differential haze-scattering for the long wavelengths 3300A and 4450A, is positive and its magnitude increases with increase in the haziness of the sky. This is similar to what is observed in Europe. But on most hazy days in the pre-monsoon hot season in North India, $(\delta' - \delta'')$ is found to be negative, which means that the apparent extinction of light at 3300A is *less than* that at 4450A.

One possible explanation is that with certain sizes of particles of given refractive index, the extinction by scattering increases with increase in wavelength as was found from observations by Götz in Switzerland and by Stratton and Houghton in U.S.A. An alternative explanation is that Dobson's instrument analyzes not only the transmitted radiation from the sun but also some scattered radiation from the surrounding hazy sky. It is probable that the North Indian summer haze scatters in the forward direction an appreciable amount of radiation which is richer in shorter wavelengths than the directly transmitted sunlight.

For calculating the daily values of ozone, it is proposed to assume the particle scattering to be nearly neutral and thus varying as λ^{-n} with $n=0$. The correction term in the generalized formula then becomes $0{\cdot}165\ (\delta' - \delta'')$ and is obtained from observations on the long wavelengths.

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DEFINITION OF SYMBOLS USED IN THE PAPER

Dobson's notation is used as far as possible.

I, I', I''	are the intensities of solar radiation transmitted by the earth's atmosphere at the three wavelengths $\lambda = 3110$A, $\lambda' = 3300$A and $\lambda'' = 4450$A,
I_0, I'_0, I_0''	the corresponding intensities outside the atmosphere,
β, β', β''	the scattering coefficients of the whole atmosphere due to small particles, *including but not solely consisting of* molecules.
β_1, β_1', β_1''	the coefficients of scattering *by molecules alone*,
δ, δ', δ''	the scattering coefficients of large particles,
α, α', α''	the absorption coefficients of ozone per centimetre at N.T.P.,
x	the thickness of ozone in the atmosphere in centimetres N.T.P.,
μ	the ratio of the thickness of ozone traversed by the solar radiation to the normal thickness, x,
m	the thickness of the atmosphere traversed by the radiation as a ratio to its normal thickness.

$$L = \log \frac{I}{I'}, \qquad L_0 = \log \frac{I_0}{I_0'};$$

$$L' = \log \frac{I'}{I''}. \qquad L_0' = \log \frac{I_0''}{I_0'};$$

$$K' = \frac{\lambda^{-4} - \lambda'^{-4}}{\lambda'^{-4} - \lambda''^{-4}} \qquad \text{and } K = \frac{\lambda^{-n} - \lambda'^{-n}}{\lambda'^{-n} - \lambda''^{-n}}$$

I. INTRODUCTION

While calculating the daily values of the amounts of atmospheric ozone over Delhi from direct sun observations with Dobson's photo-electric spectrophotometer (1931), it was found that the observations were of interest not only for calculating ozone but also for the indications they give of some of the scattering properties of the atmosphere. For example, on using Dobson's original formula, *viz.*

$$x = \frac{(L_0 - L) - K\,(L' - L_0')}{\mu\,\{\,(\alpha - \alpha') - K\alpha'\,\}} \quad . \quad . \quad . \quad (1.1)$$

the values obtained on days with very hazy skies were markedly different from those on the neighbouring clear days, although many of the hazy days were not associated with any considerable changes in barometric pressure or upper air temperatures. Examining the results on all hazy days during a year, it was found that the anomalies were of two types, hazy days in winter giving in general lower values of ozone and those in the hot season giving higher values. An effect similar to that observed at Delhi in winter had been found by Tφnsberg and Langlo Olsen (1943) working at Tromsφ in Norway and they accordingly used a simpler modified equation, *viz.*

$$x = \frac{(L_0 - L) - (\beta_1 - \beta_1')\,m}{\mu\,(\alpha - \alpha')} \quad . \quad . \quad . \quad (1.2)$$

also due to Dobson.

On recalculating the Delhi data with Eq. (1.2), it was found that contrary to what had been obtained with (1.1), hazy days in winter gave higher values of ozone and hazy days in summer lower values. On very clear days, both formulae gave practically identical results. This discrepancy suggested the need for examining further the question of the scattering of light by large particles on measurements of atmospheric ozone with Dobson's spectrophotometer. The results of the examination are summarized in the present paper.

While Dobson's original relation assumed that the scattering arising from particles other than molecules is partly neutral and partly varies as $1/\lambda^4$, Dobson's modified relation as used by Tφnsberg and Langlo at Tromsφ completely neglects non-molecular scattering. In this paper the effect of assuming the non-molecular scattering to be proportional to $1/\lambda^n$ is worked out, and in particular, the applicability of the values for $n=0$ and $n=1{\cdot}3$ is examined. The latter value was found by Ångström (1929) to hold on the average for the atmospheric transmission of solar radiation obtained by the Smithsonian workers. Some special features brought out by the Delhi observations show that the anomalies cannot be cleared up by any unique value of n. The values of the error that can be caused by haze on the measurements of x from direct sun observations are estimated.

After the examination had been completed, it came to our knowledge that, in 1941, Dr. Dobson had issued a circular in which, after analysing the results of many direct sun observations on days of varying haziness, and consulting other workers on the atmospheric transmission of sunlight, he had suggested formula (2·2). Using the values $\alpha=1{\cdot}26$, $\alpha'=0{\cdot}09$, $\beta=0{\cdot}47$ and $\beta'=0{\cdot}37$, Eq. (1.2) could be written as

$$x=\frac{L_0-L}{1{\cdot}17\mu}-0{\cdot}085 \quad . \quad . \quad . \quad (1.3)$$

when the sun is not too low and m/μ could be replaced by unity. Dobson had found that on days of haze, 0·085 had to be increased to a larger figure up to 0·100 and more, depending on the amount of haze.

2. EQUATIONS FOR CALCULATING OZONE AMOUNTS

The basic equations are:

$$\log I=\log I_0-\alpha x\mu-\beta m-\delta m \quad . \quad . \quad (2.1)$$

$$\log I'=\log I_0'-\alpha' x\mu-\beta' m-\delta' m \quad . \quad . \quad (2.2)$$

$$\text{and } \log I''=\log I_0''-\alpha'' x\mu-\beta'' m-\delta'' m \quad . \quad . \quad (2.3)$$

α'', the absorption due to ozone at 4450A, is practically equal to zero, and we get on combination,

$$\log\frac{I}{I'}=L=L_0-(\alpha-\alpha')\,x\mu-(\beta-\beta')\,m-(\delta-\delta')\,m \qquad (2.4)$$

$$\text{and } \log\frac{I''}{I'}=L=L_0'+\alpha' x\mu+(\beta'-\beta'')\,m+(\delta'-\delta'')\,m \qquad (2.5)$$

Dobson assumes that $\delta-\delta'=\delta'-\delta''=0$ and that

$$\frac{\beta-\beta'}{\beta'-\beta''}=\frac{\lambda^{-4}-\lambda'^{-4}}{\lambda'^{-4}-\lambda''^{-4}}=K,$$

and eliminating m, he gets

$$x = \frac{(L_0 - L) - K\,(L' - L_0')}{\mu\,\{(\alpha - \alpha') - K\alpha'\}} \qquad . \quad . \quad . \quad (1.1)$$

This method of obtaining $\beta - \beta'$ for the wavelengths 3110A and 3300A amounts to extrapolating its value from $\beta' - \beta''$ observed for the wavelengths 3300A and 4450A, by using the λ^{-4} relation. This assumes that the excess scattering over molecular scattering can be divided into two parts, one neutral (the δ terms) and the other governed by the λ^{-4} relation. It is a simple and convenient division but can lead to error if $\delta - \delta'$ becomes comparable in value to $\beta_1 - \beta_1'$ (where β_1 and β_1' are scattering coefficients due to *molecules alone*) and cannot therefore be neglected, or if the scattering by small particles does not follow the strict λ^{-4} relation. It very much depends on the amount of haze in the atmosphere and its differential effect on 3110A and 3300A.

In Dobson's modified relation as used by Tønsberg and Langlo, it is assumed that $\beta = \beta_1$, $\beta' = \beta_1'$ and $\delta - \delta'$ can be neglected. Eq. (2.4) then becomes

$$x = \frac{(L_0 - L) - (\beta_1 - \beta_1')\,m}{\mu\,(\alpha - \alpha')} \qquad . \quad . \quad . \quad (1.2)$$

It will be noticed that in this relation the long-wavelength observations are not used at all. Haze is completely neglected, an assumption that suits the air at Tromsø on most days. At places however where there is haze, the numerator in Eq. (1.2) would be too large because the dust-scattering term $(\delta - \delta')\,m$ has not been subtracted and this would lead to too large a value of x. On the other hand, in Dobson's original relation (1.1), an unduly large value of K is taken by assuming all non-neutral scattering to vary as λ^{-4} and this leads to too small a value of x.

3. ANGSTRÖM'S TURBIDITY MEASURE

Ångström (1930) as a result of his studies of the atmospheric transmission of solar radiation, introduced a measure of atmospheric turbidity in the form $\log I = \log I_0 - (\beta_1 + \delta)\,m$ where β_1 is the molecular extinction coefficient and δ the extinction coefficient due to dust. He showed on the basis of Lindholm's experiments with MgO, Sb_2O_3 and ZnO that δ could be expressed in the form $\delta = \gamma\lambda^{-n}$ where γ and n are independent of wavelength and $0 < n < 4$. He called n the size-exponent and γ the turbidity coefficient which, for constant n, is expected to be proportional to the amount of dust in the atmosphere. For particles of diameters from 0·25μ to 2·0μ, Lindholm found that n varied from 3·6 to 0·7. From the Smithsonian observations of atmospheric extinction coefficients, Angström concluded that n lay between 1·0 and 1·5 which corresponds to optically effective particles of diameter about 1·0μ. Under abnormal conditions such as those following volcanic outbreaks, n was found to decrease to 0·5 or less.

Linke and v. dem Borne (1932) modified Ångström's calculations by allowing for the variation of air mass with altitude and also making some corrections to the Rayleigh transmission coefficients. They found that the numerical value of the exponent increased with increase in height of the observing station. In general, the clearer and drier the air, the higher the value of n.

4. A GENERALISED EQUATION FOR OZONE AMOUNT

In view of the above, it is useful to consider how the equation for x will be modified if the dust-scattering is assumed to be proportional to λ^{-n}. Introducing β_1, β_1', β_1'', the scattering coefficients for molecules only, in place of β, β', β'', Eq. (2.4) and (2.5) can be written as

$$(\delta-\delta')\,m=(L_0-L)-(\alpha-\alpha')\,x\mu-(\beta_1-\beta_1')\,m \qquad (4.1)$$

and

$$(\delta'-\delta'')\,m=(L'-L_0')-\alpha'x\mu-(\beta_1'-\beta_1'')\,m \qquad (4.2)$$

Writing

$$K'=\frac{\delta-\delta'}{\delta'-\delta''}=\frac{\lambda^{-n}-\lambda'^{-n}}{\lambda'^{-n}-\lambda''^{-n}},$$

$$K'=\frac{(L_0-L)-(\alpha-\alpha')x\mu-(\beta_1-\beta_1')\,m}{(L'-L_0')-\alpha'x\mu-(\beta_1'-\beta_1'')\,m} \qquad (4.3)$$

$$\text{and } x=\frac{(L_0-L)-K'(L'-L_0)-m\,\{\,(\beta_1-\beta_1')-K'(\beta_1'-\beta_1'')\,\}}{\mu\,\{\,(\alpha-\alpha')-K'\alpha'\,\}} \qquad (4.4)$$

$$=\frac{(L_0-L)-K'(L'-L'_0)-m\,(\beta'_1-\beta_1'')\,(K-K')}{\mu\,\{\,(\alpha-\alpha')-K'\alpha'\,\}}. \qquad (4.5)$$

This has similarities of appearance to both (1.1) and (1.2). Comparing (4.5) and (1.1), it will be seen that they become identical when $K=K'=0.384$ corresponding to $n=4$. Judged from this approach, Dobson's original assumption was equivalent to making $n=4$ for molecular scattering and the non-neutral residue in haze-scattering. Similarly, comparing Eq. (4.4) and (1.2), it is seen that they become identical when $K'=0$, *i.e.* when $n=-\infty$.

Alternatively, and almost directly from (4·1), one may write

$$x=\frac{(L_0-L)-m\,(\beta_1-\beta_1')}{\mu\,(\alpha-\alpha')}-\frac{K'}{\mu\,(\alpha-\alpha')}\,.\,(\delta'-\delta'')\,m \qquad (4.6)$$

When the sun is not too low, $m/\mu\approx 1$ and (4.6) becomes

$$x=\frac{(L_0-L)-m\,(\beta_1-\beta_1')}{\mu\,(\alpha-\alpha')}-\frac{K}{(\alpha-\alpha')}\,.\,(\delta'-\delta'')$$

$$=x_T-\frac{K'}{(\alpha-\alpha')}\,.\,(\delta'-\delta'') \qquad (4.7)$$

It will be seen that the first term x_T on the right hand side is the same as that used by Tφnsberg and Langlo. The second term can be called the "haze term" and is a correction which depends on $(\delta'-\delta'')$, the differential dust-scattering, and on K' which is determined by the relationship we use to derive $(\delta'-\delta'')$ from $(\delta-\delta')$. $(\delta'-\delta'')$ can be obtained from the observations on the long wavelengths, the molecular scattering coefficients and $\alpha'x$. Since α' is small (0·074), $\alpha'x$ can be determined sufficiently accurately with an approximate value of x, say from x_T, the first term in (4.7). This is similar to the method of successive approximations in computing actual numerical values.

5. THE MAGNITUDE OF THE HAZE TERM IN EQUATION FOR OZONE AMOUNT

The second term in (4·7) would vanish either if $\delta' - \delta'' = 0$ or $K' = 0$. The latter alternative would mean $n = -\infty$ and is physically impossible. The values of K' and $K'/(\alpha - \alpha')$ for different values of n in the relation $K' = \dfrac{\lambda^{-n} - \lambda'^{-n}}{\lambda'^{-n} - \lambda''^{-n}}$ are given in Table I below. The value of K' when $n = 0$ can be obtained by expanding the terms and shown to approach the limit $\dfrac{\log_e \lambda/\lambda'}{\log_e \lambda'/\lambda''} = 0{\cdot}1983$ where λ, λ', λ'' have the values 3110, 3300 and 4450A.

TABLE I.—VALUES OF K' AND $K'/(\alpha-\alpha')$ FOR VARIOUS VALUES OF n
$(\alpha-\alpha') = 1.20$.

n	K'	$K'/(\alpha-\alpha')$	n	K'	$K'/(\alpha-\alpha')$
4	0·3837	0·320	−0·1	0·1948	0·162
2	0·2798	0·233	−0·5	0·1813	0·151
1·3	0·2488	0·207	−1·3	0·1562	0·130
0·5	0·2169	0·181	−2	0·1367	0·114
0·1	0·2019	0·168	−4	0·0915	0·076
0	0·1983	0·165	$-\infty$	0	0

The value of K' decreases as n decreases, continues to decrease when n becomes negative, and reaches 0 when $n = -\infty$. K' remains positive even when n is negative.

As regards $\delta' - \delta''$ which is equal to $\dfrac{L' - L_0}{m} - (\beta_1' - \beta_1'') - \alpha' x$, it is helpful to consider a few concrete instances. Table II gives the values of $\delta' - \delta''$ on a number of days, both clear and hazy, at Delhi and Simla.

The table also gives the calculated ozone amounts x_T assuming only molecular scattering and the corrections due to haze-scattering which would be applicable to x if haze-scattering varied with wavelength in proportion to λ^{-n} and n had the following values: −1·3, 0, 1·3 and 4.

The following general conclusions can be drawn from the figures in Table II.

(i) There is a marked positive correlation between the haziness of the sky as visually observed and the numerical value of $\delta' - \delta''$.

(ii) While in winter, the value of $\delta' - \delta''$ is positive, its value in the hot season is usually negative. The haze in the former season mainly arises from smoke or city dust, while in the hot season, the major part of the haze is desert sand raised by wind.

(iii) If x_T is the value of the ozone amount calculated on the assumption of a pure atmosphere, the correction to be applied to x_T on account of haze is largest when the haze is assumed to scatter according to the inverse fourth power law, and becomes smaller as the power decreases to zero and still smaller when it begins to vary with a positive power of the wavelength.

(iv) On very clear days in any season, the correction term is negligibly small whichever value of n is used. On moderately clear days, the maximum correction does not exceed 0·006 cm even with $n=4$.

(v) The facts that the magnitude of $(\delta' - \delta'')$ does not become enormously large even with the haziest of skies and that it changes sign with the season show that the scattering by haze is for the most part independent of wavelength.

TABLE II.—VALUES OF (i) $\delta' - \delta''$, (ii) CALCULATED OZONE AMOUNTS x_T ASSUMING ONLY MOLECULAR SCATTERING AND (iii) CORRECTIONS $K'\ (\delta' - \delta'')/(\alpha - \alpha')$ DUE TO HAZE-SCATTERING IF IT VARIED AS λ^{-n}, n HAVING THE VALUES -1.3, 0, 1.3 AND 4

Ozone absorption: $\alpha = 1.275$; $\alpha' = 0.074$
For Delhi (218 m a.s.l.): $\beta_1 = 0.457$; $\beta_1' = 0.361$; $\beta_1'' = 0.109$
For Simla (2.45 km a.s.l.): $\beta_1 = 0.353$; $\beta_1' = 0.279$; and $\beta_1'' = 0.084$

					$K'(\delta' - \delta'')/(\alpha - \alpha')$			
Place and season	*Date and nature of sky*	m	x_T $n = -\infty$ $K' = 0$	$\delta' - \delta''$	$n = -1.3$ $K' =$ 0.156	$n = 0$ $K' =$ 0.198	$n = 1.3$ $K' =$ 0.249	$n = 4$ $K' =$ 0.384
Delhi : Winter	12-1-47	1·90	0·208	0·002	0	0	0	·001
	very clear	2·10	0·208	0·000	0	0	0	0
	18-12-46	2·32	0·191	0·015	0·002	0·002	0·003	·005
	fairly clear	2·62	0·191	0·016	·002	·002	·003	·005
	17-11-46	2·57	0·171	0·053	·007	·009	·011	·017
	hazy	2·98	0·173	0·051	·007	·008	·011	·016
	19-12-45	2·33	0·169	0·121	·016	·020	·025	·039
	very hazy	3·17	0·165	0·111	·014	·018	·023	·035
Delhi : Hot season	24-5-46	1·25	0·190	−0·003	0	0	−·001	−·001
	v. clear	1·81	0·191	−0·003	0	0	−·001	−·001
	10-6-46	1·51	0·187	−0·020	−·003	−·003	−·004	−·006
	f. clear	1·79	0·190	−0·018	−·002	−·003	−·004	−·006
	11-5-46	1·38	0·179	−0·029	−·004	−·005	−·006	−·009
	milky	1·91	0·178	−0·028	−·004	−·005	−·006	−·009
	19-5-46	1·49	0·171	−0·067	−·009	−·011	−·014	−·021
	v. hazy	1·93	0·176	−0·053	−·007	−·009	−·011	−·017
Simla : Early hot season	16-4-47	2·21	0·195	−0·004	−·001	−·001	−·001	−·001
	v. clear	2·75	0·194	−0·003	0	0	−·001	−·001
	19-4-47	1·83	0·188	−0·005	−·001	−.001	−·001	− 002
	clear	2·10	0·189	−0·002	0	0	0	−·001
	23-4-47	1·75	0·187	−0·019	−·002	−·003	−·004	−·006
	milky	2·84	0·187	−0·017	−·002	−·003	−·004	−·006
	21-4-47	1·33	0·179	−0·024	−·003	−·004	−·005	−·008
	v. hazy	1·47	0·179	−0·024	−·003	−·004	−·005	−·008

6. SOME EXAMPLES OF THE EFFECT OF DIFFERENT POWER LAWS FOR HAZE-SCATTERING

The following examples will illustrate how the assumption of different power laws for the variation of haze-scattering with wavelength affects the calculated values of ozone amount.

(1) Fig. 1 shows the effect on a cloudless winter day in Delhi when there was marked haze between 10 and 11 hr due to the raising of dry ground haze by thermal turbulence. x_T, x_0, $x_{1.3}$ and x_4 are the values of the ozone amount calculated (*a*) when the atmosphere was treated as pure and no allowance was made for haze, *i.e.* when n in λ^{-n} was taken to be $-\infty$ and $K' = 0$, (*b*) when

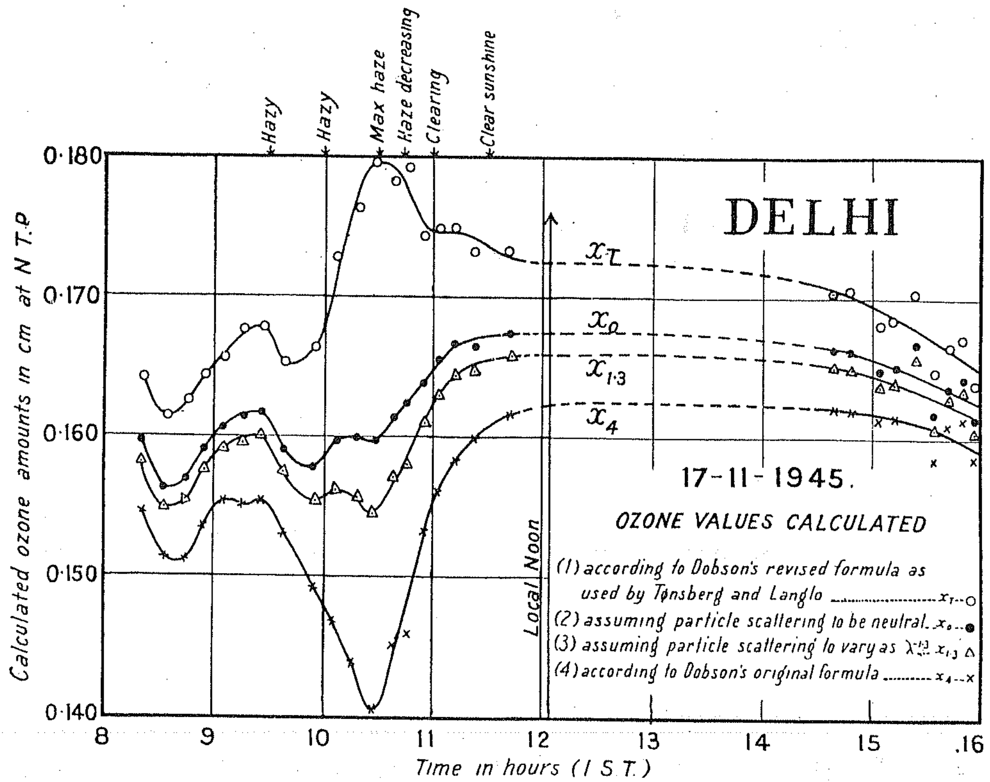

FIG. 1. Effect of assuming different formulæ for particle scattering on the calculated ozone amounts at Delhi on a winter day with marked haze. Note the scatter of values at the haziest part of the day.

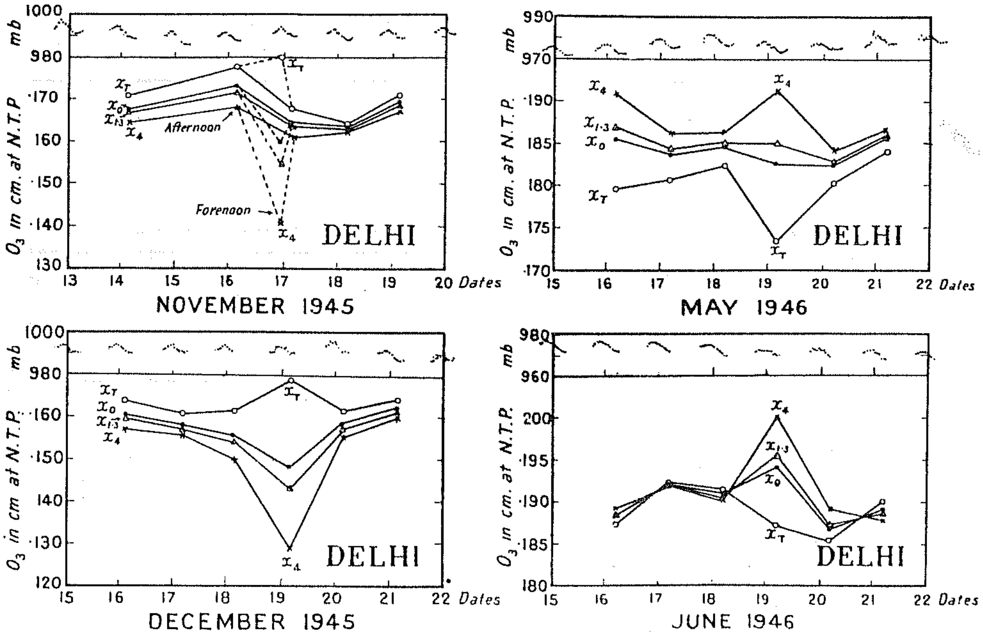

FIG. 2. Effect of assuming different formulæ for particle scattering on calculated ozone amounts at Delhi in winter and in the hot season. Afternoon observations on successive days including days with marked haze are given; forenoon observations are given for 17 November 1945 only. Some hourly readings of barometric pressure on each day are also given. Note the scatter of values on hazy days.

$n=0$ and $K'=0{\cdot}198$, (*c*) when $n=1{\cdot}3$ and $K'=0{\cdot}249$ and (*d*) when $n=4$ and $K'=0{\cdot}384$. x_4 is the value according to Dobson's original formula and x_T the value according to his revised formula for a pure atmosphere as used at Tromsφ.

It appears that the best fit for x would have been somewhere between x_0 and x_T and nearer x_0 than x_T.

(2) Fig. 2 shows similar values of x_T, x_0, $x_{1.3}$ and x_4 on a number of consecutive days in winter and in the hot season at Delhi. It may be noted that in the winter months November and December, the values of x_4 are the lowest and those of x_T the highest, while in the hot season months May and June, x_T is lowest and x_4 highest.

7. FURTHER DISCUSSION OF THE VARIATION OF HAZE-SCATTERING WITH WAVELENGTH

It seems clear that on a large number of occasions, the value of $\delta' - \delta''$ is negative. This means one of two things:

(1) Either the attenuation due to particle scattering at 3300A is smaller than that due to particle scattering at 4450A—which is anomalous—but has been observed elsewhere, particularly by Dr. F. W. Paul Götz (1932) in Switzerland, and explained on the basis of scattering by particles of a definite range of sizes in relation to wavelength, or

(2) The instrument is analyzing not directly transmitted light alone, but also some scattered light from the haze. If the scattered light is large in amount and comparable in intensity to the direct light from the sun, the mixed light may contain more of 3300A than of 4450A than the directly transmitted light alone.

(1) Following the investigations of G. Mie, Lord Rayleigh and others, Stratton and Houghton (1931) calculated the attentuation coefficients of light due to scattering by transparent spheres of refractive index 4/3 and showed that if the attentuation is expressed in the form

$$I = I_0 e^{-2\pi\nu r^2 \chi}$$

where ν is the number of particles per unit volume and r the radius of the particles, χ is a function of $2\pi r/\lambda$ whose value is as given in Table III below (1943):—

TABLE III

$2\pi r/\lambda$	0	2	4	6	8	10	11	12	16	20	30	40
χ	0	0·31	1·36	*1·93*	1·69	1·10	*0·88*	1·00	1·34	1·25	1·09	1·04

So long as $2\pi r/\lambda$ lies below 6, a decrease of wavelength for a given particle-size causes an increase of scattering, but when it lies between 6 and 11, a *decrease* of wavelength is accompanied by a *decrease* in scattering. With a suitable range of sizes of atmospheric particles, it can therefore happen that light of wavelength 4450A is scattered considerably more than light of wavelength 3300A, and there is evidence for this from the observations of Houghton in U.S.A. and of Götz in Switzerland.

(2) The character of the haze over north and central India during the dry months of the year undergoes a marked change

from winter to summer. The winter haze is dry ground-haze composed of inorganic and organic particles, mainly from places of human habitation. It is light brown in colour, generally settles during the night and rises up in the forenoon and gets dissipated by thermal turbulence and mixing with the upper air by noon. In the hot days of the pre-monsoon season, the haze is generally thicker, of a more permanent character and whitish in colour. Lapse rates are high in the first 4 or 5 km and with the rather frequent occurrence of dust-devils and dust-storms and sometimes of thunderstorms, the dust extends upwards into the atmosphere, and when the upper winds weaken, the haze persists over a large part of north India as a milky canopy. At small angles from the sun, the scattered light from the sky is of the same order of intensity as the directly transmitted light from the sun.

When taking direct sun observations with Dobson's spectrophotometer, the light from the sun is directed towards the slit of the instrument by means of a sun director, and over the slit is placed a ground quartz disc. According to the instructions issued with the instrument, " the position of the lens is adjustable, but for all standard measurements it should be in its lowest position. For certain special purposes, such as when a direct image of the sun is thrown on the slit, it is moved upwards, but the constants of the instrument are then changed, and readings are difficult." Such an adjustment allows not only light from the sun, but also light from some angular area of the surrounding sky to illuminate the ground quartz disc. If the particles are not of too large diameter and do not exercise selective absorption in the violet end of the spectrum, the scattered light will in general be richer in shorter wavelengths, though it may not be as rich as if Rayleigh's law of scattering were valid, and the quantity of light coming from an angular area of a few degrees of whitish sky round the sun would be comparable in amount with the directly transmitted light from the sun. This may account for the negative values of $(\delta' - \delta'')$ in the hot season when the sky is covered with white haze. Measurements are, however, required to establish this.

This effect would also occur in winter, but the haze in winter is generally much less thick. Moreover, if the particles show greater absorption in the blue end of the spectrum as organic matter and city haze usually do, there will not occur the same excess of light of shorter wavelengths in the scattered light.

8. CHOICE OF SCATTERING EXPONENT FOR CALCULATING DAILY VALUES OF OZONE

It now remains to choose a reasonably satisfactory value of n for the exponent in the dust-scattering term for calculating daily values of ozone. A single value of n for different seasons or even for different days in the same season can at best be only a compromise. It is known that, besides the small particles of Rayleigh scattering, there do exist in the atmosphere particles which are intermediate in size between the Rayleigh particles and the large particles which scatter strictly neutrally. But the effective value of n to be used will depend upon the relative abundance of the large particles and these intermediate particles. Though Ångström's value $n = 1\cdot3$ might be reasonably good for normal conditions, it is likely to be too high on hazy days and too low on very clear days and at high level stations.

It appears from Figs. 1 and 2 that the best fit for x would have been somewhere between x_0 and x_T and nearer x_0 than x_T, so that the value $n=0$ seems to be more reasonable than either a positive or negative power of λ. Moreover, it is seen from the magnitudes of the " haze term " in Table II that the difference in the calculated ozone amounts does not exceed 0·005 cm, even on the haziest days, by adopting $n=0$ instead of $n=1\cdot3$; on clear days it is immaterial which value of n is adopted. The assumption of strictly neutral scattering thus seems to be a good all round approximation. In this case, the formula for x would be

$$x = \frac{(L_0 - L) - (\beta_1 - \beta_1')\, m}{\mu(\alpha - \alpha')} - \frac{0\cdot198}{(\alpha - \alpha')}\,(\delta' - \delta'').$$

In addition to the short wavelength observations, observations have also to be taken for the long wavelengths 3300A and 4450A and these latter used to calculate $(\delta' - \delta'')$. If $(\alpha - \alpha')$ is assumed to be 1·20, the correction term becomes $0\cdot165\ (\delta' - \delta'')$**

9. ACKOWLEDGMENT

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**Although Ångström's exponent $n = 1.3$ has been used for calculating the ozone amounts at Delhi in a paper recently published (Proc. Ind. Acad. Sci., 1948, Vol. 28, p. 63), later considerations suggest that the assumption $n = 0$ would be more generally acceptable. It is proposed to use it for routine calculations hereafter.