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The effect of secondary scattering in the calculation of the vertical distribution of atmospheric ozone from the Götz inversion-effect

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To determine the vertical distribution of ozone in the atmosphere, two methods are in general use : (*a*) measurement of the intensities of lines in the solar spectrum in the Hartley band from photographs taken at different heights in the atmosphere with spectrographs sent up with sounding balloons (E. and V. H. Regener 1934, E. Regener 1952), or in V_2 rockets (U.S. Nav. Res. Lab. 1947, Götz 1951) and (*b*) by analysing the ratio (I/I') of the intensities of the light coming from the zenith sky at different zenith distances of the sun in two narrow spectral bands, say λ 3112 and λ 3323, the first of which is in the ozone-absorption region and the other just outside that region (Götz *et al.* 1934). The phenomenon discovered by Götz that the ratio I/I' decreases with increasing zenith distance of the sun up to about 85° and increases thereafter is known as the ' umkehr ' or inversion-effect.

The calculation of the ozone distribution from the inversion-effect assumes that $I/I' = P/P'$ where P and P' are the intensities of the light *primarily* scattered downwards along the vertical by the molecules of the air, making due allowance for the attenuation of the light by molecular scattering and ozone absorption. The neglect of higher orders of scattering in the calculation of I/I' is a source of error in the determination of vertical distribution.

The error involved would be expected to be small if the scattering and absorption coefficients for λ 3112 and λ 3323 were nearly the same; for then, multiple scattering will affect I and I' by nearly the same factor and we are concerned with I/I'. Actually the absorption coefficient of ozone for λ 3112 is much larger than that for λ 3323 and as a consequence there will be, at low altitudes of the sun, comparatively much more multiply-scattered light of λ 3323 from the denser, lower part of the atmosphere than of λ 3112. The observed ratio I_{3112}/I_{3323} will be smaller than the calculated ratio P_{3112}/P_{3323}.

It should be possible to calculate the effect of the multiple scattering in the zenith sky light by the methods introduced by Chandrasekhar (1950), but that has not yet been done. In the meantime, actual measurements of the umkehr effect made on the same morning or evening with different pairs of wavelengths enable us to obtain some idea of the errors involved in neglecting multiple scattering.

A Dobson ozone spectrophotometer of the modified type in which the shorter wavelength can be varied from about 3040 A to 3200 A and the longer from 3240 A to 3430 A has been in regular use at Mount Abu (24° N.) since October 1951. With the cloudless weather which prevails at this station for nearly nine months in the year, it has been possible to obtain umkehr-curves from the zenith sky on the same day for the pairs of wavelengths 3112-3323 and 3075-3278 on a number of days. The vertical distributions of ozone have been calculated from observations on each of these pairs of wavelengths and also with the pair 3112-3075 by eliminating the effects of 3323 and 3278. When the wavelengths under comparison are 3112 and 3075, both of which are strongly absorbed by ozone, the effects of multiple scattering on the two wavelengths roughly balance out each other. Similarly when the little-absorbed wavelengths 3323 and 3278 are compared, there is again an approximate balance.

The vertical distribution obtained from observations on wavelengths 3112-3323 is nearly the same as that obtained from those on 3075-3278 but the distribution obtained with 3075-3112 is markedly different, the centre of gravity of ozone in the last case being lower.

Table I gives comparative figures of distribution for 3 days with ozone amounts 0·153 cm, 0·188 cm and 0·209 cm respectively.

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TABLE I. VERTICAL DISTRIBUTION OF OZONE FROM GÖTZ INVERSION-EFFECT AT MOUNT ABU (24° 40′ N), INDIA.

Each layer is 9 km thick. Layer 1 is 0-9 km, layer 2, 9 km-18 km, etc.

Date	$10^3 \times$ amount of O_3 in cm	Pairs of wave lengths used	Amount of O_3 in different layers 1	2	3	4	5	6
21 Oct. 1951	153	(a) 3075/3278	9	9	62	59	9	5
		(b) 3112/3323	0	9	62	68	12	3
		(c) 3075/3112	9	18	78	41	5	3
		(c) − (b)	9	9	16	− 27	− 7	0
5 Feb. 1952	188	(a) 3075/3278	0	16	97	54	13	7
		(b) 3112/3323	0	18	99	53	14	4
		(c) 3075/3112	9	27	103	40	5	5
		(c) − (b)	9	9	4	− 13	− 9	0
7 Feb. 1952	209	(a) 3075/3278	5	13	111	63	13	5
		(b) 3112/3323	9	13	111	64	11	1
		(c) 3075/3112	0	18	131	36	15	8
		(c) − (b)	− 9	5	20	− 28	4	7

In all three instances, the effect of the substitution of λλ 3075-3112 for 3112-3323 or 3075-3278 is to increase the ozone content in the layers 9 km to 27 km and decrease it in the layer 27 km to 36 km. The maximum day-to-day variations occur in the layer 18 km to 27 km. The lowering of the centre of gravity of the ozone as a result of these revised calculations enhances the significance of ozone measurements for elucidating movements in the upper troposphere and lower stratosphere even in sub-tropical latitudes.

These results and also the day-to-day vertical ozone distributions will be discussed more fully elsewhere.

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