STUDIES IN ATMOSPHERIC OZONE

presented

by

BH.V.RAMANA MURTHY

for

the degree of

DOCTOR OF PHILOSOPHY

of

THE UNIVERSITY OF BOMBAY.

June, 1963.

PHYSICAL RESEARCH LABORATORY
AHMEDABAD.

PREFACE.

The thesis contains some of the investigations carried out during the period 1960-63 on the subject of Atmospheric Ozone. A scheme of research work on "Ozone and Weather" under Dr.K.R.Ramanathan is being supported by the Indian Council of Scientific and Industrial Research. I was the recipient of Senior Research Scholarship from the Council during this period.

In the early stages of the work, Mr.S.V.Karandikar helped me to assemble and calibrate spectrophotometer No.39, for which I am thankful to him.

My colleague Mr.R.N.Kulkarni has been responsible for taking most of the regular observations at Mt. Abu and making the connected calculations.

Messrs Sanyal and Kalyansundaram of the India Meteorological Department were responsible for taking the regular observations at Delhi.

The observations and the calculations for the special studies discussed in the thesis were made by me.

I am thankful to Mr.S.V.Venkateswaran for helping

me to prepare the diagrams and tabular material for the thesis. His help was invaluable at a time when my general health had failed.

Finally, I am grateful to Dr.K.R.Ramanathan who has guided the work at all stages.

Bh.V.Ramana Murthy.

C O N T E N T S.

I. INTRODUCTION.

1. Astronomers had found that the spectrum of the sun ended abruptly in the ultraviolet at about 3000 A. Cornu in 1879 investigated this question and suggested that the limitation of the spectrum was caused by a permanent constituent in the atmosphere which was neither water-vapour nor carbon-dioxide. In 1881, Hartley discovered the remarkable absorptive properties of ozone in the ultra-violet and found that an amount equivalent to 0.45 mm of the gas at atmospheric pressure could blot out the whole solar spectrum from 2930 A to 2320 A. He concluded that the permanent constituent limiting the solar spectrum could be ozone present in the upper levels of the atmosphere. In 1890, Huggins(1) discovered certain bands in the spectrum of Sirius between 3400 A to 3000 A. The work of Ladenburg and Lehmann(2) in 1906, and of Fowler and Strutt(3) in 1917 established that these bands were observable in the spectrum of other stars also and were due to absorption by atmospheric ozone.

Spectrum photographs of the sun taken at higher altitudes such as Mt. Rose in Switzerland and from balloons showed that most of the ozone was situated above 9 km.

Fabry and Buisson(4) began a systematic study of the subject in 1912 and developed the spectrographic method of determining the amount of ozone in the atmosphere. They repeated the quantitative laboratory experiments of Meyer on the absorption of ozone in the ultraviolet. They then photographed the solar spectrum between 3000 and 3340 A at varying solar zenith distances. Measuring the ratio of the intensities of light of different wavelengths in the solar spectrum in the ozone absorption region at known zenith distances of the sun, and using the laboratory absorption coefficients of ozone and Rayleigh-scattering coefficients of the atmosphere for the wavelengths used, they calculated the total amount of ozone present in the atmosphere. From measurements made on fourteen days in May and June 1920, Fabry and Buisson(5) found that the average amount of ozone was equivalent to a layer of pure ozone about 3 mm thick at standard temperature and pressure.

Later, Dobson developed a compact photographic spectrograph for measuring the total quantity of ozone. In this instrument he used a simple and efficient filter of bromine vapour and chlorine to eliminate the scattered light from the brighter parts of the spectrum from affecting the photographic plate. An optical wedge placed near the photographic plate with the angle of the wedge in the direction of the width of the spectral lines was used to attenuate the spectrum and photometric measurements were made on the photograph.

Day-to-day observations for the determination of the total amount of ozone were started by Dobson[6] in 1925 at Oxford and his observations showed in a clear manner that there was a definite correlation between the amount of atmospheric ozone and the barometric pressure at the surface, the ozone amount decreasing before the passage of a depression and showing a pronounced rise after it.

Dobson then started on a program of collecting data of ozone amounts from a number of stations. His first network consisted of six north-west European stations at which simultaneous observations were made with the same type of photographic spectrograph during the years 1925-28. The spectrograms were developed and photometered at Oxford. Dobson then redistributed his instruments to six stations over the globe in widely separated latitudes from Christchurch in New Zealand (44° S) to Spitzbergen (78° N) in the Arctic. One of the instruments was located at Kodaikanal in S.India (10° N). The results obtained from this world survey were summarised by Dobson and his collaborators in a few papers.[7],[8],[9]. The following were the main conclusions :-

(a) At each place, the total ozone amount undergoes a regular seasonal variation, the maximum being in spring (March-April in the northern hemisphere) and the minimum in autumn (October in the northern hemisphere).

(b) The amplitude of the seasonal variation is a function of the latitude, being large in polar latitudes (60° to 68° N) and small near the equator. In April, there is strong contrast between the amounts in different latitudes : (0.18 cm near the equator and 0.33 cm near 65° N). In September the differences are much smaller (0.18 to 0.28 cm). Equatorial regions are thus regions of small ozone content and small annual variation. As the latitude increases, both the total amount and the annual variation increase with increasing latitude upto at least 68° (Abisko).

The rate of increase of ozone with latitude is not uniform, but increases rapidly on crossing the region of the subtropics, towards the poles, particularly in spring and winter.

(c) In addition to the seasonal variation, there is at each place a day-to-day variation of ozone amount. These variations are related to weather. In middle and high latitudes, high values of ozone are found in the rear of cyclones and low ozone is associated with anticyclonic weather. The correlation with certain upper air conditions, such as the height of the tropopause and the potential temperature at 18 km were found to be even more significant.

A.J.Higgs[10] and Lejay[11a,b] used Dobson-type spectrographs to obtain measurements of the total amount of ozone at the Commonwealth Observatory at Canberra, Australia (35° S) and at the Zo-Se observatory near Shanghai in China (31° N) respectively.

2. Work done in India :

Ozone spectrograms were obtained at the Solar Physics Observatory, Kodaikanal, for one year in 1929 as part of Dobson's world survey. Later, Chiplonkar,[12] using the same spectrograph, made daily measurements of total ozone in Bombay in 1939. His results were in general agreement with those obtained at Kodaikanal both as regards the amount and the small amplitude of the seasonal variation. An interesting point however emerged from the Bombay observations, viz. the occurrence of a secondary seasonal minimum of ozone during the monsoon months. No correlation could be found between the day-to-day changes in ozone and surface meteorological conditions.

The single spectrograph and photographic photometry provided much valuable information, but the method is inconvenient for day-to-day use. Dobson's[13] next development of the photoelectric spectrophotometer greatly helped the advance of the subject, particularly on the meteorological side. In this instrument the photometry is direct and measurements can be made even when the light is very feeble. Observations can also be made with the light from the zenith sky. In the first model of Dobson's photoelectric spectrophotometer, a photocell with an amplifier was used to detect the feeble ultraviolet radiation. A double monochromator was used to select out the wavelengths and suppress scattered light of unwanted wavelengths.

One such instrument was acquired by the India Meteorological Department in the year 1939. The instrument was first set up in Poona and measurements commenced by Dr. Ramanathan. In 1945, Karandikar [14] started work with Dr. Ramanathan. An extensive study of atmospheric ozone in low latitudes has followed. Regular daily observations have been made for varying periods at Poona (18° 31' N), Delhi (28° 35' N), Simla (31° 06' N) and Kodaikanal(10°13'50"N). The effect of scattering by dust and haze on the measurements of atmospheric ozone by measurements on direct solar radiation was critically examined.[15,16]

The following are the main results of their work :-

(a) The Delhi observations showed the normal seasonal variation of ozone appropriate to its northern latitude. The amplitude of variation was larger than that at Bombay (19° N) but markedly less than at Shanghai (31° N).

(b) The day-to-day variations of ozone were very small during the period of the monsoon, just as in Bombay and Kodaikanal.

(c) During the season of western disturbances there were marked fluctuations in ozone amount; some sudden large rises and falls in ozone were associated with the passage of low pressure troughs.

3. Vertical distribution of ozone :-

J. Cabannes and Dufay,( ) and Gotz and Dobson(17), following a method originally suggested by Fabry, had made rough estimates of the height of atmospheric ozone in 1925-27 from photometric measurements of the spectrum of direct sunlight at different altitudes of the sun and obtained a mean height for it of 40 to 50 km. The method depends on the fact that the law of increase of path of the sun's rays in an atmospheric layer in a spherical atmosphere depends not only on the zenith distance of the sun but also on the height of the atmospheric layer above the ground. The method is of historical interest but is not capable of much accuracy.

In 1929 F.W.P.Gotz,(18) working in Spitzbergen, discovered that the light scattered from the zenith sky was relatively richer in shorter wavelengths in the ozone - absorbing region of the spectrum when the sun was low than when it was some degrees higher up in the sky. This is known as the umkehr-effect. The development of Dobson's photoelectric spectrophotometer made it possible to take reliable observations of zenith sky intensities when the sun was low over the horizon. Gotz, Meetham and Dobson (19) developed Gotz's discovery and worked out methods for calculating the vertical distribution of ozone from such observations. They then calculated the distributions for different amounts of ozone over Arosa( ) (47° N). Meetham and Dobson (20) used the same method to determine the distribution over Tromsø (69° 40' N). The height of maximum ozone contents over Arosa was found to be about 22 km and the ozone amount decreased with height at higher levels.

In 1934, E and V.H.Regener (21) made a direct study of the vertical distribution of ozone by sending up quartz spectrographs in balloons and obtaining photographs of the solar spectrum at different altitudes. They confirmed that the maximum density of ozone occurred at about 24 km, as had been deduced from zenith sky observations by Gotz, Meetham and Dobson. At about the same time, American investigators (22) sent up a spectrograph in a manned stratosphere balloon (Explorer II). Spectrograms obtained from V_2 rockets (23,24 in recent years have shown that there is detectable ozone amount even up to 65 km.

Information on the height distribution of atmospheric ozone in low latitudes came from the work of Karandikar and Ramanathan ( ) in India. Umkehr measurements were made at Poona, Delhi, Simla and Kodaikanal with Dobson photo-electric spectrophotometer. Recently a large number of observations of the umkehr effect made at Mt. Abu have been discussed by Ramanathan and Kulkarni (25). While the general nature of the results obtained in these latitudes is in conformity with those obtained at higher latitudes, the amount of ozone in the troposphere is found to be invariably very small. The average height of ozone has been found to vary from 25 to 30 km.

4. Problems of atmospheric ozone :-

Although within the last thirty years a great deal has been learnt about atmospheric ozone, there still remain several problems about which our knowledge is very incomplete. There is no doubt that ozone is formed by the photochemical action of sunlight,(26,27) but the actual average distribution that we find over the earth is not the equilibrium distribution under the photo-chemical action of sunlight alone. Conditions are not static; winds and turbulence move and mix up the air containing ozone. Part of the ozone is destroyed by catalytic or chemical action with constituents carried up from the lower atmosphere. The day-to-day changes of ozone that we observe with changing weather in certain parts of the world and the almost complete absence of such changes in other parts of the world are phenomena whose meaning we have not yet understood. We know however that these changes are intimately bound with movements in the upper atmosphere and there is reason to think that measurements of atmospheric ozone and its vertical distribution would enable us to get a new viewpoint from which we can study the complex phenomena of the earth's atmosphere. For example, Dobson noticed, at an early stage of his work, that high values of ozone occurred on the rear side of low pressure areas and low values in high pressure ridges. Later, he arrived at the conclusion that in many occlusions, the maximum deviation of ozone occurred directly over the surface low-pressure centre rather than in its rear as was formerly thought. Palmen (28) pointed out that the region of maximum ozone coincided with the tropopause vortex and since the upper level isobars were displaced to the rear with respect to surface isobars, there was reason to expect that positive deviations of ozone would occur on the rear side of the surface cyclone. But no two depressions are exactly alike and it has been found difficult to lay down hard-and-fast rules.

From the work of Karandikar, ( ) it became clear that in India some western disturbances produced quite large fluctuations in the total ozone amount, though the varying weather of the monsoon months showed no such effect. Again, not all active western disturbances affected the ozone. More observations in different sectors of disturbances, both of the total ozone amount and its vertical distribution were therefore necessary.

The International Ozone Commission under the chairmanship of Prof. Dobson is carrying out an extensive study of the changes of ozone with weather in W. Europe. The work is yielding extremely valuable results. It was believed that a detailed investigation of the ozone distributions and their changes in the transition region between the westerlies of temperate latitudes and the upper easterlies of the tropics would add substantially to our understanding of the general circulation of the earth's atmosphere.

5. Scope of the present work :-

A scheme of work on atmospheric ozone with this object in view was proposed to the C.S.I.R. in India by Dr.Ramanathan and accepted by them in 1950. Its aim was to establish, in the first instance, three observing stations equipped with Dobson Spectrophotometers which were calibrated so as to give strictly comparable results. It was decided that one of the stations would be Mt.Abu, 4000 ft. above sea-level and about 100 miles north of Ahmedabad, and another would be Delhi, the head-quarters of the India Meteorological Department. A third station is now at Ahmedabad but will be shifted either to Veraval(20°55'N) or to a suitable place in the Himalayas. Observations commenced at Mt.Abu in October 1951. The instrument at Delhi was recalibrated and brought into working condition, and actual measurements were started in January 1952. The author has been working on this scheme ever since its commencement.

The material presented in this thesis is a summary of the work done by the author towards 'a study of the day-to-day variations in the amount and height distribution of ozone in relation to weather in sub-tropical latitudes.' A number of interesting results have emerged as by-products.

A. Dobson and Normand (29) selected four pairs of wavelengths viz.

$\frac{3054}{3253}$; $\frac{3085}{3291}$; $\frac{3112}{3323}$ and $\frac{3175}{3399}$ in the ozone absorption region of the Hartley-Huggins bands for the measurement of atmospheric ozone and its vertical distribution. They had good reasons for making these selections. Out of these four, the pair $\lambda\lambda$ 3112/3323 is normally used as a standard for day-to-day ozone measurement. The other three pairs are used for special observations and check-up. The total amount of ozone in the atmosphere is usually calculated from measurements of the ratios of the intensities of light of two wavelengths (3112 & 3323) in direct sunlight at known zenith distances of the sun.

Corrections have to be introduced for the attenuations caused by scattering by dust or haze. The haze factor is very variable. It can be eliminated if observations are made on one more pair of wavelengths and the law of dependence of haze scattering on λ is assumed. The correction becomes very simple if the new pair of wavelengths for the additional observations is near the primary pair. It was thought desirable therefore, to use two or three of the four standard pairs of wavelengths for daily measurements of ozone. With this end in view, a series of observations were made on these different pairs and also on a number of other pairs to see if the ozone amount obtained would be the same whatever be the wavelengths employed for the measurement. We were confronted in the beginning itself with some significant differences, one of them being in the region of Dobson's second standard pair $\lambda\lambda$ 3085/3291. This prompted us to go further into the problem and it became ultimately clear that the region 3080-3100 A could not be used for ozone measurements without modifying the laboratory values of absorption coefficients. The results of this study and the meaning of the results are discussed in Chapter III.

E. Karandikar ( ) had noticed in the course of his work at Delhi that the value of the ozone amount became a minimum at about local noon. With a view to check the results of Karandikar, hourly observations were made at Mt.Abu in

February, March and in November 1952 on a number of days of clear weather when ozone was not changing; the November observations did not show the peculiarity noticed by Karandikar. Mme. Vassy and M.Abdul Khaleq (30) working at Kabul have recently reported that their observations are in general agreement with those obtained by Karandikar. These results are discussed in Chapter IV. The question is difficult and cannot be considered as closed.

C. From the photochemical theory of atmospheric ozone, one should expect that the total ozone should show an increase during night hours. Barbier, Chalonge (31) and E.Vassy made a number of observations in Switzerland by means of a star spectrograph but found no appreciable diurnal variation. Dobson's (32) measurements made at Oxford in November-December 1949 showed variations of ozone on some nights and he concluded that they were to be expected from the meteorological conditions. This question was thoroughly examined by us, both at Ahmedabad and at Mt.Abu on a number of occasions and we could establish that a definite increase in ozone amount took place shortly after sunset and a decrease shortly after sunrise. A summary of these results is given in Chapter IV.

D. Till now we had very little knowledge regarding the day-to-day changes in the vertical distribution of ozone for any station on the globe. With the persistent clear skies at Mt.Abu, it has been possible to take zenith sky observations on a number of successive days during a large part of the year. Kulkarni ( ) measured the umkehr effect on 112 days during the period October 1951 to November 1952 and the analysis of the observations revealed the following features :-

(a) Most of the changes in ozone take place in the layer 18 to 27 km.

(b) The largest increases occur shortly before or after the passage of centres of western depressions across the longitude of Abu.

(c) There is high positive correlation between the total ozone amount and the amount in 18-27 km.

Some of the changes noticed by Ramanathan and Kulkarni in the vertical distribution associated with weather are discussed in this thesis in Chapter V.

E. In the usual calculation of the vertical distribution of ozone from zenith sky measurements, the effect of secondary scattering is neglected. Calculation of the ozone distribution from the umkehr effect assumes that the ratio I/I' = P/P' where P and P' are the intensities of light primarily scattered downwards along the vertical by the molecules of the air, making due allowance for the attenuation of 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 the vertical distribution of ozone, Dobson and others assumed that the secondary scattering would affect the short and long wavelengths in the same ratio as primary scattering.

A modification in the present method of calculating the vertical distribution from umkehr observations has been suggested by Ramanathan (33) and tried out for reducing the effects of secondary scattering. Umkehr measurements made on the same morning or evening with <u>different</u> pairs of wavelengths enabled us to obtain an idea of the errors involved in neglecting multiple scattering. A marked lowering of the centre of gravity of ozone resulted on all such occasions when the calculations were made with different pairs of wavelengths ($\lambda\lambda$ 3112/3323 and $\lambda\lambda$ 3075/3378). A full discussion of the method employed and the results obtained are given in Chapter V.

E. The results of simultaneous observations of ozone made at Abu and Ahmedabad are summarised. Some of the rapid changes of ozone observed in winter and spring in association with western disturbances are described and discussed in relation to upper air conditions.

A general description of the results of the simultaneous observations made at Ahmedabad, Abu and Delhi is given. The observations suggest that the lowest ozone amounts over the earth occur not near the equator but on the southern side of upper air jet streams in the transition region between the tropical and temperate latitude stratospheres.

II. INSTRUMENTS AND THEIR ADJUSTMENT.

1. Instruments in use :-

There were three Dobson photoelectric spectrophotometers available for taking ozone observations in India. Two of them (No.36 and 39) were of the latest design made by Messrs R. & J. Beck, London. The third instrument (No.10), belonging to the India Meteorological Department, was of the older type with a photoelectric cell instead of a photomultiplier.

The Instrument No.36 was acquired by the India Meteorological Department in 1951 and installed at Delhi. The author assisted the workers in Delhi in setting it up and calibrating the wedges. The calibration was made on a number of clear days utilizing the same perforated zinc gauze that was used with the other two instruments. The original calibration curve, supplied by the makers, was found to have had a wholesale shift. A new calibration chart showing -Log(I/I') values against dial reading was therefore prepared in the usual way. The nature of the curve remained the same. Regular observations were commenced in January 1952.

Instrument No.39 belonging to the Physical Research

Laboratory, Ahmedabad, was installed at Mt.Abu (Lat.24°26'N, Long.72°43'E, height a.s.l.4000 ft.) in October 1951. The optical wedge of the instrument was recalibrated both at Ahmedabad and at Mt.Abu and the instrument is now in regular use for the study of the day-to-day changes in the amount and height distribution of ozone at Mt.Abu.

The photo-cell in Instrument No.10 was replaced by an R.C.A. 1 P28 photomultiplier by Dr.Karandikar and a suitable amplifier was also temporarily built by him. The instrument was in use in that condition for some time. This was completely reconditioned in our Laboratory by making such other alterations as were necessary to make it similar in all essential respects to the new instruments.

In the latest model of Dobson spectrophotometer( ) two thick quartz plates Q_1 and Q_2 are mounted, one immediately in front of the first slit S_1 and another in front of the photomultiplier slit S_5. (Figs.1(a),1(b),1(c)

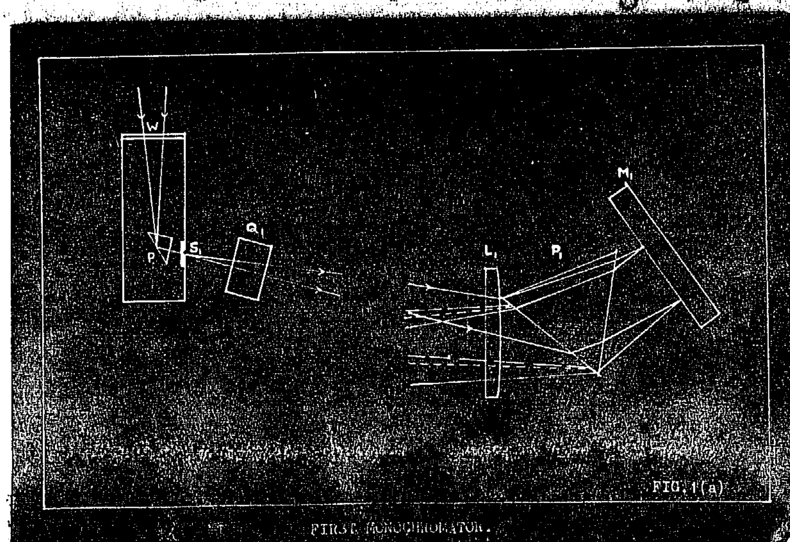


Fig.1(a)

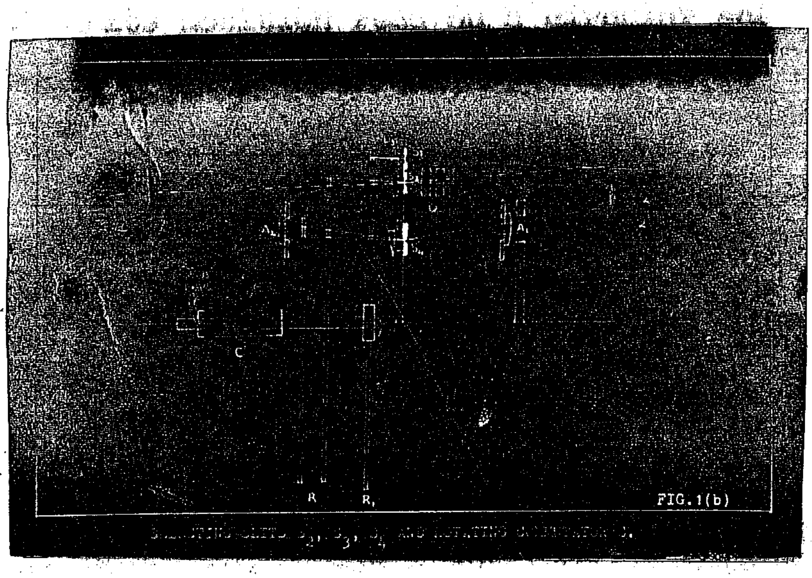


Fig. 1(b)

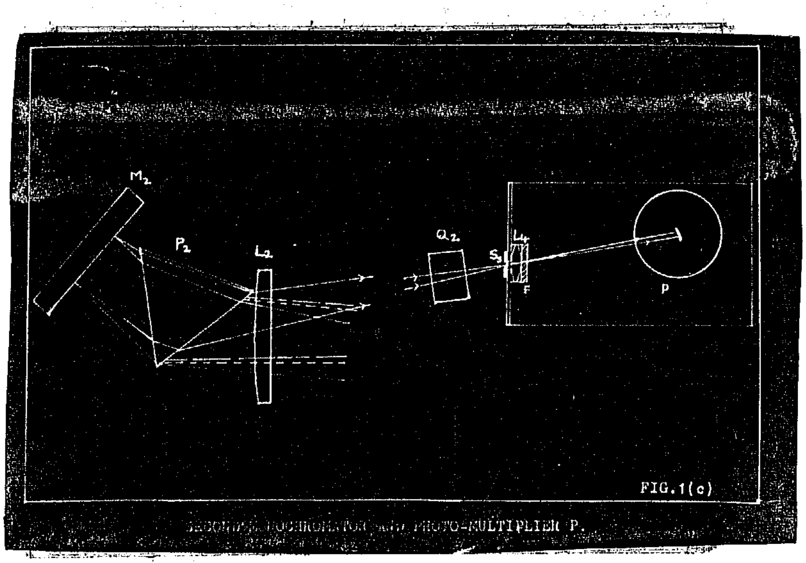


Fig. 1(c)

Each of them can be rotated about a horizontal axis and its position read on a circular scale on the outside of the cover of the instrument. This new device enables the spectrum of the incident light to be displaced and the wavelengths falling on the slits S_2 and S_3 to be changed over a moderate range by accurately known amounts. The shorter wavelength can be varied from about 3040 to 3200 A and the longer from 3240 to 3430 A. Changes in the refractive index of the quartz prisms due to changes in temperature can be compensated by making a slight additional adjustment in the setting of Q_1 at the rate of one division on the scale for every 10°C change in temperature. Similarly, a change of $0^{\circ}.5$ in the inclination of the quartz plates can compensate for a pressure difference of 100 mb.

The original slit system S_2, S_3 and S_4 in Instrument No.10 was meant to isolate wavelength regions near 3110, 3300 and 4430 A from the solar spectrum. This instrument had a thin quartz plate in front of these slits to compensate for changes in the refractive index of the prism due to temperature changes. But it was not possible to displace the spectrum by any substantial amount and observations could be made only on the single pair of wavelengths 3110/3300 for ozone measurements.

2. Changes in the old Instrument No.10 :-

The main alterations required in instrument No.10 were the following :-

(1) Since the slit system in the old instrument passed 3110 and 3300 A instead of 3112 and 3323 A as in the new instrument, the slit S_3 had to be displaced downward so as to pass 3323 A when S_1 passed 3112 A.

(2) The thin single quartz plate had to be removed and the two thick quartz plates had to be fitted in symmetrical positions in front of the first slit S_1 and of the last slit S_5.

(3) The existing lens L_4 and the ultraviolet filter OX_7 in front of the photomultiplier had to be replaced by the new lens-filter combination.

(4) The position of the photomultiplier had to be changed so as to bring its sensitive surface in the focal plane of the lens L_4.

(5) The amplifier which was built by Dr.Karandikar and which was in use for some time had to be replaced by the new amplifier appropriate to the new instrumental set-up.

Messrs R. & J. Beck, London, supplied the optical and electrical parts necessary for remodelling the old instrument. As the old optical wedges that were in use for the last ten years in this instrument were found to be deteriorating, a new set of quartz optical wedges were obtained from Messrs Beck to replace the old ones.

(a) Proper setting of the slit system :-

As already mentioned, the separation between S_2 and S_3 in the old instrument was such that if 3110 Å passed through S_2, 3300 Å would pass through S_3. There were already two new instruments in India taking observations with the wavelengths 3112/3323. It was therefore considered desirable, in remodelling the old instrument, to change the position of the slit S_3 so as to let λ 3323 fall on it when S_2 allowed λ 3112 to go through. This required the replacement of one of the knife edges and a shift of the slit S_3 downward. The original width of the slit was not altered. The position of S_4 was not changed as it was considered that this would not introduce any significant error.

(b) Fitting of the quartz plates Q_1 and Q_2 :-

The quartz plate which was fitted in the old instrument in front of the slits S_2, S_3 and S_4 to compensate for temperature changes was removed and the new plates were introduced, one after the entrance slit S_1 and the other before the exit slit S_5 behind the photomultiplier.

(c) The new combination of lens L_4 and u.v. filter OX_7 was fitted behing the slit S_5 and the old one removed.

(d) When the new lens L_4 and the Chance u.v. filter OX_7 supplied by Messrs. R. & J. Beck were introduced, the photomultiplier had to be moved back from the exit slit S_5. This required adjustment of the photomultiplier both in the transverse and vertical directions. First, it was moved by the appropriate amount in the transverse direction and then it was aligned correctly in the vertical. This required certain tests to be made and these will be described separately.

(e) <u>Replacement of the amplifier</u> :-

The old four-stage amplifier was replaced by the new three-stage one supplied by Messrs Beck. Though the old amplifier with the electrometer valve in the first stage was more sensitive then the new three-stage one, the latter had a lower noise level when the super-high-tension supply was used for the dynodes of the photomultiplier. The previous amplifier worked well only if a battery was used for the photomultiplier high tension.

3. Tests for the correct setting of the photomultiplier :-

The information contained in 'Notes on the design, adjustment and calibration of spectrophotometers' published by Sir Charles Normand and R.H.Kay (34) has been of great help in making these adjustments and tests.

(a) Vertical alignment of the photomultiplier :-

The exit slit S_5, the lens L_4 and the u.v. filter OX_7 were removed. The quartz plate Q_1 was fixed so as to transmit the desired wavelength (λ = 3129) and all other light excluded. The output currents in the galvanometer were recorded for varying positions of Q_2. By changing the position of Q_2, the slit image was made to scan the photo-sensitive surface up and down. The multiplier was now moved by computed amount vertically up or down so that when the reading of Q_2 was equal to that of Q_1 the final image fell on the area of maximum sensitiveness of the photomultiplier, as indicated by maximum current in the galvanometer. A final adjustment was then made around this position ($Q_2 = Q_1$) so that the null balance of the optical wedge was not disturbed by a small change in Q_2. This final setting ensured that the position of maximum sensitiveness of the photomultiplier was used and that the relative sensitivities between different wavelengths were constant even though the position of Q_2 was not kept exactly the same.

Fig. 2 gives the values of the current for various positions of Q_2 with Q_1 set at 98.0 and S_5, L_4 and OX_7 removed and with S_5, L_4 and OX_7 put back in position.

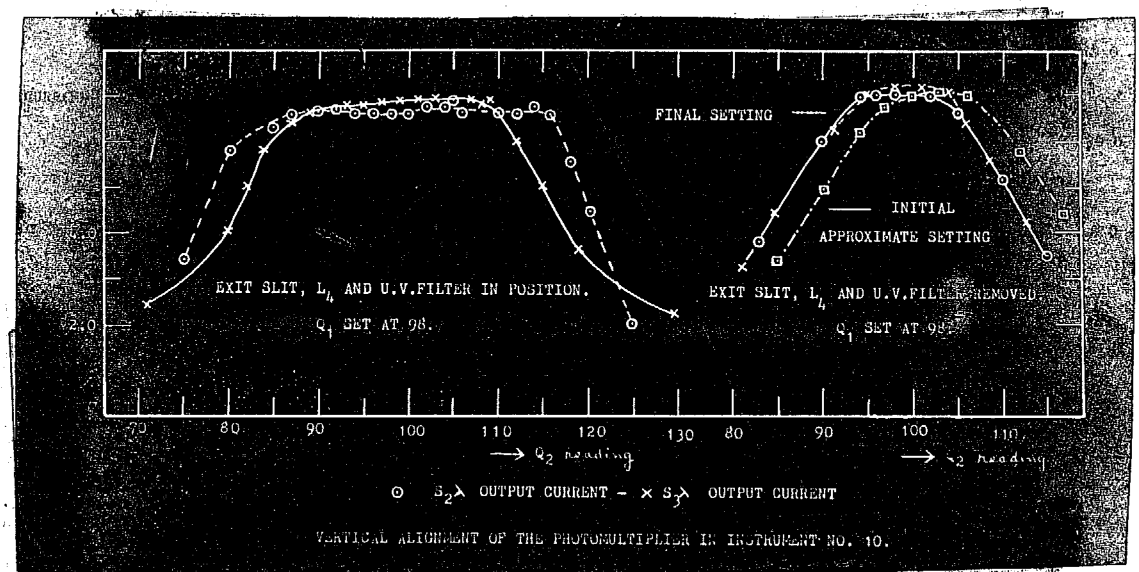


Fig. 2.

(b) <u>The setting of the lens L_4 and the u.v. filter OX_7</u> :-

If the lens L_4 were not there the light coming from the different slits S_2, S_3 and S_4 would fall at different positions of the photosensitive surface and would also move over it if their images moved on S_5. The ratio of their outputs would then depend on the position of Q_2 and the operating voltage on the photomultiplier, because the relative amplification for two different points on the photosensitive surface would depend on the potentials of the separate dynodes. With the lens L_4 adjusted in correct position, the images of different wavelengths are superposed on the maximum photo-sensitive part and remain fixed in position there. Then the wavebands passing S_2, S_3 and S_4 do not act on different parts of the photo-surface and the relative outputs become independent of the voltages.

The slit S_5 was replaced and the combination of L_4 and OX_7 was set behind it. The intensity responses and null-balance readings of the wedge were again checked as Q_2 was moved about the position $Q_2 = Q_1$. This was found to be satisfactory, thus ensuring the correct setting of the lens L_4. If the null position changed when Q_2 was moved, the lens L_4 would have to be displaced either up or down to obtain the minimum variation in the null reading of the optical wedge when Q_2 was moved around the position $Q_2 = Q_1$. The above tests were carried out when the temperature of the instrument was 20°C. The temperature correction had to be accomodated only by ~~the~~ moving Q_1 while keeping Q_2 fixed for a definite wavelength; it is much more important for the image to remain stationary on the multiplier surface than at the exit slit.

It was found in general that a movement of one division in the scale of Q_2 would compensate for a change of 10^oC in temporate.

(c) Wavelength setting :-

After the photomultiplier was adjusted in the vertical direction as mentioned above, the mercury lines 3023 and 3129 A were used to make the wavelength setting. The shutter rod was set to 'clear' position and the wavelength rod to 'short'. A quartz mercury lamp was made to illuminate the ground quartz plate placed over S_1. The dial was turned to the highest possible number to bring the most opaque portion of the wedges in front of the slit S_3. Q_2 was set at 98^o ; a change of even 10^o in the setting of Q_2 would not make any difference, as the photomultiplier had already been set in the correct position. Q_1 was varied and readings of the current in the microammeter were noted. The position of Q_1 which gave maximum deflection was taken to be the correct setting for 3129 A. It was found that in the position $Q_2 = Q_1 = 98^o$ λ 3129 passed centrally through the slit S_2.

The long wavelength 3342 A should also pass centrally through S_3 for the same position $Q_2 = Q_1 = 98^o$. The shutter rod was set to 'opaque' and the wavelength rod to 'long' and the dial turned to bring the thin end of the wedge before S_3. With Q_2 set at 98° the position of Q_1 was determined as before. It was found that 3342 A also passed centrally through S_3 for the same setting of $Q_2 = Q_1 = 98°.0$. This ensured that the resetting of the slit S_3 had been made correctly.

If studies have to be made with pairs of wave-lengths other than 3112/3329, it is necessary to find the correct setting of Q_2 and Q_1 for a few more known spectral lines.

The third mercury line 3023 A was made use of for this and the positions of Q_2 and Q_1 were determined when this line passed through S_2. The correct setting for this wavelength was found to be at $Q_2 = Q_1 = 43°$ when the temperature of the instrument was 30° C.

An average dispersion of 2 A for a change of one division of the quartz-plate scales was found from these two wavelength settings. Two more determinations, one between 3129 and 3023 A and the other beyond 3129 A are really necessary for checking the setting for any desired pair of wavelengths.

(d) <u>Calibration of the optical wedges</u> :-

As the old carbon-gelatine films in the optical wedges showed signs of deterioration, it was decided to replace them by new wedges which were obtained from Messrs Beck and Co., London. The new wedges were calibrated using a perforated zinc metal gauze of transmission coefficient 41.05 %. This was the same gauze that was used formerly by Dr.Karandikar, and later for the calibration of the wedges in Instruments No.39. The procedure adopted for this purpose was the same as that used in Oxford. The instrument was set to pass light of wavelength 3323 A by setting the shutter rod to 'opaque' and the wavelength rod to 'long'. The ground quartz plate and the sun director were used as in the 'direct sun' measurements. The dial was set at some known reading D_1 and the sensitivity of the instrument adjusted so that the galvanometer reading was near its full range when the perforated zinc gauze was introduced immediately before the reflecting prism of the sun director. The perforated metal sheet should be kept moving to average out the transmission and it should also be kept perpendicular to the beam of sunlight. The galvanometer deflection was noted, the gauze removed and the dial adjusted until the galvanometer again gave the same deflection. The corresponding dial reading D_2 was noted. The difference ΔD_2 between the two dial readings D_1 and D_2 corresponds to the attenuation caused by the zinc gauze. Similar determinations were made for all parts of the wedges in steps of 10° on the dial. The change in the dial readings $\Delta D_2 = D_2 - D_1$ was plotted against the mean dial reading $(D_1+D_2)/2$ and a smooth curve drawn through all the points. The calibration curve of ΔD_2 against $(D_1+D_2)/2$ was then drawn step by step and a chart showing the value of Log(I/I') for each dial reading was prepared.

(e) <u>Determination of the relative opacity factors</u> :-

The optical density of the wedges is not independent of the wavelength. So a correction has to be applied to the dial reading of the wedges, if the wavelength transmitted differs from the standard wavelength 3323 A.

The shutter rod and the wavelength rods were set to pass only the long wavelengths. Q_2 and Q_1 were set so as to pass the desired wavelength. Using the same metal transmission gauze which was used for calibration, the change in dial reading D_1 was noted for a mean dial reading of $(D_1+D_2)/2$. The relative percentage opacities were then calculated from measurements of ΔD_1, ΔD_2, ΔD_3 etc. The following are the opacity corrections (P) obtained for the new wedges in this way :

Wavelength.	P %
3253	3.85
3291	1.28
3323	0.0
3399	-6.5

For making the special studies described in this thesis, either of the instruments No.10 or No.39 was a used as was convenient.

III. EFFECTIVE ABSORPTION COEFFICIENTS OF ATMOSPHERIC OZONE BETWEEN 3060 AND 3175 A AND THE 3088 ANOMALY.

We have mentioned in Chapter II that in the re-modelled spectrophotometer of Dobson, two additional thick quartz plates have been introduced, one immediately after the entrance-slit of the first monochromator and a second immediately before the photo-multiplier-slit in the second monochromator. (See Fig.1). These quartz plates, when they are placed obliquely to the direction of the beam, bend the rays of light and displace them up or down. In this way, various pairs of wave-lengths can be made to enter the second monochromator through S_2 and S_3 and converge on the photo-multiplier. Owing to the finite widths of the slits, the slit S_2 passes a band about 10 A wide centred at any value between 3040 and 3300 A and the slit S_3 passes a corresponding band of width about 30 A between 3240 and 3400 A. Since the slits S_2 and S_3 are fixed, when the central wavelength passing through S_2 is defined, the wavelengths passing S_3 are also defined.

Measurements of ozone amounts were made with a large number of wavelengths. The wavelengths in which we were first interested were the pairs 3054/3253, 3085/3291, 3112/3323 and 3175/3399 - the four which Dobson and Normand have selected in their pamphlet. Soon after our observations commenced in October 1951, it was noticed that the wave-length pair 3085/3258 gave consistently lower values of ozone than 3112 and 3054. This led to a critical examination of the question, and a long series of measurements were made with different values of λ in the range 3050 to 3175. The equation used to determine the ozone amount was that given by Ramanathan and Karandikar (See Appendix).

We have first to consider what effective values of the ozone absorption coefficient α should be used for the wavelengths passed through each of the slits S_2 and S_3. Of these, the value of α for the light passing through S_2 is more important, because on the shorter wavelength side of 3175, α increases rapidly with decreasing λ, and the change is not smooth but has many abrupt changes. The slit S_2 has a width of about 10 A in the 3100 region. The entrance slit has nearly the same width as S_2. When the focussed image of the centre of S_1 is formed at the centre of S_2 in λ3110, λ3095 will be focussed at one edge of S_2 and λ3105 at the other edge. Similarly the focussed image of one edge of S_1 will be formed in 3100 at one edge of S_2 and in λ 3110 (or λ 3090) at the other edge. Thus, when S_1 and S_2 are each wide enough to pass a range of wavelengths equal to 10 A the whole range of wavelengths 3090 to 3110

Table 1.

Laboratory absorption coefficients of ozone according to Nye-Tse-Ze and Choong Shin-Piaw (NTZ. for shortness) and the same corrected for the slit widths in Dobson Spectrophotometer.

	α, α' acc. to N.T.Z.		Mean values of α, α' corrected for slit widths.		O_3 calc. with minus O_3 calc. with 3112/3323 (mean).	No. of days of comparative observations.
	α	α'	α	α'		
3054/3253	2.65	0.19	2.58	0.18	-1	6
3060/3260	2.49	0.15	2.47	0.16	-3	8
3066/3266	2.35	0.11	2.35	0.13	-2	7
3075/3278	2.00	0.14	2.03	0.12	-3	12
3081/3287	1.89	0.11	1.89	0.12	-5	6
3085/3291	1.85	0.08	1.83	0.10	-8	8
3088/3295	1.80	0.07	1.78	0.10	-15	30
3095/3303	1.48	0.10	1.57	0.09	-8	6
3102/3312	1.48	0.12	1.41	0.08	0	8
3107/3318	1.25	0.07	1.31	0.07	0	1
3112/3323	1.25	0.05	1.23	0.07	0	Standard.
3115/3323	1.25	0.05	1.19	0.07	0	2
3124/3340	0.98	0.08	1.02	0.06	-1	3
3144/3362	0.75	0.03	0.80	0.04	-1	7
3157/3378	0.70	0.04	0.67	0.03	-2	2
3162/3384	0.61	0.02	0.61	0.03	5	9
3170/3393	0.58	0.02	0.55	0.02	-3	4
3175/3399	0.56	0.02	0.54	0.02		-

will be allowed through S_2, though all wavelengths will not be given equal admittance. It can easily be shown that the relative amounts of light passed through S_2 will be maximum for 3100 A and will decrease steadily on either side of 3100 A reaching zero beyond 3090 and 3110. So the absorption coefficients should be averaged over the range 3090 to 3110 with appropriate weightages for the different wavelengths.

Similarly, it can be shown that if the width of S_3 is 30 A and that of the entrance slit corresponds to a width of 10 A in S_3, the range of wavelengths admitted through S_3 will be 40 A. The absorption coefficients of the different wavelengths passed through S_3 should also be properly weighted to obtain the effective value of α'.

Table 1 gives the decimal absorption coefficients for the central wavelengths transmitted through S_2 and S_3, according to Nye-Tse-Ze and Choong Shin-Piaw, and also the effective absorption coefficients corrected for slit-widths. For comparison, the effective absorption coefficients recommended by Dobson and Normand for 3054, 3085, 3112 and 3175 and their companion wavelengths in the Hartley band are also given below.

<u>Effective absorption coefficients of ozone suggested by Dobson and Normand.</u>

	λ	λ'	λ''	$\alpha - \alpha'$	α'
A	3054	3253	4355	2.42	0.16
B	3085	3291	4453	1.72	0.12
C	3112	3323	4536	1.15	0.08
D	3175	3399	4740	0.52	0.02

The Oxford workers have later found (35) that the value of α at 3085 should be changed from 1.72 to 1.65 so as to be in conformity with 3112 when applied to atmospheric ozone.*

Column (2) of Table 1 gives for each wavelength the absorption coefficient according to Nye-Tso-Ze and Choong Shin-Piaw's tables (interpolated where necessary) as reproduced in F.W.P.Gotz's article in 'Ergebnisse der Kosmischen Physik' Vol.IV (1938) (36).

Column (4) gives for each pair of wavelengths, the mean differences in the ozone amounts calculated from observations with the pair of wavelengths under test and the standard pair $\lambda\lambda$ 3112/3323. The α's used were the values corrected for slit-width, and given in column (3). The ozone observations were taken at different zenith distances on each of a large number of days. The number of days on which simultaneous observations were made and

* We came to know of the Oxford work only after we had completed our investigations in India.

on which the means are based are also given in the last column of the table. Many observations were made on each such day.

A result which stands out is that the value of the ozone amount x, calculated with λ/λ' = 3088/3295 is exceptionally low, much lower than can be explained by experimental errors, or errors in calculating $\alpha - \alpha'$. The difference persists in the same direction but to a smaller extent when λ = 3095 or when λ = 3082 but becomes vanishingly small when λ = 3102 or 3075. The observations with 3088 and 3112 have been repeated so often, both at Ahmedabad and at Abu with such consistent results, that there can be no question of the correctness of the facts. The abnormally small calculated value of x means that the assumed value of $\alpha - \alpha'$ * (based on laboratory observations and on slit widths in the instrument) is too large. Since α' is comparatively small and covers a wider range of wavelengths, the apparent discrepancy must be due to the fact that the effective value of α in the atmosphere is smaller than the computed value (1.78).

The following is a brief summary of the facts relating to 3088/3295.

(1) The value of ozone obtained with this pair of wavelengths was on the average 0.015 cm lower than the

value obtained with the standard pair 3112/3323 (Table 1). The graphs of -log(I/I') for 3088/3296 and 3112/3323 are given for ~~four~~ three days in Fig. 3.

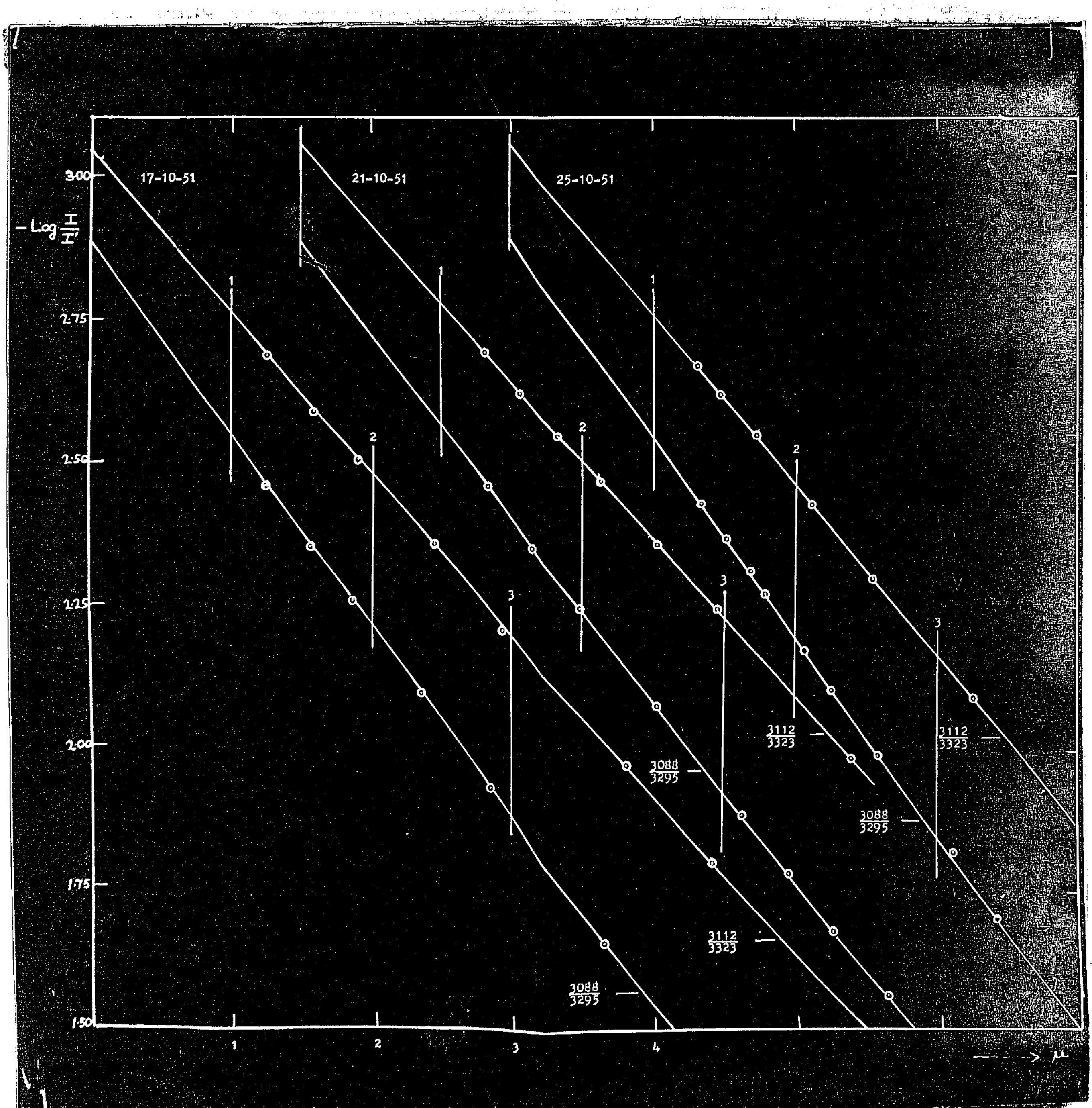


Fig. 3.

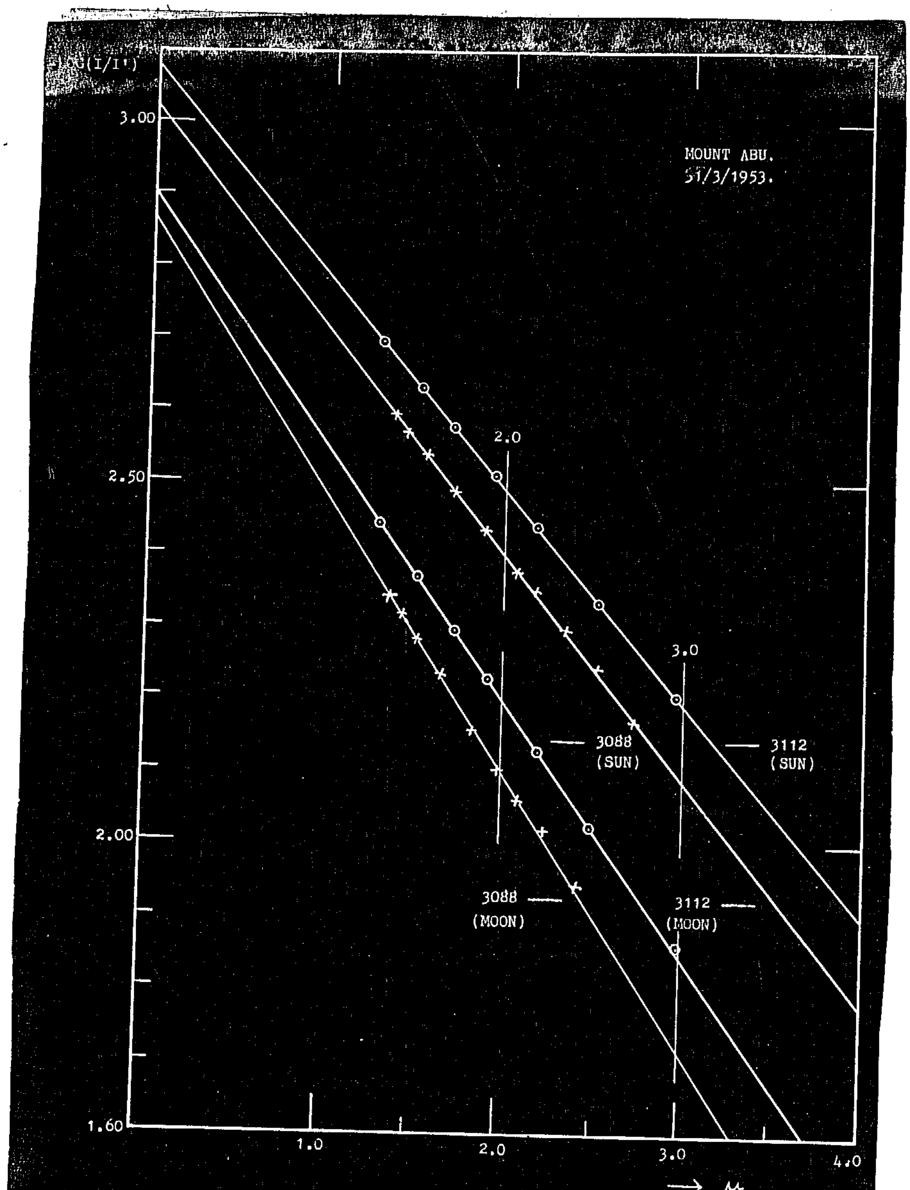
(2) The value of L_o, that is the ratio of Log I_{3088}/I_{3295} outside the earth's atmosphere, or more correctly above the main ozone layer, was always abnormally low compared to that of other wavelengths in this region. The average L_o for 3112/3323 was 3.052 and for 3088/3295, it was 2.883.

(3) Measurements of ozone made with moonlight on two clear days with the same pairs of wavelengths showed that a discrepancy of the same amount remained even during night hours.

Fig. 4 shows the graphs of -Log(I/I') for different zenith angles of the moon on two clear nights. The wavelengths 3088/3295 gave a value 0.020 cm lower than 3112/3323.

(4) Zenith-sky intensity measurements with different zenith distances of the sun also showed a behaviour similar to what might be expected if the value of $\alpha - \alpha'$ were smaller by about 0.020 cm. (See Fig.5. It will be observed that the curve of $\lambda\lambda$ 3088/3295 is nearly parallel to that of 3095/3303).

(5) Since adopting 3085/3291 as a standard pair of wavelengths for observations, Dr.Dobson and Sir Charles Normand ( ) have found that the value of $\alpha - \alpha'$ for this pair should be reduced by 4½ % in order to give self-consistent values of ozone for all the four chosen pairs of wavelengths.



$\frac{3112}{3323}$ AND $\frac{3088}{3295}$ BY SUNLIGHT AND MOONLIGHT.

Fig. 4.

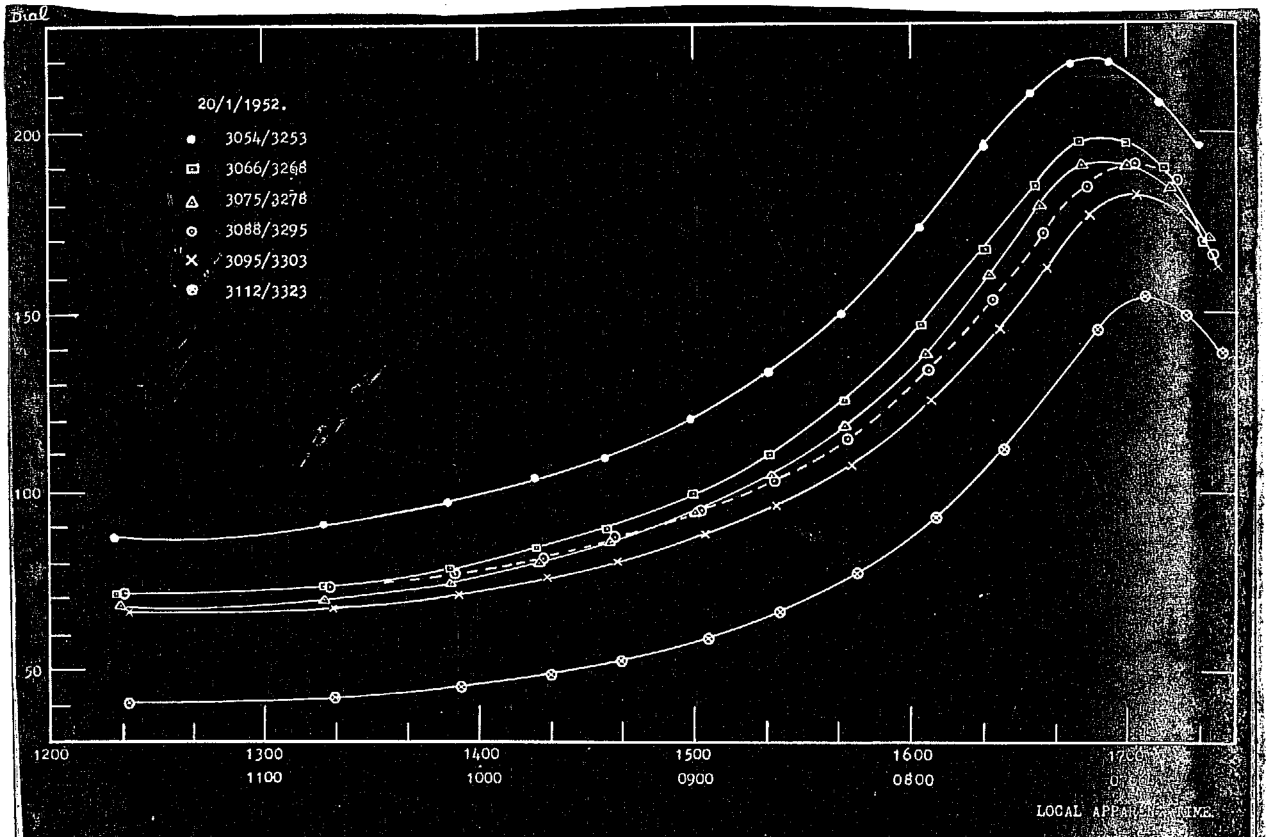


DIAGRAM SHOWING THE ABNORMAL BEHAVIOUR OF THE UMKEHR CURVE OF 3085/3295. IT IS VERY SIMILAR TO THE CURVE FOR 3095/3303.

Fig. 5.

An abnormally low value of α centred at 3088 Å demands an explanation. I give below the outlines of an interesting suggestion made by Dr. Ramanathan.

<u>Explanation of the abnormally low value of α for λ 3088.</u>

As already pointed out, the low value of x obtained with 3088 is only apparent; it means that we have attributed too high a value to the effective atmospheric absorption coefficient α. The slit S_2 being about 10 A wide transmits radiations of $\lambda \pm$ 10 A on either side of the central wave-length. α varies with λ in this interval. The effective mean value of α will depend both on the distribution of intensity in the original incident radiation and on the values of α for the wavelengths transmitted.

Let I_o be the total intensity of radiation above the ozone layer in the region of wavelengths let through by the slit S_2, duly weighted at different wavelengths to correct for the finite slit-width.

Let I_o be made up of I_1, I_2, I_3, etc., to I_n each with a separate value of absorption coefficient, α_1, α_2, α_3 . . . . α_n. Then after passing through a thickness x of ozone (neglecting atmospheric scattering), the <u>total intensity</u> will be

$$I = I_1 e^{-\alpha_1 x} + I_2 e^{-\alpha_2 x} + I_3 e^{-\alpha_3 x} + \cdots\cdots + I_n e^{-\alpha_n x}.$$

If α is the effective mean absorption coefficient, $I = I_0 e^{-\alpha x}$ where α is given by the equation

$$e^{-\alpha x} = \frac{I_1}{I_0} e^{-\alpha_1 x} + \frac{I_2}{I_0} e^{-\alpha_2 x} + \cdots + \frac{I_n}{I_0} e^{-\alpha_n x}$$

In calculating the values given in column (3) of Table 1, it has been assumed that $I_1 = I_2 = I_n$ for equal wavelength intervals. This is not however true because of Fraunhofer lines and possible atmospheric absorptions in the earth's upper atmosphere above the ozone layer. In general, for equal intervals of $d\lambda$; I_1, I_2 etc. will be different. If α_1, α_2, α_3 . . . . α_n differ by more than a small amount from each other, it is not possible to find a single-term exponential to replace the sum of the exponentials. The portion of the incident radiation for which α is largest will get attenuated first and the last surviving portion will be the one with the small value of α .

In the range 2080 to 3100, the following are the laboratory absorption coefficients for ozone :-

λ	α
3080	1.91
3085	1.85
3088	1.80
3090	1.75
3095	1.50
3100	1.47

The absorption coefficients decrease rapidly on the longer wavelength side of 3090.

The atmospheric ozone measurements show that although the calculated value of α for 3088, corrected for slit-width and based on laboratory measurements, is 1.78, the actual atmospheric value is smaller and only about 1.58. This is much nearer the mean absorption coefficient in the range 3090 to 3100 than in the range 3080 to 3090. This suggests that the solar radiation incident on the ozone layer is relatively deficient in intensity in the region 3080 to 3090.

It is of interest to enquire whether there is a possible reason for this.

(1) An examination of the photographs of solar spectrum shows that there is a moderately intense, isolated, closely packed set of Fraunhofer lines between 3086 and 3089 and it

is possible that when 3088 is focussed on the centre of the slit, these Fraunhofer lines cut out an important part of the incident radiation in a region where α lies between 1.80 and 1.85, leaving the longer wavelengths with their absorption coefficients to have greater control. The effect of the difference of ozone absorption coefficient between two parts of the radiation passed into the detector, becomes accentuated when the incident radiation is itself relatively weaker in one part.

The suppression of the shorter wavelength in the incident radiation will lower the value of $-\log I_o / I'_o$ and also reduce the apparent value of the ozone amount.

(2) It is still something of a puzzle to understand why Fraunhofer lines in this particular region should affect the ozone measurements so conspicuously.

The question was also considered whether any unrecognized substance present in the upper atmosphere could produce such an effect.

Meinel (37) has recently discovered conspicuous bright bands in the infra-red spectrum of the night sky and it is now definitely known that OH is a permanent constituent of the earth's atmosphere. The $^2\Sigma - {}^2\Pi$ bands of OH have been identified in the emission spectra of some comets by Swings and Page (37a) near 3088 A. F.W.P.Gotz and M.Nicolet (38) have identified a feature in the night sky spectrum near 3083 A and suggest that it may be due to the band 0 → 0 in the $^2\Sigma \rightarrow {}^2\Pi$ system of OH. F.E.Roach, Helen Pettit and D.R.Williams (39) have found that OH exists in the upper atmosphere at a height of 70 ± 20 km.

If as the above observations indicate, OH is present as a permanent feature in the atmosphere at a height of 70 ± 20 km, we should expect it to exercise some absorption on the solar spectrum. We have however the following difficulties :-

(1) If a group of lines near 3083 due to absorption in the earth's atmosphere existed, solar physicists would have discovered it by its Doppler shifts due to the earth's rotation.

(2) Any absorption in the atmosphere, additional to that of ozone would show itself as increased absorption in the ozone region and not as a decrease in effective α. Conclusion (2) will however be modified if the upper air absorption is so intense that even at normal incidence light of certain wavelengths is nearly wiped out before it reaches the ozone layer.

The problem is of great interest and required more experimental study with additional equipment.

IV. DAILY VARIATION OF OZONE AMOUNT.

A. Midday variation :

Karandikar made frequent observations of ozone amount with direct sunlight at Delhi at different times of the day on six consecutive clear days of settled weather in September 1946. He found in all instances that the afternoon values were higher than the morning ones and that there was a 'marked dip' in ozone amount at about local noon. His observations made on many other occasions supported this. In the few instances when the morning values were higher than the afternoon ones, the general trend of variation of daily ozone amount was towards a decrease.

A diurnal variation was suspected for some time at Arosa, but Gotz (40) traced this to a change in the temperature correction of the Dobson spectrophotometer.

Recently, Mme. Vassy and Mr. Abdul Khaleq ( ) have reported measurements made at Kabul from which they infer a daily variation of reduced thickness of ozone similar to that observed by Karandikar. They made observations at Kabul during the period December 1950 to December 1951 with a quartz photographic spectrograph. They found that the noon-day dip was about 5 % of the total reduced ozone amount in winter and about 20 % in spring and autumn. They also observed that on some occasions the total ozone amount was greater in the afternoon than in the morning. They infer that there are, on many occasions, a heating of the ozone layer at about noon.

As contradictory results on the day-time variation of ozone were obtained by Karandikar in India and Gotz at Arosa, it was thought necessary to investigate this problem further.

A large number of direct sun observations were accordingly made during the period 18-11-52 to 23-11-52 with the standard pair of wavelengths λλ 3112/3323 when the weather was clear and the total ozone content was not changing appreciably from day-to-day. Regular observations were taken during this time to keep a watch on the constancy of I_o and I_o'. This check-up of the instrumental constants is very necessary if we are to get reliable information about small changes in ozone amounts. An under estimate of I_o will lead to a low value of ozone when the sun is near the zenith.

The results obtained by me do not agree with those of Karandikar or of Mme.Vassy and Mr.Khaleq. No noon-day dip could be noticed on any of the days. The total ozone amount remained steady throughout the day. Generally the afternoon values were found to be a little lower than the morning ones. There were however also instances when the afternoon values were a little higher than the morning ones. This happed only when a rise in ozone was noticed on the next morning.

The following table gives the hourly observations made during a period of six days in November 1952. For abbreviating the table, the time has been given only to the nearest half hour of actual mean time of observation. The difference in time was in no case greater than 10 minutes. The days were cloudless and clear; there was a small haze correction of 0.005 cm but it remained constant to within ± 0.001 cm. Similar detailed observations were made ~~for~~ on four days in December 1952 and they gave ~~them~~ similar results.

Table 2.

I.S.T.	x in cm.					
	18-11-52	19-11-52	20-11-52	21-11-52	22-11-52	23-11-52
0800	-	0.150	0.151	0.152	-	0.157
0830	0.149	0.150	0.149	0.152	0.153	0.159
0900	0.151	0.149	0.148	0.151	0.165	0.157
0930	0.156	0.148	0.147	0.151	0.157	0.157
1000	0.149	0.148	0.147	0.154	0.155	0.158
1030	0.151	0.148	0.147	0.152	0.155	0.155
1100	0.152	0.148	0.148	0.154	0.156	0.156
1130	0.151	0.147	0.149	0.154	0.156	0.156
1200	0.151	0.146	0.148	0.155	0.155	0.156
1230	0.152	0.144	0.149	0.156	0.155	0.157
1300	0.152	0.147	0.149	0.155	0.154	0.156
1330	0.151	0.143	0.149	0.156	0.156	0.155
1400	0.151	0.147	0.149	0.157	0.154	0.155
1430	0.150	0.150	0.146	0.156	0.153	0.153
1500	0.149	0.143	0.147	0.154	0.155	0.154
1530	0.148	0.145	0.147	0.155	0.153	0.154
1600	0.149	0.143	0.146	0.154	0.152	0.152
1630	0.137	0.141	0.146	0.154	0.150	0.150

'x' indicates the total reduced thickness of ozone in atmos- cm.

Any error either in the calibration of the optical wedges or in the adopted constants L_0 and L_0' of the instrument, particularly in L_0, will affect the calculated values of the ozone amounts. For example, if the value of L_0 is taken a little higher than the true L_0, an apparent mid-day maximum will result; similarly, a lowering of L_0 will lead to a mid-day dip.

The present series of observations do not support the belief that there is a regular diurnal decrease in ozone when the sun is near the zenith. Whenever a noon-day maximum or minimum is suspected, the assumed value of L_0 requires careful scrutiny, as a change of ΔL_0 in L_0 causes a change in the calculated ozone amount by $\Delta L_0/\mu(\alpha - \alpha')$ and is therefore a function of the sun's zenith distance.

B. Night variations :

The improved form of Dobson spectrophotometer with an R.C.A. IP28 photomultiplier is sufficiently sensitive to enable measurements of atmospheric ozone to be made with moonlight.

Dobson ( ) himself made some measurements at Oxford in November-December 1948 and these showed variations of ozone on some nights. The variations were however not systematic and he concluded that they were such as might be expected from the meteorological conditions.

As the day-to-day variations of ozone amount in middle latitudes are large, any systematic difference in the ozone amount between day and night cannot be firmly established without prolonged observations. In low latitudes, however, both the total ozone content and the day-to-day variations are small during most of the year and therefore if there is a regular daily variation as might be expected from the photochemical theory of atmospheric ozone, it should be possible to determine it even with a short series of observations. Accordingly, observations were made at Mt. Abu and Ahmedabad in the period November 1952 to April 1953, and these indicated clearly a substantial increase of ozone in night hours as compared to the day hours.

Observational technique :-

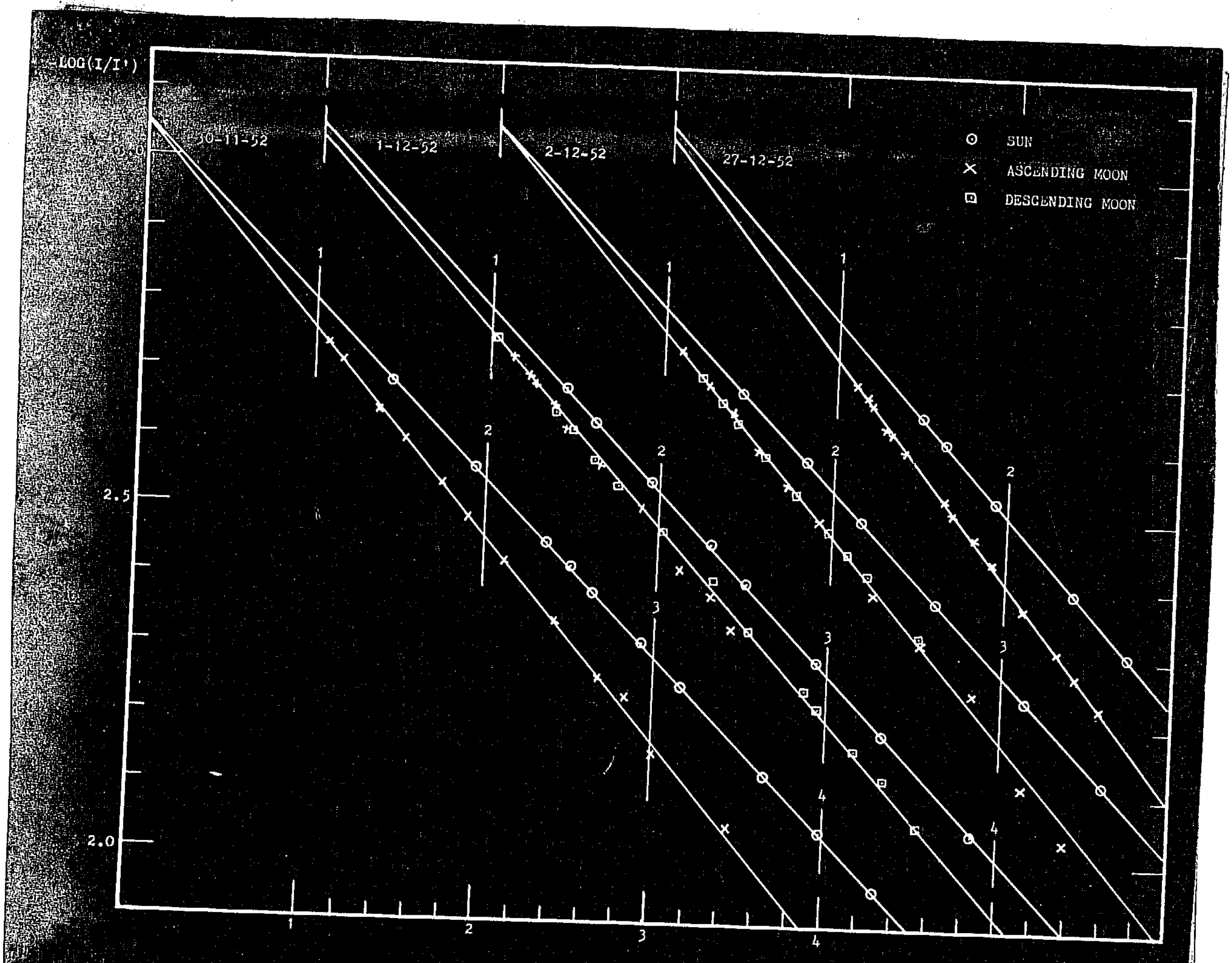
The ground quartz plate meant for direct sun observations was removed and a quartz lens fitted in the sun director to form an image of the moon on the entrance slit S_1. This was necessary as the intensity of moonlight is very small compared to that of the sun. The image was always maintained at the centre of the slit S_1 and the sun director adjusted every twenty seconds to keep the image always in the right position. The bright light-spot indicating the image of the moon could be viewed from outside through the window at the bottom of the sun director. The image had to be brought carefully to the centre of the slit and kept in the same position throughout the period of observation.

It was observed that a little de-focussing of the image did not have any effect on the reading but if the image of the moon was not maintained in the centre of the entrance slit S_1, considerable error could be caused. All possible care was taken to avoid such error and each observation was repeated at least half a dozen times.

Results :-

On many days, observations were made both at the time of rising and setting moon. On most of these days, it was found that the total ozone remained nearly steady throughout the night. The early morning observations showed however a tendency for a decrease in the ozone amount.

Fig. 7 shows the values of -log I/I' at different zenith distances of the sun or moon where 'I' is the intensity of 3112 A and I' the corresponding intensity of 3323 A on four clear sunny days and the moonlit nights. It will be seen that on each of these days, the mean line



OBSERVATIONS OF LOG 3112/3323 WITH DIRECT SUN- AND MOONLIGHT FOR MEASURING OZONE AMOUNTS.

connecting the day observations indicate a smaller amount of ozone than the night ones.

Observations were made on 17 nights in all. The plots of -Log I/I' against the zenith distance of the sun on all these days gave nearly the same constant L_o (ratio of the intensities of λ 3112 to λ 3323 outside the atmosphere). There was a little scatter in the plots on a few days but there were still sufficient points on such days to give a satisfactory straight line through them.

The mean L_o (3.04) obtained from all the moon observations was slightly lower than the value adopted for sun observations (3.05). During the day-time L_o remained the same throughout. But a difference in its value was noticed on a few occasions between the first and second half of the night. It is to be expected that if a regular variation in the ozone amount during the period of observations took place, a value of L_o slightly different from the normal would result. The mean of all the 'L_o's was used for the calculation of the hourly values of ozone during the night. It was found that :-

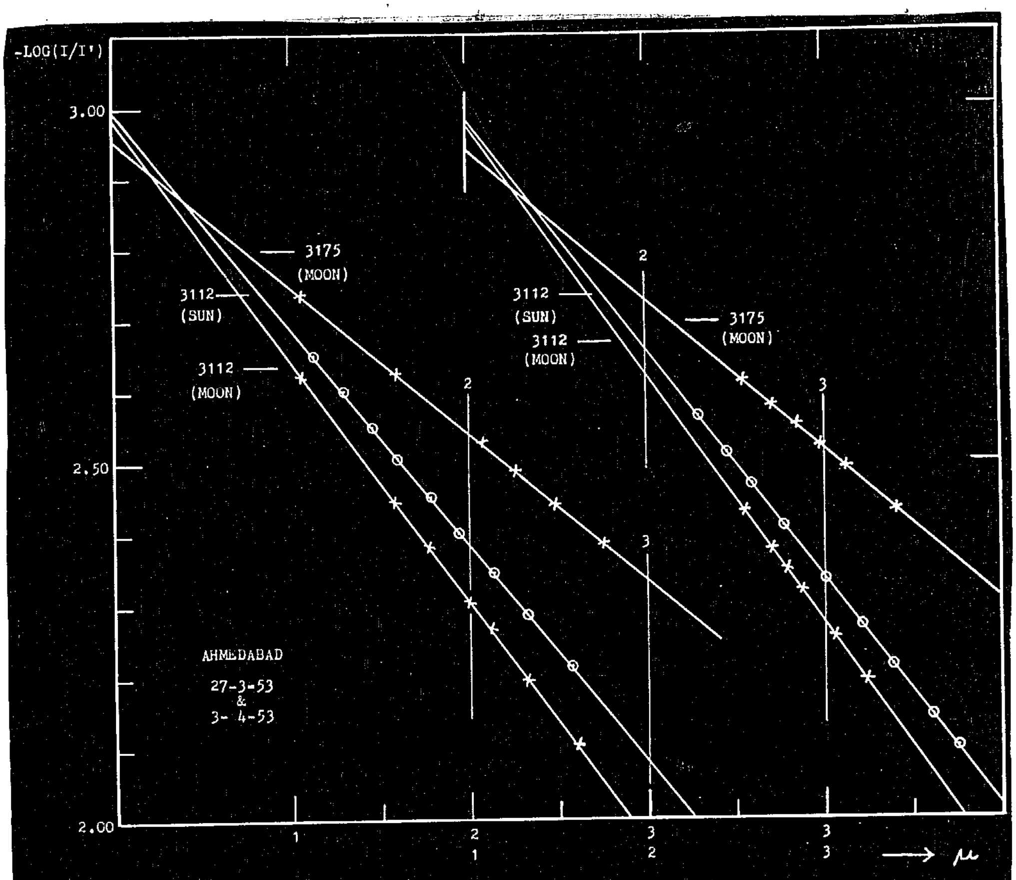
(a) On all these days, the night values were higher than the corresponding day values.

(b) The increase of ozone from the day value to the night value took place within an hour after sunset, and the change from night to day value was also extremely rapid.

(c) The ozone amount generally remained steady during nights, but there were occasions when it showed a tendency to decrease during the early hours of dawn. There were one or two occasions when the value went up gradually after sunset. On no occasion in the night was a value equal to or less than that of the day time reached.

Simultaneous observations were made on two pairs of wavelengths λλ 3112/3323 and λλ 3175/3399 to confirm the values obtained. Both the pairs yielded the same ozone content.

Observations were also made on three nights at Ahmedabad on both the pairs of wavelengths λλ 3112/3323 and 3175/3399. As at Mt.Abu the night 'L_o's agreed well with the day 'L_o's; and the value of ozone calculated from either of the pairs showed a definite increase during the night. The straight lines obtained from Ahmedabad observations when -Log I/I' was plotted against the zenith distance of the moon are illustrated for both the pairs in Fig. 8 for the two days 27-3-53 and 3-4-53. They are very satisfactory.



- LOG(I/I') WITH DIRECT SUN- AND MOON-LIGHT. THE CURVES OF λλ 3112/3323 FOR SUN AND MOON AND OF λλ 3175/3399 FOR MOON ALONE SHOW CLEARLY THE INCREASE OF O_3 AT NIGHT.

Fig. 8

The following table gives the mean day and night values of ozone (both uncorrected for haze) on 17 days and nights together with the corresponding night 'I_o's. In every instance the night value was larger than the day value. The average excess during the night was 0.030 cm of ozone and the extreme differences 0.019 cm and 0.044 cm.

Table 8.

Mt. Abu (24° 26'N)

Summary of ozone values by day and by night.

Mean daily values and mean night values.

Date.	Day value of x_t	Night value of x_t	Difference.	Night I_o
29-11-52	0.138	0.163	0.025	3.050
30-11-52	0.137	0.162	0.025	3.050
1-12-52	0.136	0.160	0.024	3.045
2-12-52	0.135	0.157	0.022	3.050
3-12-52	0.138	-	-	-
22-12-52	0.141	0.171	0.030	3.050
23-12-52	0.139	0.172	0.033	-
24-12-52	0.147	0.174	0.027	-
25-12-52	0.145	-	-	-
26-12-52	0.146	0.188	0.042	3.040
27-12-52	0.147	0.191	0.044	3.045
28-12-52	0.151	0.170	0.019	3.050

Date.	Day value of x_t	Night value of x_t	Difference.	Night L_o
29-12-52	0.148	0.184	0.036	3.035
30-12-52	0.147	0.177	0.030	3.025
1- 1-53	0.141	0.173	0.032	3.035
2- 1-53	0.140	0.176	0.036	3.045
Ahmedabad *(23° 02'N)				
23- 3-53	0.164	0.207	0.033	2.965
27- 3-53	0.166	0.196	0.030	2.985
3- 4-53	0.179	0.205	0.026	2.970

The value of day L_o adopted for instrument No.29 at Mt. Abu is 3.050.

*The value of day L_o adopted for instrument No.10 at Ahmedabad is 2.985.

Table 4 gives the comparative values of ozone obtained with the two pairs of wavelengths $\lambda\lambda$ 3112/3323 and $\lambda\lambda$ 3175/3399.

F indicates observations made in the first half of the night, and S in the second half.

Table 4.

Date.	Day x_t	Night x_t 3112/3323	Night x_t 3175/3399
30-11-52	0.137	0.168	0.174
1-12-52 (F)	0.137	0.165	0.168
1-12-52 (S)	0.136	0.161	0.149
2-12-52 (F)	0.135	0.163	0.162
2-12-52 (S)	0.135	0.160	0.165
27- 3-53	0.166	0.196	0.197
3- 4-53	0.179	0.205	0.203

Fig. 9 shows the values of ozone calculated from the individual observations of sunlight and moonlight on a number of days. The times of sunrise and sunset on all these days have been marked in the figure.

<u>Discussion</u> :-

The fact that the ozone amount increases rapidly after sunset and falls rapidly after sunrise shows that we are here dealing with a photochemical phenomenon whose seat is mainly in the upper levels of the atmosphere where the formation of ozone molecules after sunset from O and O_2 and the decomposition of O_3 after sunrise by photolysis are very rapid. The occurrence of these phenomena at low altitudes of the sun also suggests that, at high latitudes

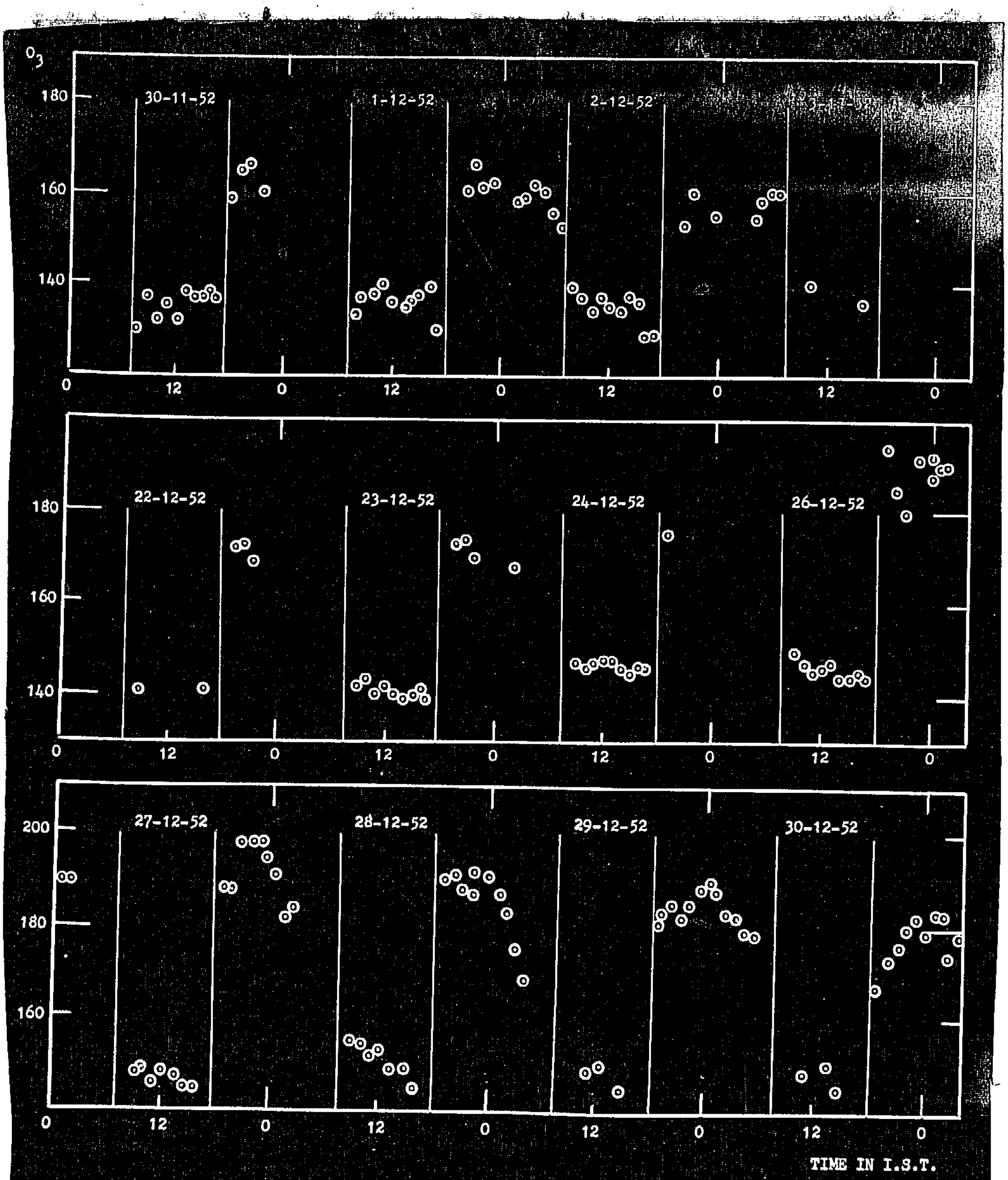


Fig 9. OBSERVATIONS OF O_3 WITH DIRECT SUN AND MOON.
MOUNT ABU.

Fig. 9

during winter when the altitudes of the sun are low and nights much longer than day, the average amount of ozone corresponding to photo-chemical equilibrium may be slightly larger than at low latitudes.

H.U.Dutsch,[41] R.A.Craig,[42] D.R.Bates and M.Nicolet[43] F.S.Johnson, Purcell, Tousey and Watanabe(...) have made estimates of the number of oxygen atoms at different levels in the atmosphere from 30 to 90 km during day time. From the values calculated by Johnson and collaborators using the rocket data of intensity distribution in solar radiation in the ultraviolet, the equilibrium amount of day-time atomic oxygen in the atmosphere can be shown to be approximately 0.020 cm between 70 and 90 km and 0.010 cm between 40 and 70 km. The amount decreases rapidly at lower heights. This suggests that the night time increase of O_3 takes place in the region of Chapman's 'odd oxygen atoms' above the level of maximum ozone concentration and below the region of Schumann-Runge oxygen absorption.

Short account of the work of Johnson, Purcell and others and Nicolet and Bates :-

Following Chapman's earlier suggestions, various authors have calculated the equilibrium of oxygen atoms and ozone molecules at different levels.

Considering vertical incidence of sunlight, the equations representing the rates of change of density of atomic oxygen and ozone are given by

$$\frac{dn_1}{dt} = 2 J_2 n_2 + J_3 n_3 - 2 k_1 n_1^2 n_m - k_2 n_1 n_2 n_m - k_3 n_1$$

$$\frac{dn_3}{dt} = k_2 n_1 n_2 n_m - J_3 n_3 - k_3 n_1 n_3$$

Here n_1, n_2, n_3 and n_M represent the number of particles per cubic centimeter of O, O_2, O_3 and of the third body M respectively. J_2 and J_3 are the rates of photochemical dissociation per unit density of O_2 and O_3; they depend on the number of photons of wavelength < 2420 A and < 11000 A in the solar spectrum outside the earth's atmosphere. k_2, k_3 are the coefficients of ozone-forming reaction ($O + O_2 + M \rightarrow O_3 + M$) and ozone-destroying reaction $O + O_3 \rightarrow 2 O_2^*$ respectively. k_1 is the coefficient of reaction in $O + O + M \rightarrow O_2 + M$. Johnson and others also take two less important terms into consideration.

After sunset $J_2 = J_3 = 0$ and the above two equations become :

$$\frac{dn_1}{dt} = -(2 K_1 n_M) n_1^2 - (K_2 n_2 n_M) n_1 - (K_3) n_1 n_3$$

$$\frac{dn_3}{dt} = (K_2 n_2 n_M) n_1 - (K_3) n_1 n_3$$

The ratio $(dn_3/dt)/(dn_1/dt)$ becomes, according to Johnson and others, -0.1 initially at 90 km and -1 at altitudes below about 70 km, a fact which shows that the number of O_2 molecules should increase with time after sunset and the number of atomic oxygen atoms decrease. They consider that the rise in the amount of ozone that may take place above the main ozone layer after sunset would be negligible in comparison with the total amount of ozone.

It is easy to show that

$$n_{1_t} = n_{1t_0} e^{-K_2 n_2 n_M t} \quad \text{and}$$

$$n_{3_t} = n_{3t_0} (1 + J_3 t)$$

Here t is the time measured from the time of sunset, t_0. n_{3_t} increases rapidly after sunset, but n_{1_t} does not. Substituting the numerical value of 7.6×10^{-3}/sec for J_3, Bates and Nicolet point out that :

(1) The ozone concentration initially increases at the hourly rate of twenty seven times the amount of total ozone at the time of sunset.

(2) Such a rise in total O_3 is controlled by the abundance of 'odd oxygen atoms' at the time of sunset and

(3) Within a few minutes after sunrise the ratio n_3/n_1 falls to its equilibrium value. However, the sum n_1+n_3 recovers slowly.

The moonlight observations of ozone made at Ahmedabad and Abu show that ozone increases after sunset as expected from photo-chemical theory. On some days the observations were begun 45 minutes after sunset and even the very first observation showed almost the whole of the night-time increase in ozone.

There were some days when observations were continued till half an hour before the time of sunrise and all such observations showed a high value of ozone. Direct sun observations could not be begun immediately after sunrise due to the weakness of the ultraviolet light available for the observations.

<u>Conclusion</u> :-

The main conclusions of direct moonlight observations made at Ahmedabad and Abu have been reported by Ramanathan and the author ( ) and they are as follows :-

(1) Significant changes in O_3 content take place immediately after sunset and immediately after sunrise giving a higher value during the sunless hours.

(2) New equilibrium conditions are reached in less than an hour after sunset or sunrise, and

(3) The average excess of ozone during night is 0.030 cm, the extreme differences being 0.019 and 0.044 cm.

V. VERTICAL DISTRIBUTION OF ATMOSPHERIC OZONE.

1. Calculation of the vertical distribution of ozone :-

The usual method of calculating the ozone distribution from the umkehr effect assumes that the ratio I/I' = F/F', where F and F' are the intensities of light primarily scattered downwards along the vertical by air molecules and attenuated by molecular scattering and ozone absorption. The intensity of light of wave-length λ incident at any point in the atmosphere situated at a height 'H' above the observer is given by

$$I_o \times 10^{-\int_H^{\infty} (\alpha x_h + \beta_h) \sec \xi_h \, dh}$$

where I_o is the intensity of the sun's radiation outside the earth's atmosphere at wavelength ,

α the decimal absorption coefficient of ozone absorption at ,

$x_h dh$ the amount of ozone in thickness dh of the atmosphere at height 'h' above the ground,

β_h the scattering coefficient of air at height h,

ξ_h , the zenith distance of the sun as seen from a point in the path of the light beam at a height h above ground.

A fraction of this light is scattered by the air vertically downward, into the instrument. The intensity of light scattered downward by unit volume of air will be

$$K \rho_H (1+\cos^2 Z)\, I_o \times 10^{-\int_H^\infty (\alpha x_h + \beta_h) \sec \xi_h \, dh}$$

where K is a constant given by $\frac{3}{16\pi} \cdot \frac{\beta}{H\rho_o}$ and Z is the zenith distance of the sun as seen from the ground. $K(1+\cos^2 Z)$ represents the primary scattering in a direction making an angle Z with the incident direction. β is the scattering by a homogeneous atmosphere of thickness H. ρ_o and ρ_h are the densities of air at standard level and at height h.

The light travelling vertically downwards would have undergone (1) absorption by ozone and (2) scattering by air between H and the instrument. The intensity of light scattered at a height H and reaching the instrument will be

$$K \rho_H (1+\cos^2 Z)\, I_o \times 10^{-\int_H^\infty (\alpha x_h + \beta_h) \sec \xi_h \, dh} \times 10^{-\int_0^H (\alpha x_h + \beta_h)\, dh}$$

Thus the total amount of light I reaching the instrument from all heights will be :

$$K (1+\cos^2 Z)\, I_o \int_h^\infty \rho_h \, 10^{-\int_h^\infty (\alpha x_h + \beta_h) \sec \xi_h \, dh} \times 10^{-\int_0^h (\alpha x_h + \beta_h)\, dh}$$

The equation can be put into the form :

$$I = K(1+\cos^2 z)\, I_0 \int_0^\infty \rho_h \left[10^{-\alpha \int_h^\infty x_h \sec \xi_h \, dh \; - \; \alpha \int_0^h x_h \, dh} \times 10^{-\int_h^\infty \beta_h \sec \xi_h \, dh \; - \; \int_0^h \beta_h \, dh} \right]$$

$$= K(1+\cos^2 z)\, I_0 \int_0^\infty \rho_h \, 10^{-\alpha Y} \cdot 10^{-\beta F}$$

Here Y represents the total integrated thickness of ozone traversed by sunlight from outside the atmosphere to height H and from there vertically downward into the instrument. Its magnitude is a function of the height distribution of ozone.

F denotes the integrated air mass traversed in terms of a unit atmosphere.

Tables of F and Y used for the calculation of vertical distribution of ozone are given in the Appendix.

A similar equation can be written for the longer wavelength λ' with corresponding symbols α' & β' in place of α and β. Thus we can obtain log I/I' theoretically for any assumed distribution of ozone.

Two narrow regions in the solar ultraviolet spectrum in the ozone absorption band are chosen for comparison. Suppose we choose one at 3112 A in the

Hartley band system and another at 3323 A in the Huggins band. The ozone absorption coefficient at 3112 is much larger than at 3323. The relative intensities of the zenith scattered solar radiation are measured in these two narrow wave bands for different zenith distances of the sun by means of the calibrated optical wedge introduced in the path of the brighter component 3323 A so as to bring down its intensity to that of the shorter one 3112 A. The curve representing Log I/I' against ϕ (Z) is known as the umkehr curve and such a curve can be obtained on any clear day. Knowing the total quantity of ozone at the time of observation, a number of theoretical umkehr curves can be prepared by direct calculation for different assumed distributions of ozone. The distribution for which the calculated umkehr curve fits best with the observed one is taken to represent the distribution of ozone in the atmosphere. This is the method B adopted by Gotz, Meetham and Dobson.( )

The method used at Mt. Abu is the same as that originally used by Gotz ( ) Meetham and Dobson in Europe and modified by Karandikar and Ramanathan for use in India.

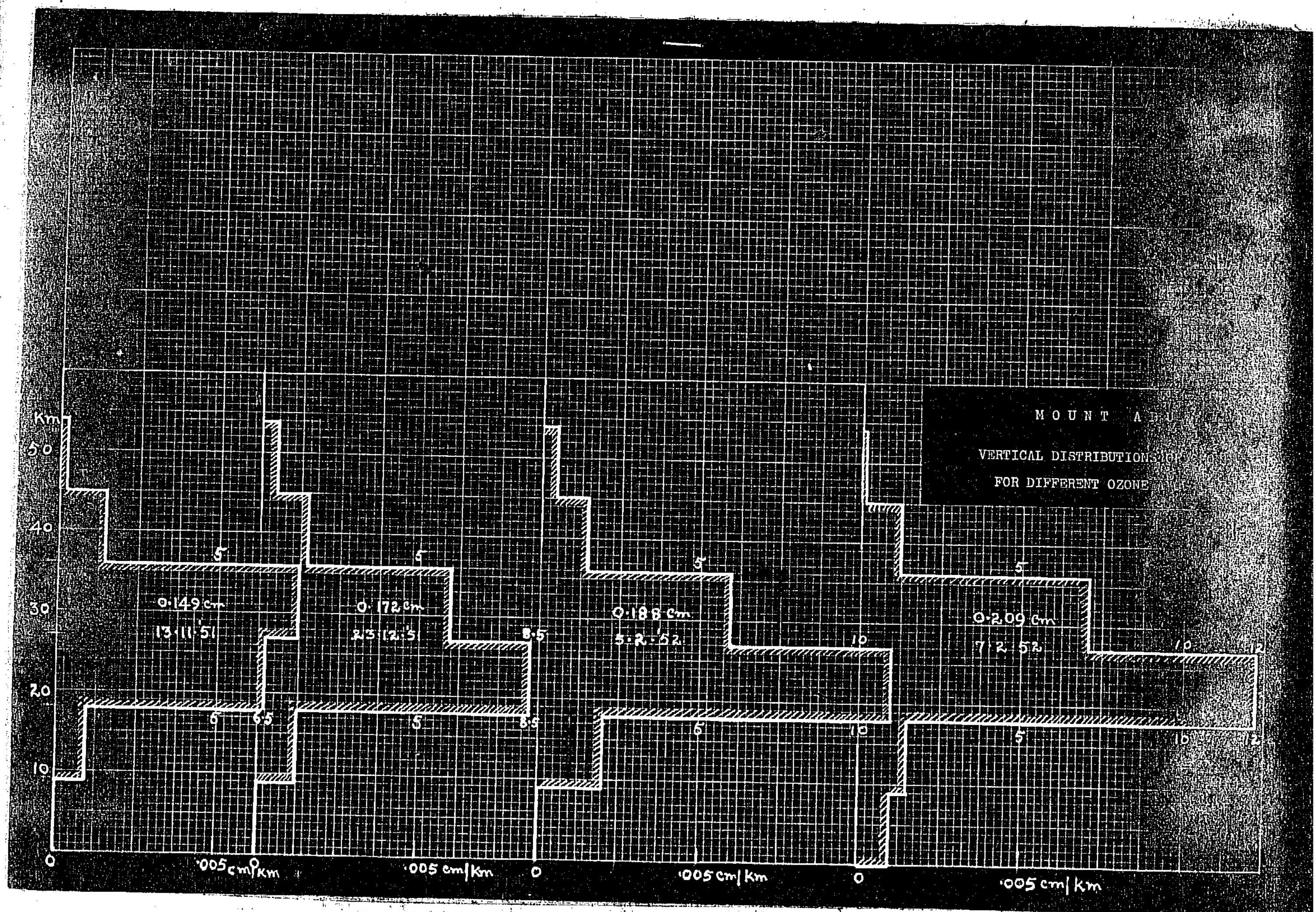
The first 54 km of the atmosphere was divided into six sections each of 9 km. thickness. It was supposed that practically no ozone existed above 54 km, and that the centre of mass of each 9 km section was situated at a height of 3 km above the base of that section. Further, the ozone was assumed to be uniformly distributed within each section.

Using a step-by-step numerical method, the values of βF and $\beta' F$ were calculated for each layer for the first eight layers above sea level for different fixed zenith distances of the sun. The tables of $\text{Log } \rho_k - \beta F$ and $\text{Log } \rho_k - \beta' F$ were prepared for zenith distances 70°, 80°, 84°, $86^{\circ}.5$, 88°, 90°, using the same pressures and temperatures as given by Karandikar and Ramanathan in their paper.

Tables of αY and $\alpha' Y$ were prepared for different zenith distances of the sun for a value of ozone of 0.001 cm at S.T.P. in each kilometer of the layer. For any other quantity, the appropriate values could then be obtained by simple multiplication.

2. <u>Some results of the study of the vertical distribution of ozone over Mt. Abu and other places</u> :-

It has been found from an analysis of the umkehr curves obtained at Mt. Abu that all major changes in ozone take place in the layer 18-27 km, the amount in



MOUNT ABU
VERTICAL DISTRIBUTIONS OF
FOR DIFFERENT OZONE
Km
50
40
30
20
10
0
0.149 cm
13.11.51
0.172 cm
23.12.51
0.188 cm
5.2.52
0.209 cm
7.2.52
·005 cm/Km

Fig. 10.

(a) The ozone amount above 27 km was practically the same over all the three places and nearly independent of the total ozone amount. Over Abu, there was just a tendency for the ozone amount in the layer 27-36 km to decrease when the amount in the immediate lower layer 18-27 km showed an increase.

(b) Both at Abu and Delhi the main increase in the ozone amounts took place in the layer 18-27 km i.e. in the first ten kilometers above the permanent inversion tropopause of low latitudes.

(c) The amount of ozone in the layer 0-18 km was generally more at Delhi than at Mt. Abu and increased with increasing ozone amounts. Not much reliance can however be placed on the small ozone amounts found in the first layer 0-9 km.

The following table gives the distributions over the three places Abu, Delhi and Poona.

Table 6.

Place.	Ozone amount.	Ozone amount in different layers. 0-18 km	18-27 km	27-36 km	above 36 km.
	0.153	10	67	76	17
Abu	0.172	12	84	78	20
	0.209	25	123	71	13
	0.155	26	55	77	14
Delhi	0.175	30	70	80	16
	0.200	36	91	80	15
Poona	0.169	14	65	65	25

The unit used in specifying the ozone distribution is 0.001 cm/km.

Comparing the distributions over tropical latitudes with those over higher latitudes, Ramanathan and Kulkarni( ) drew the following conclusions :

(a) There is very little variation of ozone above 27 km at different latitudes in the sunlit portion of the earth.

(b) An increase in the total ozone amount is associated with an increase mainly in the layer 18-27 km in Indian latitudes.

(c) In higher latitudes there is an appreciable rise in the amount, in the lower layers also; the greater the total amount the greater is the descent of ozone.

Discussion of the results :-

In the tropics generally, it is found that most of the ozone resides in the stratosphere. From the observed small day-to-day variation it appears that the amount is largely controlled by the photochemical action of sunlight. What part the convection in the upper troposphere plays in the ozone equilibrium is not yet clear.

Gotz [44] suggested that with larger amounts of ozone, there probably existed two levels of maxima, one between 25 and 30 km and another at a lower level. Durand and his co-workers ( ) with their measurements of the solar ultraviolet spectra obtained upto an altitude of 88 km during a V-2 rocket flight over White Sands, New Mexico found two peaks in ozone density, one at about 17 km and another at 25 km when the total ozone amount was 0.270 cm. But the inference is said not to be conclusive. The distributions at Tromsø and Delhi showed a pouch of high ozone at lower levels when the total ozone amount was high; the upper maximum was a few kilometers below 30 km at both the places. No Abu distribution showed evidence of any double maximum.

3. Mean height of the ozone layer and the results obtained at various places :-

Gotz, Meetham and Dobson found that the average height of ozone at Arosa (47° N) was 22 km a.s.l. and that the nature of the vertical distribution changed more or less systematically with the total amount of ozone, higher ozone amounts in general lowering the centre of gravity. Meetham and Dobson ( ) found at Tromsø (69° 40' N) in Norway in the summer of 1934 that the average height of ozone was slightly lower than 20.8 km. The maximum concentration of ozone was also in a region centred at 21 km. Tonsberg and Langlo( ) made a number of measurements at Tromsø during the years 1935-42. They measured the total quantity of ozone by sunlight, star-light and moonlight with different types of instruments and the vertical distribution by zenith sky measurements. These later observations for Tromsø showed a variation in the C.G. from 26.7 km for 0.160 cm of ozone to 20.8 km for 0.400 cm instead of a more or less steady height of 20.8 km. The new distributions showed that marked changes in ozone content took place between 5 and 20 km. They also found a lowering of the centre of gravity with an increase in the total amount of ozone as was found at Arosa.

Karandikar and Ramanathan ( ) found that for the same ozone amount (0.220 cm) the average height of the ozone layer at the latitude of Delhi was higher (25.1 km) than that of Arosa (22.5 km). For this amount of ozone at Tromsø, Meetham and Dobson's measurements indicated a mean height of about 20.8 km, while for the same amount those of Tonsberg and Langlo showed 25.7 km. The average heights deduced for Simla were approximately the same as those obtained at Delhi. The observations at Poona yielded more or less a constant height of 23 km.

Umkehr calculations at Mt. Abu showed the mean height of the ozone layer to be 28 km for low total amounts (.153 cm) and 25.9 km for high amounts (0.209 cm) of ozone.

The average height of the ozone deduced from observations of zenith-scattered sunlight was confirmed by E. and V. Regener ( ) from their independent studies with spectrographs carried in sounding balloons at Stuttgart in Germany. They determined the amount of ozone above the balloon at different heights from which the vertical distribution could be deduced. Their experiments revealed a maximum at about 24 km in agreement with the results of umkehr calculations. The earlier flight in 1934 extending upto 31 km showed considerable ozone in the troposphere but the latter two flights in 1937 extending only upto 15 km showed much less ozone in this region.

O'Brien, Stewart and Mohler ( ) measured the vertical distribution of ozone in the Stratosphere Flight of Explorer II on Nov.11, 1935. The values upto 22 km were obtained from the spectra of direct sunlight and the values at higher levels were determined from sky spectra. They found a sharp maximum of 18×10^{-3} cm km^{-1} at 22 km.

Measurements of Coblentz and Stair (45) using a cadmium photoelectric cell and filter radiometer connected to a balanced amplifier, relaxation oscillator and radio transmitter showed maximum amounts of ozone in the region between 23 and 27 km.

More recently measurements made with solar spectra photographed in the V-2 rocket flights ( ) over White Sands, New Mexico have provided ozone data up to the greatest altitudes. The measurements made in October 10, 1946 showed two ozone maxima, one at about 25 km and the other at 17-18 km. Unlike Regener's measurements and the umkehr computations, the data of both the Explorer II and the V-2 rocket showed very little ozone below 12-15 km (less than 10^{-3} cm km $^{-1}$). The revised calculation of the same data gave one broad maximum instead of two.

The three rocket flights gave three different heights for maximum ozone concentration. They were 23.5 km, 18.5 km, and 26 km for the flights taken on October 10, 1946, April 2, 1948 and June 14, 1949 respectively. The shapes of the three distribution curves were also somewhat different. An approximately exponential fall of ozone was noticed above 35 km in the latest flight. Measurements could be made only up to 38 km in the first two flights which took place when the sun was high, but in the third flight, they could be extended upto 70 km as the rocket was fired at a time when the sun was setting.

The work of Watanabe (1943) (46) at Pasadena, California showed a mean height of ozone varying between 20.4 and 24.7 km for total ozone amounts between 0.271 and 0.215 cm which corresponded well with umkehr effect measurements. Watanabe used Strong's method of absorption of ozone in the 9.6 μ band in the infra-red assuming that absorption varied as the fourth root of the pressure under which the ozone existed. His method did not give any detailed information about the vertical distribution of ozone.

Table 7 taken from Karandikar ( ) summarizes theavailable information regarding the average heights of atmospheric ozone at different latitudes.

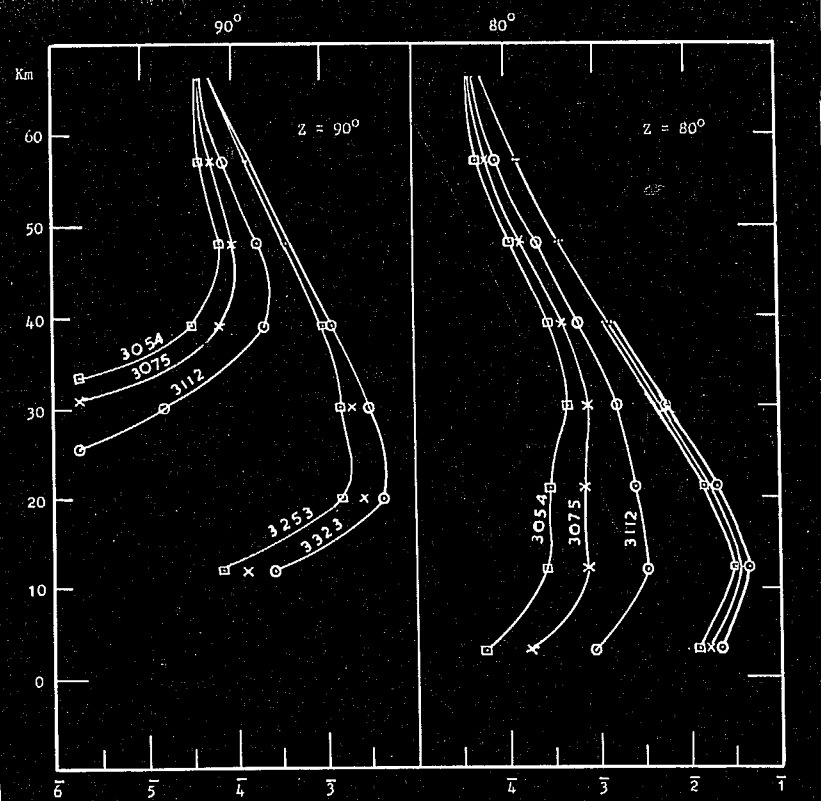
Table 7.

Place.	Latitude.	Method.	Total ozone in cm. at N.T.P.	Average height in km.
Kodaikanal	10° 14' N	Umkehr B.	0.175	29.1
Poona	18° 31'	"	0.174	28.0
Mt. Abu	24° 36'	"	0.172	28.0
Delhi	28° 35'	"	0.175	25.9
Arosa	47°	"	0.180	22.6
Tromsø	69° 48'	"	0.220	20.8
"	"	" A.	0.175	26.5
Mt. Palomar	33° 22'	Residual Ray apparatus.	0.234	22.2
Stuttgart	48° 47'	Sounding balloon.	0.270	22.0
Black-hills South Dakota.	44°	Explorer II.	0.190	28.0
Beltswille. Mary land.	39°	Photocell filter radio transmitter, balloon.	0.200 to 0.210	22.0
White Sands New Mexico.	33°	V_2 rocket I	0.238	22.6
		II	0.200	20.5

B. Effect of multiple scattering on the calculation of the vertical distribution of ozone from the umkehr effect.

In the usual method of determining the vertical distribution of ozone from the umkehr-curve as developed by Gotz, Meetham and Dobson, we measure the ratios of the intensities of zenith-scattered light in two wave-lengths at different zenith distances of the sun to as low altitudes of the sun as possible. The two wavelengths chosen are similar to (usually the same as) those used for direct sun ozone determinations. We calculate, by trial and error or by the solution of a number of simultaneous equations, what distribution of ozone will give the same ratios as those observed, assuming that the scattered light received at the ground from the zenith-sky is only primarily scattered light. Gotz, Meetham and Dobson were well aware that the light actually received at the ground would include both primary and multiply scattered light, but considered that the inclusion of the latter would not change the shape of the -Log I/I' curve, but would only displace it bodily.

This is not quite acceptable, because of the two wavelengths under comparison, one is much more absorbed by ozone than the other. As a consequence, the contribution of different layers of the atmosphere to the total primarily scattered light from the zenith is not the same and does not vary similarly with the zenith distance of the sun. The multiply scattered light which depends on the distribution of the primarily scattered light will also change differently for the two wavelengths. This is illustrated in Fig. 11 which shows the relative amount of primary scattered light received at the ground for Z = 80° and Z = 90° in the wavelengths λλ 3323, 3293 and 3253 which are only slightly absorbed by ozone, and in wavelengths λλ 3112, 3076 and 3054 which are strongly absorbed by ozone. The problem will perhaps be clearer if expressed with symbols. The intensity of light of wavelengths λ or λ' received from the atmosphere in a vertical direction is composed of primary scattered light (P or P') and of multiply scattered light (M or M'). What we measure with our instrument is Log (I/I') or Log $\frac{P+M}{P'+M'}$ for different zenith distances of the sun. If M/P = M'/P', Log(I/I') will be equal to Log(P/P'). Even if M/P differs from M'/P', but each remains constant as Z varies, $\left(1+\frac{M}{P}\right)/\left(1+\frac{M'}{P'}\right)$ will remain constant and Log(I/I') will differ from Log(P/P') only by a constant.



RELATIVE INTENSITIES OF PRIMARY SCATTERED LIGHT RECEIVED AT GROUND FROM DIFFERENT LAYERS IN THE ATMOSPHERE IN λλ 3323, 3278, 3253 AND λλ 3112, 3075 AND 3054. OZONE AMOUNT 0.152 cm AS ON 17-1-1953. SOLAR ZENITH DISTANCES 80° AND 90°.

Fig. 11.

I/I' being equal to $\frac{P}{P'} \cdot \frac{1 + M/P}{1 + M'/P'}$,

we could correct the I/I' curve to give P/P' if we know M/P and M'/P' for different zenith distances of the sun. The secondary scattering, which is by far the most important part of M, has been calculated by Dr. Walton for certain simple distributions of ozone. A brief summary of his conclusions is given in I.U.G.G. News Letter for April 1953.

We started work on this subject at Ahmedabad before we were aware of Dr. Walton's results, and our approach was different.

M/P and M'/P' vary differently with changes in sec Z because the absorption coefficients of ozone are so widely different, and the lower atmosphere continues to be illuminated by light of wavelength λ' (say 3323), even after light of wavelength λ 3112 has withdrawn into the upper atmosphere. If, instead of comparing light of $\lambda\lambda$ 3112 and 3323, we could compare light of two wavelengths like $\lambda\lambda$ 3112 and 3075, both of which are absorbed by ozone though differently, and whose scattering coefficients are near each other, the manner in which M/P and M'/P' change with wavelength may be expected to be more similar and we may accept the Log(I/I') curve observed with them to be a better approximation to the corresponding Log(P/P') curve.

The problem therefore was to determine the $\text{Log}(I_{3112}/I_{3075})$ curve against sec Z or μ. The distance between the slits S_2 and S_3 in Dobson's spectrophotometer is fixed, and for various reasons, it was not considered advisable to disturb them. We could however determine umkehr curves separately with the two pairs $\lambda\lambda$ 3112 and 3323 and with $\lambda\lambda$ 3075 and 3278. Since Log(I 3323/I 3278) could be calculated with all the required accuracy with an approximate vertical distribution, an umkehr curve for (I_{3112} / I_{3075}) could be derived from the two umkehr curves by subtraction. A calculated Log(P 3112 / P 3075) curve could then be fitted to this derived "observed" curve.

The essential steps of the calculation are given below :-

1. From many direct-sun observations made simultaneously with 3112/3323 and 3075/3278, it was found that 3075/3278 gave consistently lower ozone amounts than 3112/3323 by about 0.005 cm. The value of α for λ 3075 was accordingly adjusted so that the values of ozone amount obtained from either of the wavelength pairs 3112/3323 or 3075/3278 was the same. The corrected value of α was 1.96. This value was adopted for all subsequent calculations.

2. The vertical distributions calculated from the umkehr curves of either 3112/3323 or 3075/3278 were found to be practically the same.

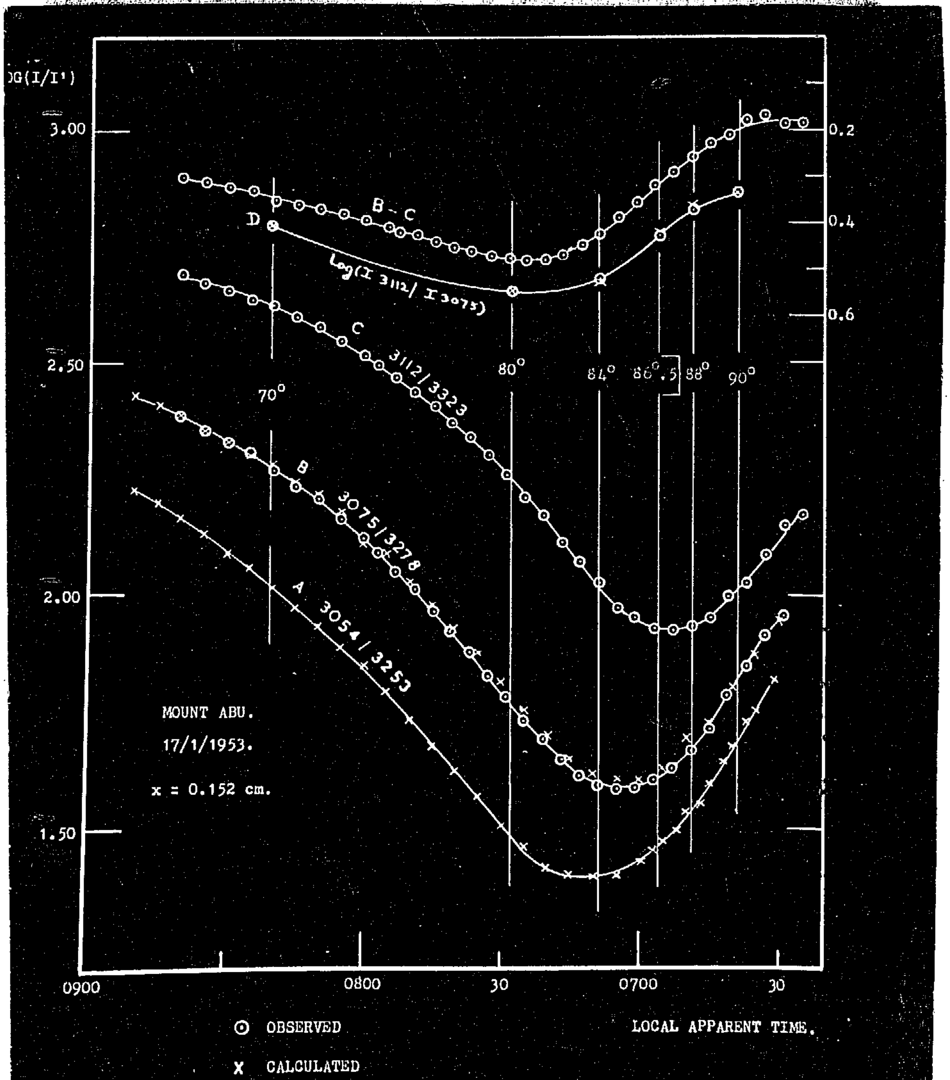
3. The difference curve (B - C) in Fig.12 between Log($^{I}3112/^{I'}3323$) and Log($^{I}3075/^{I'}3278$) was obtained. From this difference curve, the calculated curve of Log($^{I}3278/^{I}3323$), (assuming only primary scattering for 3278 and 3323) was subtracted. This gave the Log($^{I}3112/^{I}3075$) curve that would have been obtained if equal slits had been placed in the instrument, so as to transmit those wavelengths at the same time.

4. Calculations of vertical distribution of ozone were now made to satisfy the derived umkehr curve of Log($^{I}3112/^{I}3075$).

Fig. 12 explains the different steps.

The new distribution obtained from the derived curve is

We can test whether the revised values of ozone distribution fit the umkehr curves obtained with other pairs of wavelength. On 17-1-53, we had umkehr observations with the three pairs 3112/3323, 3075/3278 and 3054/3253. Fig. 13 shows the fits that were obtained in the derived difference-curves of $\lambda\lambda$ 3112/3054 and of $\lambda\lambda$ 3075/3054 if the distribution were made to fit the umkehr curve of 3112/3075. These are satisfactory, although of the three, only two really are independent.



UMKEHR CURVES WITH 3112/3323, 3075/3278 & 3054/3257. THE DIFFERENCE CURVE - 3112/3323 - 3075/3278 & THE DERIVED CURVE 3075/3112 ARE ALSO GIVEN.
OZONE DISTRIBUTION ACC. TO B & C = B : 0,1.0,6.9,7.4,1.3,0.3; C:1.0,1.0,6.8,6.5,1.0,0.6
OZONE DISTRIBUTION ACC. TO DERIVED CURVE D = 1.0,1.0,8.3,5.0,1.3,0.3

Fig. 12.

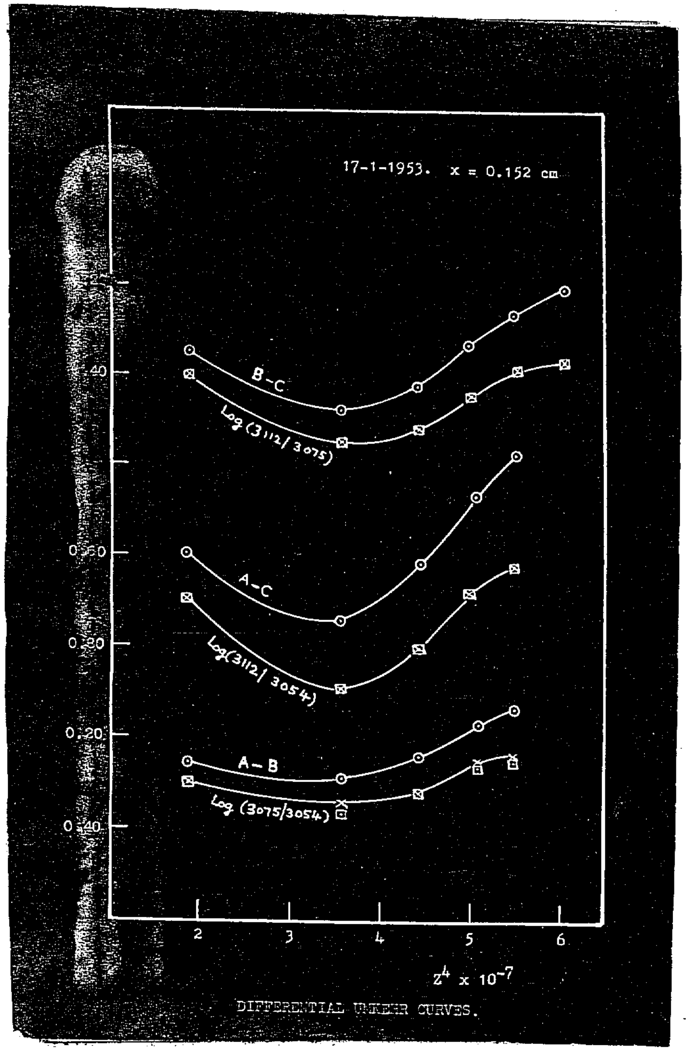


Fig. 13(a)

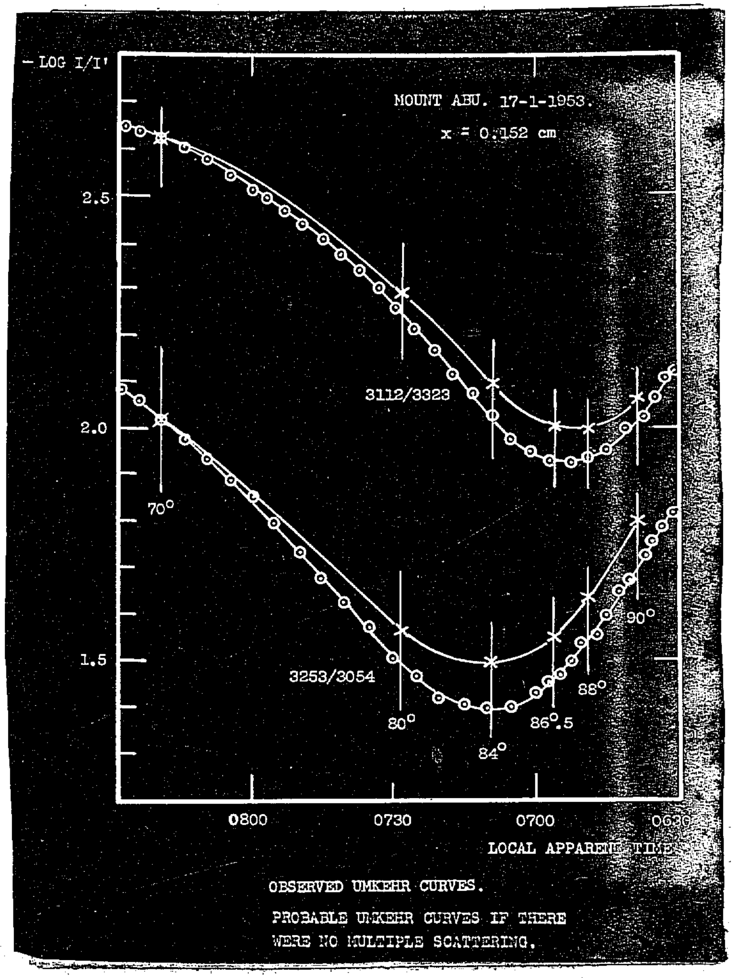


Fig. 13(b)

	70°	80°	84°	86.5
C	-2.62	-2.28	-2.04	-1.96
a	-2.02	-1.50	-1.40	-1.50

Fig. 13.

Table 8.

Date.	Quantity of O_3		Distribution.	C.G. of the mean O_3 layer, km.
21-10-51	0.153	A*	0.0, 1.0, 6.9, 7.5, 1.3, 0.3	27.8
		B	1.0, 1.0, 6.9, 6.5, 1.0, 0.6	26.4
		C	1.0, 1.0, 8.4, 5.0, 1.3, 0.3	25.5
1-11-51	0.170	A	0.0, 1.0, 8.2, 7.7, 1.8, 0.1	27.6
		C	1.0, 2.0, 9.8, 4.2, 1.8, 0.1	24.5
5- 2-52	*0.188	A	0.0, 2.0, 11.0, 5.9, 1.6, 0.4	26.1
		B	0.0, 1.7, 10.8, 6.1, 1.5, 0.8	27.2
		C	2.0, 2.1, 12.0, 3.1, 1.3, 0.4	22.9
7- 2-52	0.208	A	1.0, 1.5, 12.3, 7.1, 1.2, 0.1	25.1
		B	0.5, 1.5, 12.3, 7.0, 1.4, 0.5	26.6
		C	2.0, 2.1, 13.6, 4.1, 1.2, 0.1	22.8
10- 6-52	0.190	A	0.0, 1.0, 11.0, 7.4, 1.3, 0.4	26.9
		B	0.0, 1.0, 11.0, 7.4, 1.3, 0.4	26.9
		C	1.0, 2.0, 12.0, 4.4, 1.3, 0.4	23.4
20-12-52	0.146	A	0.0, 1.0, 6.9, 7.1, 1.0, 0.3	27.6
		C	0.5, 2.0, 7.4, 4.8, 1.0, 0.3	24.9
17- 1-53	0.152	A	0.0, 1.0, 6.9, 7.4, 1.3, 0.3	27.8
		C	1.0, 1.0, 8.3, 5.0, 1.8, 0.3	25.5
20- 1-53	0.170	A	0.0, 1.0, 8.3, 8.0, 1.5, 0.1	27.4
		C	1.0, 2.0, 9.8, 4.5, 1.5, 0.1	24.4

*A, B, C are the vertical distributions of ozone as calculated from the pairs of wavelengths 3112/3323, 3075/3278 and 3075/3112 respectively.

Dr. Walton, from his theoretical calculations with a plane atmosphere has come to practically the same conclusion. He says, "Plotting the ratio of secondary to primary scattered light received vertically at the ground as a function of Z where Z = sec Z - 1, and Z is the solar zenith distance, we see that the ratio varies with the zenith distance, the wavelength and the height of the layer - - - - - - - We infer from the result for a hypothetical layer, that if the natural vertical distribution of ozone is determined from zenith observations and secondary scattering is neglected in the calculations, then the mean height of ozone is slightly over-estimated."

VI. OZONE AND WEATHER.

Comparative observations at Abu, Ahmedabad and Delhi:-

1. The relationship of atmospheric ozone to weather is one of the live problems of modern meteorology. Prof. Dobson's papers remain a perennial source of information on this subject. Recently, there have appeared a number of monographs and review articles which summarise our knowledge of this subject. The most important of them are listed below :-

(1) Prof. Ch.Fabry's posthumous work on 'L'ozone atmospherique' edited by Prof.Vassy and Madame Vassy.

(2) Dr.R.A.Craig's monograph on "The Observations and Photochemistry of Atmospheric Ozone and their meteorological significance".

(3) Mr.R.J.Reed's paper on "The role of vertical motions in Ozone-Weather relationships" in the Journal of Meteorology, (1950).

(4) Dr.F.W.P.Gotz's article on "Ozone in the Atmosphere" in the "Compendium of Meteorology".

(5) Mr.K.Langlo's memoir "On the amount of atmospheric ozone and its relation to meteorological conditions" in the Norwegian Geophysical Memoirs and

(6) Sir Charles Normand's Presidential Address to the Royal Meteorological Society (1952). All these papers deal with different aspects of ozone and weather in the region of the upper westerlies of middle and high latitudes, and include discussions of the causes of the day-to-day variations of ozone in these regions.

The International Ozone Commission under the Chairmanship of Prof. Dobson is collecting daily data of ozone from a group of 10-12- stations in Europe and some of the results obtained from a study of these data are contained in Sir Charles Normand's address referred to above and in the Proceedings of a Symposium on Atmospheric Ozone held at Oxford in September 1952.

2. The first world-wide ozone survey made by Dobson and the later observations of Chiplonkar at Bombay showed that there was little day-to-day change of ozone in low latitudes. But observations made at Delhi in 1946-47 by Dr.Karandikar showed that while the behaviour of ozone there in the monsoon and autumn months was similar to

those at Bombay and Kodaikanal, there were marked fluctuations of ozone amount in winter and spring in connection with the "western disturbances" which are a regular feature of N.Indian weather in these seasons and are undoubtedly connected with the southern branch of the northern hemisphere jet-stream.

The following features were noticed about the ozone variations at Delhi :-

(1) The ozone increases came in a series of surges commencing in November or December. Pronounced surges were associated with decreased night temperatures at Simla but there was no consistent correlation between each day's ozone amount and the succeeding night's temperature.

(2) Upper air temperatures at 6 km did not show any definite correlation with ozone amount. Daily data at higher levels were not available.

(3) In general, fresh northerly air was associated with higher ozone amounts in winter.

(4) In the monsoon season, the average ozone amount was low, and the day-to-day fluctuations were small.

The Delhi observations made it clear that the middle latitude variations of ozone associated with weather were observable in N.India during winter and spring, though in a less pronounced manner. The southern edge of the upper westerlies, being the region where the transition between the tropical and temperate latitude tropopauses occur, is a particularly interesting region to study.

3. For comparing the ozone amounts at two places, it is necessary to ensure that the instruments which are used for the measurements are standardised and give the same values when used at the same place. Before instrument No.39 was transferred to Mt.Abu, observations were made on many days with instruments No.39 and 10 simultaneously at Ahmedabad. After satisfactory adjustment and comparison, No.39 was transferred to Mount Abu and observations commenced there in October 1951.

4. At the time the comparisons were made at Ahmedabad, Instrument No.10 had not been re-modelled and wavelengths 3110/3300 were used for the observations. When the instrument was later changed by the introduction of the two quartz plates and replacement of the old wedges by new ones, the calibration was re-done at both the places

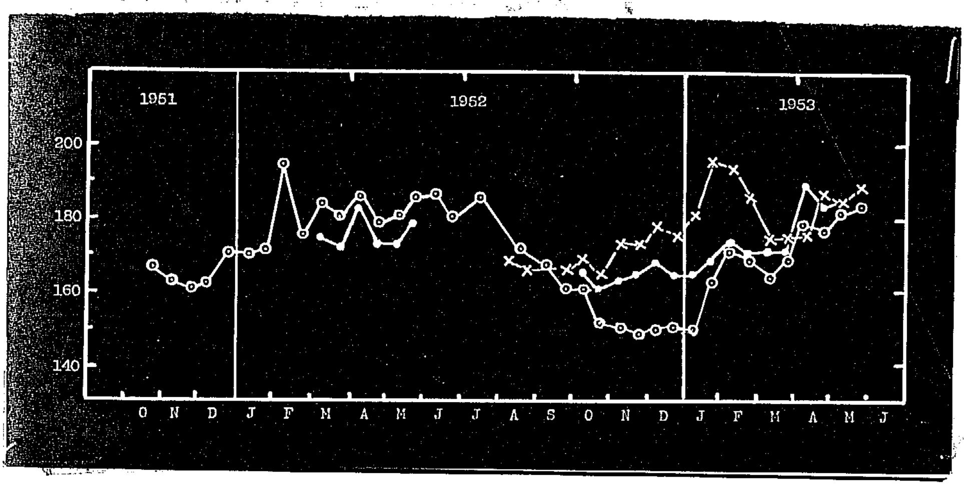


FIG. 14

with the same perforated metal gauze. The I.M.D's. new instrument at Delhi also was calibrated with the same metal gauze and by the same method.

The half-monthly mean values of ozone obtained at Mt. Abu and Ahmedabad are tabulated in Table 9 (Appendix) and plotted in Fig. 14. In the same figure, the mean half-monthly values so far obtained by the observers of the India Meteorological Department at Delhi are also plotted for comparison. The observations were mostly taken in the afternoons when μ was between 2 and 3.

The instrumental constants L_o and L_o' were determined at frequent intervals, and any change was made only when there was definite evidence for it. The calibration of the optical wedges in instrument No.39 did not undergo any marked change between October 1951 and October 1952. A slight increase in opacity in the darker half of the wedge has recently come to notice and a revised calibration has been adopted for the Abu instrument after November 1952.

The new wedges of instrument No.30 at Ahmedabad have retained their calibration. There was some stiffness in the movement of the quartz plates in the Delhi instrument No.36 in October 1952; this stiffness was ceased between the 21st and 25th October and the calibration has shown a small change since then.

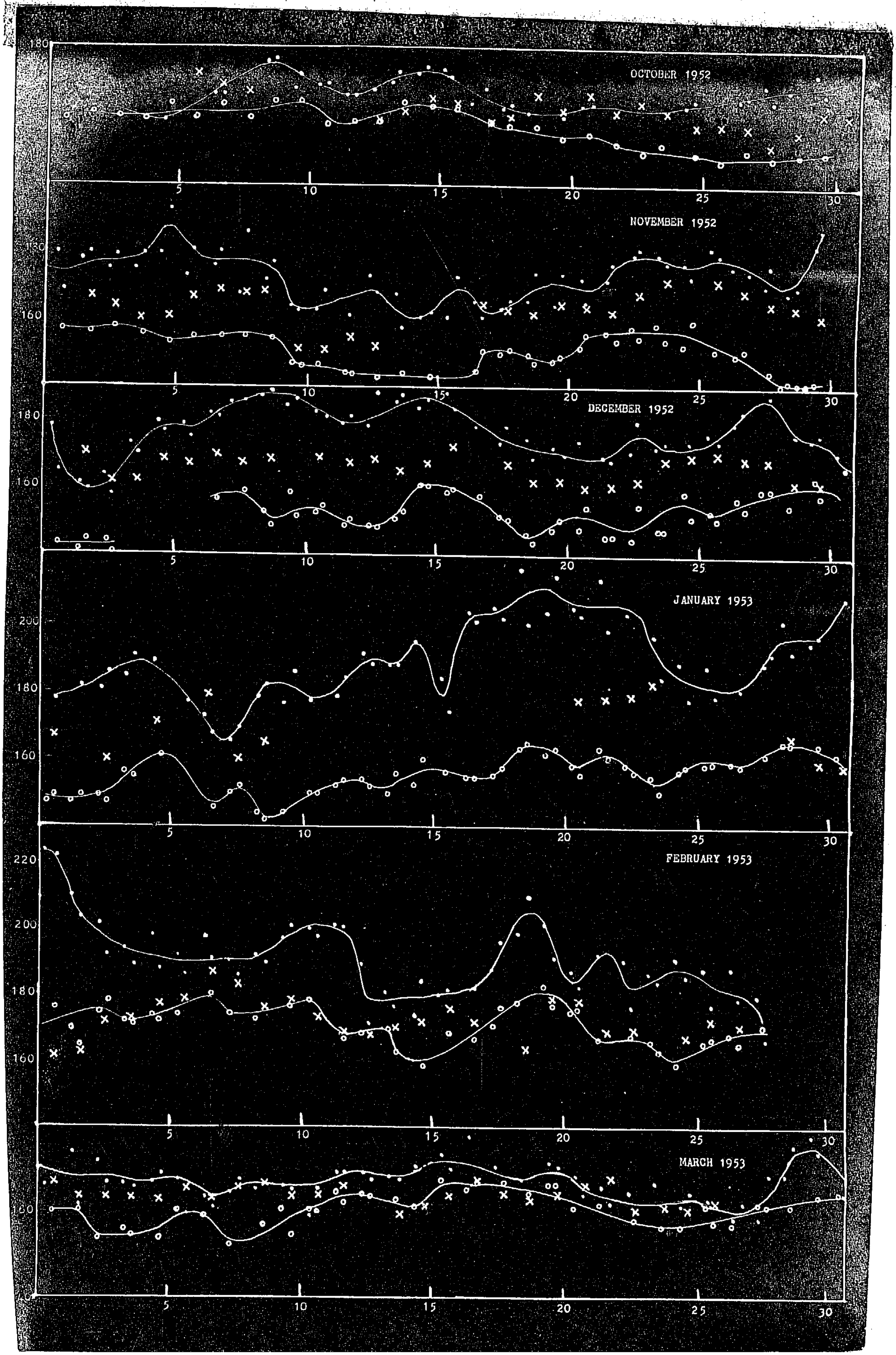
The daily ozone values at Ahmedabad and Abu are shown in Table in the Appendix. 4.

Fig. 15 brings out the following points regarding the seasonal variation of ozone at Abu.

(1) Although the annual variation conforms in a general way to the normal variation appropriate to northern latitudes, there are significant differences from Bombay and Delhi to which attention may be drawn.

It is difficult to say whether there was a secondary minimum of ozone in the monsoon months July and August. For one thing, the number of observations were very few in the second half of July and in August till the 20th, and even the remaining observations in July were taken through monsoon clouds, and unusually large haze corrections (0.012 to 0.016) had to be applied. The apparent large fluctuations of ozone amount in that period may therefore be spurious.

(2) There was a steady fall of ozone amount from the end of August to October leading to an exceptionally low and flat minimum from late October 1952 to the first week of January 1953.


OCTOBER 1952
NOVEMBER 1952
DECEMBER 1952
JANUARY 1953
FEBRUARY 1953
MARCH 1953
180
160
200
220
5
10
15
20
25
30

(3) A very interesting feature of the ozone distribution was that in November, December and January, ozone values at Abu were lower than those at Delhi and Ahmedabad, and indeed lower than any recorded anywhere outside the polar regions. This suggests that in autumn the lowest ozone values often (and perhaps always) occur not over equatorial regions, but over the sub-tropics. Dr. Ramanathan has suggested that this feature may be connected with a seasonal ascent of air in the upper troposphere and lower stratosphere on the southern border of the zone of westerly jet streams. The ascending air would either be tropical air or middle latitude air which has gradually climbed up from lower levels. The high level upper wind charts published by the India Met. Department (S.P. Venkiteshwaran, Mem. Ind. Met. Dep., 1950, Vol. 28, Pt. II) show a regular south-westerly flow from 12 to 20 km in October and November.

Fig. 16a, b, c shows the daily values of ozone amount at Abu, surface pressures at Abu at 12 hrs G.M.T. reduced to 1 km above sea-level, and the 300 mb pressure levels over Jodhpur, the nearest radio-sonde station of the India Meteorological Department. These charts bring out the following additional points :-

(1) From August to October, the surface pressure

increases, the 900 mb level comes down and the ozone amount decreases. The analysis of vertical distributions at Mt.Abu and at other places in India shows that there is very little ozone present in the tropical troposphere. The decrease of ozone amount can be explained if in these latitudes, there is a slow but steady upward leakage of ozone-poor air from the troposphere into the stratosphere.

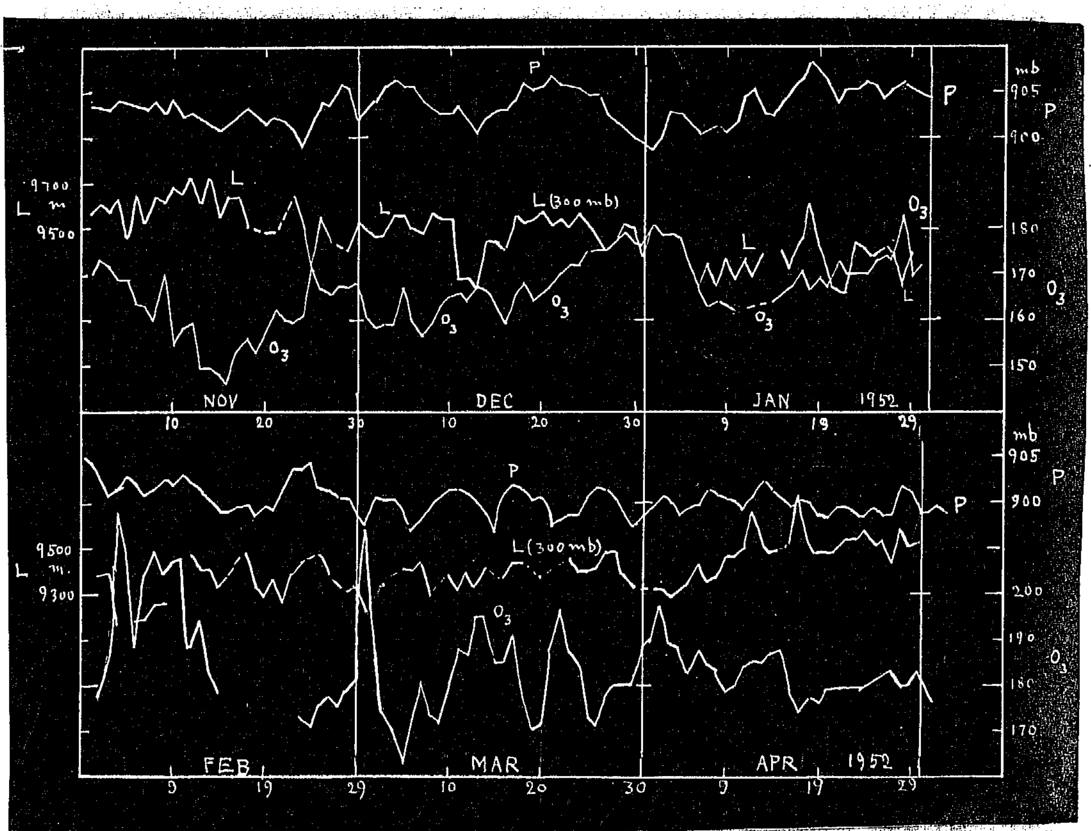


Fig. 16a

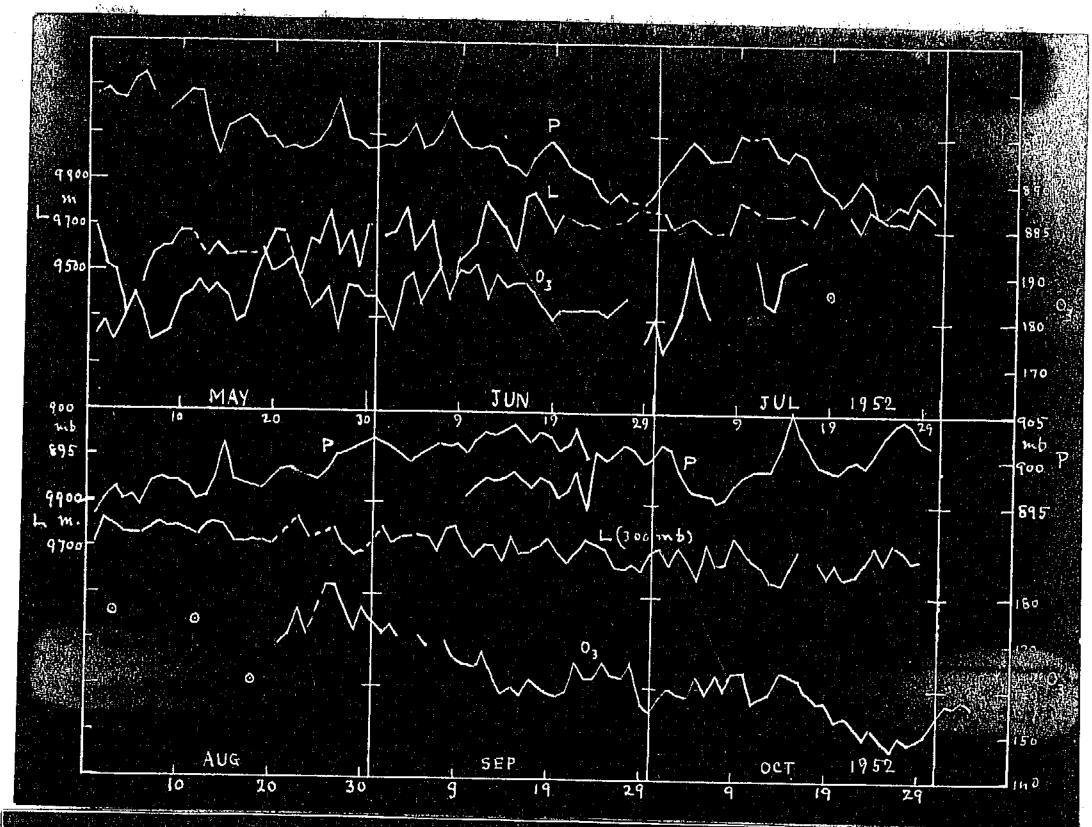


FIG. 16b

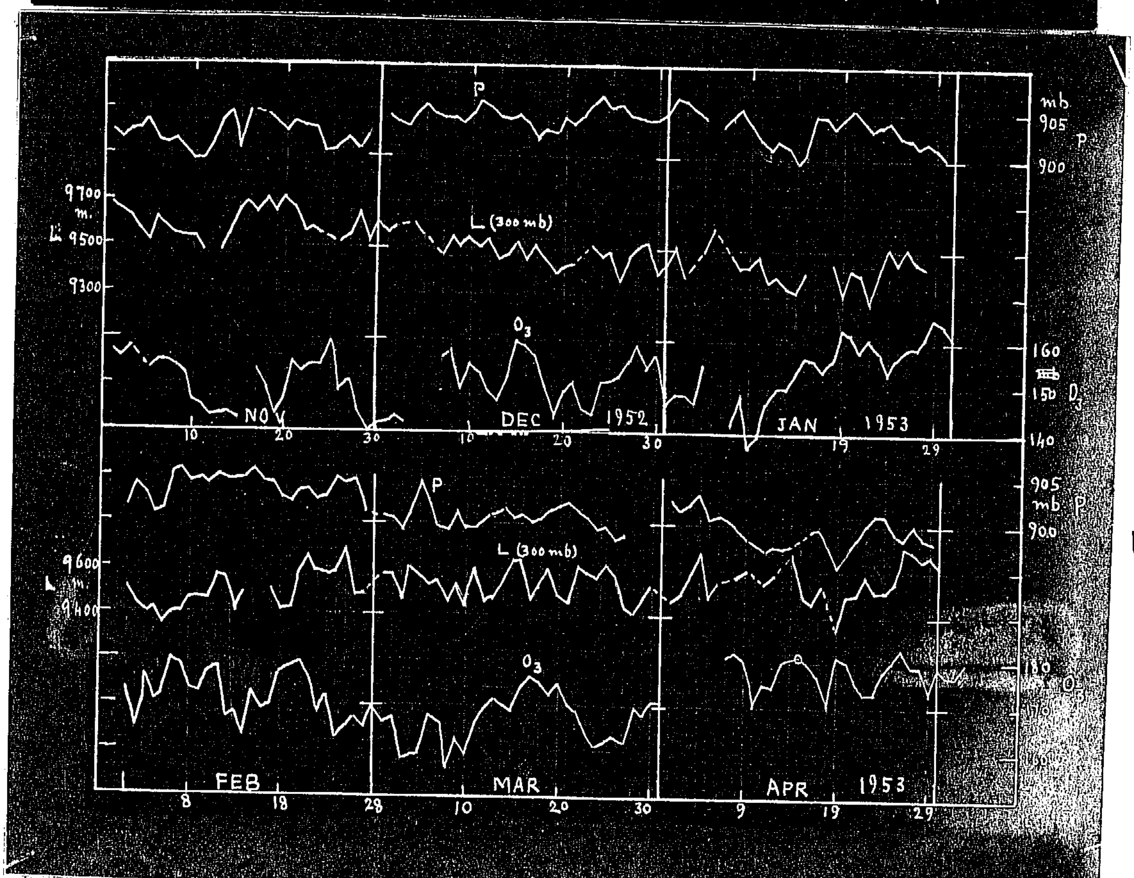


FIG. 16c

(2) When the ozone amount increases from its period of minimum in November or December, the increase takes place in a series of waves or surges. Some of the surges show corresponding inverse changes of the 300 mb level, but the correlation is not at all close. Some of the exceptionally large increases of ozone such as those on 3-2-52 and on 1-3-52 accompanied or followed by passages of low pressure troughs across the latitude of Mt.Abu. There is however no quantitative relationship between the rise of ozone and the negative departure of pressure.

(3) In addition to the long-period surges, there are surges of period 5 to 10 days in February and March in which positive deviations of ozone correspond to negative deviations of pressure. No correlation is discernible with the 300 mb contours.

It may be that owing to the greater height of the tropopause in the tropics and the sub-tropics, correlation between ozone amount and upper air conditions would be met with only at higher levels than in temperate latitudes. The necessary upper air data are not however available. Further examination of all sources of information is being pursued in the Physical Research Laboratory.

I give below summarised information of a few individual disturbances in which some definite connection could be observed between changes in ozone amount and changes in upper air conditions.

Western disturbance : January 1 to 9, 1952 :-

The ozone amount steadily decreased from the 5th to 9th January 1952. The decrease stopped on the 9th. These changes were connected with a pronounced western disturbance. The following table gives the day-to-day values of ozone and the general character of air-flow at 6-9 km during that period.

Table 9..

Date.	X	Weather remarks.
5-1-52	0.272	Winds at 6-9 km WSW, 60-70 knots. Axis of jet stream was at about 25°N. Winds over the Peninsula were from SE and S.
6-1-52	0.197	Weak low pressure area over Gujarat.
7-1-52	0.163	The low pressure area was over W. Rajasthan, and there was a broad,deep SW to WSW current. Rain fell in the North-west Frontier, Punjab, West U.P. and Rajasthan.

Date.	x	Weather remarks.
8-1-52	0.163	NW air had come over the Punjab and Rajasthan and pressure had risen there.
9-1-52	0.156	Winds at 6-9 km, WNW, 50-70 knots. The lowest ozone amount was observed immediately after the surface low had moved away.
10-1-52	0.163	-

No information was available about the air flow at levels higher than 9 km. In this instance, the decrease of ozone was associated with southerly and south-westerly air-flow at 6 to 9 km, and the minimum ozone amount was recorded at about the time when the northerly stream replaced the south-westerly current.

<u>Disturbances in February and March 1952</u> :-

The ozone amount rose from the 30th January to the 2nd February and this was followed by a rapid fall on the 4th and 5th. There was again a rise on the 6th and the high value persisted till the 10th.(See Fig.17). A western disturbance was active over the Punjab and the West U.P. on the 5th when the ozone over Abu was a minimum. The following table gives the day-to-day values of ozone during that period.

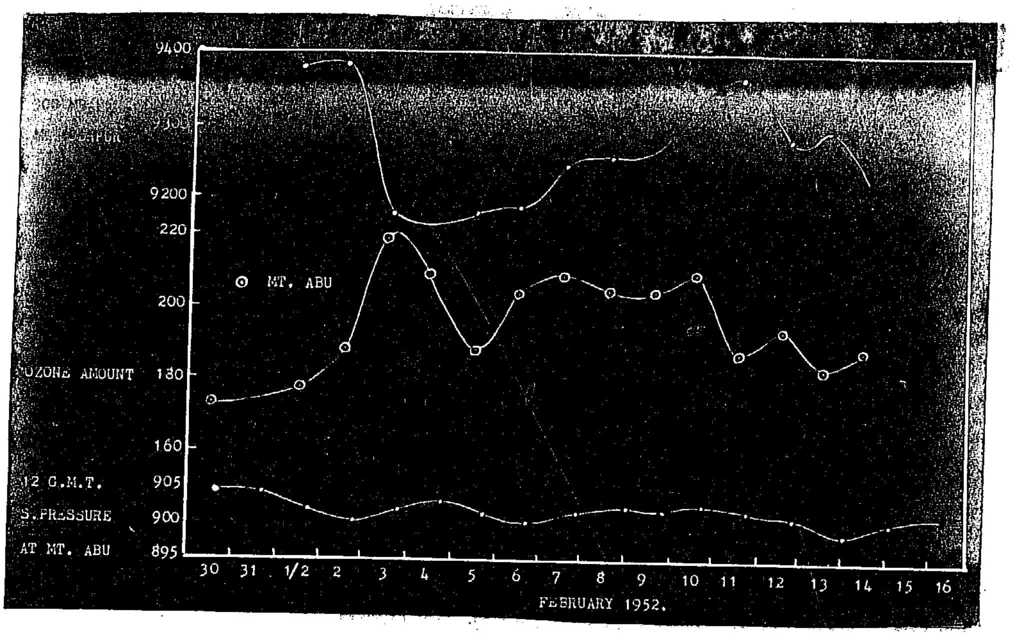

9400
9200
220
200
180
160
905
900
895
MT. ABU
OZONE AMOUNT
12 G.M.T.
S.PRESSURE
AT MT. ABU
30
31
1/2
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
FEBRUARY 1952.

FIG. 17

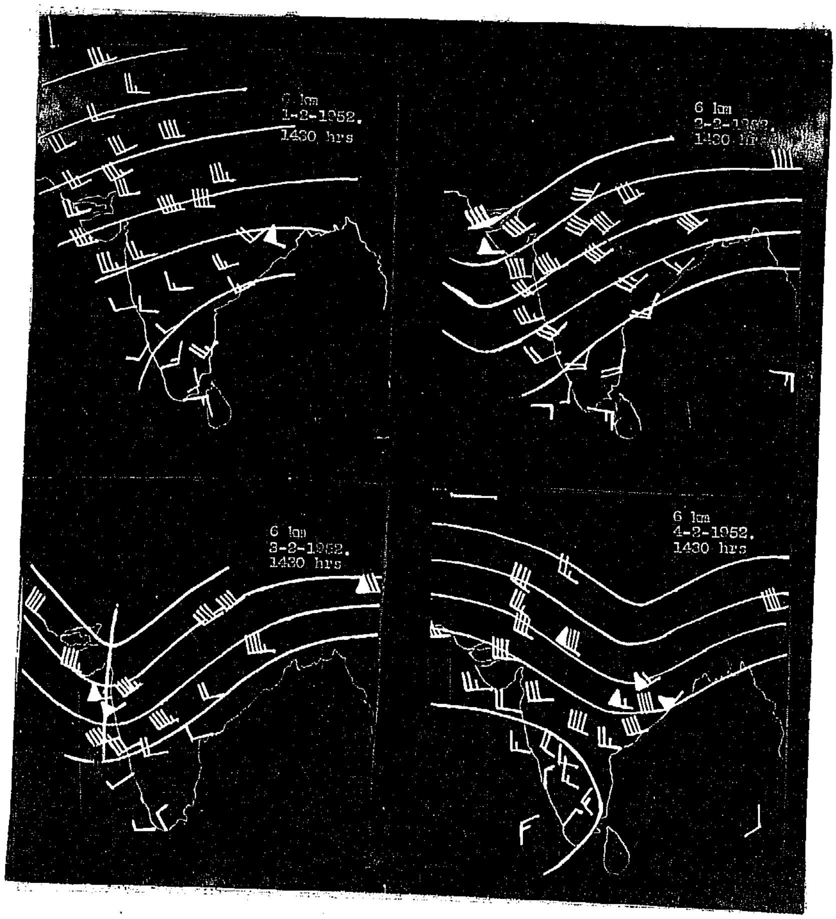

1-2-1952.
1430 hrs
6 km
6 km
3-2-1952.
1430 hrs
6 km
4-2-1952.
1430 hrs

FIG. 18

Table 10.

Date.	X	Weather remarks.
1-2-52	0.177	
2-2-52	0.197	Centre of active W. disturbance was over Bikaner. Wind stream at 6-9 km W to WSW, 50-70 knots. Upper westerlies extended to south of 15° N.
3-2-52	0.228	Pressure minimum was over Ganganagar. On the 2nd evening, W to NW winds were coming over Baluchistan and Sind.
4-2-52	0.209	Deep, broad NW winds from 4-10 km.
5-2-52	0.199	" " " " " " "
6-2-52	0.204	Upper winds become westerly.
7-2-52	0.209	
8-2-52	0.206	
9-2-52	0.207	
10-2-52	0.210	

The changes in the wind distribution at 6 km are plotted in Fig. 18. The rise of ozone took place when winds of north-westerly origin were replacing those of south-westerly. When the former got settled, the ozone content began to return to normal.

There was a similar rapid rise and fall of ozone in the first week of March 1952. The ozone amount was 0.180 cm on the 29th February and no appreciable change in its amount was noticed during the day. Cu, Scu, and Ci were forming and disappearing at Abu throughout the day. On the morning of 1-3-52, the ozone amount went up to 0.202 cm. The sky was clear till about 0800 hrs and cumulus clouds then started forming. Hourly observations were made on that day, and on a few subsequent days to follow the changes in ozone.

Table 11.

Date :-29-2-52.

I.S.T.	x	Weather remarks.
0900	0.188	The sky was overcast from the previous
0950	0.186	day. Cleared up after 1030 hrs. Cumulus
1040	0.182	formation at 1600 hrs. By 1700 hrs. the
1200	0.180	sky was covered with cirrus, cumulus
1430	0.177	and strato-cumulus.
1530	0.180	
1557	0.180	
1628	0.183	
1649	0.182	

Date :- 1-3-52.

0811	0.203	Clear sky till about 0815 hrs. Sky full
0832	0.203	of cumulus by 0900 hrs. Sky continued to
0911	0.205	be clouded with cu throughout the day.

1030	0.208
1156	0.209
1450	0.212
1530	0.215
1640	0.217
1606	0.218
1632	0.216
1650	0.213
1709	0.212
1723	0.208
1740	0.200

Date :- 9-2-52.

0807	0.206	Very clear sky from morning till about 1720 hrs. Thin ci appeared in the evening.
0823	0.207	
0845	0.204	
0915	0.203	
0933	0.204	
0955	0.203	
1113	0.194	
1313	0.194	
1424	0.195	
1523	0.196	
1600	0.195	
1649	0.192	
1710	0.192	

1722	0.190
1723	0.193
1724	0.193

Date :- 3-3-52.

0813	0.183	Thin cirrus throughout the day.
0834	0.188	
0907	0.190	
0946	0.186	
1027	0.183	
1118	0.180	
1404	0.176	
1503	0.177	
1550	0.171	
1623	0.174	

Date :- 4-3-52.

0818	0.178	Clear.
0902	0.176	
1020	0.178	
1110	0.171	
1229	0.169	
1403	0.168	

The upper wind charts relating to 6 Km of the days 29-2-52 to 4-3-52 are given in Fig. 19 . They show that on the afternoon of 1-3-52 a strong Wly stream was replacing Nly to SWly stream of the previous day. This swept eastwards and extended over the whole of India by the 3rd. From the ozone changes, one should infer that the NWly stream was a very deep one.

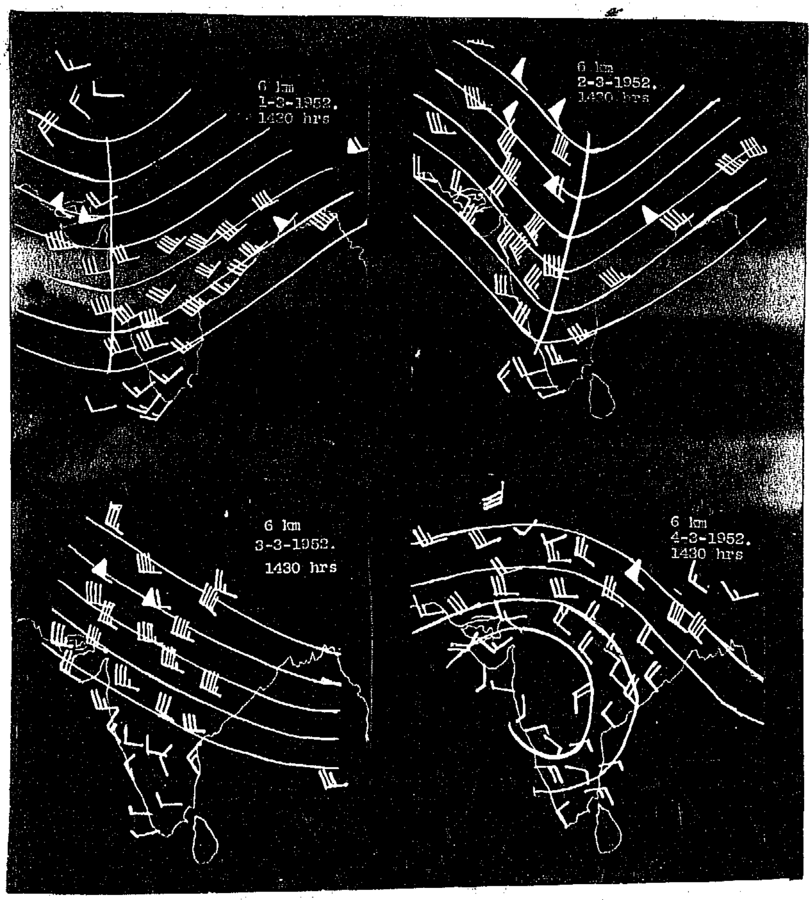
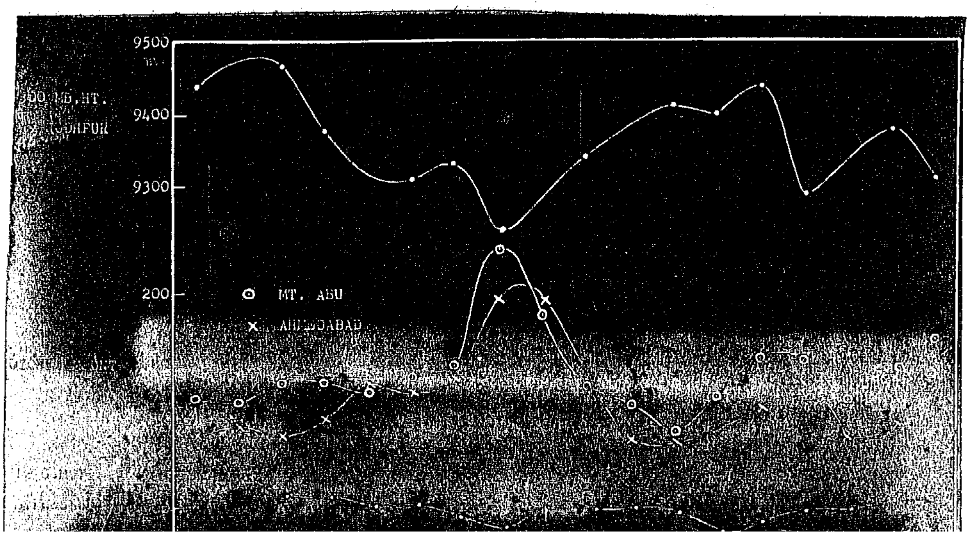


FIG. 19



Ozone changes connected with an Arabian Sea storm in November 1951 :-

There was a fall of ozone from 0.170 to 0.146 cm during the period 9th to 16 th November 1951. This occurred when a storm developed in the Arabian Sea at 10½° N and 66° E on the 13th morning and moved northwards to Kathiawar. It was at 19½° N, 66° E on the 16th. The ozone amount reached a minimum value of 0.146 cm on the 16th. After this, the depression became shallow and there was a small increase in ozone. On the 17th morning, the winds became northerly and the ozone amount began to increase. The following table gives the ozone values during the period.

Table 12.

Date.	X
9-11-51	0.170
10-11-51	0.164
11-11-51	0.152
12-11-51	0.153
13-11-51	0.149
14-11-51	0.140
16-11-51	0.146
17-11-51	0.163

On the 8th, the upper winds at 6 and 9 km over N NW India changed and became N to NNW. On the 9th morning there was a broad sweep of NWly winds from 3 to 10 km. A low pressure trough appeared over S.Arabian Sea on the 11th morning and developed into a depression on the 13th morning at Lat.10½° N, Long.68° E. On the 13th and the 14th, the strong westerly stream over N.India between 7 and 10 km seemed to pull up SWly to NWly winds from the region of the disturbance. On the 15th the sky was overcast at Abu and pressure was lowest in the Veraval-Dwarka region in Kathiawar. On the 16th, there were SW winds at 6 and 9 km over Kathiawar. The depression became shallow on the 17th.

We do not know how high the outflow from a tropical storm extends, but from the steady decrease of ozone observed at Abu during the period when the storm was approaching the station, and from the fact that low ozone amounts in our latitudes mean decreased ozone in 18-27 km, one can venture the guess that in the outer field of a tropical storm, there is an ascent of air even in the lower stratosphere. From the work of Nicolet and Reed, it is known that in a region of decreasing ozone-mixing-ratio with height, ascent of air will cause a lowering of ozone amount. (R.J.Reed, 1950, Jour.Met., 7, p.263).

Conclusion :-

The study of the relationship between ozone and weather is much more difficult in tropical and sub-tropical regions than in middle latitudes. In the tropics, the day-to-day variations are small and systematic study can be expected to lead to a better understanding of the photochemical equilibrium of ozone in the earth's atmosphere, and its correlation with changes in ultra-violet solar radiation during the solar cycle. Sub-tropical latitudes in autumn, winter and spring offer a favourable field for the study of the causes of the seasonal changes in ozone and of the effect of the churning-up processes that occur between tropical and temperate latitude tropopauses in the region of one of the most important jet-stream zones of the earth.

REFERENCES.

1. Huggins, M.L., (1890), "A new group of lines in the photographic spectrum of Sirius", Proc.Roy.Soc.,A, 48, p.216.
2. Ladenburg, R., and Lehmann, , (1906), "Uber Versuche mit hochprozentigem Ozon". Ann.Phys. 21, p.330.
3. Fowler, A., and Strutt, Hon.R.J., (1917), "Absorption bands of atmospheric ozone in the spectrum of sun and stars", Proc.Roy.Soc.,A, 93, p.577.
4. Fabry, C., and Buisson M., (1913), "L'absorption de l'ultraviolet par l'ozone et la limite du spectre solaire", J.Phys.Radium, Ser 5, 3, p.196.
5. ______________, (1921), "Etude de l'extremite' ultraviolette du spectre solaire", J.Phys.Radium, Ser 6, 2, p.197.
6. Dobson, G.M.B., and Harrison D.N., (1926), "Measurements of the amount of ozone in the Earth's Atmosphere and its relation to other Geophysical conditions" - Part I, Proc.Roy.Soc.,A, 110, p.660.
7. ______________, (1927), Idem, Part II, Proc.Roy.Soc.,A, 114, p.521.
8. ______________, (1929), Idem, Part III, Proc.Roy.Soc.,A, 122, p.456.

9. Dobson G.M.B., with reports by Kimball, Dr. H., and Kidson, Dr. E., (1930), "Observations of the Amount of Ozone in the Earth's atmosphere and its relation to other Geophysical conditions" - Part IV, Proc. Roy. Soc., A, 129, p.411.

10. Higgs A.J., (1934), "Measurements of atmospheric ozone", Mem. Commonwealth sol. Obs. No.3, p.29pp.

11.a Lejay P., (1934), "Mesures de la quantite d'ozone contenue dans l'atmosphere, Janvier 1932-December 1933", Notes Meteor. Phys., Obs. de Zi-Ka-Wei, Fasc.3, 16pp.

11.b ________, (1937), "Mesures de la quantite d'ozone contenue dans l'atmosphere a l'Observatoire de Zo-se, 1934-1935-1936; les variations de l'ozone et les situations meteorologiques." Notes Meteor. Phys., Obs. de Zi-Ka-Wei, Fasc. 7, 16pp.

12. Chiplonkar, M.W., "Measurements of Atmospheric ozone at Bombay", Proc. Ind. Acad. Scs., A, 10, p.105.

13. Dobson G.M.B., (1931), "A Photoelectric Spectrophotometer for Measuring the Amount of Atmospheric Ozone", Proc. Phys. Soc., Lond., 43, p.324.

14. Karandikar, R.V., (1948), "Studies in Atmospheric Ozone" Part II : "Daily Measurements of Atmospheric Ozone and of (δ-δ'), a Measure of Atmospheric Turbidity, at Delhi". Proc. Ind. Acad. Sci., A, 28, p.63.

15. Karandikar, R.V., and Ramanathan K.R., (1949), "Vertical Distribution of Atmospheric Ozone in Low Latitudes", Proc.Ind.Acad.Sci.,A,29, p.330.

16. Ramanathan, K.R., and Karandikar, R.V., (1949), "Effect of Dust and Haze on Measurements of Atmospheric Ozone Made with Dobson's Spectrophotometer", Quart.Jour.Roy.Met.Soc., 75, p.587.

17. Gotz, F.W.P., and Dobson, G.M.B., (1928), "Observations of the Height of Ozone in the Upper Atmosphere", Proc.Roy.Soc.,A, 120, p.251.

18. Gotz, F.W.P., (1929), "Zum Strahlungsklima des Spitzbergen-sommers Strahlungs-und Ozonmessungen in der Konigsbucht", Gerl.Beitr.Geophys., 31, p.119.

19. Gotz, F.W.P., Meetham, A.R., and Dobson, G.M.B., (1934), "The vertical distribution of ozone in the atmosphere", Proc.Roy.Soc.,A, 145, p.416.

20. Gotz, F.W.P., and Dobson, G.M.B., (1929), "Observations of the Height of Ozone in the Upper Atmosphere" - Part II, Proc.Roy.Soc.,A, 125, p.292.

21. Regener, E., and Regener, V.H., (1934), "Aufnahmen des ultravioletten Sonnenspektrums in der Stratosphere und die vertikale Ozonverteilung", Phys.Z., 35, p.788.

22. O'Brien, B., Stewart, H.S., and Mohler, F.L., (1936), "Vertical distribution of ozone in the atmosphere", Nat.geogr.Soc.Cont.tech.Pap.,Stratosphere Series, No.2, p.49.

23. Johnson, F.S., Purcell, J.D., and Tousey, R., (1951), "Measurements of the Vertical Distribution of Atmospheric Ozone from Rockets", Jour. Geophys. Res., 56, p.583.

24. ____________________________________, Watanabe, K., (1952), "Direct Measurements of the Vertical Distribution of Atmospheric Ozone to 70 km Altitude", Jour. Geophys. Res., 57, p.157.

25. Ramanathan, K.R., and Kulkarni, R.N., (1953), "Height distribution of Atmospheric Ozone", Proc. Ind. Acad. Sci., A, 37, p.321.

26. Chapman, S., (1930), "A theory of upper atmospheric ozone", Mem. Roy. Meteor. Soc., 3, p.103.

27. Wulf, O.R., and Deming, L.S., (1937), "The Distribution of Atmospheric Ozone in Equilibrium with Solar Radiation and the Rate of Maintenance of the Distribution", Terr. Magn. Atmos. Elect., 42, p.195.

28. Palmen, E., (1939), "Uber die dreidimensionale Luftstromung in einer Zyklone und die Ozonverteilung," U.G.G.I., Proc. Verb., Ass. Meteor., Washington, p.75.

29. Dobson, G.M.B., and Normand, C.W.B., (1930), "Operator's Manual for the Dobson's spectrophotometer" issued by R. & J. Beck.

30. Vassy, Mme., and Abdul Khaleq, M., (1952), "Variation diurne de l'e'paisseur r'eduite et de la temperature moyenne de l'ozone atmospherique aux basses latitudes", Comptes Rendus, 235, p.737.

31. Barbier, D., and Chalogne, D., (1939), "Recherches sur l'ozone atmospherique", Jour. Phys. Rad., Ser 7, 10, p.113.

32. Dobson, G.M.B., (1951), "Recent work on the stratosphere" Quart. Jour. Roy. Met. Soc., 77, p.499.

33. Ramanathan, K.R., Murthy, Bh.V.R., and Kulkarni, R.N., (1952), "The effect of secondary scattering in the calculation of the vertical distribution of atmospheric ozone from the Gotz inversion-effect", Quart. Jour. Roy. Met. Soc., 78, p.625.

34. Normand, Sir Charles and Kay, R.H., (1952), "Note on the design, adjustment and calibration of spectrophotometers", Jour. Sci. Instrum., 29, p.33.

35. Kay, R.J., (1953), Symposium on Atmospheric Ozone, I.G.U.G. Newsletter, p.303.

36. Gotz, F.W.P., (1939), "Die Vertikale Verteilung des atmospharischen ozons" Ergeb. kosm. Phys., 3, p.253.

37. Meinel, A.B., (1951), "The Spectrum of the Air-glow and the aurora", Report on Progress in Physics, 14, p.121.

37 a Swings, P., and Page, T., (1950), "The spectrum of Comet Bester", Astrophys. Jour., 3, p.530.

38. Gotz, F.W.P., and Nicolet, M., (1951), "Sur des observations a la limite ultraviolette des spectra du ciel nocturne", Jour. Geophys. Res., 56, p.577.

39. Roach, F.E., Pettit, H., and Williams, D.R., (1950), "The height of the atmospheric OH emission", Jour. Geophys. Res., 55, p.183.

40. Gotz, F.W.P., (1951), "Ozone in the Atmosphere", Compendium of Meteorology, p.

41. Dutsch, H.U., (1946), "Photochemische theorie des atmospharischen ozons unter Berucksichtigung von Nichtgleichgewichtszustanden und Luftbewegungen", Zurich, Doctoral Dissertation.

42. Craig, R.A., (1950), "The observations and photochemistry of Atmospheric Ozone and their Meteorological Significance" Meteorological Monograph, Published by the American Meteorological Society, Vol.1, No.2.

43. Bates, D.R., and Nicolet, M., (1950), "The photochemistry of atmospheric water-vapour", Jour. Geophys. Res., 55, p.301.

44. Gotz, F.W.P., (1944), "Der Stand des Ozonproblems", Vierteljahrsschrift der Naturforschenden Gesellschaft in Zurich", 89, p.250.

45. Coblentz, W.W., and Stair, R., (1939), "Distribution of Ozone in the Stratosphere", Jour.Res.Nat.Bur.Stand. 22, p.573.

46. Watanabe, K., (1943), "On a new method of measuring the mean height of the ozone in the atmosphere", Jour.Frank.Inst., [illegible], 236, p.461.

APPENDIX.

Appendix 1.

The equation used to determine the ozone amount is that (?) given by Ramanathan and Karandikar (Quart.Jour.Roy. Met.Soc., 75, p.257, 1949).

The basic equations are :-

$$\log I = \log I_0 - \alpha x \mu - \beta m - \delta \sec Z \qquad (1)$$

$$\log I' = \log I_0' - \alpha' x \mu - \beta' m - \delta' \sec Z \qquad (2)$$

$$\log I'' = \log I_0'' - \beta'' m - \delta'' \sec Z \qquad (3)$$

Here, I_0, I_0', I_0'' are the intensities of solar radiation of wavelengths λ, λ' and λ'' outside the earth's atmosphere,

I, I', I'' are the intensities of the same wavelengths as received on the instrument,

α, α', α'' are the absorption coefficients of ozone for λ, λ', λ'' for atmo-cm,

m and μ are the "air amount" and ozone amount" passed through by the sun's rays from outside the atmosphere to the instrument,

Z is the zenith distance of the sun as seen from the instrument ,

, , are the scattering coefficients of pure air for the wavelengths , and ,

, , are the scattering coefficients of the atmosphere due to particles which are large in comparison with .

$$L_o = \text{Log}(I_o/I_o'); \qquad L = \text{Log}(I/I')$$
$$L_o' = \text{Log}(I_o''/I_o'); \qquad L' = \text{Log}(I''/I')$$

The first term is the value of x that would be obtained from the observations, if the scattering in the atmosphere were due only to molecules, and the second term is a correction term due to scattering by large particles. If haze scattering is assumed to be neutral, the value of K' is 0.211, if = 3112, = 3323 and = 4532 A. It has to be remembered that as Mount Abu is about 4000 ft above sea level, the value of there, is smaller than that at sea-level in the ratio, mean pressure at Mt. Abu/mean pressure at sea-level.

Appendix 2.

Tables of F (slant vertical) - Air path - in atmosphere for different layers above ground for different zenith distances. The centres of mass of the layers 1,2,3,4 etc. have been assumed to be at 3 km, 12 km, 21 km, 30 km etc. i.e. 3 km above the bottom of the 9 km layer.

	LAYERS :-									
Z	1	2	3	4	5	6	7	8	9	10
70°	2.3263	1.3948	1.0900	1.0220	1.0061	1.0022	1.0009	1.0004	1.0002	1.0000
80°	4.1837	1.9501	1.2163	1.0526	1.0143	1.0049	1.0017	1.0006	1.0002	1.0000
84°	6.4149	2.6257	1.3692	1.0895	1.0241	1.0081	1.0030	1.0011	1.0003	1.0001
86°.5	9.5841	3.6069	1.5903	1.1427	1.0381	1.0218	1.0086	1.0017	1.0005	1.0001
88°	13.6632	4.9269	1.8838	1.2115	1.0556	1.0188	1.0068	1.0022	1.0005	1.0002
90°	23.2079	8.1249	2.5971	1.3803	1.0971	1.0323	1.0122	1.0042	1.0012	1.0004

Vertical path (in atmos.) from different layers on the assumption that the centre of mass of each layer is situated at a point 3 km above the base of that layer.

0.3022	0.7928	0.9528	0.9885	0.9969	0.9990	0.9997	1.0000	1.0000	1.0000

Appendix 3.

Y — Ozone path in each layer when the amount of ozone in the layer is 0.001 cm / km.

Z = 70°

Ozone path in layer No.	1	2	3	4	5	6
6	0.0250	0.0252	0.0255	0.0257	0.0260	0.0205
5	0.0252	0.0255	0.0257	0.0260	0.0205	0.0090
4	0.0255	0.0257	0.0260	0.0205	0.0090	0.0090
3	0.0257	0.0260	0.0205	0.0090	0.0090	0.0090
2	0.0260	0.0205	0.0090	0.0090	0.0090	0.0090
1	0.0205	0.0090	0.0090	0.0090	0.0090	0.0090

Z = 80°

Ozone path in layer No.	1	2	3	4	5	6
6	0.0428	0.0442	0.0458	0.0473	0.0493	0.0371
5	0.0442	0.0458	0.0473	0.0493	0.0371	0.0090
4	0.0458	0.0473	0.0493	0.0371	0.0090	0.0090
3	0.0473	0.0493	0.0371	0.0090	0.0090	0.0090
2	0.0493	0.0371	0.0090	0.0090	0.0090	0.0090
1	0.0371	0.0090	0.0090	0.0090	0.0090	0.0090

$Z = 84^{\circ}$

Ozone path in layer No.	1	2	3	4	5	6
6	0.0567	0.0601	0.0641	0.0692	0.0757	0.0611
5	0.0601	0.0641	0.0692	0.0757	0.0611	0.0090
4	0.0641	0.0692	0.0757	0.0611	0.0090	0.0090
3	0.0692	0.0757	0.0611	0.0090	0.0090	0.0090
2	0.0757	0.0611	0.0090	0.0090	0.0090	0.0090
1	0.0611	0.0090	0.0090	0.0090	0.0090	0.0090

$Z = 86^{\circ}.5$

Ozone path in layer No.	1	2	3	4	5	6
6	0.0669	0.0726	0.0803	0.0913	0.1082	0.0913
5	0.0726	0.0803	0.0913	0.1082	0.0913	0.0090
4	0.0803	0.0913	0.1082	0.0913	0.0090	0.0090
3	0.0913	0.1082	0.0913	0.0090	0.0090	0.0090
2	0.1082	0.0913	0.0090	0.0090	0.0090	0.0090
1	0.0913	0.0090	0.0090	0.0090	0.0090	0.0090

Z = 88°

Ozone path in layer No.	1	2	3	4	5	6
6	0.0703	0.0750	0.0886	0.1040	0.1359	0.1423
5	0.0750	0.0886	0.1040	0.1359	0.1423	0.0090
4	0.0886	0.1040	0.1359	0.1423	0.0090	0.0090
3	0.1040	0.1359	0.1423	0.0090	0.0090	0.0090
2	0.1359	0.1423	0.0090	0.0090	0.0090	0.0090
1	0.1423	0.0090	0.0090	0.0090	0.0090	0.0090

Z = 90°

Ozone path in layer No.	1	2	3	4	5	6
6	0.0741	0.0840	0.0954	0.1165	0.1602	0.2809
5	0.0840	0.0954	0.1165	0.1602	0.2809	0.0090
4	0.0954	0.1165	0.1602	0.2809	0.0090	0.0090
3	0.1165	0.1602	0.2809	0.0090	0.0090	0.0090
2	0.1602	0.2809	0.0090	0.0090	0.0090	0.0090
1	0.2809	0.0090	0.0090	0.0090	0.0090	0.0090

Path length of ozone traversed by the ray coming from the first layer for $Z = 70^{\circ}$ is, from the above table,

$$Y_1 = 0.0205x_1 + 0.0260x_2 + 0.0257x_3 + 0.0255x_4$$
$$0.0252x_5 + 0.0250x_6 \text{ and so on}$$

where x_1, x_2, x_3, x_4, x_5, x_6 are the amounts of ozone in layers 1, 2, 3, 4, 5 and respectively.

Appendix 4.

Daily ozone values at Mt. Abu and Ahmedabad.

Date.	Abu pressure at 12 G.M.T.	Weather at Abu.	Mean x at Abu	x at Ahmedabad.
25-10-51	902.4	Slight haze.	0.171	-
26-10-51	903.4	Clear.	0.172	-
27-10-51	903.5	"	0.169	-
28-10-51	905.4	Slight haze.	0.161	-
29-10-51	904.8	Hazy.	0.162	-
30-10-51	901.5	"	0.169	-
31-10-51	901.3	Clear.	0.162	-
1-11-51	903.4	Slight haze.	0.170	-
2-11-51	903.2	Clear.	0.173	-
3-11-51	903.1	"	0.172	-
4-11-51	904.2	Slight haze.	0.169	-
5-11-51	903.7	Clear.	0.169	-
6-11-51	-	"	0.164	-
7-11-51	903.1	Slight haze.	0.163	-
8-11-51	903.3	Clear.	0.160	-
9-11-51	902.3	"	0.170	-
10-11-51	904.2	"	0.194	-

11-11-51	902.1	Clear.	0.158	-
12-11-51	902.8	Slight haze, thin Ci at the horizon.	0.159	-
13-11-51	902.2	Morning light Ci, evening clear sky.	0.149	-
14-11-51	901.5	Over cast.	0.149	-
15-11-51	900.5	"	-	-
16-11-51	901.4	Obs.on foggy sun.	0.146	-
17-11-51	902.3	Light Ci.covering the entire sky, a little rain in the evening,night overcast.	0.153	-
18-11-51	903.2	Cu,CuNi,9/10 till 1100 hrs.Light rain in the evening.1700hrs overcast.	0.156	-
19-11-51	902.7	Cloudy till 0900hrs. 5/10 Cu.	0.153	-
20-11-51	901.3	Cu 2/10.	0.157	-
21-11-51	902.1	Slight haze.	0.162	-
22-11-51	901.8	Light Ci covering entire sky in the morning.Evening clear.	0.160	-
23-11-51	900.6	Morning thick Ci 1300hrs CuNi thunder 1330hrs heavy shower till 1500hrs.Rain again at 1530hrs.	0.159	-
24-11-51	898.6	1100hrs overcast. 1330hrs thunder shower. 1500hrs 7/10 Cu.	0.161	-
25-11-51	901.7	Clear.	0.173	-
26-11-51	903.8	Slight haze.	0.157	-
27-11-51	903.3	Clear.	0.166	-
28-11-51	905.4	"	0.167	-
29-11-51	905.1	"	0.167	-
30-11-51	902.0	"	0.168	-

1-12-51	903.0	Clear.	0.160	-
2-12-51	904.0	"	0.158	-
3-12-51	905.6	Slight haze.	0.159	-
4-12-51	906.0	Clear.	0.159	-
5-12-51	905.7	"	0.167	-
6-12-51	905.3	Slight haze.	0.160	-
7-12-51	903.8	Clear.	0.156	-
8-12-51	903.2	Very clear.	0.159	-
9-12-51	902.8	Clear.	0.163	-
10-12-51	902.7	Slight haze, 1600 hrs Ci developing.	0.165	-
11-12-51	903.4	Morning Ci St. evening clear.	0.166	-
12-12-51	901.6	Clear.	0.164	-
13-12-51	900.5	Clear.	0.168	-
14-12-51	902.2	Slight haze.	0.167	-
15-12-51	902.9	Clear.	0.164	-
16-12-51	903.0	Morning thick Ci, Ci St. enveloping the entire sky, afternoon clear.	0.159	-
17-12-51	904.0	Clear.	0.166	-
18-12-51	906.0	"	0.163	-
19-12-51	905.3	"	0.164	-
20-12-51	905.5	"	x -	-
21-12-51	906.7	Morning thick Ci, evening slight haze.	0.167	-
22-12-51	906.9	Morning Ci St. Evening hazy.	0.170	-
23-12-51	905.5	Clear.	0.172	-

24-12-51	905.4	Very hazy.	0.172	-
25-12-51	904.8	Hazy.	0.175	-
26-12-51	904.8	Clear.	0.176	-
27-12-51	902.7	"	0.175	-
28-12-51	901.6	"	0.177	-
29-12-51	900.7	Slight haze.	0.179	-
30-12-51	899.9	Clear.	0.177	-
31-12-51	899.8	"	0.176	-
1-1-52	902.3	Very clear.	0.181	-
2-1-52	-	Clear.	0.179	-
3-1-52	902.0	Slight haze.	0.179	-
4-1-52	902.6	Morning thin Ci covering the entire sky, evening clear.	0.178	-
5-1-52	902.2	Hazy.	0.172	-
6-1-52	900.9	Clear.	-	-
7-1-52	901.0	"	0.160	-
8-1-52	-	"	0.164	-
9-1-52	900.7	"	-	-
10-1-52	901.5	Slight haze.	0.162	-
11-1-52)				
12-1-52)	AMPLIFIER NOT WORKING.			
13-1-52)				
14-1-52	902.3	Clear.	0.164	-
15-1-52	904.0	"	0.166	-

16-1-52	905.5	Hazy.	0.167	-
17-1-52	906.2	Slight haze.	0.171	-
18-1-52	908.1	Clear.	0.166	-
19-1-52	907.5	"	0.170	-
20-1-52	905.5	"	0.167	-
21-1-52	903.7	Slight haze.	0.173	-
22-1-52	905.2	Clear.	0.170	-
23-1-52	905.2	"	0.170	-
24-1-52	905.9	Evening cloudy.	0.170	-
25-1-52	905.7	" Cu 5/10.	0.173	-
26-1-52	904.4	Very clear.	0.174	-
27-1-52	905.4	Clear.	0.173	-
28-1-52	905.7	Morning overcast. 1200hrs Cu 5/10. 1700hrs Cu 7/10.	0.183	-
29-1-52	905.5	Cu, Ci St. 7/10 whole day.	0.169	-
30-1-52	904.5	Morning overcast. Evening 5/10 Cu	0.172	-
31-1-52	SKY OVERCAST. NO OBSERVATIONS POSSIBLE.			
1-2-52	902.6	Light Ci covering the entire sky throughout the day.	0.177	-
2-2-52	900.7	Morning overcast. Evening Cu, 8/10, obs. when clouds are in front of the sun. Low over N.Rajasthan.	0.197	-
3-2-52	901.3	Morning overcast. Very windy, Stormy, 1200hrs a little rainfall obs. on clear sun. Evening sky condition improved.	-	-

4-2-52	902.9	Morning clear with slight haze. Afternoon Cu 6/10.	0.209	-
5-2-52	901.8	Early morning cloudy 6/10. Afternoon getting clear.	0.188	-
6-2-52	900.7	Clear.	0.204	-
7-2-52	901.3	Morning Cu 7/10. Afternoon clear with slight haze.	0.209	-
8-2-52	902.2	Cu 6/10 throughout the day.	0.205	-
9-2-52	902.0	Cu 7/10 throughout the day.	0.207	-
10-2-52	903.0	Clear.	0.202	-
11-2-52	902.0	"	0.188	-
12-2-52	901.4	Very clear.	0.194	-
13-2-52	900.2	Clear.	0.183	-
14-2-52	898.8	Clear.	-	-
15-2-52				
16-2-52				
17-2-52				
18-2-52		NO OBSERVATIONS.		
19-2-52				
20-2-52				
21-2-52				
22-2-52				
23-2-52	903.7	Morning Ci, evening clear.	0.172	0.160
24-2-52	904.2	Ci.	0.171	0.168
25-2-52	901.9	Thin Ci all over the sky.	0.176	0.160

26-2-52	901.6	Morning clear, evening Ci.	0.177	0.166
27-2-52	900.6	Thin Ci all over the sky	0.175	0.174
28-2-52	900.5	Overcast.	0.179	0.172
29-2-52	900.7	Morning Cu 6/10. 1500hrs Ci Cu St Cu.	0.181	0.176
1-3-52	897.8	Clear.	0.214	0.198
2-3-52	900.4	"	0.194	0.198
3-3-52	900.1	Ci all over the sky.	0.174	0.180
4-3-52	900.2	Early morning clear. Ci appearing after 0900 hrs.	0.170	0.159
5-3-52	899.3	Ci covering the entire sky.	0.163	0.159
6-3-52	896.8	Almost overcast.	0.171	0.160
7-3-52	898.2	Clear.	0.181	0.167
8-3-52	899.9	"	0.174	0.176
9-3-52	900.1	"	0.171	0.000
10-3-52	901.1	Cu 5/10.	0.179	0.164
11-3-52	901.1	Morning very clear. Evening Ci covering the sky.	0.183	0.179
12-3-52	901.1	Ci spreading the sky.	0.187	-
13-3-52	900.0	Very thick Ci in the evening.	0.185	-
14-3-52	898.6	Thick Ci.	0.198	0.183
15-3-52	896.6	Very hazy, windy. Evening Cu, Cu St 7/10.	0.186	0.182
16-3-52	-	Hazy.	0.183	0.169
17-3-52	898.0	"	0.191	0.157
18-3-52	901.4	Very hazy.	0.177	0.155
19-3-52	900.4	Slightly hazy.	0.170	0.160
20-3-52	900.5	Clear.	0.171	0.163

21-3-52	897.6	Morning thin Ci covering the sky 1700hrs overcast.	0.189	0.173
22-3-52	898.0	Morning Cu 6/10 Evening very clear.	0.197	0.180
23-3-52	898.9	Clear.	0.183	0.173
24-3-52	898.7	"	0.185	0.165
25-3-52	900.8	Light Ci in the morning. 1000hrs clear.	0.173	0.164
26-3-52	901.6	Thick Ci till 1230hrs.	0.171	0.164
27-3-52	901.1	Morning thin Ci.	0.177	0.172
28-3-52	900.2	" Ci, Ci St.1200hrs clear.	0.180	0.185
29-3-52	898.7	Light Ci throughout the day.	0.190	0.191
30-3-52	897.5	Hazy.	0.180	0.185
31-3-52	898.0	Clear.	0.189	0.184
1-4-52	899.5	Hazy and dusty.	0.191	0.183
2-4-52	900.7	Hazy.	0.198	0.189
3-4-52	900.0	Morning clear, evening thick Ci.	0.189	0.188
4-4-52	898.7	Almost overcast.	0.190	0.181
5-4-52	899.4	"	0.183	0.182
6-4-52	899.8	Overcast.	0.187	0.181
7-4-52	901.1	Cu, Alto Cu, 8/10.	0.185	0.178
8-4-52	900.3	Clear.	0.183	0.184
9-4-52	900.7	Slightly hazy.	0.179	0.179
10-4-52	900.2	Clear.	0.180	0.182
11-4-52	899.8	"	0.184	0.180
12-4-52	900.4	Hazy.	0.185	0.184

13-4-52	902.8	Morning clear, Ci in afternoon.	0.185	0.185
14-4-52	901.5	Slight haze.	0.187	0.189
15-4-52	900.8	Clear.	0.180	0.185
16-4-52	899.7	"	0.173	0.170
17-4-52	900.3	Very clear.	0.174	0.168
18-4-52	900.1	"	0.177	0.173
19-4-52	898.9	Clear.	0.170	0.170
20-4-52	898.1	Slight haze.	0.179	0.167
21-4-52	899.4	Very hazy.	0.179	0.173
22-4-52	899.2	"	0.179	0.179
23-4-52	898.8	"	0.179	0.177
24-4-52	898.6	"	0.180	0.175
25-4-52	899.3	Dusty and Hazy.	0.181	0.177
26-4-52	898.6	Clear.	0.182	0.176
27-4-52	898.6	Slight haze.	0.183	0.173
28-4-52	901.6	Hazy.	0.180	0.171
29-4-52	901.2	Ci at low angles, very hazy.	0.180	0.175
30-4-52	899.1	Very hazy.	0.183	0.173
1-5-52	899.0	Clear.	0.176	0.173
2-5-52	899.4	"	0.179	0.176
3-5-52	899.9	Slight haze.	0.175	0.169
4-5-52	898.6	Clear.	0.180	0.183
5-5-52	900.8	Very hazy.	0.185	0.186
6-5-52	901.1	Hazy.	0.188	0.184

7-5-52	899.4	Slight haze.	0.176	0.178
8-5-52	-	"	0.176	0.178
9-5-52	897.5	Hazy.	0.177	-
10-5-52	898.3	Very hazy, windy and very dusty.	0.184	-
11-5-52	899.6	Extremely dusty.	0.185	-
12-5-52	899.5	" Windy. Very ~~dim~~ sunshine available.	0.188	-
13-5-52	896.4	Dusty and hazy.	0.195	-
14-5-52	892.6	Haze decreased, still hazy.	0.187	-
15-5-52	895.7	Hazy.	0.186	-
16-5-52	896.1	Clear.	0.179	-
17-5-52	896.0	Slightly hazy.	0.180	-
18-5-52	896.2	Hazy.	0.189	-
19-5-52	894.2	"	0.195	-
20-5-52	894.2	Morning Cu 2/10. Evening very hazy.	0.190	-
21-5-52	893.1	Whole day Cu 5/10.	0.191	-
22-5-52	892.6	Morning light Ci covering the sky. 1200hrs a few drops of rainfall.	0.193	-
23-5-52	893.1	Evening Cu 7/10.	0.188	-
24-5-52	893.3	Cu 2/10 whole day.	0.182	-
25-5-52	894.3	Hazy.	0.184	-
26-5-52	895.8	Slight haze.	0.187	-
27-5-52	899.0	"	0.177	-
28-5-52	894.1	Little haze.	0.187	-
29-5-52	894.0	Hazy.	0.187	
30-5-52	893.4	Clear.	0.185	
31-5-52	893.4	"	0.185	

1-6-52	893.0	Cu 7/10. Evening very hazy.	0.181	-
2-6-52	893.8	Overcast.	0.177	-
3-6-52	894.4	"	0.183	-
4-6-52	896.1	Very hazy.	0.180	-
5-6-52	893.2	Hazy.	0.183	-
6-6-52	894.0	-	-	-
7-6-52	895.2	Very hazy and dusty.	0.192	-
8-6-52	896.8	St, St Cu.	0.194	-
9-6-52	894.7	Full of Cu.	0.191	-
10-6-52	893.8	Hazy.	0.190	-
11-6-52	893.5	Clear.	0.192	-
12-6-52	893.9	"	0.194	-
13-6-52	892.7	Cu 7/10.	0.190	-
14-6-52	891.9	Almost overcast.	0.187	-
15-6-52	891.4	Cu, dust storm.	0.188	-
16-6-52	890.8	Ci, Cu, CuNi 8/10.	0.182	-
17-6-52	892.7	Thick Ci and Cu.	0.186	-
18-6-52	893.9	Morning almost overcast. Evening Cu 7/10.	0.183	-
19-6-52	894.1	Morning overcast.	0.180	-
20-6-52	893.1	Overcast.	0.182	-
21-6-52	891.7	Rainy and cloudy weather	0.182	-
22-6-52	891.0	"	0.182	-
23-6-52	890.6	"	-	-
24-6-52	893.2	"	0.182	-

25-6-52	887.0	Rainy and cloudy weather.	0.191	-
26-6-52	888.3	"	0.123	-
27-6-52	888.0	"	0.125	-
28-6-52	[illegible]	OVERCAST.		
29-6-52	887.8	Rainy and cloudy.	0.175	-
30-6-52	888.0	"	0.181	-
1-7-52	890.4		0.173	-
2-7-52	892.0		0.177	-
3-7-52	-	CLOUDY	0.182	-
4-7-52	894.2	MONSOON WEATHER.	0.195	-
5-7-52	893.8		0.187	-
6-7-52	892.3		0.181	-
7-7-52		NO SUNSHINE AVAILABLE, RAINY WEATHER.		
8-7-52				
9-7-52				
10-7-52				
11-7-52	-		0.194	-
12-7-52	895.1		0.184	-
13-7-52	893.1	DIM SUN THROUGH	0.183	-
14-7-52	892.3	MONSOON CLOUDS.	0.191	-
15-7-52	892.3		0.192	-
16-7-52	893.1		0.193	-
17-7-52		NO SUNSHINE.		
18-7-52				
19-7-52	889.2		0.186	-
20-7-52				

21-7-52			
22-7-52			
23-7-52			
24-7-52			
25-7-52	CLOUDY, RAINY WEATHER.		
26-7-52	NO SUNSHINE, NO OBSERVATIONS.		
27-7-52			
28-7-52			
29-7-52			
30-7-52			
31-7-52			
1-8-52			
2-8-52			
3-8-52	891.9	0.176	-
4-8-52			
5-8-52			
6-8-52			
7-8-52	CLOUDY, RAINY WEATHER.		
8-8-52	NO OBSERVATIONS.		
9-8-52			
10-8-52			
11-8-52			
12-8-52	890.0	0.174	-
13-8-52	NO SUNSHINE AVAILABLE.		
14-8-52			

15-8-52	NO SUNSHINE AVAILABLE.			
16-8-52				
17-8-52				
18-8-52	891.9 @	RAINY WEATHER.	0.161	-
19-8-52	893.2		-	-
20-8-52	892.5		-	-
21-8-52	893.6		0.169	-
22-8-52	892.7		0.171	-
23-8-52	893.2		0.177	-
24-8-52	892.9		0.171	-
25-8-52	892.7		£ -	-
26-8-52	893.5		0.182	-
27-8-52	895.2		0.172	-
28-8-52	895.4		0.177	-
29-8-52	895.9	CLOUDY WEATHER.	0.172	-
30-8-52	896.4		0.177	-
31-8-52	896.3		0.174	-
1-9-52	896.3		0.171	-
2-9-52	895.9		0.173	-
3-9-52	895.2		0.171	-
4-9-52	894.4	OVER CAST.	-	-
5-9-52	895.1		0.171	-
6-9-52	895.8		0.169	-
7-9-52	896.4	OVER CAST.	-	-

8-9-52	896.2		0.170	-
9-9-52	896.3		0.166	-
10-9-52	895.6		0.165	-
11-9-52	896.9		0.164	-
12-9-52	897.7		0.163	-
13-9-52	897.6	Cu 3/10.	0.163	-
14-9-52	897.9	Cu 5/10. Hazy.	0.159	-
15-9-52	898.2		0.160	-
16-9-52	897.6		0.158	-
17-9-52	896.9	Cloudy weather.	0.162	-
18-9-52	897.9		0.160	-
19-9-52	897.4		0.159	-
20-9-52	895.9		0.158	-
21-9-52				
21-9-52	896.5	Almost overcast.	fl. -	-
22-9-52	898.7		0.166	-
23-9-52	894.7		0.162	-
24-9-52	900.6		0.162	-
25-9-52	899.9		0.166	-
26-9-52	900.3		0.163	-
27-9-52	901.3		--	-
28-9-52	901.0		0.166	-
29-9-52	899.5		0.156	-
30-9-52	899.9		0.155	-

1-10-52	901.4	Morning cloudy, Cu 6/10.	0.158	-
2-10-52	901.1	Cu St 4/10.	0.160	-
3-10-52	898.6		0.159	-
4-10-52	896.8		0.158	-
5-10-52	896.6		0.163	-
6-10-52	896.0		0.159	0.172
7-10-52	895.2	Clear.	0.163	0.169
8-10-52	895.6	Slightly hazy.	0.159	0.167
9-10-52	897.3	Clear.	0.164	-
10-10-52	898.2	Very clear.	0.164	-
11-10-52	898.8	Clear.	0.157	-
12-10-52	898.8	Almost overcast.	0.158	-
13-10-52	898.9	Cu 5/10.	0.159	0.159
14-10-52	901.7	Clear.	0.164	0.162
15-10-52	905.2	"	0.163	0.165
16-10-52	903.6	Hazy.	0.162	0.163
17-10-52	901.0	Very hazy.	0.159	0.159
18-10-52	899.1	Slightly hazy.	0.157	0.160
19-10-52	-	Clear.	0.157	0.166
20-10-52	898.8	"	0.157	0.162
21-10-52	899.6	"	0.155	0.167
22-10-52	899.9	"	0.152	0.162
23-10-52	899.4	"	0.149	0.165

	(mmV)			
24-10-52	900.9	Clear.	0.152	0.162
25-10-52	902.4	"	0.149	0.158
26-10-52	903.7	"	0.147	0.158
27-10-52	904.3	"	0.150	0.159
28-10-52	903.3	Hazy, Ci all over sky.	0.148	0.152
29-10-52	902.0	Clear.	0.149	0.156
30-10-52	901.8	Hazy.	0.150	0.168
31-10-52	-	Clear.	0.154	0.161
1-11-52	902.2	Slightly hazy.	0.157	-
2-11-52	901.7	Hazy.	0.156	0.167
3-11-52	902.4	Clear.	0.158	0.164
4-11-52	902.5	"	0.156	0.160
5-11-52	903.7	"	0.153	0.161
6-11-52	901.3	"	0.155	0.175
7-11-52	901.1	"	0.155	0.169
8-11-52	901.4	"	0.155	0.168
9-11-52	900.5	"	0.154	0.171
10-11-52	899.5	"	0.146	-
11-11-52	899.5		0.146	0.153
12-11-52	901.4		0.148	0.155
13-11-52	903.6		0.143	0.152
14-11-52	904.5		0.144	-
15-11-52	900.2		0.143	-
16-11-52	904.5		0.-	-

(contd.)

17-11-52	900.8	0.160	0.163
18-11-52	904.2	0.149	0.163
19-11-52	903.4	0.146	0.162
20-11-52	902.9	0.147	0.165
21-11-52	903.4	0.153	0.164
22-11-52	903.2	0.154	0.163
23-11-52	903.0	0.168	0.163
24-11-52	900.1	0.157	0.172
25-11-52	900.4	0.157	8.-
26-11-52	901.2	0.149	0.172
27-11-52	901.9	0.142	0.169
28-11-52	900.9	0.142	0.165
29-11-52	902.7	0.141	0.164
30-11-52	-	0.141	0.161
1-12-52	904.6	0.142	0.170
2-12-52	903.8	0.143	0.171
3-12-52	903.2	0.142	0.162
4-12-52	904.9	-	0.162
5-12-52	905.6	-	0.168
6-12-52	904.3	-	0.167
7-12-52	904.2	0.156	0.176
8-12-52	904.1	0.153	0.167
9-12-52	903.9	0.149	0.168
10-12-52	904.9	0.155	0.177

(xxvii)

11-12-52	906.0		0.153	0.169
12-12-52	905.2		0.149	0.167
13-12-52	904.3		0.147	0.168
14-12-52	904.0		0.152	0.165
15-12-52	904.4		0.160	0.167
16-12-52	903.8		0.159	0.172
17-12-52	901.7		0.157	-
18-12-52	902.8		0.150	0.167
19-12-52	903.9		0.143	0.161
20-12-52	904.3		0.149	0.162
21-12-52	903.8	Overcast.	0.151	-
22-12-52	904.5		0.145	0.160
23-12-52	905.9		0.144	0.162
24-12-52	906.9		0.151	0.168
25-12-52	905.8		0.151	0.169
26-12-52	905.4		0.152	0.170
27-12-52	904.8		0.155	0.169
28-12-52	904.4		0.159	0.168
29-12-52	904.0		0.154	0.161
30-12-52	904.0		0.157	0.161
31-12-52	904.8		0.146	0.166
1-1-53	906.3		0.145	0.166
2-1-53	906.1		0.145	0.148
3-1-53	905.1		0.147	0.161
4-1-53	904.2	Overcast.	0.155	-

(contd.)

5-1-53	904.9	Morning slight rain. Raining.		-
6-1-53	906.6	Raining.	-	-
7-1-53	904.1		0.142	0.181
8-1-53	905.2		0.137	0.159
9-1-53	903.6		0.140	0.164
10-1-53	902.0		-	-
11-1-53	901.0		0.147	-
12-1-53	904.0		0.150	-
13-1-53	903.7		0.150	-
14-1-53	900.6		0.153	-
15-1-53	900.2		0.157	-
16-1-53	902.9		-	-
17-1-53	904.6		0.154	-
18-1-53	903.4		0.156	-
19-1-53	904.4		0.153	-
20-1-53	905.3		0.162	-
21-1-53	904.3		0.158	0.178
22-1-53	903.0		0.161	0.178
23-1-53	903.2		0.158	0.179
24-1-53	904.0		0.153	0.183
25-1-53	902.5		0.157	-
26-1-53	902.3		0.159	-
27-1-53	901.6		0.162	-
28-1-53	901.9		0.161	-
29-1-53	901.8		0.166	0.167
30-1-53	900.0		0.164	0.169
31-1-53	-		0.161	0.168

1-2-53	901.8	Ci and CiS	0.173	0.192
2-2-53	904.0	"	0.165	0.163
3-2-53	903.0	Observation through Ci.	0.176	0.172
4-2-53	900.9	Ci.	0.171	0.172
5-2-53	901.3	Light Ci off and on.	0.172	0.177
6-2-53	905.4	Clear.	0.180	0.172
7-2-53	905.6	"	0.179	0.187
8-2-53	904.6	"	0.174	0.183
9-2-53	904.7	"	0.173	0.176
10-2-53	904.2	"	0.177	0.175
11-2-53	904.8	Overcast. CiS or Ci.	0.175	0.173
12-2-53	904.7	"	0.167	0.169
13-2-53	904.7	"	0.168	0.168
14-2-53	904.9	Ci or CiS.	0.171	0.175
15-2-53	905.8	Cloudy, CiS - AS.	0.173	0.172
16-2-53	904.5	Ci, Cu and ACu.	0.169	0.166
17-2-53	904.5	Clear.	0.170	0.168
18-2-53	902.6	Thick Ci.	0.177	0.142
19-2-53	902.3	Cold, windy.	0.178	0.174
20-2-53	903.1	Thick Ci.	0.179	0.174
21-2-53	903.5	Ci.	0.176	0.171
22-2-53	902.2	Clear.	0.168	0.163
23-2-53	903.0	Ci covering sky.	0.172	0.165
24-2-53	904.8	Clear.	0.163	0.157

25-2-53	904.4	Clear.	0.165	0.167
26-2-53	904.9	"	0.167	0.172
27-2-53	901.1	Ci towards S in the evening.	0.165	0.170
28-2-53	-	Clear.	0.170	0.170
1-3-53	900.9	Cloudy.	0.166	0.175
2-3-53	-	Ci Cis.	0.167	0.171
3-3-53	899.2	Clear.	0.158	0.171
4-3-53	901.3	"	0.159	0.171
5-3-53	904.4	Sl. hazy.	0.159	0.170
6-3-53	902.0	"	0.168	0.173
7-3-53	899.6	Clear.	0.166	0.170
8-3-53	899.1	Hazy sky.	0.156	0.172
9-3-53	901.2	"	0.163	0.173
10-3-53	899.5	"	0.159	0.171
11-3-53	899.5	V.hazy, dusty wind.	0.166	0.171
12-3-53	-	Calm, haze.	0.169	0.174
13-3-53	900.8	Haze decreased.	0.171	0.171
14-3-53	901.4	Very light Ci.	0.170	0.165
15-3-53	900.7	Sl.haze.	0.169	0.168
16-3-53	901.0	"	0.174	0.171
17-3-53	900.1	Ci spreading.	0.176	0.176
18-3-53	900.4	Ci & dusty sky.	0.175	0.172
19-3-53	901.3	Almost overcast.	0.172	0.170
20-3-53	901.9	Clear.	0.175	0.170

21-3-53	902.2	Clear.	0.170	0.174
22-3-53	901.7	"	0.169	0.176
23-3-53	900.9	Morning Ci, afternoon clear.	0.164	0.167
24-3-53	899.5	Dusty morning.	0.161	0.168
25-3-53	899.7	Clear.	0.162	0.167
26-3-53	898.1	"	0.163	0.169
27-3-53	898.4	South wind with cloud.	0.162	-
28-3-53	-	Very hazy.	0.170	-
29-3-53	-	Morning mist, evening cloud.	0.168	-
30-3-53	-	Clear.	0.171	-
31-3-53	-	"	0.171	-
1-4-53	902.9	Clear.	0.173	-
2-4-53	901.5	"	0.174	-
3-4-53	902.3	"	0.173	-
4-4-53	903.3	Ci, CiS.	0.176	-
5-4-53	900.5	Thick Ci.	0.174	-
6-4-53	900.8	Ci, CiS	0.175	-
7-4-53	900.3	Cloudy.	0.183	0.198
8-4-53	899.4	Morning clear, afternoon cloudy.	0.184	0.200
9-4-53	898.6	Cloudy north, clear zenith.	0.183	0.189
10-4-53	898.0	Clear or ACu.	0.170	0.183
11-4-53	897.2	Windy, W.	0.175	0.180
12-4-53	897.8	Ci, CiS.	0.174	B. -
13-4-53	897.3	Breezy.	0.180	0.184
14-4-53	897.9	CiS throughout sky.	-	0.190

15-4-53	-	Overcast.	0.181	0.195
16-4-53	899.1	"	2.-	0.186
17-4-53	899.4	" , cleared in evening.	0.177	0.177
18-4-53	897.3	Clear.	0.170	0.171
19-4-53	896.6	"	0.181	0.188
20-4-53	897.7	"	0.180	0.189
21-4-53	898.6	Hazy.	0.176	0.184
22-4-53	900.1	Clear.	0.173	0.179
23-4-53	901.2	Slight haze.	0.173	0.182
24-4-53	901.1	"	0.178	0.193
25-4-53	899.1	-	0.180	0.180
26-4-53	898.8	Cu 5/10.	0.188	0.182
27-4-53	900.0	Clear.	0.179	0.191
28-4-53	898.7	Ci in morning.	0.179	0.190
29-4-53	898.3	Thick Ci - Sun dim.	0.173	0.185
30-4-53	-	Ci cleared in afternoon.	0.179	0.190

Half monthly averages of O_3.

Period.	x at Mt.Abu.	x at Ahmedabad.
25-10-51 to 31-10-51	0.167 *(7)	
1-11-51 to 15-11-51	0.168 (14)	
16-11-51 to 30-11-51	0.161 (15)	
1-12-51 to 15-12-51	0.162 (15)	
16-12-51 to 31-12-51	0.171 (17)	
1- 1-52 to 15- 1-52	0.170 (11)	
16- 1-52 to 31 -1-52	0.171 (15)	
1- 2-52 to 15- 2-52	0.185 (13)	
16- 2-52 to 29- 2-52	0.176 (7)	
1- 3-52 to 15- 3-52	0.184 (15)	0.175 (12)
16- 3-52 to 31- 3-52	0.181 (16)	0.172 (16)
1- 4-52 to 15- 4-52	0.186 (15)	0.183 (16)
16- 4-52 to 30- 4-52	0.179 (15)	0.173 (15)
1- 5-52 to 15- 5-52	0.191 (15)	0.172 (15)
16- 5-52 to 31- 5-52	0.186 (16)	0.178 (8)
1- 6-52 to 15- 6-52	0.187 (14)	
16- 6-52 to 30- 6-52	0.181 (14)	
1- 7-52 to 15- 7-52	0.185 (11)	0.186 (13) July.
16- 7-52 to 31- 7-52	0.180 (2)	

([illegible])

1- 8-52 to 15- 8-52	0.175 (2)	0.172 (16) August.
16- 8-52 to 31- 8-52	0.171 (14)	
1- 9-52 to 15- 9-52	0.168 (13)	
16- 9-52 to 30- 9-52	0.161 (15)	
1-10-52 to 15-10-52	0.161 (15)	0.166 (6)
16-10-52 to 31-10-52	0.153 (16)*	0.161 (16)
1-11-52 to 15-11-52	0.151 (15)	0.169 (11)
16-11-52 to 30-11-52	0.149 (14)	0.165 (12)
1-12-52 to 15-12-52	0.160 (12)	0.162 (15)
16-12-52 to 31-12-52	0.161 (13)	0.165 (14)
1- 1-53 to 15- 1-53	0.149 (14)	0.165 (8)
16- 1-53 to 31- 1-53	0.150 (15)	0.169 (10)
1- 2-53 to 15- 2-53	0.1713 (15)	0.173 (15)
16-2- 53 to 28- 2-53	0.1[illegible] (13)	0.170 (12)
1- 3-53 to 15- 3-53	0.164 (15)	0.171 (15)
16- 3-53 to 31- 3-53	0.169 (16)	0.171 (11)
1- 4-53 to 15- 4-53	0.179 (8)	0.189 (9)
16- 4-53 to 30- 4-53	0.177 (15)	0.183 (15)
1- 5-53 to 15- 5-53	0.182 (15)	0.186 (12)
16- 5-53 to 31- 5-53	0.184 (15)	0.183 (14)
1- 6-53 to 15- 6-53	0.186 (14)	
16- 6-53 to 30- 6-53		

---

*The figure in bracket refers to number of days on which the observations were available during the period.