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Rocket Measurement of Molecular Oxygen Density in the Altitude Range 70-90 km at the Geomagnetic Equator

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Three instrumented rockets were flown from Thumba on 19 March 1970 for measuring the concentration of molecular oxygen using absorption photometry technique. From the rocket data, the molecular oxygen density profiles were derived in the altitude range of 70-90 km. The density values derived from noon time and afternoon flights are found to be consistently lower than those given by standard atmospheric models by about 20%. These values can be made consistent with Groves model if the Lyman-alpha absorption cross-section of molecular oxygen is reduced by about 10% from the assumed value of 1×10^{-20} cm^2. A comparison of the molecular oxygen density values for the three flights shows a possible diurnal variation with early morning values being the highest and the afternoon values the lowest.

1. Introduction

ABSORPTION photometry of the euv (1050 – 1450 Å) band of solar radiation by rocket-borne ionization chamber provides a powerful technique for deriving the altitude distribution of molecular oxygen concentration in the height range of 70-110 km[1,2]. This is because, in this spectral range, there are a series of steep windows through which these radiations come down to the lower altitudes and are absorbed mainly by molecular oxygen. In the spectral band 1050–1350 Å solar Lyman-alpha radiation (1216 Å) is the most intense line and accounts for 90% of the total flux, while the background continuum accounts for only 10%. Since at wavelength of Lyman-alpha the atmospheric absorption is lowest, most of the other radiations in this spectral region are extinguished well above the altitude of unit optical depth for Lyman-alpha line. Thus the absorption photometry of solar Lyman-alpha line provides sufficiently accurate determination of the molecular oxygen concentration in the altitude range of interest. Several measurements using this technique have been reported for midlatitudes[2,5]. These investigators have reported significant deviations of molecular oxygen concentration profile determined using this technique and that given by the mean CIRA 1965 model[2,3,6]. Similar measurements made at the equator are useful in distinguishing any further deviations due to latitude. Subbaraya *et al.*[7] have recently reported molecular oxygen densities obtained from a noon time rocket flight at the equator. This paper describes the results of Lyman-alpha absorption photometer experiments aboard the rocket flights during March 1970 conducted from Thumba, India, located at the geomagnetic equator.

2. Experimental Details

Three rocket flights were conducted on the same day, i. e. 19 March 1970, carrying Lyman-alpha chambers as part of D-region payloads from Thumba (8°31′N; 76°52′E). Relevant details of these flights are given in Table 1.

The experiments of Lyman-α absorption photometry usually employs an ionization chamber with a suitable combination of window material and gas filling inside the chamber, as the detector. The window material determines the lower wavelength cut-off and the gas filling sets the upper wavelength cut-off. Thus, the window-gas filling combination constitutes a bandpass filter for the incident radiation. In the case of measurement of Lyman-α intensity usually a combination of LiF as the window material and nitric oxide gas filling is used. This gives a passband of 1050-1350 Å.

In the rocket flights 17·05 and 17·04 the Lyman-alpha sensors were located in the nose-cone sections of

Table 1—Details of the Three Flights Conducted on 19 March 1970

Flight No.	Time of day hrs LMT	Solar zenith angle deg	Detector	Spectral range Å
ISRO 17·04/ NASA 14·425	0827	53·2	Lyman-α Chamber	1050–1350
ISRO 17·05/ NASA 14·424	1017	27·8	Lyman-α Chamber	1050–1350
ISRO 17·06/ NASA 14·372	1509	48·3	Lyman-α Chamber	1050–1350

the payload. The nose-cone sections were split open during flight at about 55 km height. For the third flight 17·06, the sensors were mounted in the cylindrical section, looking out of the side. A solar aspect sensor was used on each of the three flights to provide data on the aspect angle between the longitudinal axis of the rocket and sensor sun line. Using the data from the aspect sensor, the output of the ion chamber was then corrected for the off-axis response due to angle of the incident radiation with axis of the sensor.

The solar radiations incident on the gas inside ionization chamber ionizes it causing an ionization current to flow. The current from the ion chamber is measured by an electrometer with a linear response having maximum or full scale current of 2×10^{-8} A based on currently known values of the unattenuated Lyman-alpha flux at the top of the atmosphere. This current produces a five-volt dc output form the electrometer amplifier, which is then telemetered to the ground. An inflight calibration for each experiment was also provided on all the flights to check the consistency of the performance of the electrometer during the flight.

3. Theory of the Technique

The intensity I_z of Lyman-alpha radiation at any altitude is given by

$$I_z = I_0 \exp \left(-\sigma \int_z^\infty n(O_2) \sec \chi \, dh\right) \qquad \ldots(1)$$

where I_0 is the intensity at the top of atmosphere, σ is the absorption cross-section and χ is the solar zenith angle.

Weeks and Smith[2] have pointed out that a flat earth approximation for the sensor-sun geometry is accurate to within 1% error for solar zenith angles less than 73°. Thus, with this approximation the above expression in Eq. (1) reduces to

$$n(O_2) = \frac{1}{\sigma \sec \chi . I} \frac{dI}{dz} = \frac{\cos \chi}{\sigma} \frac{d}{dz} (\log I) \qquad \ldots(2)$$

Eq. (2) assumes a constant value for the absorption cross-section within the spectral range concerned. This is usually taken to be 1×10^{-20} cm^2 as reported by Watanabe[8]. However, the measurements of Ogawa[9] and Ogawa and Yamawaki[10] have shown that σ has a wavelength dependence even in the vicinity of Lyman-alpha line which in fact is a doublet in the spectrum. Because of the wavelength dependence of absorption cross-section σ, the spectral shape of the profile gets distroted, as the radiation penetrates deeper into the lower atmosphere resulting in spectral softening. Quessette[4] has estimated that using

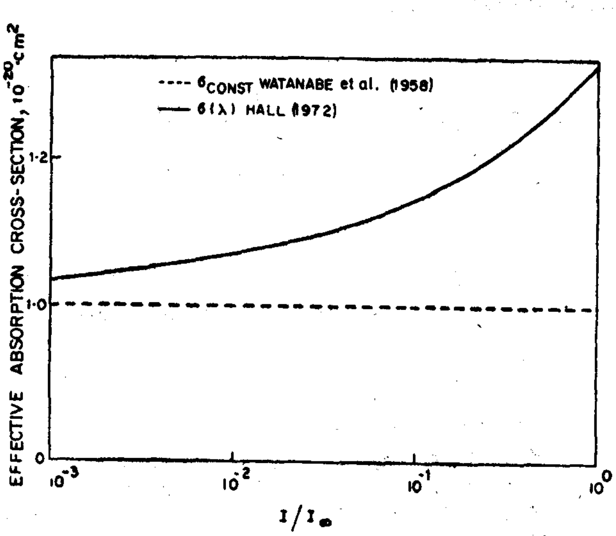

Fig. 1—Graph showing the effective absorption cross-section in molecular oxygen as a function of I/I_∞

a constant value for σ results in values of molecular oxygen densities higher by about 12% at 95 km for $\chi = 32°$. This error decreases with increasing optical depth. Hall[5] has outlined a method of analysis for the Lyman-alpha absorption photometry observation allowing for the variations in the cross-section with wavelength.

To account for the wavelength dependence of σ, Eq. (2) can be written in the modified form as given by Hall[5]:

$$n(O_2) = \frac{\cos \chi}{\sigma_e} \frac{d}{dz} (\log I_T) \qquad \ldots(3)$$

where $I_T = \int I(\lambda) \, d\lambda$ is the total intensity of Lyman-alpha line and σ_e the effective absorption cross-section and is given by

$$\sigma_e = \frac{\int \sigma(\lambda) I(\lambda) \, d\lambda}{\int I(\lambda) \, d\lambda} \qquad \ldots(4)$$

Hall[5] has derived an effective absorption cross-section profile as a function of I/I_∞ which is shown in Fig. 1.

4. Data Analysis

The ion chamber current measured during the ascent and descent of the three flights on 19 March 1970 are shown in Fig. 2. The currents are normalized to the maximum current measured during each flight. The maximum value is attained in the altitude range 95-100 km and it remained fairly constant at higher altitudes. Thus, this value is taken to be the one corresponding to the unattenuated Lyman-alpha flux. It is seen that the ion chamber current profiles during ascent and descent agree very well on flights 17·06 and 17·05. The departures on flight 17·04 are only equivalent to shifting the descent trajectory by about 2 km. In all the three cases the ascent data is consi-

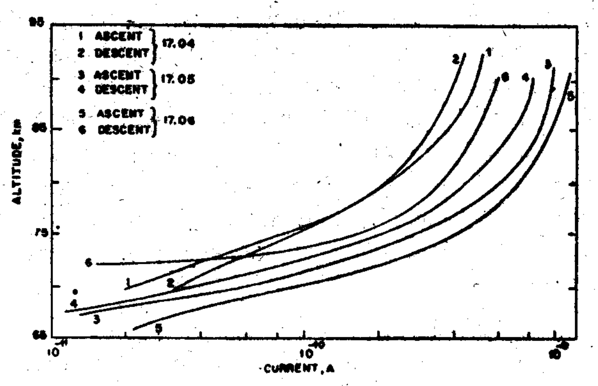

Fig. 2—Altitude variation of ion chamber currents measured during ascent and descent, for the three rocket flights from Thumba, India

dered to be more accurate and thus greater weightage is given to the data obtained during ascent. The data have been corrected for the angle dependence aspect in the detector response.

The Lyman-alpha ionization current profiles are then used to derive the molecular oxygen number densities values for different heights using an effective absorption cross-section derived according to the procedure given by Hall[5] and using Eq. (3).

For each altitude the value of σ_e is obtained from Fig. 1, using the measured value of I/I_0. Considering the various sources of error, viz. scaling errors, error due to assuming σ_e as derived by Hall[5], trajectory uncertainties, etc., the final results are considered to be accurate to $\pm$ 10% except on flight 17·04 where the data on the descent portion may have errors as large as 20%.

5. Results and Discussion

The molecular oxygen density values derived from the rocket experiment data alongwith the smooth fits are shown in Fig. 3. For comparison, the appropriate standard density model of molecular oxygen from CIRA, 1972 which is essentially the same as Grove's[11] model for a latitude of 10°N and for the month March, is also shown in Fig. 3. It is seen that the profiles show very good agreement between the flights throughout the altitude range while some small but significant differences are present. Each of these profiles in the altitude range of 70-85 km shows a constant scale height. The scale height values derived are 6·2, 6·6, and 6·1 km for flights 17·05, 17·04 and 17·06, respectively. The neutral temperatures derived from the scale height value are found to be 211, 225 and 208°K for the three flights 17·05, 17·04 and 17·06, respectively, while the temperature reported by Ramakrishna *et al.*[12] for Thumba, at night for the month of March is about 202°K.

All the three profiles alongwith the Grove's[11] model are plotted in Fig. 4. It may be seen that the profiles from all the three flights are consistently lower than the Grove's model by about 20% throughout the altitude range except for the early morning flight 17·04 where the values in the altitude range 80-90 km are higher than those given by Grove's model, with the difference increasing with altitude and at 90 km the values are higher by about 25%. The experimental accuracy and the accuracy of the method of analysis are expected to yield results with an error no greater than about 10% and the departures observed are larger than this error range. Thus, it would appear that the molecular oxygen concentration below about 80 km are lower than those given by standard atmospheric model by about 20%. Recently Subbaraya *et al.*[7] have reported molecular oxygen densities in the altitude range 65-95 km obtained from two rocket flights at Thumba around noon time.

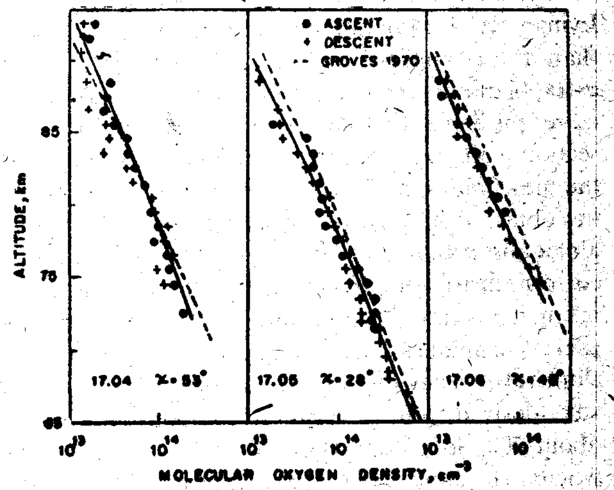

Fig. 3—Derived molecular oxygen density values as a function of altitude, both for ascent and descent, for the three rocket flights shown in three separate parts (The solid lines represent the smooth fits)

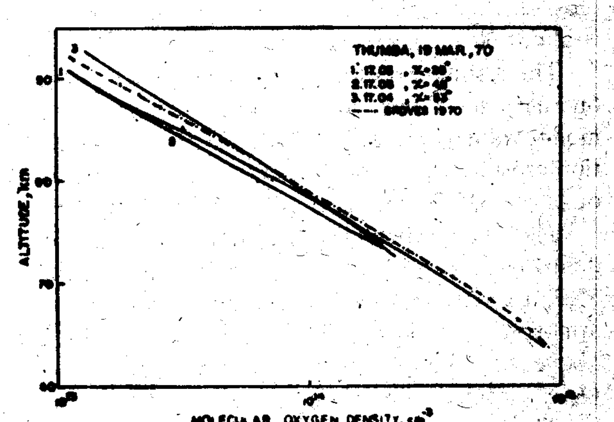

Fig. 4—Smoothed molecular oxygen density profiles for the three rocket flights (For comparison Grove's 1970 model[11] for 10° N and month March is also shown)

They also conclude that the measured molecular oxygen concentration below about 80 km are in general lower than those given by standard atmospheric model of Groves. Above 90 km the differences in the values obtained by two rocket flights, one in winter other in equinox, are large.

The result that the molecular oxygen densities derived from the Lyman-alpha absorption photometry technique are consistently lower than those given by the standard model can be interpreted in two ways. The first one is that the densities are actually lower than those given by the standard model. The other is that the absorption cross-section assumed to be 1×10^{-20} cm^2 based on laboratory measurements is in error. It may be noted that Groves model is based on independent experimental measurements of density and so it is less probable that the actual molecular oxygen densities are lower than those given by the model. Since the laboratory determination of the absorption cross-section of molecular oxygen for Lyman-alpha radiation are made at higher pressures than those appropriate for the ionosphere and an extrapolation is made for ionospheric pressure, it is more probable that the assumed absorption cross-section is in error. Smith and Miller[13] have compared the measurements of molecular oxygen number densities obtained from rocket observations by the Lyman-alpha absorption photometery with the values obtained from nearly simultaneous measurements, at a mid-latitude location, of atmospheric density from other rocket techniques using grenades, falling sphere and Pitot tube. They observed that the atmospheric density derived from absorption photometery data is about 20% less than that of the other techniques when a constant value of absorption cross-section of 1×10^{-20} cm^2 is used. They have concluded, using the wavelength dependence of absorption cross-section that the average value of effective absorption cross-section σ_e should be about 8×10^{-21} cm^2, which is about 30% lower than that given by Hall[5].

The results reported in this paper, particularly the one near noon time, can be made consistent with the model value if the value of the Lyman-alpha absorption cross-section is taken as $0{\cdot}9 \times 10^{-20}$ cm^2, instead of as 1×10^{-20} cm^2, i. e. reduced by about 10%.

Thus, it is concluded that the molecular oxygen densities measured near the equator (at a latitude of 8°N) are consistent with those given by the standard atmospheric model, if in the light of the discussion above, the Lyman-alpha absorption cross-section for O_2 is assumed to be about $0{\cdot}8$-$0{\cdot}9 \times 10^{-20}$ cm^2.

The differences between the three individual profiles of the O_2 density reported here seem to indicate a diurnal variation with the largest values occurring in the early morning. It may be noted that from mid-latitude data using the same technique Weeks and Smith[2] have noticed a diurnal variation in O_2 density of about 33% above about 92 km, with the early morning values lower than the afternoon values. The diurnal trend observed by Weeks and Smith[2], viz. whether the apparent diurnal trend is genuine or not, can be decided only by making more systematic measurements.

6. Conclusions

From a study of molecular oxygen concentration profiles obtained by Lyman-alpha photo-absorption technique carried out on a single day it is observed that :

(i) The molecular oxygen concentration in the altitude range 70-90 km is systematically lower by about 20% than those given by the appropriate standard atmospheric models. But these values can be reconciled if the currently assumed value of absorption cross-section is reduced by about 10%.

(ii) A small diurnal variation is noticed with the early morning values being the highest and the afternoon values the lowest. At present this is to be taken as only indicative of diurnal variation. More systematic experiments will have to be carried out to establish this aspect.

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