Laser Radar for Upper Atmosphere Researches

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Laser Radar for Upper Atmosphere Researches

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Abstract: A brief description is given of the characteristics of the ruby laser radar system which has recently come into operation at Zao Observatory, Tohoku University. This lidar can transmit more than 5 joules per shot, and a dye laser is adaptable between the ruby head and the telescope for resonant scattering measurements. Due to Rayleigh scattering, the atmospheric density up to 100 km will be deducible by 1000 shots of ruby laser, and any existing dust layer will be easily detected by this lidar. For aeronomic researches, a resonant scattering lidar system is shown to be of invaluable use. For a groundbased observation and a rocketborn measurement, the minimum detectable density is estimated as the function of altitude for O, N, Na, K, N_2, NO, and N_2^+.

1. Introduction

After Elterman (1951) estimated the atmospheric density up to the altitude of about 60 km by measuring the light intensity scattered from a searchlight beam, attempts have been made to utilize the powerful artificial light source for atmospheric researches. In 1960, Mainman (1961) first succeeded in devicing a so-called laser by exciting optically a solid state ruby. The monochromatic and coherent features of a laser light at optical frequencies are quite advantageous for atmospheric researches. When a laser is operated with the use of the Q-switching technique, an extremely powerful light can be generated in a very short pulse. The first actual use of a laser in atmospheric studies was made by Fiocco and Smullin (1963). They used a ruby laser radar and received echoes from the altitude of about 140 km. In subsequent years, the laser radar technique was developed markedly and the utility has been increasingly recognized in the fields of meteorology and space physics. For the atmospheric research, a laser radar has the advantage of detecting much smaller particles, atoms, or molecules.

Table 1 summarizes the history of laser radar measurements performed in recent several years. Fiocco *et al.* (1963, 1964) ascribed the scattering light echoes from the altitude ranging from 110 km to 140 km to a dust layer, but this is now entertained with a doubt by themselves. Collis (1965), Ligda (1966), and Northend *et al.* (1966) utilized the laser radar for meteorological observations. Bain and Sandford (1966) in England measured the light due to Rayleigh scattering from altitudes up to 90 km, and found the enhancement of echoes from hights near 70 km. Kent *et al.* (1967) in Jamaica also detected the enhancement of returns from altitudes 15–30 km. McCormick *et al.* (1967) of Maryland University found the enhancement of signals from

Table 1.
Summary of laser radar measurements for upper atmosphere researches.

	1963−4	1964−7	1996−7	1966	1967	1969
Institution	M. I. T. (Fiocco *et al.*)	Standford Res. Inst. (Collis *et al.*)	Radio and Space Res. Station, Backs (Bain *et al.*)	Univ. of West Indies, Jamaica (Kent *et al.*)	Univ. of Maryland (McCormick *et al.*)	Rad. and Space Res. Station, Backs (Bowman *et al.*)
Laser	Ruby	Ruby Neodymium-glass	Ruby	Ruby	Ruby	Dye
Energy/Shot	0.5*J*	0.2 *J* 0.5 *J*	5*J*	3*J*	1-5*J*	3-10 m*J*
Diameter of Receiving Telescope	30 cm	10 cm 15 cm		50 cm	50 cm	100 cm
Maximum Observed Altitude	140 km(?)	20 km	90 km	80 km	100km	140 km
Object	Upper Atmospheric Research	Meteorological Res.	Up. Atm. Res.	Up. Atm. Res.	Up. Atm. Res.	Up. Atm. Res. (Resonant Scat.)
Results	110–140 km Dust layer (?)		~70 km Dust layer	15-30 km Dust layer	~80 km Dust layer	~90 km Na layer

the altitude of about 80 km. The last three experiments employed the mechanical shutter in the giant pulsed laser radar system in order to reduce the optical noises resulting from the fluorescence of a ruby. In 1969, using a dye laser, Bowman *et al.* (1969) succeeded in the experiment to detect the upper atmospheric sodium layer at the altitude near 90 km on the basis of the measurement of light echoes due to the resonant scattering. Thus, the measurement of the density of atomes or molecules in the upper atmosphere by laser radar is shown to be quite fruitful in the aeronomic study.

This paper describes the characteristics of the laser radar which has recently come into operation at Zao Observatory and the theoretical basis are given for the observation of the upper atmospheric constitutents.

2. Laser Radar at Zao Observatory for Upper Atmosphere Researches

Fig. 1 shows the block diagram of the laser radar system established at Zao Observatory for Upper Atmosphere Researches. The siting of the Observatory is 38.1°N, 140.5°E, and the elevation is 430 meters above the sea-level. The characteristics of the equipment are tabulated in Table 2. The Q-switched

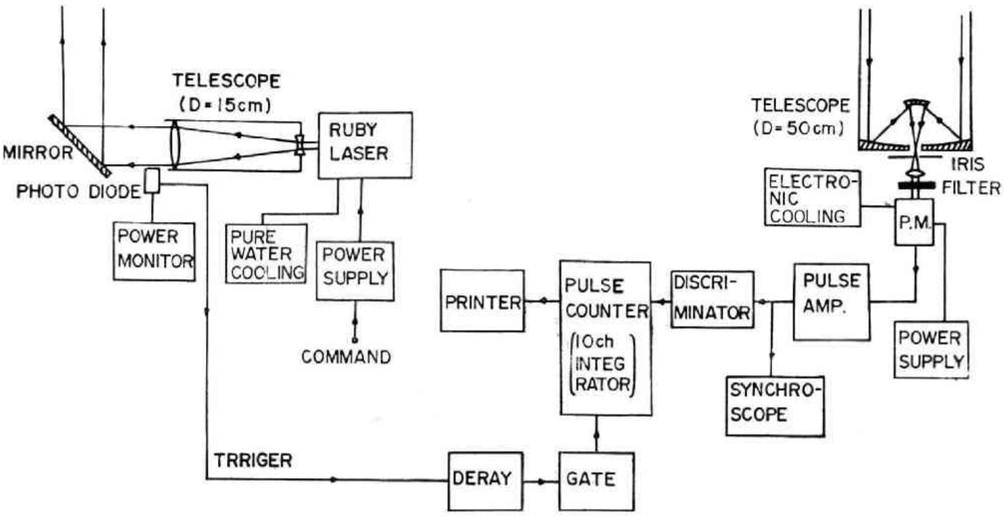


Fig. 1. Block diagram of the laser radar system at Zao Observatory for Upper Atmosphere Researches.

Table 2.

Characteristics of the laser radar operating at Zao Observatory, Tohoku University.

Transmitter	
Laser	Q-switched ruby laser
Wavelength	6943A
Output energy	>5 Joule/shot
Pulse length	<1μsec
Max. SRR	0.2/sec
Telescope	$D=15$ cm
Beam divergence	<1 mrad
Receiver	
Telescope	$D=50$ cm Cassegrain
Field of view	<5 mrad
Filter bandwidth	30A
Detector (P.M.)	EMI 9558 QB (S-20)
Counter	10 channel
Cooling system	EMI Electronic
Gate width	5 km (33 μ sec), 10 km (66 μ sec)

ruby laser is employed for the optical source. The oscillation threshold is found to be 2.4 kv. As shown in Fig. 2, the out-put power exceeds 5 joules per one shot. A powerful pulsed laser at 6943A is tranmitted through a 15 cm diameter telescope and reflected to the vertical by a plane mirror. The duration of a shot of a laser beam is confined within 1μ sec, and each shot consists of several short pules of about 40–50 nsec width. This corresponds to the range resolution of 150 meters. The beam divergence is measured to be within 1 m rad. The photograph of the transmitter is shown in Fig. 3. The detection of the back scattered radiation at a single photoelectron level is achieved by the use of a 50 cm diameter Cassegrain telescope and a photomuliplier tube (P.M.). Photon pulses are counted by a counter with 10-channelled integraters after

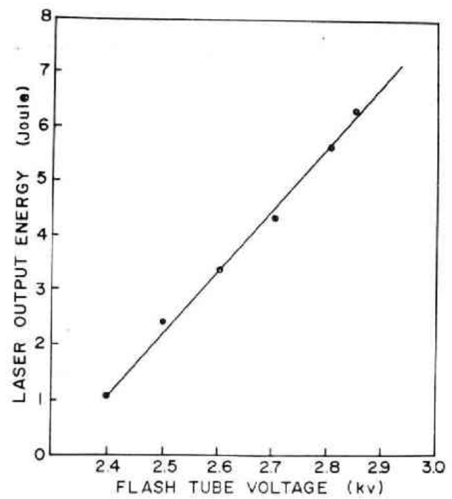


Fig. 2. Output energy as the function of an input voltage at the flash tubes.

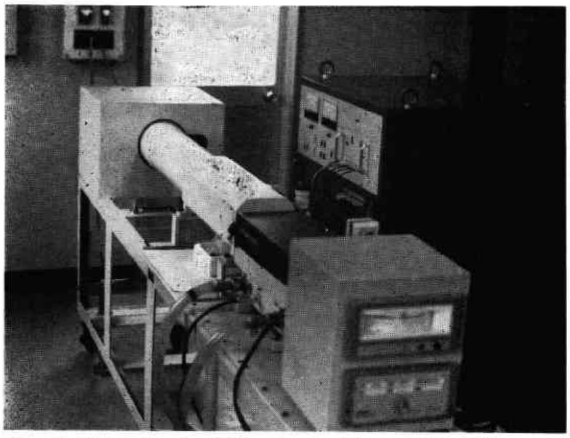


Fig. 3. A photograph of the transmitter at Zao Observatory.

passing an amplifier and a pulse height discriminator. Simultaneously, the echo train can be displayed on a Brown tube by means of an A-scope. The gate width time for each of the channels is selected to be 33 μ sec or 66 μ sec corresponding to the height range of 5 km or 10 km, respectively.

3. Rayleigh Scattering Observations

The laser radar equation for measuring the upper atmospheric density can be written as

$$W_R = W_o \Delta h T^2 N \left(\frac{d\sigma}{d\Omega} \right) \frac{A}{h^2} K\eta \ , \qquad (1)$$

in which

$$T^2 = \exp\left[-2\int_0^h \alpha(h)dh\right] . \tag{2}$$

Here, W_R denotes the energy received, W_o the transmitting energy, Δh the height range under consideration, N the number density of scattering centers, $\left(\frac{d\sigma}{d\Omega}\right)$ the differential back scattering cross section, A the effective area of the receiving objective, h a range (altitude) of relevant scattering volume, K the transmission of the optical system, η the quantum efficiency of the detector, T^2 an attenuation factor on a two-way path in the atmosphere, and α is an extinction coefficient for absorption and scattering in the atmosphere. The SN ratio in photon counting is given by

$$\frac{S}{N} = \frac{n_s}{\sqrt{n_s + n_n}} , \tag{3}$$

where n_s is the number of photoelectrons due to the reception of signals and n_n the number of photoelectrons caused by the instrumental noises and contaminating lights.

Now, an estimate will be given of the possible detection of Rayleigh scattering returns from an altitude ranging from 30 km to 100 km. In Eq. (1), put W_o=5J, Δh=5 km, $A=2\times10^3 cm^2$, $K=0.5$, and $\eta=3\times10^{-2}$. Since a laser light suffers extinctions mainly in the lower atmosphere, we are allowed to take roughly $T^2=0.2$ when the upper atmosphere above 30 km is concerned (Kent, *et al.*, 1967; Sandford, 1967). The differential cross section for the Rayleigh scattering is known to be $1.8\times10^{-28}cm^2\ ster^{-1}$ for O_2 and $2.1\times10^{-28}cm^2\ ster^{-1}$ for N_2. In Eq. (3), n_n depends essentially on background light which is about 1 Rayleigh/A at midnight. Other kinds of noises such as a dark current in P.M. are negligible as compared with the background noise.

Employing the CIRA Standard Atmosphere, the photon numbers scattered from the altitudes 30-100 km and the SN ratio can be calculated on the basis of the characteristics of our new laser radar, and the results are shown in Figs. 4 and 5. In

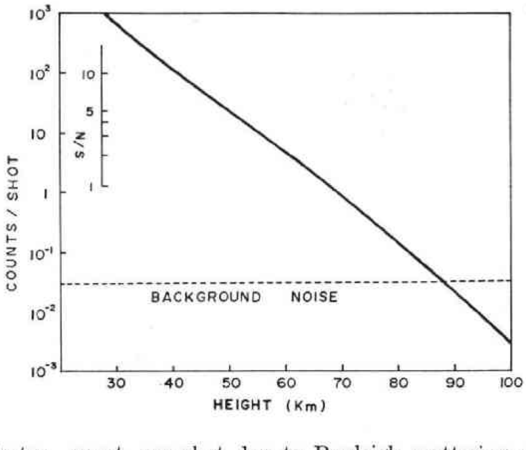


Fig. 4. Calculated photon count per shot due to Rayleigh scattering and the expected SN ratio as the function of altitude.

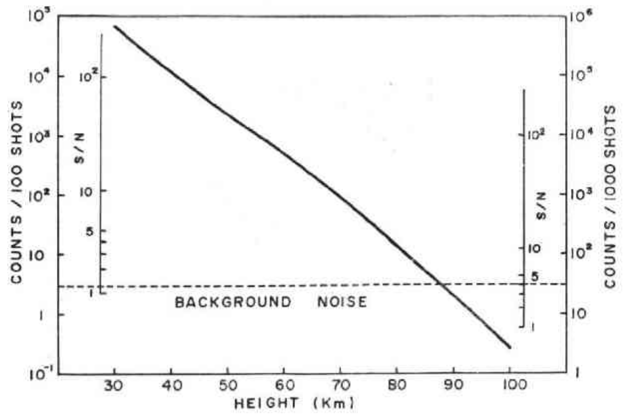


Fig. 5. Calculated photon count per 100 or 1000 shots due to Rayleigh scattering and the expected *SN* ratio as the function of altitude.

Fig. 4, count of signals per one shot are shown as the function of alitutde. The background noise level is given by the dashed line, and the consequent *SN* ratio is indicated on the ordinate. If the repetition of measurements is made, and a statistical treatment of the data is employed, the *SN* ratio is improved markedly as shown in Fig. 5. The reliable limit for the data reduction is thought to be at $S/N=3$, so that the atmospheric density profile will be obtained up to about 60 km, 80 km, and 90 km, by 1, 100, and 1000 shots, respectively. If particles such as "noctilucent clounds" exist in the region concerned, a photon number enhancement will be possibly detected.

4. Resonant Scattering Laser Radar System

As mentioned above, measurements of the atmospheric density are limited in the region below 100 km, because of the very small cross section, being of the order of 10^{-28} cm^2 $ster^{-1}$, for Rayleigh scattering. If the incident light can be tuned at the frequency equivalent to the difference between two energy levels of an atom or a molecule, the so-called resonant scattering will be expected. Differential cross sections for resonant scatterings are extremely large as compared with those for Rayleigh scattering, being of the order of $10^{-12}cm^2$ $ster^{-1}$ for Na and K. Therefore, with the use of a resonant wavelength laser, a very small amount of specified atmospheric atoms or molecules will possibly become detectable. Attempts have recently been made to tune the wavelength at the sodium D line with the use of a dye laser, and the detection of sodium vapor in the upper atmosphere has been succeeded in England on the basis of the resonant scattering (Bowman *et al.* 1969). In this section, after presenting briefly the theory of resonant scattering, expected resonant scatterings will be considered for atoms and molecules existing in the upper atmosphere, and estimates will be given of the minimum dectectable number densities for some of the atmospheric constituents.

4.1. Theoretical Consideration of Resonant Scattering

The classical theory of the resonant scattering was treated by Chamberlain (1961), Hirono (1964), and others on the basis of the one photon process. Recently, Huber (1968) has developed the quantum mechanical theory based on the two photons process. According to the results given by the Huber's theory, the resonant scattering cross section for a single atom can be calculated for the three limited cases: i) $\gamma_N \gg \gamma_C \gg \gamma_D$, ii) $\gamma_D \gg \gamma_N \gg \gamma_C$, and iii) $\gamma_C \gg \gamma_N \gg \gamma_D$. Here, γ_N denotes the natural linewidth, γ_C the collision width, and γ_D the Doppler width. The cross section will be considered below in each of the three cases.

i) $\gamma_N \gg \gamma_C \gg \gamma_D$. In this limit, the expression for the cross section takes the form

$$\frac{d^2\sigma(\omega_1)}{d\Omega\, d\omega_2} = \frac{2\pi X \omega_1 \omega_2^3}{(\omega_1-\omega_0)^2+\gamma_N^2}\, \delta(\omega_1-\omega_2) \ , \tag{4}$$

in which

$$X = \frac{|\alpha_i|^2 |\alpha_f|^2}{2\pi c^4 h^2} \ .$$

In the above expressions, w_0 is the resonance frequency, w_1, w_2 the angular frequencies of an incident and a scattered light, respectively, c the light velocity, h the Plank's constant, and α_i, α_f are the matrix elements for the component of the dipole moment operator along the direction of polarization of an incident and a scattered light.

ii) $\gamma_D \gg \gamma_N \gg \gamma_C$. The cross section for the resonant scattering is given by

$$\frac{d^2\sigma(\omega_1)}{d\Omega\, d\omega_2} = \frac{\pi X \gamma_N^{-1} \omega_2^3 mc^2}{\omega_1 kT \sin\theta} \exp\left[-\frac{(\omega_2-\omega_1)^2 mc^2}{4\omega_1^2 kT(1-\cos\theta)} - \frac{(2\omega_0-\omega_1-\omega_2)^2 mc^2}{4\omega_1^2 kT(1+\cos\theta)}\right] , \tag{5}$$

where k is the Boltzmann's constant, T the gas temperature, m the mass of an atom, and θ denotes the scattering angle ($\theta=0$ corresponds to a forward scattering).

iii) $\gamma_C \gg \gamma_N \gg \gamma_D$. The cross section is given by

$$\frac{d^2\sigma(\omega_1)}{d\Omega\, d\omega_2} = \frac{2\pi X \omega_1 \omega_2^3}{(\omega_1-\bar{\omega}_0)^2+\gamma_C^2} \left[\delta(\omega_1-\omega_2) + \frac{\gamma_C}{\gamma_N}\left\{\frac{\gamma_C/\pi}{(\omega_2-\bar{\omega}_0)^2+\gamma_C^2}\right\}\right] , \tag{6}$$

where $\bar{w}_0 = w_0 + w_0{}^c$ with $w_0{}^c$ being the shift frequency resulting from collisions. In Eq. (6), the delta function characterizes the coherent scattering, while the second term is the cross section for resonance fluorescence.

Now, let us consider what is the case in the upper atmosphere. Table 3 tabulates the calculated γ_D and γ_C for N_2. Since

$$\gamma_D \propto \sqrt{\frac{T}{M}}\,\omega_1 \ , \qquad \text{and} \qquad \gamma_C \propto \frac{D^2 p}{\sqrt{MT}} \ , \tag{7}$$

where T is the absolute temperature, M atomic or molecular weight, D the diameter of a particle, and p the pressure of a gas concerned. The values of γ_D and γ_C for gases in which we are interested are of the same orders of magnitude as those for N_2, respectively. As for the natural linewidth, γ_N is known to be usually less than 10^{-2}cm^{-1}.

Table 3.
Doppler width and collisional width for N_2 in the atmosphere for an incident light at 5000A.

h (km)	T (°k)	p (atm)	$\frac{\gamma_D}{2\pi}$ (cm^{-1})	$\frac{\gamma_C}{2\pi}$ (cm^{-1})
0	290	1	4.6×10^{-2}	1.8×10^{-1}
10	230	2.76×10^{-1}	4.1×10^{-2}	1.7×10^{-3}
20	210	5.51×10^{-2}	3.9×10^{-2}	3.6×10^{-3}
30	235	1.25×10^{-2}	4.2×10^{-2}	7.6×10^{-4}
40	260	3.16×10^{-3}	4.4×10^{-2}	1.8×10^{-4}
50	270	9.86×10^{-4}	4.5×10^{-2}	5.6×10^{-5}
60	260	2.76×10^{-4}	4.5×10^{-2}	1.6×10^{-5}
70	210	7.10×10^{-5}	4.0×10^{-2}	4.6×10^{-6}
80	190	1.32×10^{-5}	3.9×10^{-2}	9.0×10^{-7}
90	210	2.90×10^{-6}	3.9×10^{-2}	1.9×10^{-7}
100	240	5.52×10^{-7}	4.1×10^{-2}	3.3×10^{-8}

Hence, the second limit in which $\gamma_D \gg \gamma_N \gg \gamma_C$ is thought to be the case in the upper atmosphere above 10 km. From Eq. (5),

$$\frac{d\sigma(\omega_1)}{d\Omega} = \frac{(2\pi^3)^{1/2} X \gamma_N^{-1} \omega_1^3}{(kT/mc^2)^{1/2}} \exp\left[-\frac{(\omega_1-\omega_0)^2 mc^2}{2\omega_1^2 kT}\right]$$

$$= \frac{(2\pi^3)^{1/2} X \omega_1^4}{\gamma_N \gamma_D} \exp\left[-\frac{(\omega_1-\omega_0)^2}{2\gamma_D^2}\right], \tag{8}$$

where

$$\gamma_D = \omega_1 (kT/mc^2)^{1/2} . \tag{9}$$

4.2. *Expectable Resonant Scattering*

Some resonant transitions which are likely to be caused by a laser light are listed in Table 4 for constitutents in the upper atmosphere. The conditions for a resonant transition are described as follows: i) The energy difference between the two levels should be equivalent to the frequency in visible or near ultrared region. ii) The lower level should be the ground state or a metastable state. Table 4 shows the wavelengths of possible transitions and the corresponding differential scattering cross sections calculated from Eqs. (8) and (9) for the condition at the altitude of 80 km. It is almost impossible to calculate matrix elements of respective atoms and molecules, so that the cross sections are estimated by employing transition probabilities which are already obtained by many workers (Corlliss and Bozman, 1962; Nicholls, 1964). In the table, the transitions from the excited levels are marked by stars, and circles indicate those which are of practical use for a resonant scattering laser radar system. For reference, the partial energy diagrams for N_2, N_+^2, NO, O, N are shown in Figs. 6 through 10. In the figures, the transitions in which the resonant scattering is probable are marked with "※".

Table 4.
Expectable resonant transitions and relevant differential scattering cross sections.

Transition		Wavelength (A)	$(\frac{d\delta}{d\Omega})_D$ (cm^{2}ster^{-1})
Na $(1s^22s^22p^63s^2S_{1/2})$			
3 or$^2S_{1/2}$—$3p^2P_{1/2}$		5895.92	6.6×10^{-13}
$3s^2s_{1/2}$—$3p^2P_{3/2}$		5889.95	1.2×10^{-12}
K $(1s^22s^22p^63s^23p^64s^2S_{1/2}$			
○ $4s^2S_{1/2}$—$4p^2P_{1/2}$		7698.98	1.7×10^{-12}
$4s^2S_{1/2}$—$4p^2P_{3/2}$		7664.91	3.0×10^{-12}
N*			
○ $3s^4P_{5/2}$—$3p^4P^0_{5/2}$		8216.32	5.8×10^{-13}
$3s^2P_{3/2}$—$4p^2S^0_{1/2}$		4935.03	1.8×10^{-14}
O*			
$3s^5S_2{}^0$—$3p^5P_1$		7775.39	8.8×10^{-13}
○ $3s^3S_1{}^0$—$4p^5P_2$		7774.17	
$3s^3S_1{}^0$—$4p^3P$		4368.3	3.4×10^{-15}
N^*_2			
1st Positive Band $(B^3\Pi_g-A^3\Sigma_u{}^+)$	○ 2,0 band	7694	4.2×10^{-13}
	3,0	6824	3.0×10^{-13}
N^+_2			
1st Negative Band $(B\Sigma_u{}^+-X^2\Sigma_g{}^+)$	○ 0,0	3914.4	3.5×10^{-14}
	1,0	3582.1	1.2×10^{-14}
Meinel Band $(A^2\Pi_u-X^2\Sigma_g{}^+)$	○ 2,0	7850	9.3×10^{-13}
	3,0	6872	3.1×10^{-13}
NO*			
Ogawa 2 Band $(b^4\Sigma^--a^4\Pi)$	1,0	8683	$\sim10^{-14}$
	2,0	7898	(by Nugent)

4.3. *Minimum Detectable Number Densitiy*

The laser radar equation for the resonant scattering system can be written as shown below, in the two cases in which an observation is made on the ground (G) and in space (S), respectively (Kamiyama *et al.* 1970);

$$W_G = W_{0G}\Delta h\, T_G^2\, N\left(\frac{d\sigma}{d\Omega}\right)_D \frac{A_G}{h^2}\, K_G\eta L\ , \tag{10}$$

and

$$W_S = W_{0S}T_S^2\, N\left(\frac{d\sigma}{d\Omega}\right)_D \frac{A_S}{R_0}\, K_S\eta L\ , \tag{11}$$

where $(d\sigma/d\Omega)_D$ is the differential back scattering cross section for a resonant scattering at the altitude h, L the resonant scattering efficiency, R_0 the nearest distance of relevant scattering volume from the instrument, and the other symbols have the same meanings as in Section 3. The number density of atoms at a lower energy level is denoted by N.

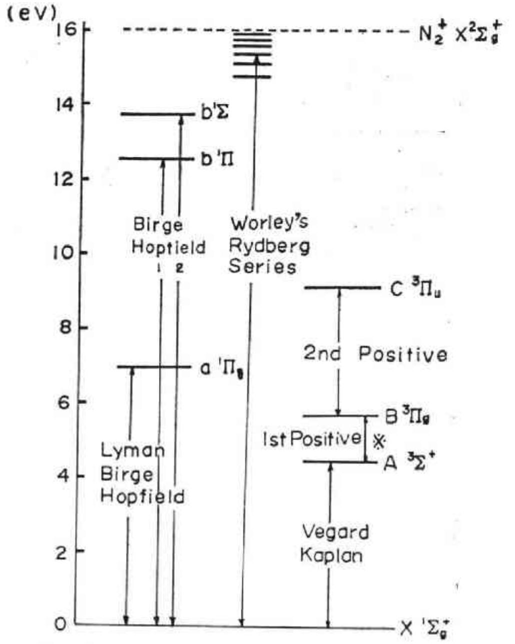


Fig. 6. Partial energy diagram of N_2.

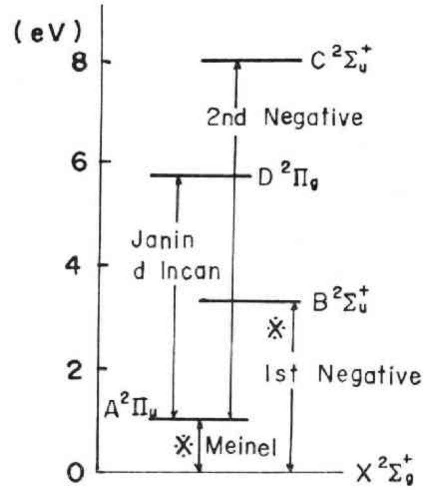


Fig. 7. Partial energy diagram of N_2^+.

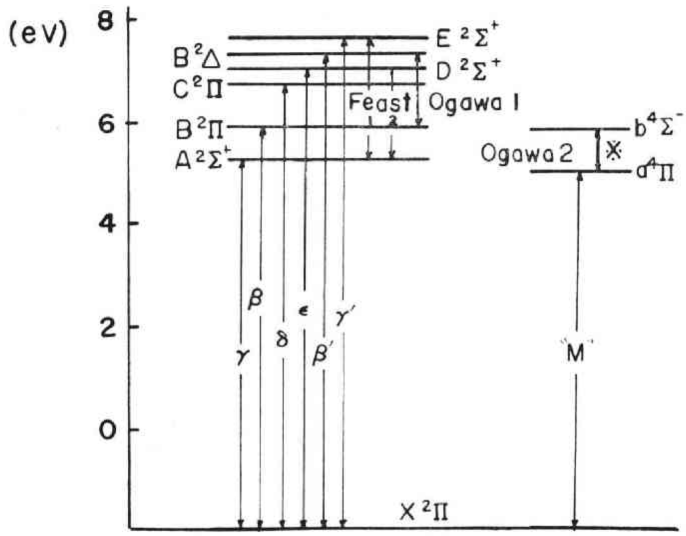


Fig. 8. Partial energy diagram of NO.

In the case of molecules, although almost all of the molecules at an usual temperature lie at the level $v=0$, N should be given as the function of a rotational quantum number J by

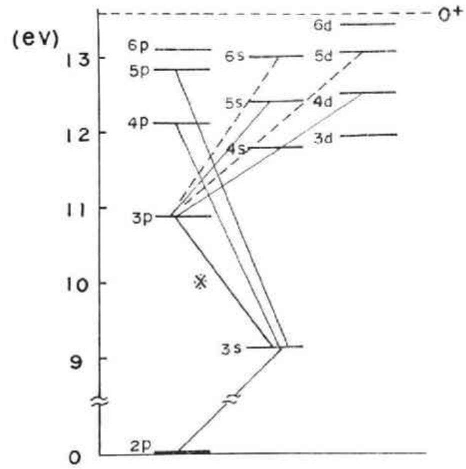


Fig. 9. Partial energy diagram of O.

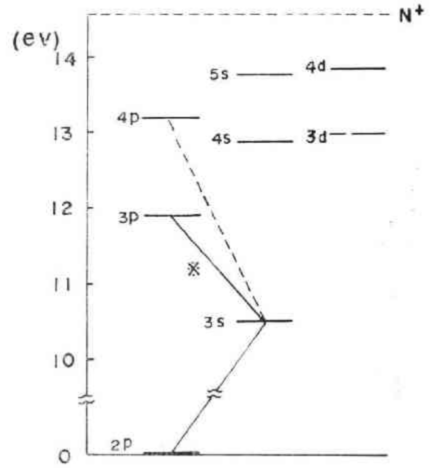


Fig. 10. Partial energy diagram of N.

$$N=(N)_{v=0}\frac{N_J}{\sum_J N_J}=(N)_{v=0}\frac{S(J)\exp\left[-F(J)hc/kT\right]}{\sum_J S(J)\exp\left[-F(J)hc/kT\right]}\ , \tag{12}$$

where $S(J)$ and $F(J)$ are the functions of J. When the spectral width of the laser light is Δw_1, L takes the following values;

$$L \simeq 1 \qquad (\text{for } \Delta\omega_1 \leq \gamma_D)\ ,$$

and

$$L \simeq \frac{\gamma_D}{\Delta\omega_1} \qquad (\text{for } \Delta\omega_1 > \gamma_D)\ . \tag{13}$$

In view of the pumping system and the quantum efficiency of P.M., it is appropriate to devide the wavelength region into two parts. One (denoted by I) is the region where $\lambda \geq 7000$A and the other (II) is that in which $\lambda < 7000$A. Designating by G or S a ground-based or rocket-born laser radar system, respectively, a symbolic expression, G-I, is used for the case in which a laser light at a wavelength exceeding 7000A is employed in the ground-based radar system, and so on. Assuming the pulse width of a laser to be 100 nsec and the band width of the interference filter to be 30A, the values given in Table 5 are adopted for W and W_0 in the four cases. Again assuming that $A_G=0.2\text{m}^2$, $T_G=0.5$, $\Delta h=10$ km, $K_G=0.1$, $T_S=1$, $R_0=1$ m, $K_S=0.1$ and $L=1$ (the technique of the wavelength tuning has already been achieved as accurate as a Doppler width (Gibson, 1969)), the minimum detectable density, n, in a twilight condition can be calculated for N_2, NO, N, O, Na, K, and N_2^+ as shown in Figs. 11 through 14. In each of the figures, dashed lines show the probable distributions of the number densities of atoms or molecules under consideration.

4.4. *Discussion*

The minimum detectable densities of some of the atmospheric constitutents are calculated for a twilight condition. From Figs. 11 through 14, the measurement in

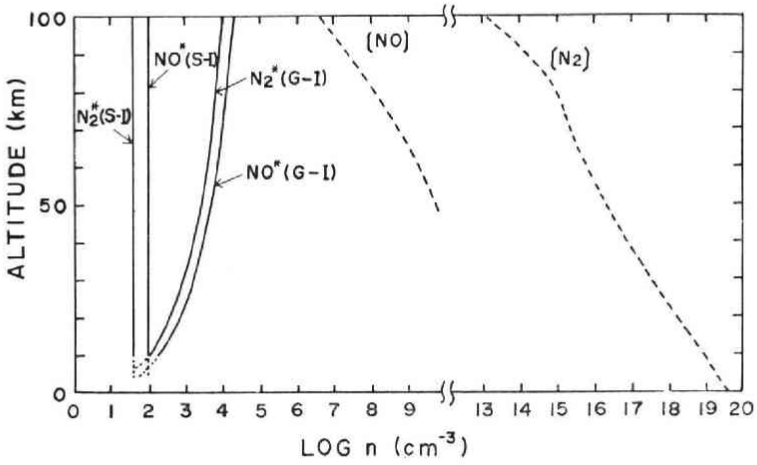


Fig. 11. The minimum detectable densities of excited N_2 and NO in a twilight condition as the function of altitude.

Table 5.

	λ≥7000A	λ<7000A
Groundbased laser radar	$W_G=2\times10^{-18}$ Joules G-I $W_{0G}=0.1$ Joules	$W_G=2\times10^{-19}$ Joules G-II $W_{0G}=10^{-2}$ Joules
Laser radar on a space vehicle	$W_S=2\times10^{-17}$ Joules S-I $W_{0S}=5\times10^{-4}$ Joules	$W_S=2\times10^{-18}$ Joules S-II $W_{0S}=5\times10^{-4}$ Joules

space is found to be of greater use than that on the ground. In addition, the former has an advantage to improve the altitude resolution.

From Fig. 13, one finds that Na and K are easily measured by a ground-based observation. Especially, Na seems to be detectable even in the daytime. Fig. 12 implies that excited O* and N* may be detectable at high altitudes, since the excitation of O and N are expectable when the ultraviolet radiations at about 10ev (1200A) or particles having the same order of energies are incident in the upper atmosphere. A little is known, however, as to the abundances of N_2*, NO*, and N_2^+. A resonant scattering laser radar measurement might provide an information about the fundamental quantities in aeronomic problems.

5. Summary

In this paper, an outline is described about the characteristics of the ruby laser radar which has recently come into operation at Zao Observatory for Upper Atmosphere Researches, Tohoku University. The output energy is measured to be more than 5 joules per shot at input voltages exceeding 2.75 kv at the flash tubes. The transmit-

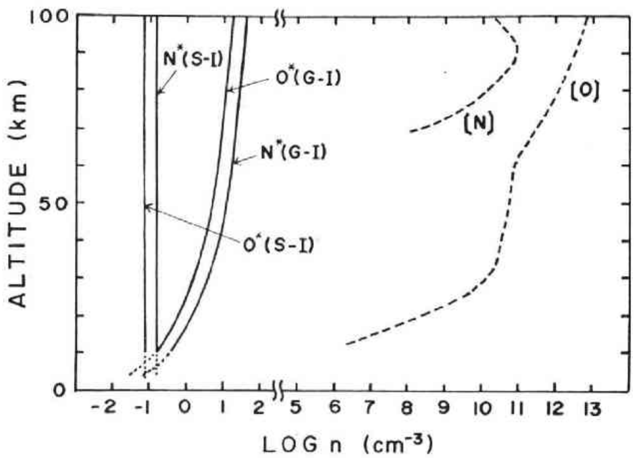
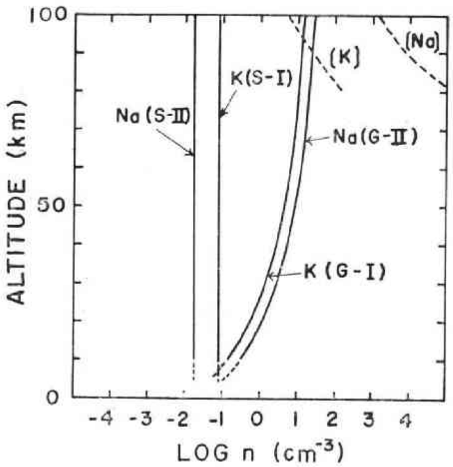


Fig. 12. The minimum detectable densities of excited N and O in a twilight condition as the function of altitude.



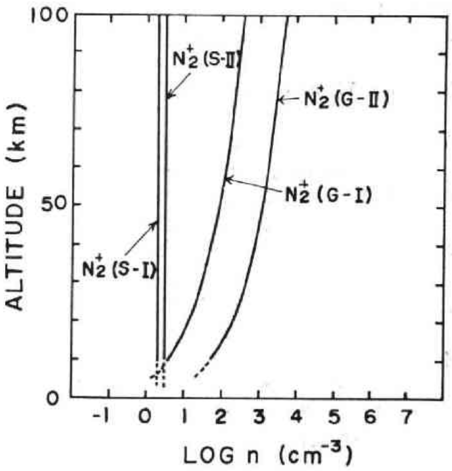


Fig. 13. The minimum detectable densities of Na and K in a twilight condition as the function of altitude.

Fig. 14. The minimum detectable densities of N_2^+ in a twilight condition as the function of altitude.

ter is designed so that a dye laser is adaptable between the ruby laser head and the telescope.

With the use of the 50cm-diameter receiving telescope, the atmospheric density will be deducible up to about 100 km with 1000 shots of ruby laser by the reception of photons due to Rayleigh scattering. Any dust layer, if exist below this altitude, will be easily detected by this lidar. In Section 4, a resonant scattering laser radar system is shown to be of great use for aeronomic researches. In the two cases, a ground-based observation and a rocket-born measurement, the minimum detectable density is estimated as the function of altitude for specified constituents such as O, N, Na, K, N_2, NO, and N_2^+. According to our estimate, Na is possibly detectable up to about 150 km by a ground-based observation. If small fractions of O, N, N_2, and NO are in the excited states, they are also shown to be detectable in the region in which we are interested. In view of an insufficient knowledge about the density distributions of these constituents, especially in the excited states, a resonant scattering lidar system is concluded to be of invaluable use for aeronomic studies.

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