BALLOON OBSERVATION OF SMALL ION DENSITY AND ELECTRIC CONDUCTIVITY IN THE STRATOSPHEHE*

Haruji ISHIKAWA, Yasuhiro MORITA, Masumi TAKAGI
and Akira IWATA

Abstract

The measurement of atmospheric small ions with a Gerdien condenser was carried out in the altitude up to 25 km using a plastic balloon. Ion density, electric conductivity and this weighted mean mobility are deduced from simple I-V characteristics of the condenser used. The conductivity profile observed is found to be fairly well coincident with the profile caluculated from a small ion balance theory below 12km, however, a disagreement between them is found to show up above 12km. The function of aerosols in the stratosphere is discussed as a plausible cause of the disagreement. We see that the number density, 0.5 per cm^3, of ten-micron size aerosols must be asssumed at 25km altitude, if we prefer an interpretation of the disagreement exclusively by the aerosol effect.

1. Introduction

Studies on the electrical state of the upper atmosphere has increased its importance in the present day of our space age and attracted the interest of many investigators. Many observations at balloon altitude have been made with nearly the same method as it has been done on the ground, yet it does not seem that our knowledge on electric conductivity, ion density and ion mobility in the upper atmosphere is very comprehensive. The results given by different investigators are not always consistent and we can notice here the possibilty that this depends on the difference in meteorological conditions. Therefore, measurements of meteorological factors, especially pressure and temperature, along with the atmospheric electrical elements, are to be simultaneously done. Electric conductivity

---

* Revised version of a short paper presented to the Fourth International Conference on the Universal Aspects of Atmospheric Electricity held in Tokyo, May, 1968.

measurement at the balloon altitude is important with respect to the study of Global Electric Circuit problem too. Conductivity at balloon altitude have already been measured many times by Sagalyn, Curtis and Stergis (1960) up to the present. Recently, Paltridge (1965) measured the conductivity and small ion density in Australia. Cole and Pierce (1965) discussed the electrification in the atmosphere up to 100 km with a small ion balance theory. Using a balloon Gerdien condenser we have made the second stratosphere measurement of electric conductivity, small ion density and weighted mean of mobilities late in the fall 1967.

In this paper we discuss the results of our observation and compare it with the theoretical ion density profile based on the small ion theory which assumes the ion-ionization equilibrium in the atmosphere.

2. Observation

A balloon mounted with a Gerdien condenser was launched in to a clear starry night sky from Taiyo-mura, Ibaragi Prefecture at 0308 a.m. on 21 October, 1967. The balloon acended with a velocity about 250 meter per minute and got in to level flight at altitude 24.8 km above sea level from the distance 170 km east of Taiyo-mura about 90 minutes after the release. The trajectory of the balloon is shown in Figure 1. The

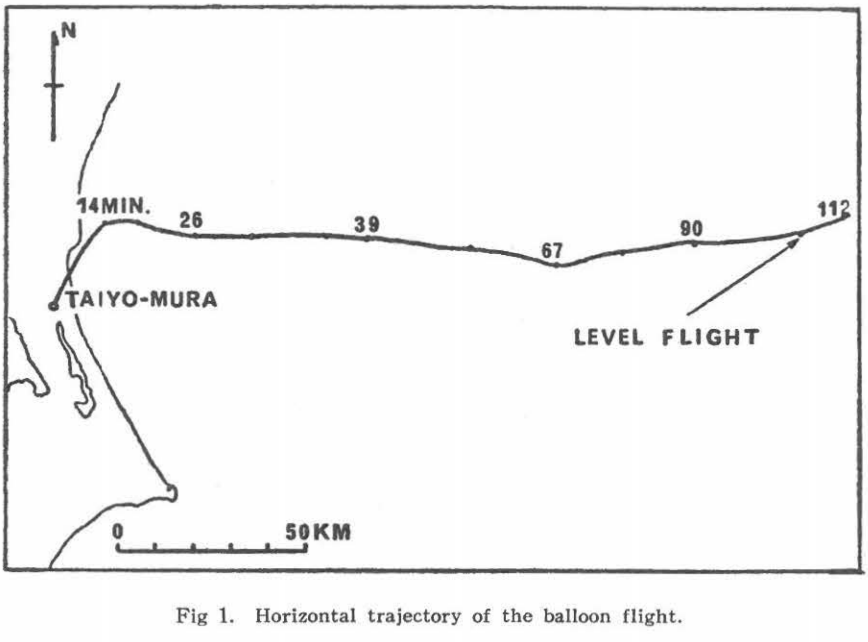

Fig 1. Horizontal trajectory of the balloon flight.

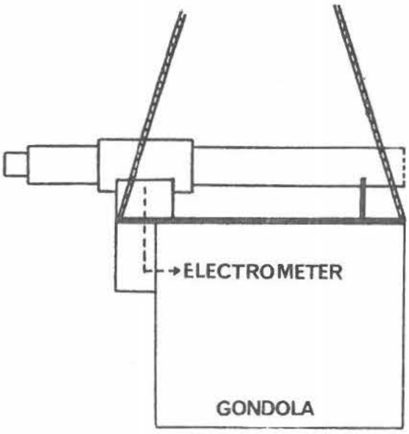

Fig. 2. Balloon payload ; Gerdien condenser mounted on a gondla.

whole apparatus of 30 kg in weight was suspended 20 meter below the balloon. It was tracked by a rader system and observation information was telemetered with a standard 1680 MHZ radio sonde transmitter. Shown in Figure 2, is a side view of the apparatus consisting of a Gerdien condenser horizontally mounted on the top and a gondla beneath it which contained an electrometer, a DC amplifier, dry batteries and a telemeter system. The Gerdien condenser was designed on the similar principle to that described by Misaki (1960). The condenser chamber of an ordinary cylindrical type, has been designed to be operated in a laminar air flow drawn by a DC micro blower. Figure 3 shows construction of the condenser. The airflow rate was adjusted in the laboratory so as to be 273 liter per minute by applying an appropriate regulated DC voltage to the blower. The condenser was so designed that we can obtain the conductivity up to 25 km following the well known equation, $K_c=(\varepsilon/c)\cdot(\Phi/v)$, for $V \geqq 1.5$ volts, assuming the same mobility spectrum as on the ground level. K_c, C, ε and Φ are critical mobility, electric capacity, dielectric constant of the air and airflow rate going through the condenser respectively. The steel surface of the condenser cylinder was coated with a chromium plating to keep the possible photoelectric emissions to a minimum because of high work function of it. The capacity of the condenser composed of outer and inner cylindrical electrodes was measured to be 17 pF. The outer electrode highly insulated with four sappire rods was shielded by a cover from external field as show in Figure 3. The ion current flowing out of the outer

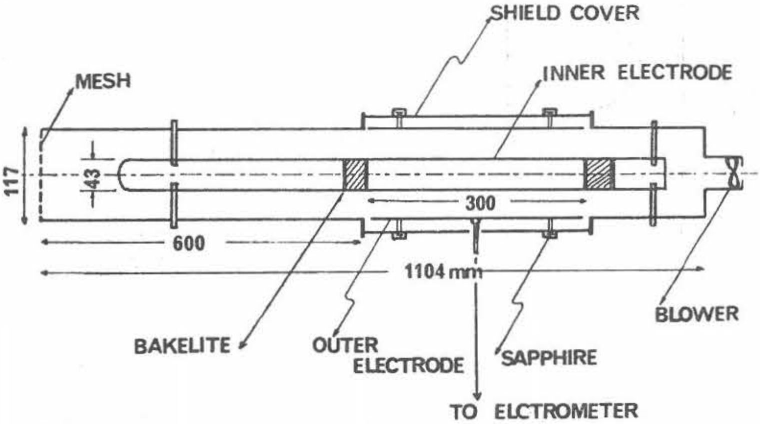

Fig. 3 Shematic construction of Gerdien condenser.

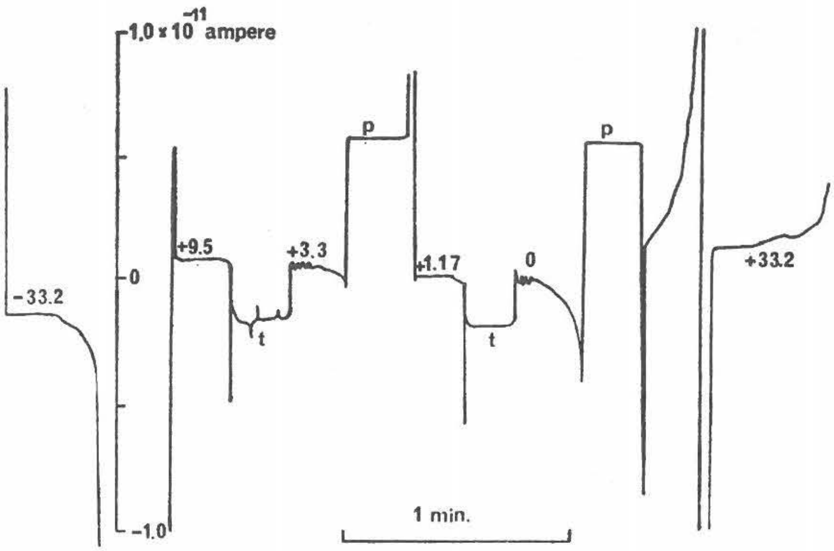

Fig. 4. An example of the record of atmospheric ion measurement with Gerdien condenser.

electrode goes through a 10^{11} ohm high resister and the voltage across it is applied to the radio sonde after amplified with a solid state DC amplifier.

The voltages O, 1.17, 3.3, 9.5 and 33.2 volt were applied to the inner electrode to produce positive electric field between the two electrodes of the condenser in succession,

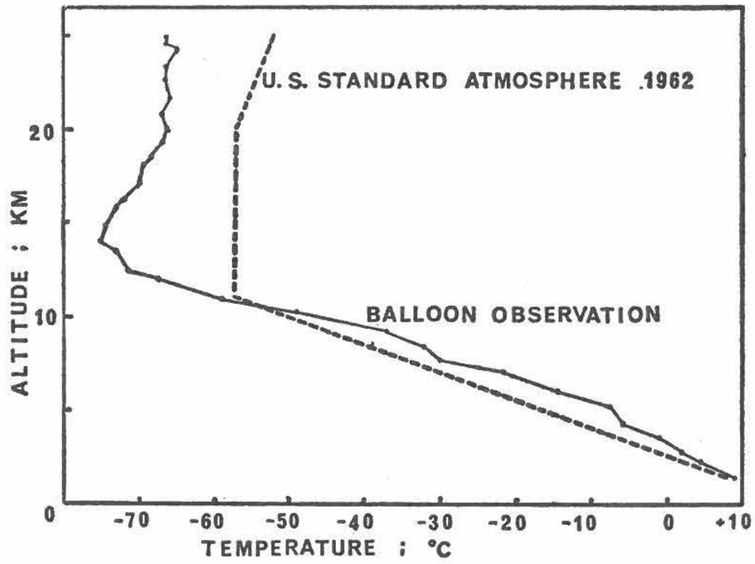

Fig. 5. Temperature profile observed in comparison with that of the standard atmosphere.

then the negative voltages are applied in a similar manner. Time duration of application of the five voltages was 30 seconds for the first four and 50 seconds for the last one. Thereafter the circuit was made open for 10 seconds. Consequently the measurement needed three minutes for positive ion and three minutes for negative ion, therefore the information obtained for positive, and negative, ion in this experiment is an average of about 750 meter in altitude for each polarity of the ions. Shown in Figure 4 is an example of the record obtained. These rather a long time interval of applying the voltages has been chosen, because it can eliminate the transient effect in the ion current after every voltage change. To make the observation cycle as short as possible, the information of temperature and pressure was transmitted during the first half of each of the 30 seconds period, where the transient effect was expected to be the most dominant. In Figure 5, where the observed temperature profile is compared with that of the U.S. standard atmosphere, we see no remarkable temperature inversion existed in the balloon altitude at the time of this observation.

3. Discussion of the results

From the readings of the record in each of 750 meter altitude sections in the ascent period we can obtain the average relation of applied voltage versus ion current, i. e. I-V curve, for each of sections. Figure 6 shows examples of I-V curves. Solid, and dotted, lines correspond to positive and negative ion current respectively. It is obvious that we can certainly rely on the I-V characteristics for positive ions rather than the negative one. Because the I-V charcteristics for negative ions do not show an expected typical trend of a saturation curve above 19 km altitude. For example, the negative ion I-V characteristics at 19 km and 25 km above sea level shown in Figure 6 is irregular, and we can not deduce a reliable value of conductivity and ion density in this case. The typical I-V characteristics are composed of the two straight lines, proportional part and saturation part, from which we can estimate conductivity and ion density respectively. These two values lead the weighted mean mobility.

The result of estimation of the ion density profile is shown in Figure 7 with black and white circles. The ion density profile given by Paltridge (1965) based on his balloon observation in South Victoria in Australia has been corrected for geomagnetic latitude at Taiyo-mura, 26° N and plotted with brocken line (2) in the same figure. We see almost coincidence between the two profiles below 10 km. Above 10 km the two profiles have a similar tendency of increasing with altitude up to about 12 km and of decreaseing with altitude. A small difference between the two beyond 12 km may be reduced to the difference of the mobility of ions caught and measured with the two respective Gerdien condenser experiments using balloons in Australia and in Japan. To compare the result with a small ion theory, we have computed an ion density

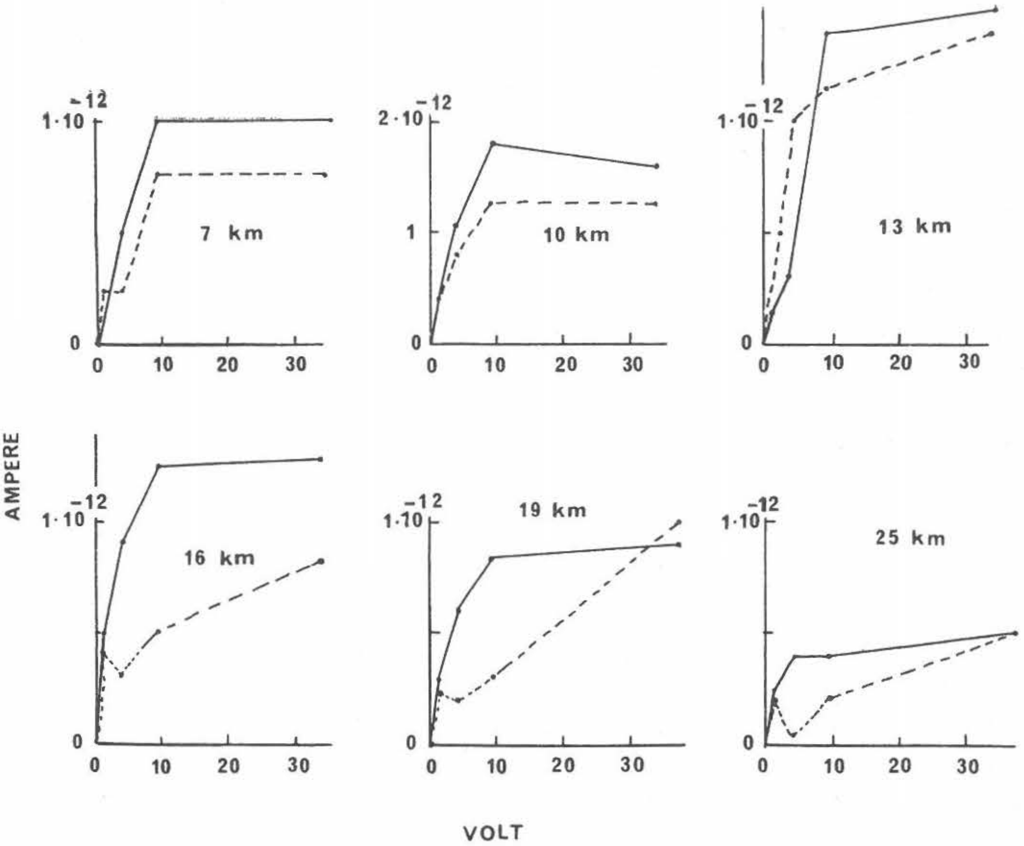

Fig. 6. Ion current versus applied voltage curves ; full, and dotted, line respectively shows positive, and negative, ion current.

profile referring to the result of ioninzation measurement made by Pror. M. Kawano et al. late in fall 1967. The result of calculation of positive ion density profile is depicted with a dotted line (3) in the same figure. The result of ion density measurement by means of a parachute borne Gerdien condenser using a small roket (Ishikawa et al. 1968) is reproduced with a full line (1) in the same figure for the purpose of comparing them. The total conductivity can be evaluated from the inclination of the proportional part of I-V characteristics, and the profile thus obtained is shown in Figure 8, with a full line. The conductivity profile can easily be calculated from a small ion density profile if we assume the mobility of small ions to be 1.1×10^{-4} in MKS unit reduced to the ground level. The dotted line (2) in the figure shows the result of conductivity calculation assuming an ion density profile of the small ion theory of ionization equilibrium. The broken line (1) shows the profile given by Uchikawa (1961) based on his balloon observation at Tateno. We see the coincidence between our observation and present calculation to be fairly well up to 12 km altitude. On the other hand, the ion density profile of our observation is found in Figure 7 everywhere to have smaller values that which is derived from small ion theory. This seems to be dependent on the mobility difference of the ion to be considered in the two respective cases under discussion. Coincidence of the conductivity profiles between observation and calculation

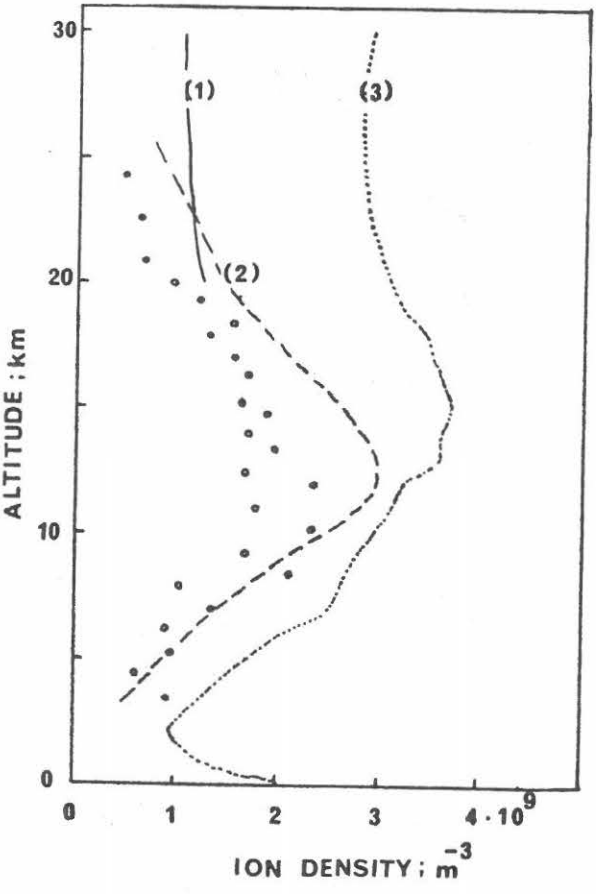

Fig 7. Ion density profiles, black and white circle : positve and negative ions. (Balloon measurement by authors)

(1) Rocket measurment (authors)

(2) Balloon measurement (Paltridge)

(3) Calculation based on a small ion theory of ionization equilibrium

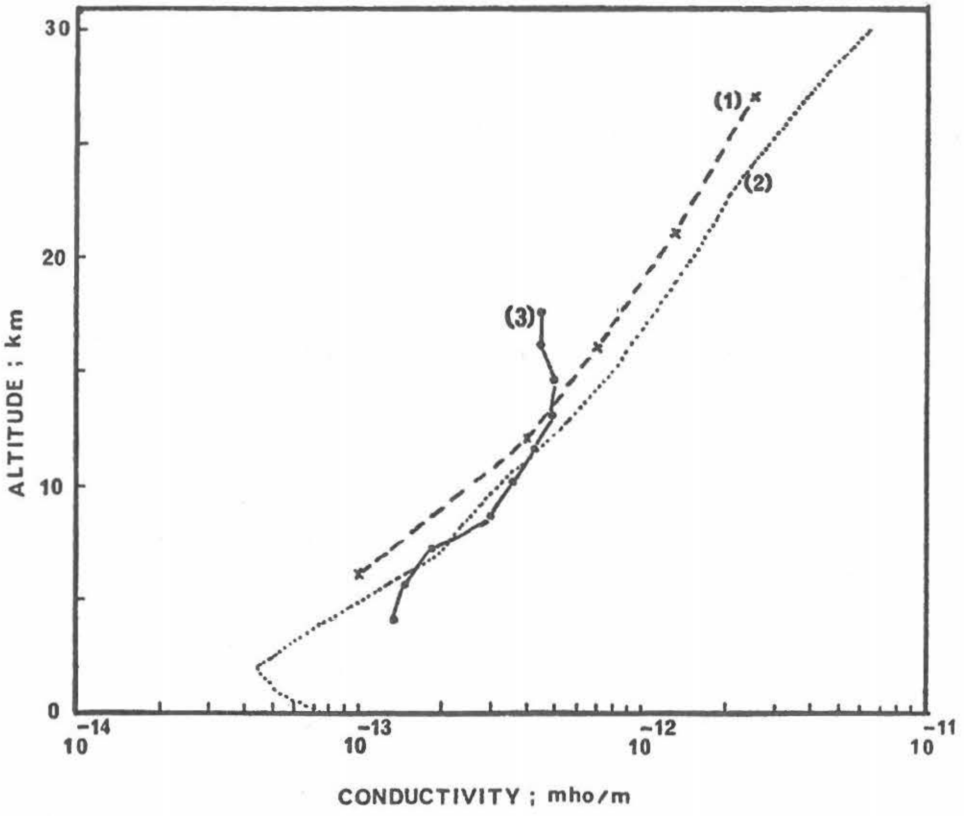

Fig. 8. Conductivity profiles

(1) Balloon measurement (Uchikawa)

(2) Calculation based on a small ion theory of ionization equiliblrium

(3) Balloon measurement (authors)

in Figure 8 seems very roughly to indicate also that the ions we observed were actually the small ion whose mobility were roughly the same as that of small ions usually observed on the ground level. Misaki (1961) pointed out that the maximum in the ion mobility spectrum is usually found in the interval between 0.7×10^{-4} and 1.0×10^{-4} in MKS unit, while the maximum partial contribution to the conductivity is made by the ions lying in the interval between 1.0×10^{-4} and 1.3×10^{-4} in MKS unit. The weighted mean mobility estimated up to 20 km altitude in our observation are found to be in the interval between 1.1×10^{-4} and 2.0×10^{-4} in MKS unit reduced to the ground level. Therefore we are certain that the ions we observed were actually the small ions.

The profile obtained of the weighted mean mobility is indicated with black and white circles in Figure 9. The weighted mean mobilities given by Paltridge is plotted with crosses on the same diagram for the purpose of the comparison.

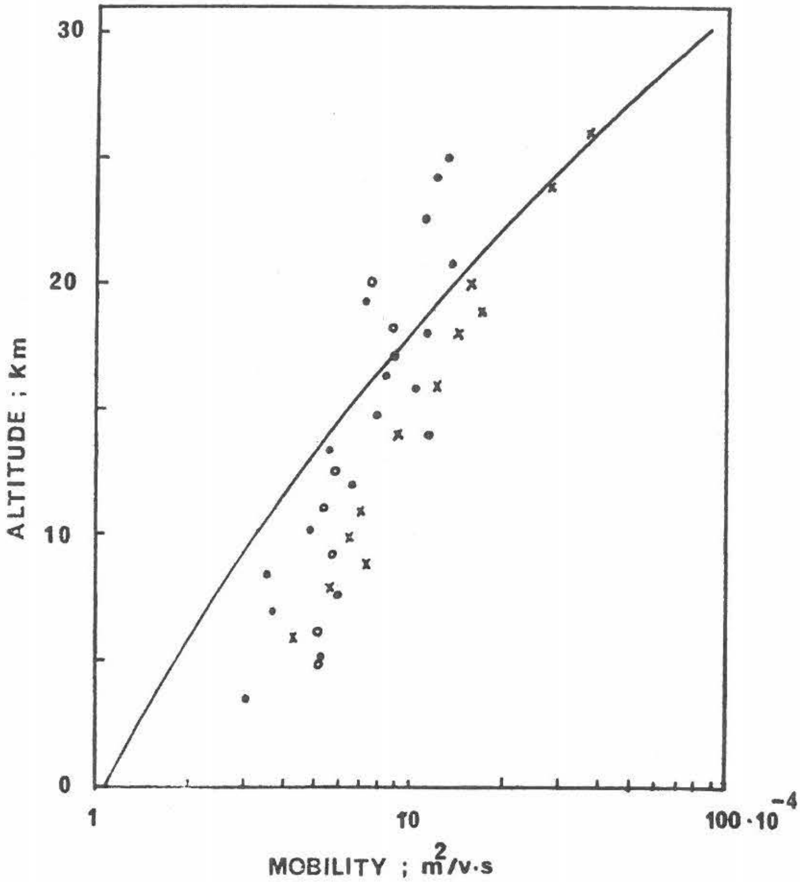

Fig. 9. Weighted mean mobility versus altitude ;
Black and white circle ; positive and negative ions (authors)
Cross ; Balloon measurement of mobility (Paltridge)
Full line ; The mobility profile of small ions being assumed to be 1.1×10^{-4} in MKS unit on the ground level.

We can see no essential difference between the two observation in Australia and in Japan. The highest value of critical mobility of the condenser is designed to be 20.5×10^{-4} in MKS unit by applying 1.17 volt to it and the value is not perfectly sufficient for the measuring conductivity even up to about 22 km altitude, if we assuming the same mobility spectrum in the stratosphere as that on the ground level. The trend may be supported by an experimental evidence we obtained that the observed mobility, if reduced to the value on the ground level, is found gradually to decrease as the altitude increases. The experimental evidence seems to be explained, if the ions entering the condenser were partly trapped by a stray electric field, which more or less existed at the entrance of the present condenser design and, if the high mobility limit of the spectrum would have a spreading out toward the higher part of it in the stratosphere, in contrast to our expectation of conservation of a ground level mobility spectrum at any altitude. The mobility spectra of small ions the troposphere up to 5 km altitude, were already obtained by Hoppel and Kraakevik (1965). They indicated a spreading out of the high mobility limit of the spectrum and the existense of a peak near the low mobilty limit of it, if the mobilities reduced to the values at STP, would be investigated. The lowest value of critical mobility of the condenser was designed to be 0.72×10^{-4} in MKS unis by applying 33.2 volt to it and this was to secure the ion density measurement assuming a conservation of the mobility spectrum on the ground at all altitude. However, the voltage tended to produce a stray electric field at the intake front of the condenser, and the ions will become considerably to be trapped by the field as the condenser goes up to the balloon altitude. The trend will be much enhanced, if the spectrum would broaden twards the high mobility region of it. Other possibilities of interpreting the disagreement of the ion density profiles between observation and calculation based on a small ion theory seems to be the influence on small ion density of aerosols existing in the upper atmosphere, and the contribution of photochemical effect of ozone to it.

A possible influence of the upper atmospheric aerosols on the ion density profile up to 30 km was suggested by Morita and Ishikawa (1969) using equations of ion-ionization equilibrium in aerosol contaminated atmosphere. The results of the computation indicated that the ion density in the aerosol contaminated stratosphere deviated only about 8 percent from aerosol free atmosphere so long as we would assume the aerosol content observed by Junge et al. (1961). It is possible to compute the aerosol number density assuming the observed ion density. We estimated the possible size and number density of aerosols which are sufficient exclusively to interpret the discrepency between obsevation and small ion theory. We reached a conclusion that number density of 9 per cm^3 of one-micron size aerosol or 0.5 per cm^3 of ten-micron size aerosol are necessary at 25 km altitude to account for it. Concerning the upper atmospheric dust, Whipple (1964) pointed out that a dust density of about one per cm^3 of one-micron particle is necessary to account for the observed decrease in ion density above 30 km altitude. So far the informations are very much limited of the large particles found in the stratosphere. A reliable measurement of the upper atmospheric large particles are very necessary to see their influence on the ion-ionization equilibrium.

The possible photochemical effect of ozone in the stratosphere may be reduced to the estimation of the effective coefficients of ion-ion and ion-elecron recombination. For the altitude below about 35 km Thomson three body reaction is the most important and this is closely related with atmospheric ozone distributing in the stratosphere. Therefore the effect will be discussed to see the importance of role the two effects in the stratosphere in the near future.

4. Conclusions

The small ion densily profiles in balloon altitude have been compared between the two countories, Japan and Australia. But we could not find any essential difference existing between the two. The possibility of existence of the large particles in the stratosphere was suggested as a way of accounting for the discrepency between the observed and calculated ion density profiles. However, the photochemical effect of atmospheric ozone in the stratosphere seems to be very important too, and will be studied in the future.

5. Acknowledgements

We wish to express our sincere thanks to Prof. M. Kawano and his group Nagoya University who made co-operative balloon observation ionization the same date as that of ion density. Our thanks are due to Prof. Nishimura and his staffs from Research Institute of Space and Aeronautical Science, University of Tokyo, who gave us the opportunity of carrying out the present balloon experiment.

References

Cole, R. K. and E. T. Pierce : Electrification in the Earth's Atmosphere for Altitudes between O and 100 km, J. Geophys. Research, **70**, 2735-2749 (1965)

Hoppel, W. A. and J. H. Kraakevik : The Mobility of Tropospheric Ions above the Exchange Layer, J. Atmos. Sci., **22**, 509-517 (1965)

Ishikawa, H., T. Takeuti, A. Iwata and Y. Morita : Preliminary Experiment of Atmospheric Ion Measurement in the Transitional Region of the Atmosphere, Proc. Res. Inst. Atmospherics, Nagoya Univ., **15**, 29-41 (1968)

Junge, C. E. : Vertical Profiles of Condensation Nuclei in the stratosphere, J. Atmos. Sci., **18**, 501-509 (1961)

Misaki, M. : Determination of Air Flow in an Ion Chamber, Meteorology and Geophysics, 11, 348-355 (1960)

Misaki, M. : Studies on the Atmospheric Ion Spectrum (II), Pap. Met. & Geophys., **12**, 261-276 (1960)

Morita, Y. and H. Ishikawa : Influence of the Atmospheric Aerosols on the Ion Density Profile up to 30 km Altitude, this volume.

Paltridge, G. W. : Experimental Measurements of the Small Ion Density and Electrical Conductivity of the Stratosphere, J Geophys. Research, **70**, 2751-2761 (1965)

Sagalyn, R. C., H. O. Curtis and C. Stergis : Atmospheric Electricity, Handbook of Geophysics, Macmillan, New York, chaper 9, 1-4 (1960)

Uchikawa, K. : Atmospheric Electric Phenomena in the Upper Air over Japan (Ⅱ), Geophys. Mag., 30, 643-672 (1961)

Whipple, E. C. : Electricity in the Terrestrial Atmophere above the Exchange Layer, Problems of Atmospheric and Space Electricity, Elsevier Pub. Co., 123-139 (1965)