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Payload B III – an Instrument Package for the Measurement of Conductivity, Concentration and Mobility of Positive and Negative Ions in the Mesosphere

H.U. Widdel, G. Rose, R. Borchers

Max-Planck-Institut für Aeronomie, D-3411 Katlenburg-Lindau 3, Federal Republic of Germany

Abstract. Payload BIII was a rocket-borne parachuted, self-tracking Gerdien-type aspiration analyzer designed for the measurement of concentration and mobility of positive and negative ions, electron concentration and polar conductivity in the height range below 80–85 km.

The goal of this instrument was to gather information about the height distribution of charged particles, especially negative and positive ions, their relative size and their seasonal variation in this range.

The instrument is described and results are communicated. The steep increase of conductivity found during the winter season above 43 km was caused by an increase of number density of charged particles and not by a change of carrier mobility. Following model calculations made by Mohnen (1971) the most abundant positive carriers have a particle radius of $3.5–4.10^{-10}$ m. This value corresponds to the size expected for small cluster ions. Below 40 km, little variation of conductivity with season was found. It did not exceed a factor of two in certain height levels. One observation made in summer suggests that an increase of conductivity (also caused by an increase of number density of ions) can occur occasionally also during the summer season.

Key words: Rocket experiments – Gerdien condenser – Lower D-region – Mobility – Seasonal changes.

The role of large particles in the stratosphere, mesosphere and D-region has been discussed in the literature from time to time in an attempt to explain certain peculiarities of atmospheric behaviour observed either by ground-based facilities or by space-borne experiments (e.g. Reid, 1967, 1971; Farlow and Ferry, 1972; Ferry and Farlow, 1972; Rauser and Fechtig, 1972; Roessler, 1972, 1974; Fiocco and Visconti, 1973; Witt, 1974; Hughes, 1974; Fiocco, Grams and Visconti, 1975). Such particles affect heat balance, infrared radiation loss and atmospheric composition and can be, directly or indirectly, source of additional ionization too. There is no doubt that such large particles exist and that their presence is subject to seasonal changes as is proven by the existence of noctilucent clouds. Their measurement, however, is difficult. A first approach to get information about such particles is the measurement of the concentration and the mobility of charged species of both signs. An instrument package for this purpose was developed and flown in certain numbers.

The Instrument Package

1.1. The Gerdien-Probe

A suitable tool to measure mobilities and concentration of charged particles is a cylindric condenser through which an airstream is drawn. When a time-variable voltage is applied to the electrodes, the charged particles inside the airstream are forced to move perpendicular to the direction of the axial air flow and cause a current. When the voltage is high enough the probe current saturates on a certain level which is proportional to concentration and flow velocity. From the shape of the current-voltage characteristics and from the saturation current, mobilities, polar conductivities and concentrations can be derived provided the flow velocity through the condenser is known. This kind of instrument was first proposed by H. Gerdien in 1905 and has since then found a wide application in the field of atmospheric electricity.

A first practical attempt to use Gerdien condensers for ionospheric D-region research was made by A. Pedersen (1966). Our own development of a Gerdien-type aspiration analyzer started in 1963 and was flown for the first time in 1968 (Widdel, Rose, Borchers, 1971) after being thoroughly tested in the laboratory under equivalent environmental conditions (Borchers, 1971). A cross section of the instrument is shown in Figure 1. A double-guard ring arrangement was used which helps to solve the problem of confining the front and back end stray field of the cylindrical condenser. Further, it allows to define a reliable reference potential. The Gerdien-analyzer was therefore double-walled. The outer shell was used as the reference for the driving potential and for the probe current measurements. The inner conductor was connected to reference ground through the current measuring device and to a guard ring at the front of the analyzer. The latter confined the front end stray field of the capacitor to the interior of the analyzer in order to prevent mobility discrimination outside of the instrument. A small stray field however was left in order to prevent electrons from entering the analyzer and to guide them to the outside reference shell where their contribution to probe current is then not measured. Ions are not affected by this stray field because their mobility is very much lower than the mobilities of electrons.

When different ion mobilities are present, a serious "grounding" problem exists because not all ions are intercepted inside the analyzer by the time-variable probe voltage during the analyzing process. As the result of this imbalance in charge collection, the probe assumes a charge against the environment which distorts the charge distribution of the environment and disturbs the condition

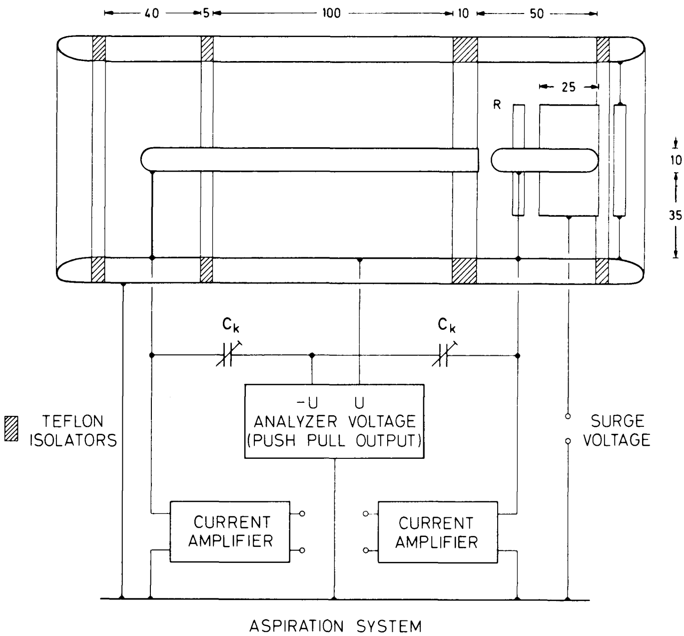

Fig. 1. Semi-quantitative cross section through the Gerdien aspiration instrument. Dimensions are given in millimetres. The capacitors C_k are compensation capacitors for the displacement current generated by the probe sweep. They are adjusted to yield zero output of the current meters when no ionization current is present

of quasi-neutrality. This problem is avoided when a second Gerdien section is used which follows the analyzer. Its electrodes are kept to a constant potential high enough to intercept all charged particles which otherwise might leave the analyzer section. This section is called the "neutralizer". The probe current of the "neutralizer" is inverse to that of the analyzer and can be used to check the proper function of the instrument.

In order to keep the length of the instrument as short as possible, the neutralizer is folded. Guard rings confine the stray field of the neutralizer potential.

The analyzer voltage is of triangular waveform. Its amplitude is matched to the different height regions in which measurements are taken. It varies from 5 Volt applied for 80 s after deployment of the probe at apogee, then it is changed to 15 Volt from flight second 80 to 160, switched to 30 Volt from second 160 to 240 and then to 60 Volt for the rest of the flight.

1.2. The Flow Meter

The accuracy of the Gerdien measurements depends upon the accuracy which can be attained for the measurement of air flow through the Gerdien system.

It can be assumed that the flow through the tube is the same as the flow in the environment for most parts of the probe trajectory. By this, radar tracking data could in principle be used to determine the flow velocity, but, because one cannot exclude the possibility that the probe is not properly orientated along its descend path and that the actual flow velocity through the Gerdien is then different from the ambient flow, it was decided to supplement the Gerdien analyzer by a second separate system. This flow meter was nearly identical in its mechanical details but operated in a different mode to obtain the flow by modulating the plasma inside the Gerdien tube with square waves of different frequencies and measuring the output in the neutralizer section (Rose and Widdel, 1967). Laboratory measurements made under conditions equivalent to actual flight conditions yielded a fairly good accuracy of the flow measurement (5% was achieved).

1.3. The Radio Altimeter System

The radar tracking of probes which are ejected from rockets during flight poses a lot of problems which are worst during the initial phase of ejection when the two targets are not separated by a distance large enough to allow discrimination. Cases are not too rare in which the wrong target was picked up by the radar for tracking and the right object was lost because it is almost impossible for conventional narrow-beam radars to pick up again the wanted object. The situation becomes aggravated when the tracked target splits up into more than two objects during a separation or expulsion process. Finding the right target in the multitude of objects may become very difficult and needs considerable experience. This problem does not exist when the payload is equipped with a self-tracking device which supplies trajectory data and operates independently from any radar track. Such a device was developed (Widdel, 1964; Rose, Widdel, 1971) and was used to advantage in the payloads. It allows automatic and continuous tracking of the payload on command from a ground station. Its working principle is displayed in Figure 2.

1.3.1. Working Principle

A short (10 μsec.) pulse is emitted from a ground station on VHF frequencies and is received in the payload. The payload receiver is set to a fairly low sensitivity in order to minimize response to foreign emissions and to electrostatic discharges which are often observed to be generated in large cumulus clouds. The received pulse is re-emitted from the probe on the same frequency. After the emission of the pulse, the receiver in the probe is set to a higher sensitivity which increases linearly with time and waits for the direct return pulse from the ground. Because the return pulse is (to a very good approximation) a true reflexion from the ground and not a radar scatter signal, very low transmitter power is sufficient to achieve a useful signal—to noise—ratio (100 milliwatts suffice when no external noise sources are present). The ground return pulse

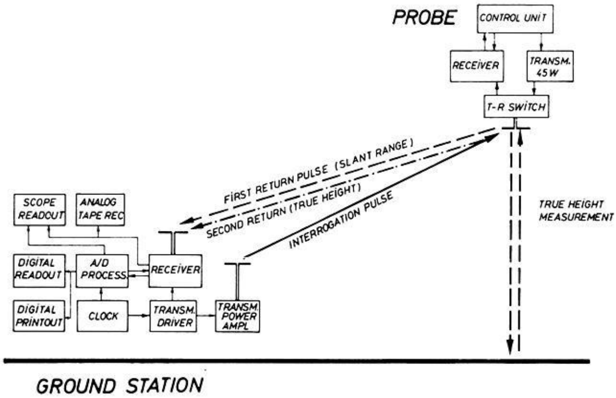

Fig. 2. Working principle of the radio altimeter

is re-transmitted and the receiver is then set to a very low sensitivity in order to suppress multiple response to ground echoes.

1.3.2. Data Evaluation and Display

When the interrogation pulse is emitted from the ground station, a counting device is started. It is stopped by the first return pulse (which corresponds to slant range to the probe) and is started again at its end. At the first stop, the slant range is edited and stored. The second stop of the counting device is provided by the second response pulse from the probe which corresponds to true height. If no second pulse is received, the counting is stopped at a preset time and a fixed value is edited. In the counting process, corrections for receiver and transmitter phase lag are added to achieve true values for slant range and true height above ground.

The results of the measurements are printed out on paper together with real time, flight time and a code which describes the operation mode. These data are also stored on magnetic tape and displayed both on digital readouts and on an oscilloscope. All ground equipment is housed in a small rack which is easily transportable. Simple dipole antennas are sufficient for operation. This radiolocation unit proved to be very useful especially in cases when no radar tracking of the probe was available. It is especially helpful for tracking objects from moving bases (for example, from a ship) which do not allow the installation of elaborate radar or other tracking systems. An example for an actual tracking of a small probe is given in Figure 3.

1.4. The Pressure Probe

Because mobility is a function of pressure, the payload package was supplemented by a Pirani—type pressure gauge which was developed by modification of an available commercial unit.

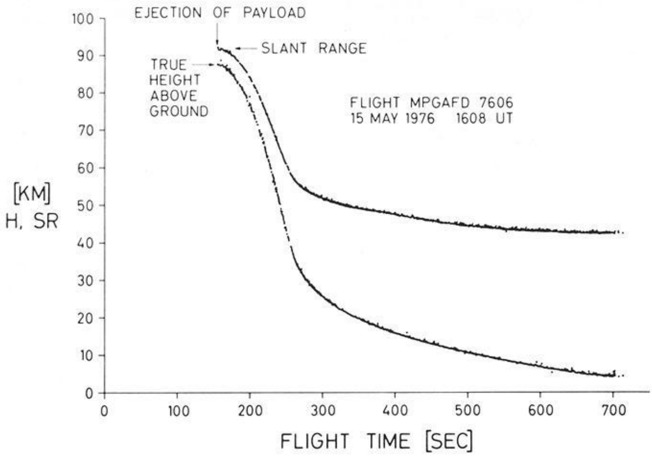

Fig. 3. Example for a probe tracking with the altimeter system. Actual plot of data

2. Probe Arrangement and Deployment

All instruments were designed into a parachuted package which contained the batteries, telemetry systems (IRIG FM/FM) and antennas. The two cylindrical probes (Gerdien condenser and flow meter) were mounted on spring-loaded latching pivots which folded out when the probe was ejected. The probe was mounted in a tube which was fixed to the package plate between the two cylindrical probes.

A conical parachute with very long shroud lines was used to limit the descend velocity and to stabilize the probe. An inflatable torus was provided to open the parachute. The probe was deployed near apogeee of the rocket's trajectory backwards into the opposite direction of flight. This is advantageous to the conventional way of ejection in which the probe is thrown out into the forward direction because probe and parachute are put into flight position from the very beginning. Some amount of compensation of the trajectory speed is achieved also in the "backwards" mode. A modified "Petrel I" rocket carried the payload to an apogee of not more than 85 km. To achieve this, the payload was made quite heavy (34.5 kg) and drag buttons (5 mm long) were attached to each of the six fins of the "Petrel" to reduce performance.

To assure stable flight of the deployed probe, de-spinning of the rocket before ejection is mandatory. If this is not done, the probe shall produce precession movements which may render data evaluation of the Gerdien probe almost impossible. Also, the motor has to be jettisoned from the payload as early as possible in order to provide a good separation between payload and burnt-out motor. This is necessary to avoid collision between payload and motor and to minimize the possibility of contamination of the measurements which might occur when the probe crosses the cloud of combustion products of the outgassing motor. The sequence of motor separation and payload deployment is shown in Figure 4.

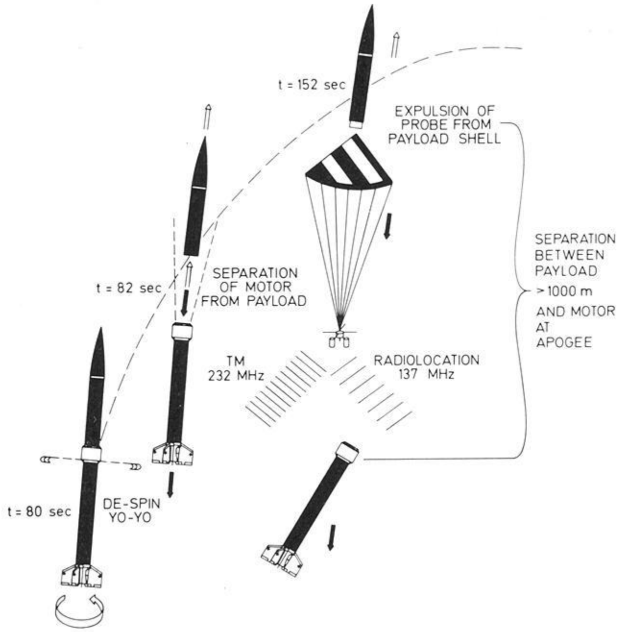

Fig. 4. Payload separation sequence: At flight second 80, the rocket is de-spun by a yoyo-device. Two seconds later, payload and motor are separated by release of compressed nitrogen. Near apogee, the payload and parachute are thrown out the of the payload with a piston driven by compressed nitrogen (the piston serves as the gas reservoir). The piston jams into a conical taper serving as a brake shoe. The parachute is opened by a toroidal inflation aid. As soon as the probe leaves the payload shell it is activated and starts to work

3. Results

Some results which we obtained during the flights are shown in Figures 5 to 7. We found a rather good agreement of the mobility measurements for the most abundant species of positive ions on different flights (see Fig. 5). There seems to be no dramatic change for this ion species. Our mobility measurements agreed also well with those communicated by Conley (1972, 1974). He flew his Gerdien system on a supersonic rocket. As expected, we found that the ledge of conductivity increase is in lower heights during winter than in summer (see Figs. 6 and 7). We can also say that this increase in conductivity is not primarily caused by a change in the mobilities of ions but by a significant increase in the number densities of carriers (Fig. 8). Below 40 km there is not much difference in conductivity between summer and winter conditions. Above 40 km however, it looks as if the summer atmosphere can occasionally turn into a state similar to that found in winter (Widdel, Rose, Borchers, 1976). The reason for this effect is not known yet. Extrapolating mobility calculations made by Mohnen (1971), we found that the particle radius of the positively charged carriers was $3.5–4.10^{-10}$ m which is approximately the size to be expected for small cluster ions. Good agreement was found with earlier data.

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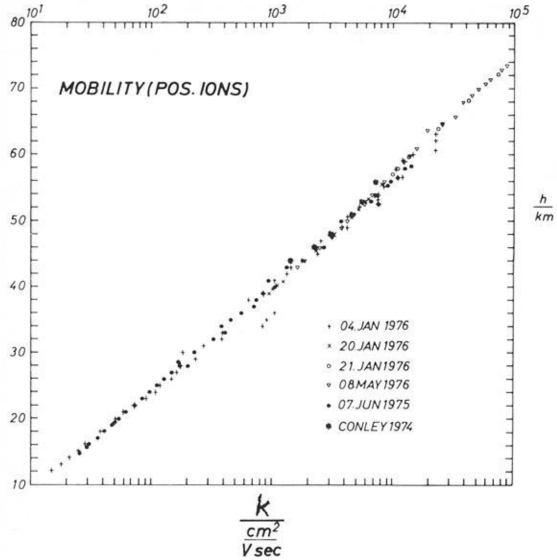

Fig. 5. Results of mobility measurements (positive ions). Below about 50 km, differences in mobility of positive and negative ions cannot be resolved by the instrument. Therefore, the mobilities shown for this height region correspond to negative ions as well. The mobility corresponds to small molecular ions

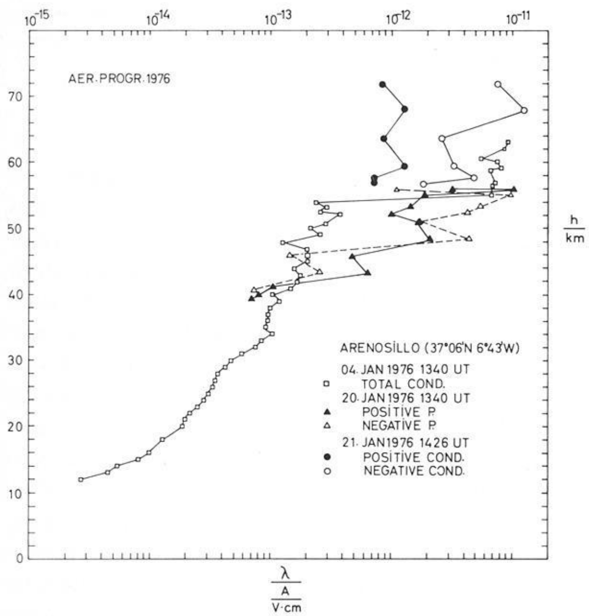

Fig. 6. Height variation of conductivity measured under winter conditions

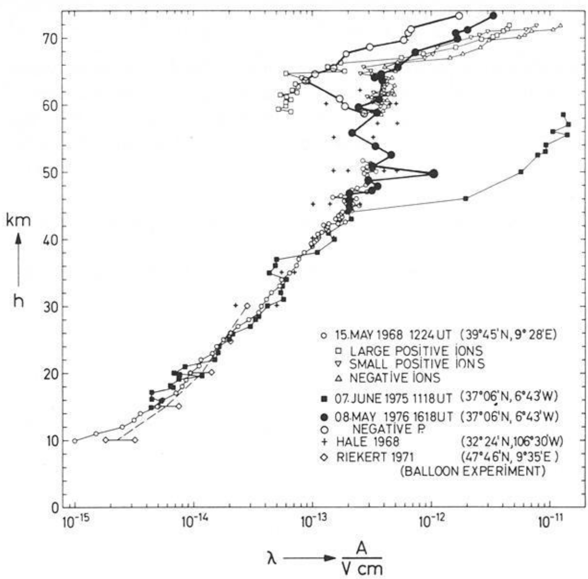

Fig. 7. Height variation of conductivity measured under summer conditions. The cause for the low-level ledge in conductivity observed on 7, June, 1975, is unknown

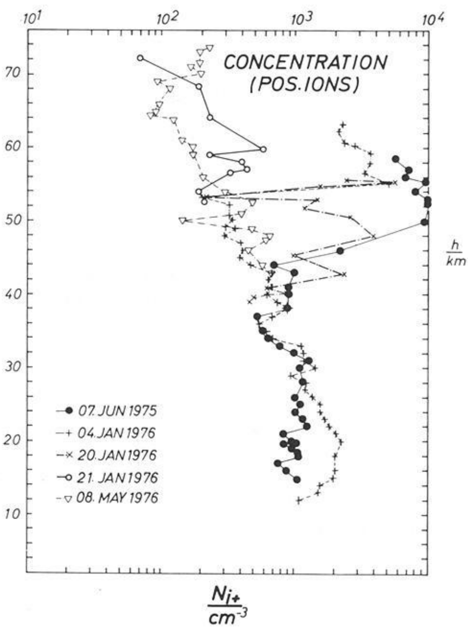

Fig. 8. Height profile of ion concentration

References

Borchers, R.: Untersuchungen der Eigenschaften einer Aspirationssonde (Gerdien-Kondensator) zur Bestimmung der Konzentration und Beweglichkeiten von Ladungsträgern beiderlei Vorzeichens im Höhenbereich zwischen 80 und 40 km. Forschungsbericht BMBW-FB W71-39, 1971

Conley, T.D.: Positive ion concentrations in the lower D-region during the November 1969 solar particle event measured by a rocket-borne Gerdien chamber. Spec. Rep. 144, Air Force Cambridge Res. Lab. Beford, Mass, 1972

Conley, T.D.: Mesospheric positive ion concentrations, mobilities, and loss rates obtained from rocket-borne Gerdien condenser measurements. Radio Sci. **9**, (6) 575–595, 1974

Farlow, N.H., Ferry, G.V.: Cosmic dust in the mesosphere. In: Space Res. XII, 369–380. Berlin: Adademie-Verlag 1972

Ferry, G.V., Farlow, N.H.: Upper atmospheric dust concentrations in polar regions. In: Space Res. XII, pp. 381–390, 1972

Fiocco, G., Visconti, G.: On the seasonal variation of upper atmospheric sodium. J. Atmospheric Terrest. Phys. **35**, 165–171, 1973

Fiocco, G., Grams, G., Visconti,, G.: Equilibrium temperatures of small particles in the earth's upper atmosphere (50–110 km). J. Atmospheric Terrest. Phys. **37**, 1327–1337, 1975

Hughes, D.W.: Cosmic dust influx to the upper atmosphere during the major meteor showers. In: Space Res. XIX, pp. 709–713 Berlin: Akademie-Verlag 1974

Mohnen, V.: The formation of major positive and negative ions up to the 50 km level. In: Mesospheric models and related experiments, G. Fiocco ed., pp. 210–218. Dordrecht: D. Reidel Publ. 1971

Pedersen, A.: Measurements of ion concentration in the D-region of the ionosphere. Uppsala Ionosfaerobserv. Rep. 15, pp. 9–32, Uppsala/Schweden, 1966

Rauser, P., Fechtig, H.: Combined dust collection and detection experiment during a noctilucent cloud display above Kiruna, Sweden. In: Space Res. XII, pp. 391–402 Berlin: Akademie-Verlag 1972

Reid, G.C.: Ionospheric implications of minor constituents. In: Space Res. VII. pp. 197–210. Amsterdam: North Holland 1967

Reid, G.C.: The roles of water vapor and nitric oxide in determining electron densities in the D-region. In: Mesospheric models and related experiments, G. Fiocco, ed., p. 198–209. Holland: D. Reidel Publ. Comp. Dordrecht 1971

Roessler, F.: Aerosol layers in the atmosphere. In: Space Res. XII, pp. 423–431. Berlin: Akademie-Verlag 1972

Roessler, F.: Optical measurements on noctilucent clouds by rockets. In: Space Res. XIV. pp. 695–699. Berlin: Akademie-Verlag 1974

Rose, G., Widdel, H.U.: Ein Meßgerät zur Bestimmung der Strömungsgeschwindigkeit in kurzen Rohren (Ionenzählern) bei niedrigem Gasdruck. Mitteilungen aus dem Max-Planck-Institut für Aeronomie, Nr. 30. Berlin-Heidelberg-New York: Springer 1967

Rose, G., Widdel, H.U.: An Altimeter/Telemetry System for small sounding rockets. J. Brit. Inerplan. Soc. **24**, 209–213, 1971

Widdel, H.U., Rose, G., Borchers, R.: Results of concentration and mobility measurements of positively and negatively charged particles taken by a rocket-borne parachuted aspiration (Gerdien) probe in the height region from 72 to 39 km. Pure Appl. Geophys. **84**, 154–160, 1971

Widdel, H.U., Rose, G., Borchers, R.: Experimental results on the variation of electric conductivity and ion mobility in the mesosphere. J. Geophys. Res. **81**, 6217–6220, 1976

Widdel, H.U.: Suggestion for an active rocket-borne radio altimeter system for sounding probes. Internal Rep. Max-Planck-Institut für Aeronomie, Lindau/Harz, 1964

Witt, G.: Solid particles at the mesopause. In: Space Res. XIV, p. 691. Berlin: Akademie-Verlag 1974

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