I N S T I T U T D ' A E R O N O M I E S P A T I A L E D E B E L G I Q U E

3 - Avenue Circulaire
B - 1180 BRUXELLES

# AERONOMICA ACTA

C - N° 39 - 1974

## A balloon borne mass spectrometer for the measurement of ion densities in the lower ionosphere

by

E. ARIJS, J. INGELS and D. NEVEJANS

B E L G I S C H I N S T I T U U T V O O R R U I M T E - A E R O N O M I E

3 - Ringlaan
B - 1180 BRUSSEL

## FOREWORD

The present work contains more details about a method for the analysis of the ion composition of the stratosphere. An introductory description of this method was already given in the Aeronomica Acta C - N° 24 - 1969.

## AVANT-PROPOS

Dans le présent travail nous donnons les détails techniques d'une méthode d'analyse de la composition ionique de la stratosphère. Un avant-projet de cette méthode était déjà décrite dans l'Aeronomica Acta C - n° 24 - 1969.

## VOORWOORD

In dit werk geven we meer technische bijzonderheden over een metode om de ionaire samenstelling van de stratosfeer te bepalen. Een ontwerp van deze metode werd reeds voorgesteld in de Aeronomica Acta C - nr. 24 - 1969.

## VORWORT

In dieser Arbeit wird eine Messmethode für die Analyse der Ionen-komposition der Stratosphäre , umständlich beschrieben. Diese Methode wird schon in dem Aeronomica Acta C - Nr. 24 - 1969, kurz auseinandergesetzt.

# A BALLOON BORNE MASS SPECTROMETER FOR THE MEASUREMENT OF ION DENSITIES IN THE LOWER IONOSPHERE

by

E. ARIJS, J. INGELS and D. NEVEJANS

## Abstract

A system combining a quadrupole massspectrometer with a helium cooled cryopump has been developped for the measurement of the ion composition above 35 km altitude. The technical characteristiecs of the instrument are discussed.

## Résumé

Un système comprenant, un spectromètre de masse quadrupolaire combiné à une pompe cryogénique à l'hélium liquide, a été développé afin d'analyser la composition ionique de l'atmosphère au dessus de 35 km. Les caractéristiques techniques de l'instrumentation sont discutées.

Samenvatting

Een meetapparatuur waarin een quadrupolaire massaspektrometer gekombineerd is met een helium gekoelde kryopomp, werd ontwikkeld om de samenstelling van de atmosfeer boven 35 km te bepalen. De technische bijzonderheden van het apparaat worden uitvoerig beschreven.

Zusammenfassung

Ein System wobei ein quadrupoläre Massenspektrometer kombiniert ist mit einer flüssigen Helium Kryopumpe wird entwikkelt, für Messungen der Ionendichte über 35 km Höhe. Die technische Gegebens dieser Apparatur werden diskutiert.

## 1. INTRODUCTION

Positive and negative ion composition of the upper atmosphere has been the subject of many experimental investigations. Early measurements using radio-frequency mass spectrometers carried by rockets and satellites, have been primarily concerned with ion compositions at altitudes between 100 and 250 km (1-5). Very few experimental data however are available on the charged particle composition of the stratosphere. Global ion densities have been measured using blunt probe techniques by Hale and his group (7-9), Pederson and coworkers (10-11) and Bragin (12-13). So far identification of ion species in the stratosphere has only been realised very recently by Krankowky and Arnold (14), who obtained ion spectra between 55 and 35 km on the downleg portion of a rocket flight from Andoya.

One of the disadvantages of rocket borne experiments is the formation of the shock wave, which alters the charged particle concentration as well as its composition. This can be avoided by the use of stratospherical balloons. Therefore a balloon borne mass spectrometer, for the measurement of the positive ion composition between 35 and 40 km altitude, has been designed at our institute. The underlying principles of this experiment have already been published (15). A more detailed description of this arrangement will be given in the following sections.

## 2. GENERAL EXPERIMENTAL ARRANGEMENT

Figure 1 shows a cross section of the balloon gondola, which consists of two different sections. The first one is a light weight aluminium vessel (A1), which is pressurized and contains the electronics (B1). The second section is evacuated by a cryopump (C1) and contains the ion lens (D1), the quadrupole mass filter (E1) and the electron multiplier (F1). On the upper flange of the cryopump a perforated platinum membrane (G1) is mounted, through which the ions can effuse into the apparatus, where they are focussed by the ion lens into the mass filter. If their m/e

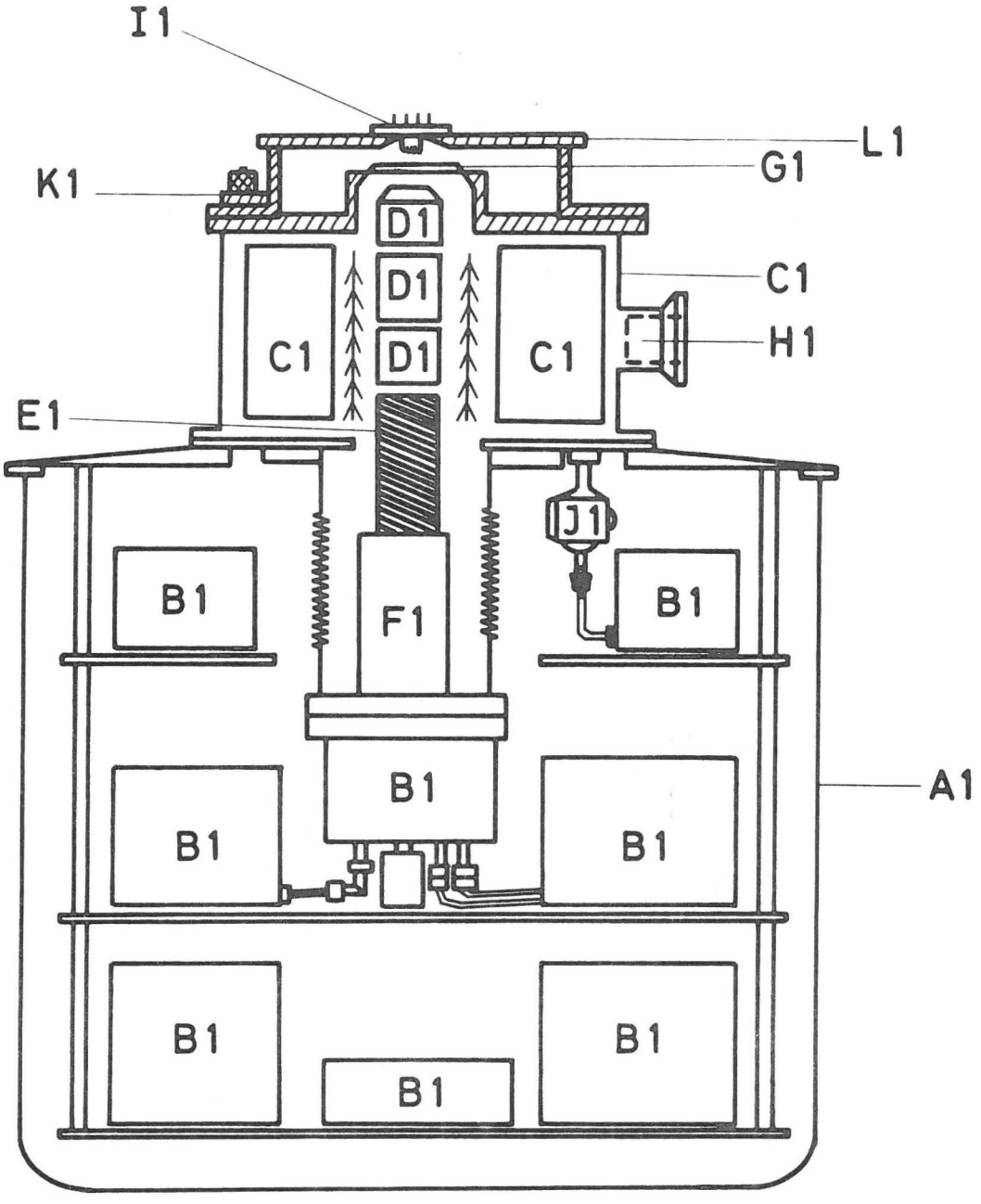



Fig. 1.-

ratio lies in the mass domain, passed by the quadrupole, they reach the electron multiplier. Each ion then gives rise to a pulse which after preamplification is stored in the pulse counter, the content of which is, after the appropriate measuring time, transmitted by the telemetry. A discriminator between the pulse amplifier and counter rejects the low pulses arising from noise.

On top of the system a protective aluminum cap (L1) is mounted, which can be ejected by means of a pyrotechnical system, as soon as the vehicle reaches the desired altitude. A small ion source (I1) is built in the protective cap, which allows a final testing before launching.

The instrument is initially evacuated by a separate pumping unit on the ground. When a pressure of $10^{-6}$ Torr is reached the cryopump is filled with liquid helium and a small auxilliary ion pump (J1) is started. This ion pump is a commercially available 2 l/sec pump (Leybold IZ 2) and apart from pumping helium and hydrogen, which are not adsorbed on the cryopump, it also features as a vacuum gauge during flight. The separate pumping unit is then disconnected and the instrument is sealed off by a valve (H1). The system is now ready to be launched.

Apart from the ion counting rate in different mass domains, several parameters are measured and transmitted by telemetry during the flight. These control parameters are atmospheric pressure, pressure in the electronics compartment, the vacuum and temperature in the cryopump.

In a first experiment the ion counting rate will be measured in four mass domains (5-30 amu, 30-55 amu, 55-80 amu, 80-105 amu). A more detailed description of the different parts of the apparatus will now be given.

## 3. THE CRYOPUMP

The cryopump (type K-5064/1969) used in the experiment, was designed and manufactured by Leybold-Hereaus GmbH & Co-KG (fig. 2). Certain specifications in constructing the top and bottom flanges were followed, to allow an easy mounting of the molecular leak (A2) and its protective cap and an easy fixing of the pump unit on the balloon gondola (B2).

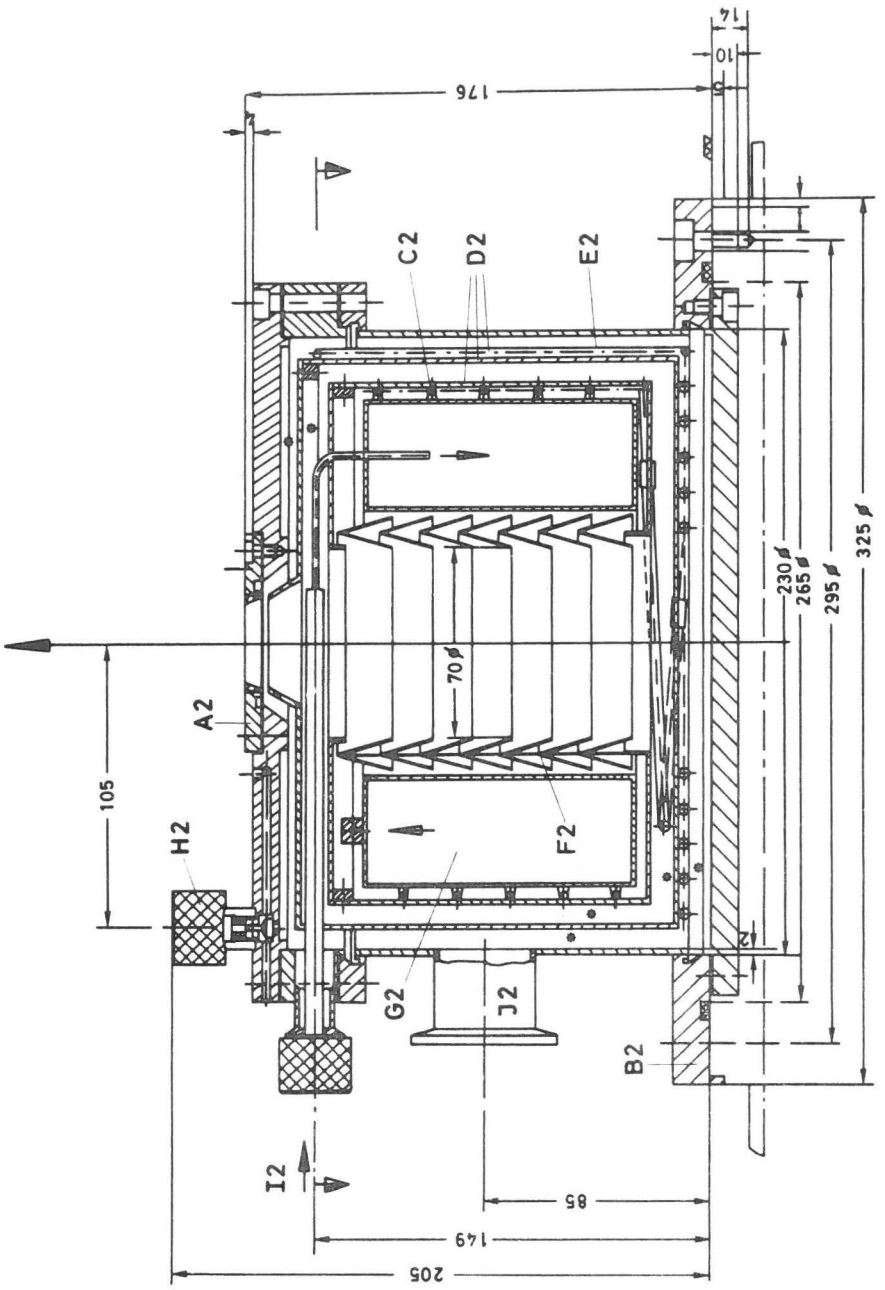
The cryopump is a super-insulated one, shielded by leading the cold helium exhaust gas through a cooling spiral (C2) attached to the radiation shields (D2), and by wrapping the whole pump body in several layers of aluminumized insulating foil (E2). The inner radiation shield (F2) separates the ion lens and the head of the quadrupole from the liquid helium reservoir (G2). The protective cap cavity of the molecular leak can be evacuated through a by-pass valve (H2).

The content of the liquid helium reservoir is about 1,5 l and its surface temperature can be measured by a carbon resistor attached to the bottom, the resistance of which changes from R = 110Ω at 300°K, to R = 140Ω at 77°K and R = 1100Ω at 4,2°K.

The cryopump is evacuated by a rotary and diffusion pump unit from 760 down to $6.10^{-6}$ Torr in about 48 hours. The pressure decreases to about $5.10^{-7}$ and $5.10^{-8}$ Torr, when the cryopump is cooled down with liquid nitrogen and liquid helium, respectively.

The cooling down to 77°K takes between 2 1/2 and 3 1/2 hours, and about 2,5 l of liquid nitrogen is used. The liquid nitrogen transfer system is connected to the normal helium gas exhaust, to obtain a good pre-cooling of the exhaust spiral, and the evaporated nitrogen gas escapes through a by-pass exhaust in the level sensor connection.

The cooling down to liquid helium temperature takes about 1 hour, and 1,5 to 2 l of liquid helium is used. The liquid helium transfer system




CRYOGENIC PUMP (3000 l. sec$^{-1}$)

Fig. 2.-

is connected to the normal liquid helium filling inlet (12), the by-pass in the level sensor connection is closed and the helium exhaust gas is evacuated through the exhaust spiral with a Leybold S 12-helium tight rotary pump. During transferring, the liquid helium level is controlled by a carbon resistor level sensor introduced through a separate connection into the liquid reservoir.

After transferring, the level sensor is removed to reduce heat inflow and the liquid helium reservoir is sealed-off (J2) by an overflow valve with an adjustable actuating pressure, keeping the liquid helium under a slight overpressure during the experimental flight. The normal liquid helium evaporation rate is about 125 l/hour helium gas (or 0,18 l/hour liquid helium), giving an effective operation period of 8 to 9 hours. The effective pumping speed was experimentally measured to be about 350 l/hour. The complete evaporation of all liquid helium is indicated by a drop in resistance of the carbon resistor, fixed to the liquid helium reservoir bottom.

## 4. MOLECULAR LEAK FOR ION SAMPLING

The problem to be solved here is : sampling ions from a relatively high pressure region (a few Torr) into a vacuum, without introducing too much gas in the mass spectrometer part, in order to maintain a vacuum of approximately $10^{-5}$ Torr in this region. Therefore a molecular leak has been constructed by glueing a circular platinum sheet, with a diameter of 25 mm and a thickness of 12 µm on a stainless steel flange. In the central part of this sheet, 800 holes with an average diameter of 12 µm have been bored at Siemens-München, with a ruby laser SHL5-10 with a working energy of 2,6 watt. The quadrangular perforated area is approximately $9 mm^2$.

The conductance of such a molecular leak for neutral gas is of the order of 5 $cm^3$ $sec^{-1}$ and has already been measured by Aillet et al. (16). The flow rate or ions however is much smaller and has been calculated assuming that Maxwell-Boltzmann statistics can be applied to the ion energy distribution. The results of these calculations (17) are summarised by :

$$N = \frac{1}{4} n \langle u \rangle S \frac{\sqrt{1 + v^2} - v}{\sqrt{1 + v^2} + v}$$

where N represents the number of ions flowing through the leak per second, n the plasma density, $\langle u \rangle$ the mean velocity of the ions, S the total surface area of the holes and v the ratio height/radius of the holes.

The ion sampling leak can withstand an overpressure of 20 Torr maximum and is therefore only exposed to the atmosphere when the gondola has reached its working altitude of about 37 km. During the mounting time period of the balloon it is covered by the protective cap.

## 5. THE ION FOCUSSING SYSTEM

After passing through the sampling orifice the ions must be focussed into the quadrupole mass filter. It has been assumed that the incoming ions have thermal energy. Therefore a bias potential $U_o$ must be applied to the quadrupole rods, as well as the adequate D.C. and R.F. mass selection voltages. For this bias potential $U_o$, which features as an ion injection energy, a value of 15 V has been chosen.

The stainless steel ion lens has been constructed in such a way, that the open ioniser as well as the ion optics of the mass filter, delivered by the quadrupole manufacturer are preserved. This enables us to test the spectrometer and the ion detector before the flight.

The complete ion focussing system and the applied potentials are schematically shown in figure 3.

The focussing potentials have been determined experimentally. For this purpose an electron bombardment ion source with planar geometry has been placed in front of the ion sampling holes. The ion repeller plate of

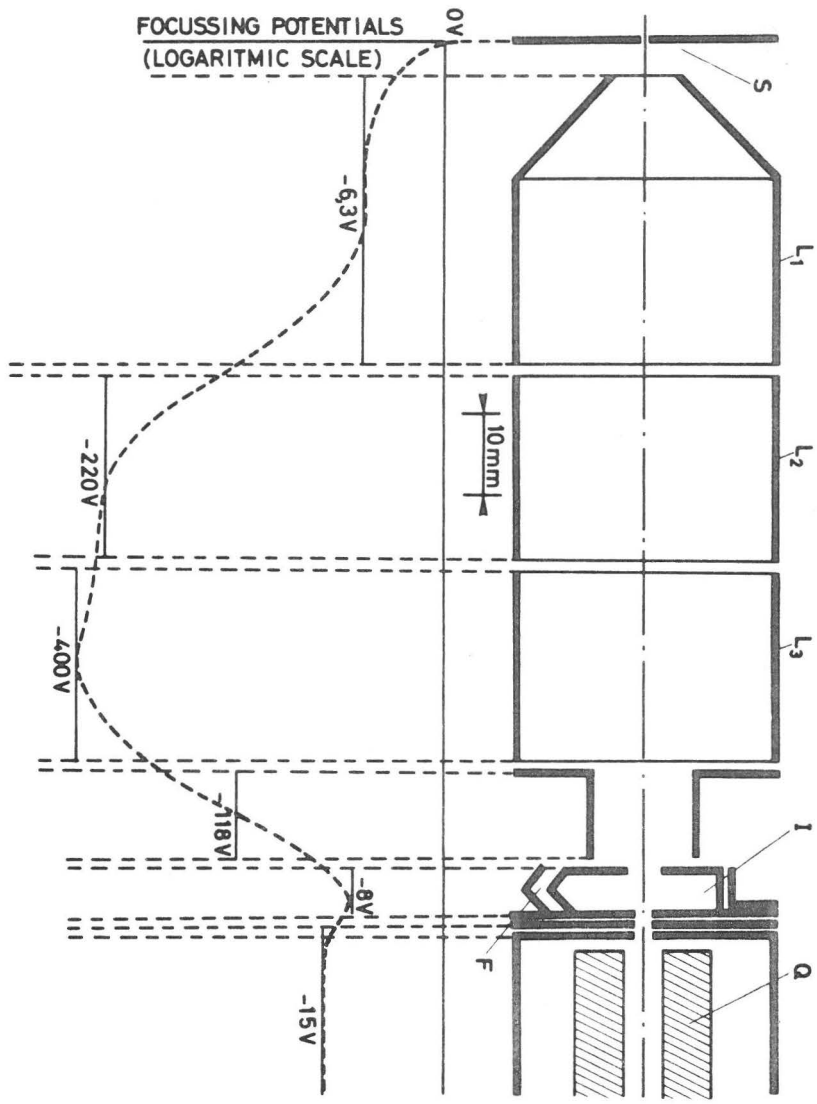

FOCUSSING POTENTIALS
(LOGARITMIC SCALE)
0V
-6,3V
-220V
-400V
-118V
-8V
-15V
10mm
S
L1
L2
L3
I
F
Q

Fig. 3.-

this source, which was mounted in vacuum ($10^{-5}$ Torr) together with the ion lens, the mass filter and the electron multiplier, was grounded in order to obtain ions with an energy close to thermal energy.

Analogous experiments have been performed with a gas discharge as an ion source. The focussing potentials obtained in this way are slightly different, due to the higher energy of the ions*.

## 6. THE QUADRUPOLE MASS FILTER

For the mass filtering of the emerging ions a quadrupole spectrometer has been chosen for several reasons. First of all the quadrupole is a light weight instrument, the cylindrical geometry of which is most suited for our experimental set up. As an ion filtering device it accepts ions with a relatively large distribution of energy and wide entrance angles. Furthermore it is capable of working at pressures as high as $10^{-4}$ Torr.

One of its major advantages however, which is very important in our case, is the electrically adjustable resolution, which makes it possible to use the quadrupole as a mass filter with band pass characteristics. As has been shown by Paul, Reinhard and von Zahn (18) the equations of motion of an ion within the quadrupole field are Mathieu differential equations. These equations can be solved in terms of the ion mass (m), the D.C. (U) and R.F. voltage ($V. \cos\omega_o t$) applied on the quadrupole rods and the field radius ($r_o$). By putting :

$$a = \frac{8\ e\ U}{m\ r_o^2\ \omega_o^2} \qquad \text{and} \qquad q = \frac{4\ e\ V}{m\ r_o^2\ \omega_o^2}$$

---

* In this set up the perforated platinum sheet was used as one of the discharge electrodes. The ions are then accelerated in the field between the cathode and the sheet, in its immediate vicinity.

one obtains a stability diagram as shown in figure 4. The shaded area in this figure is the region of stable ion trajectories. It is obvious that this area will depend upon the field radius ($r_o$) and the frequency $\omega_o$ of the applied R.F. voltage. For any particular U and V value applied to the quadrupole rods, only ions with a m/e value falling inside the stable trajectory region are passed by the mass filter and reach the ion collector.

Under normal operation, such as in residual gas analysis, the ratio U/V is chosen so as to make the scanning line (the slope of which is determined by U/V) intersect the top of the stability region and to obtain a high resolution. Therefore most commercially available power supplies of quadrupole mass filters are built in such a way that the D.C. voltage U is derived from the R.F. voltage V and that their ratio is constant or only slightly variable. For our experiments a voltage supply (see section 7.1) has been constructed which allows an independant setting of U and V. Thus the scanning line can be chosen such as to allow filtering of a mass domain, the starting and end mass-values of which are given by :

$$m_{start} = \frac{4\ e\ V}{q_2\ r_o^2\ \omega_o^2} \qquad \text{and} \qquad m_{end} = \frac{4\ e\ V}{q_1\ r_o^2\ \omega_o^2}$$

where $q_1$ and $q_2$ are the ordinates of the two points of intersection of the scanning line with the curves (A and B) bounding the stability region.

The quadrupole mass filter used in our arrangement is the Finnigan model 750. Its characheristics are summarised in the following table :

| | |
|---|---|
| Rod radius | : .25 inch |
| Field length | : 4.5 inch |
| Radiofrequency | : 2.14 MHz |
| Maximum injection angle | : 60° (at reduced resolution) |
| Ion injection energy | : 0 - 150 eV |
| Peak R.F./voltage (ampl.) | : 300 V |
| Mass range | : 5 - 110 amu |

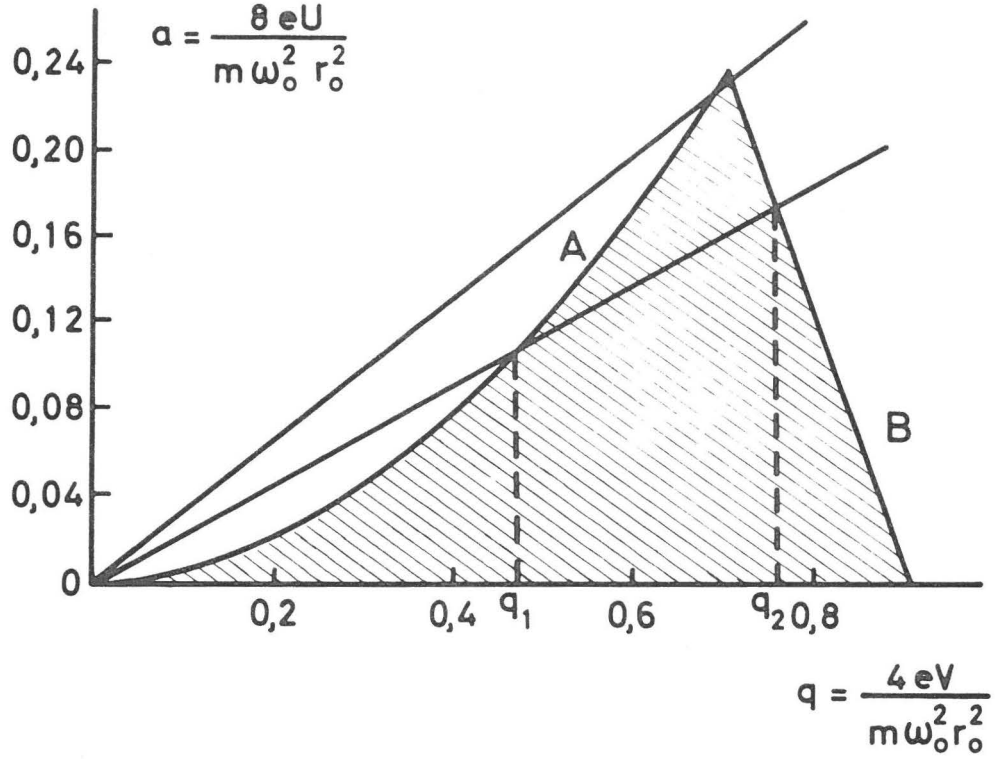

$a = \frac{8eU}{m\omega_o^2 r_o^2}$
0,24
0,20
0,16
0,12
0,08
0,04
0
A
B
0,2
0,4
$q_1$
0,6
$q_2$
0,8
$q = \frac{4eV}{m\omega_o^2 r_o^2}$

Fig. 4.-

The last two parameters are determined by the quadrupole voltage supply, which is described in section 7.1.
As an ion detector an 18-stage venetian blind electron multiplier (EMI) with a gain of approximately $10^5$ at the applied high tension (about 2500 V) was used. Vacuum and photon noise was reduced by the use of an X-ray mask, which could also be used as a Faraday cup.

## 7. ELECTRONICS

### 7.1. Quadrupole voltage supply

The function of the quadrupole voltage supply is to furnish the quadrupole mass filter rod pairs with the adequate mass selection voltages. The expressions for these voltages are

$U_o + (U + V \cos \omega_o t)$ on one pair

and $U_o - (U + V \cos \omega_o t)$ on the other one.

The values of the D.C. and R.F. voltages U and V cos $\omega_o t$ which determine the selected mass range, are controlled by applying proportional control voltages $U_c$ and $V_c$ to the unit's input. These control voltages are produced in the Microprogrammed Scan Controller, which offers the capability to examine isolated mass peaks or groups of peaks or also complete mass domains (see section 7.4).

The R.F. section of the quadrupole power unit, which is schematically shown in figure 5, is composed of a crystal controlled oscillator working at 2.14 MHz, a driver stage, a power amplifier and an automatic gain control unit. The D.C. section is built of 2 high voltage operational amplifiers having an output offset equal to $U_o$ and which translate the $U_c$ control voltage into the D.C. rod voltages.

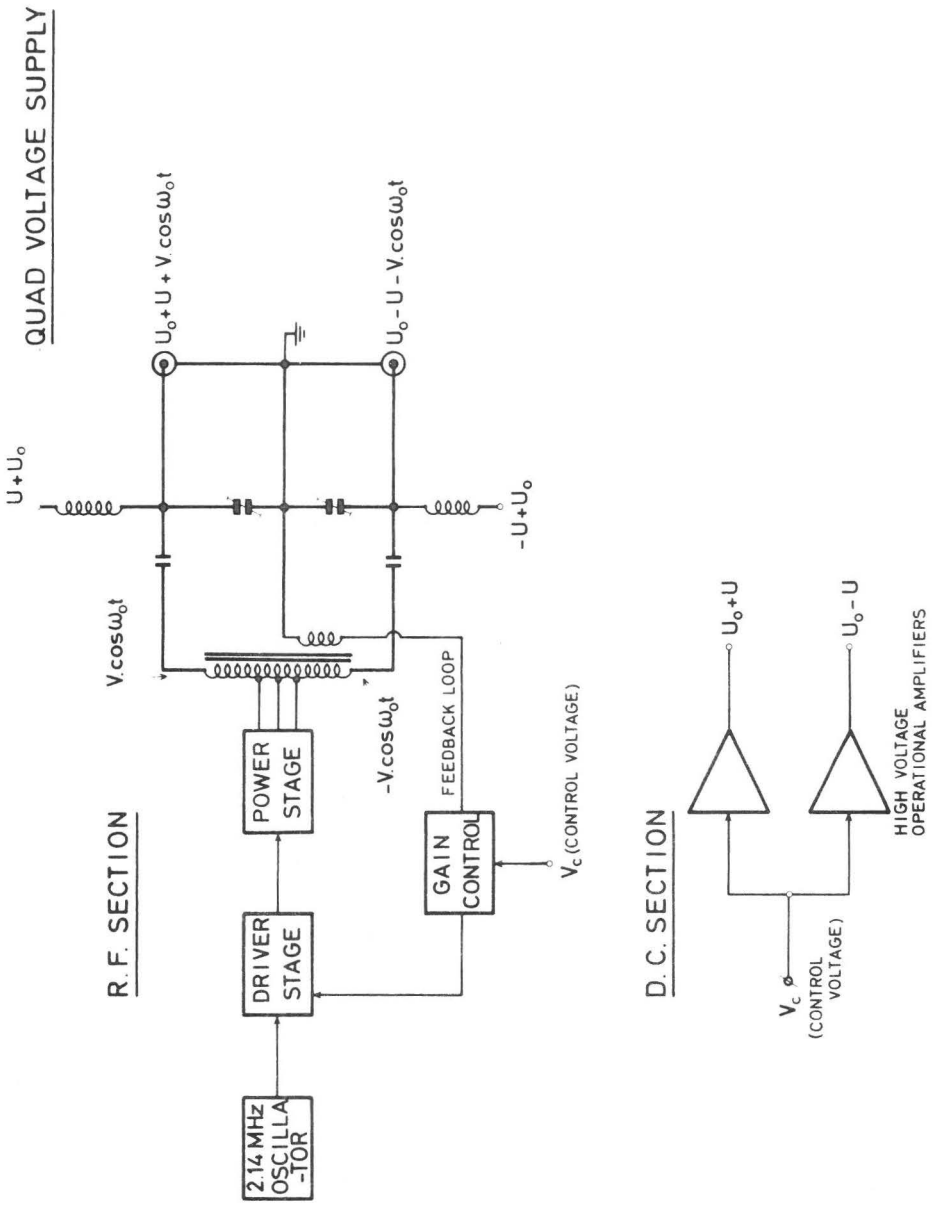

QUAD VOLTAGE SUPPLY
R.F. SECTION
D.C. SECTION
2.14 MHz OSCILLATOR
DRIVER STAGE
POWER STAGE
GAIN CONTROL
FEEDBACK LOOP
$V_c$ (CONTROL VOLTAGE)
$U+U_o$
$V.\cos\omega_o t$
$-V.\cos\omega_o t$
$-U+U_o$
$U_o+U+V.\cos\omega_o t$
$U_o-U-V.\cos\omega_o t$
$U_o+U$
$U_o-U$
$V_c$
(CONTROL VOLTAGE)
HIGH VOLTAGE OPERATIONAL AMPLIFIERS

Fig. 5.-

## 7.2. Pulse amplifier

The charge pulses, arriving at the anode of the electron multiplier, enter into a small sized preamplifier which plugs directly on the multiplier's output connector. The circuitry of the amplifier is composed of a 2 stage amplifier section and an output buffer section having an output impedance of 50Ω. Overall gain is 200.

More details about the preamplifier are to be published later.

## 7.3. Pulse counter/discriminator

The output pulses of the preamplifier enter into a pulse height discriminator consisting of a high speed voltage comparator with TTL compatible output (type µA 760). The response times of this comparator are typically 20 nanoseconds.

After passing through an overflow gate the comparator's output pulses are stored in the pulse counter, which is built of six 4-bit synchronous counters Hence, the maximum number of pulses which can be accumulated by the pulse counter is $2^{24} - 1$ or 16.777.215. Any overflow in excess of this number is neglected due to the closing of the overflow gate.

The contents of the counter are saved in a 24-bit shift register on a "save data" command. This register is part of the digital telemetry interface circuitry to be described in section 7.7. The schematic of the pulse counter discriminator is shown in figure 6.

## 7.4. Microprogrammed Scan Controller

The scan controller, schematically shown in figure 7, gives the possibility of programming the course of the experiment. This unit, which is the command center for the quadrupole power supply, allows an examination of ion counting rate in different mass domains or a mass scanning with variable resolution in a given mass region. A more detailed description of this unit will be published later (19).

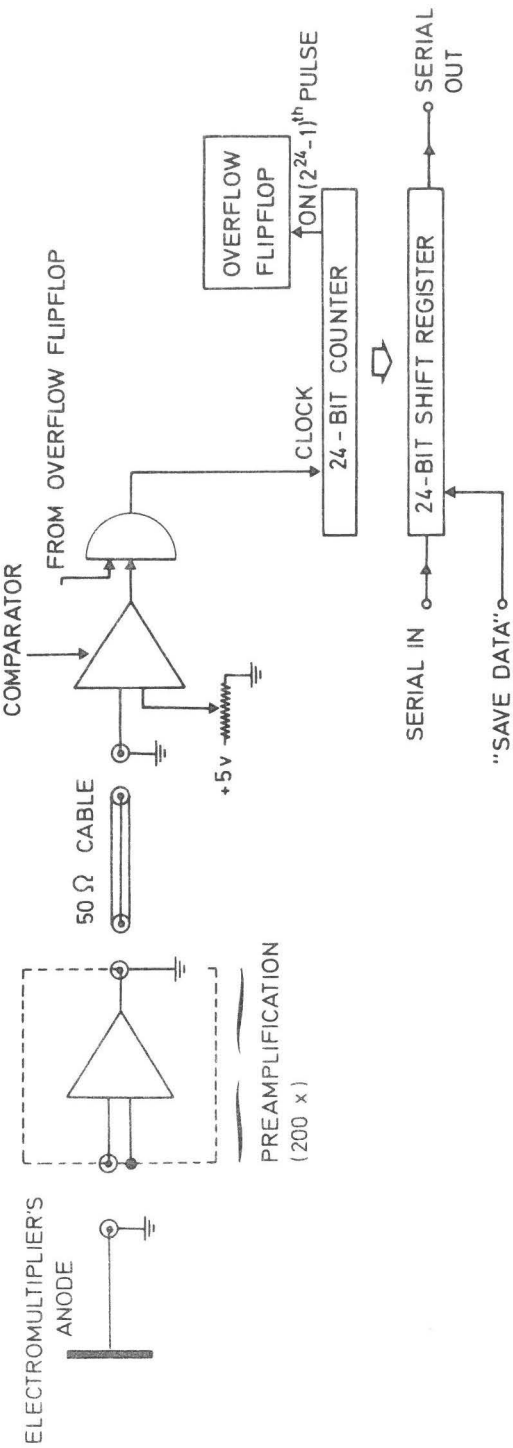

PULSE COUNTER - DISCRIMINATOR
ELECTROMULTIPLIER'S ANODE
PREAMPLIFICATION (200 x)
50 Ω CABLE
+5v
COMPARATOR
FROM OVERFLOW FLIPFLOP
CLOCK
24-BIT COUNTER
OVERFLOW FLIPFLOP
ON $(2^{24}-1)^{th}$ PULSE
24-BIT SHIFT REGISTER
SERIAL OUT
SERIAL IN
"SAVE DATA"

Fig. 6.-

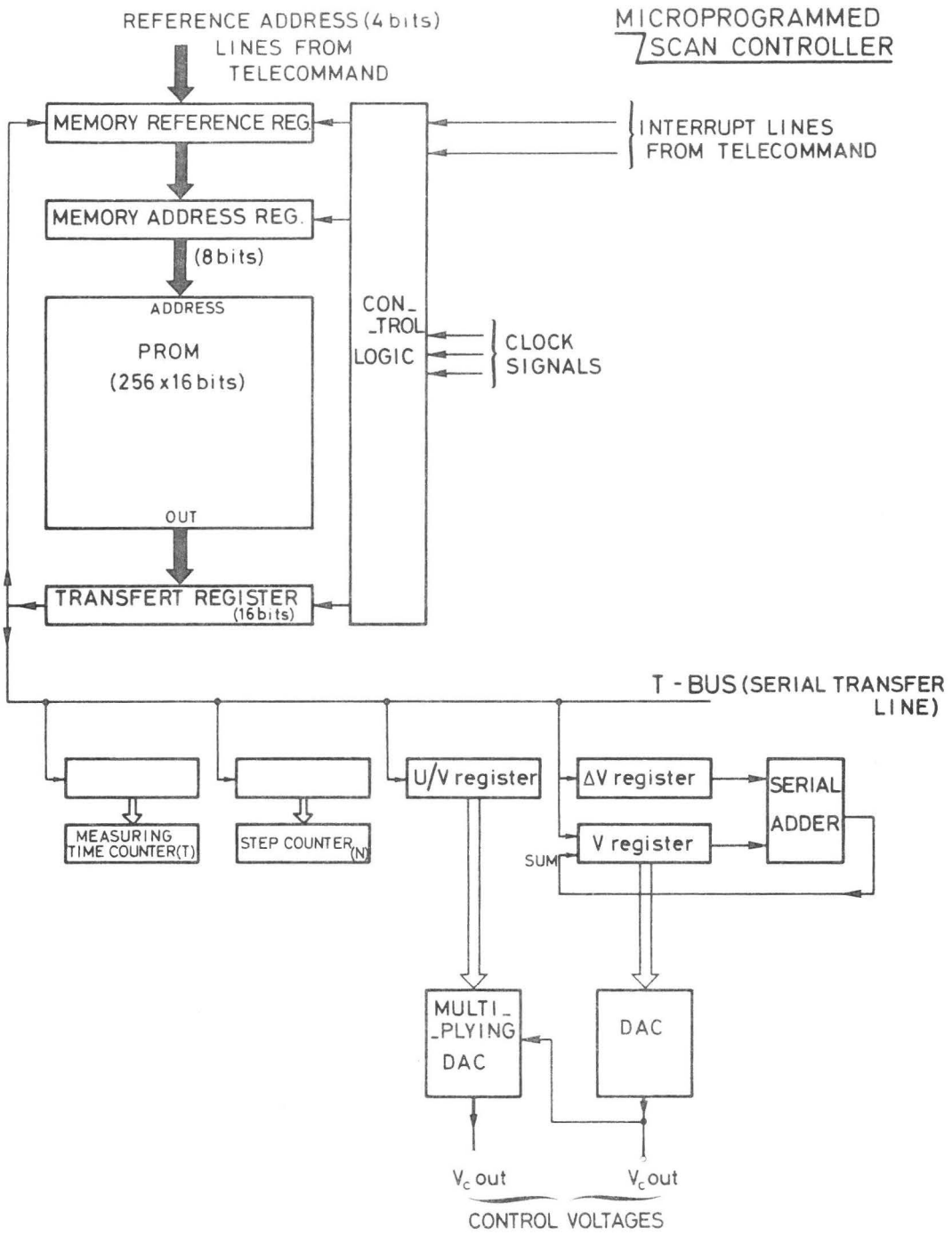

REFERENCE ADDRESS (4 bits)
LINES FROM
TELECOMMAND
MICROPROGRAMMED
SCAN CONTROLLER
MEMORY REFERENCE REG.
INTERRUPT LINES
FROM TELECOMMAND
MEMORY ADDRESS REG.
(8 bits)
ADDRESS
PROM
(256 x 16 bits)
OUT
CON-
-TROL
LOGIC
CLOCK
SIGNALS
TRANSFERT REGISTER
(16 bits)
T - BUS (SERIAL TRANSFER
LINE)
MEASURING
TIME COUNTER (T)
STEP COUNTER (N)
U/V register
ΔV register
V register
SERIAL
ADDER
SUM
MULTI-
-PLYING
DAC
DAC
$V_c$ out
$V_c$ out
CONTROL VOLTAGES

Fig. 7.-

7.4.1. Memory section

The controller produces the control voltages $U_c$ and $V_c$ needed for the driving of the quadrupole voltage supply. The core of this unit consists of two PROM's (programmable read only memories), organized as 256 words of 18 bits.

The available memory space is divided in two parts : the reference address area and the task area. The task area stores groups of binary words called "tasks". Each task contains all the information needed to examine a specific mass domain. This means : the R.F. voltage amplitude V, the ratio U/V, the measuring time T and two additional parameters ($\Delta V$ and N), which offer the possibility to measure in succeeding mass domains, while holding measuring time and ratio U/V constant.

The reference addresses area covers the first 16 words in memory and contains the addresses of the first word of each task. This area is used by the controller to get access to each group of parameters V, U/V, T, $\Delta V$ and N.

7.4.2. Parameter transfer

Another part of the controller is the transfer- or T-register which holds the contents of a selected memory location. The T-register's serial output is connected to the T-bus, a wire acting as medium of serial communication with other parts of the controller. The binary information from the T-register and hence from the task area can be transferred to five different registers, which are :

- the measuring time counter,
- a set of digital to analog converters, generating the proportional scan control voltages $V_c$ and $U_c$ ( two registers),
- two registers for the parameters $\Delta V$ and N.

7.4.3. Additional features

The Scan Controller normally works in an automatic mode : the control logic automatically initiates the next task after completion of the preceeding one. An exception to this rule occurs when the logic block detects in memory a word commanding a jump to another memory location. This feature offers the possibility to predetermine the course of the experiment.

Once the experiment is in progress the programm can be restarted at one of the 16 entry points stored in the reference address area, by sending the appropriate telecommand signals to the controller.

7.5. Electrostatic lens supply

The electrostatic lens supply consists in a D.C./D.C voltage converter followed by a high voltage regulator which delivers a constant floating voltage of 400 V. An external resistor division network is added to obtain the potentials needed for the ion lens located between the mass filter and the perforated input membrane.

7.6. Ion pump supply

The ion pump, associated with the cryopump system, is connected to the ion pump supply, which delivers a 4 kV supply voltage up to a current consumption of 5 mA maximum.

This supply is designed following a classical concept. The 4 kV voltage results from the rectification of a rectangular waveform appearing at the secondary winding of a D.C./A.C. converter. A fraction of the high voltage output is fed back and controls the supply voltage of the converter so that the output stays at 4 kV. Figure 8 gives a general view of the pump supply.

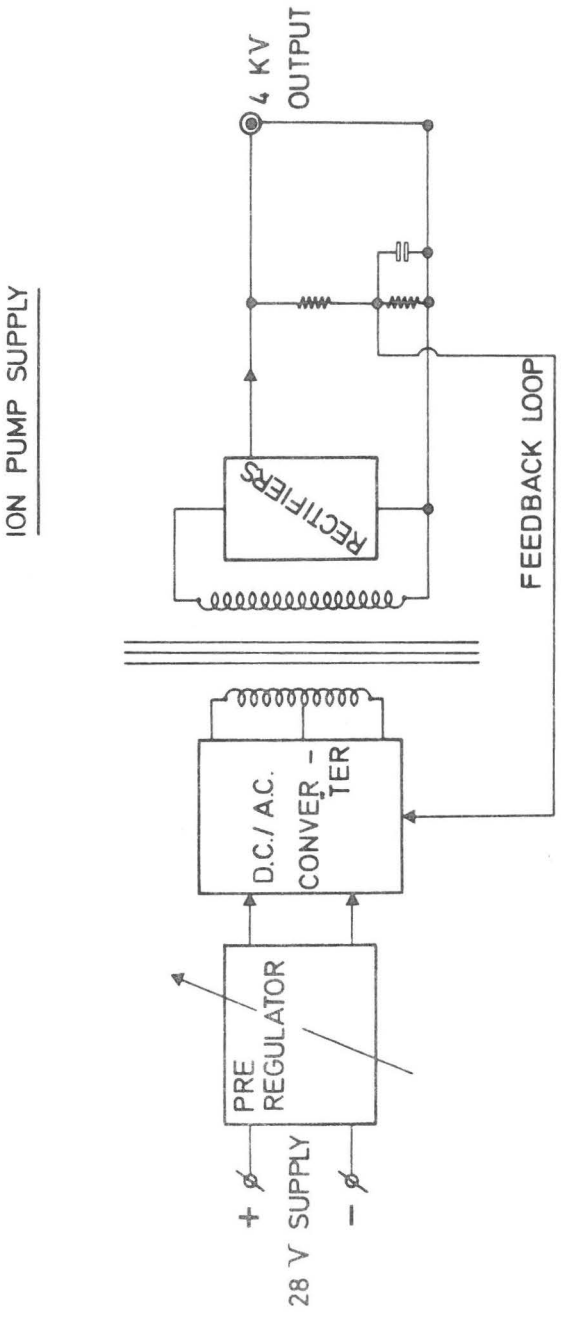

ION PUMP SUPPLY
4 KV
OUTPUT
RECTIFIERS
FEEDBACK LOOP
D.C./ A.C.
CONVER -
TER
PRE
REGULATOR
+
28 V SUPPLY
-

Fig. 8.-

## 7.7. Telemetry interface circuitry

This unit collects all the digital information which will be sent to the data receiving system and transmits it all over a PCM (pulse code modulated) data line.

The digital information forms a string of 10 x 16 bits and includes the contents of the pulse counter (see section 7.3) and the signals moving along the T-bus (see section 7.4.2.). Furthermore a 32 bit synchronization pattern is added to complete the PCM format.

## ACKNOWLEDGEMENTS

We wish to express our gratitude to Prof. Dr. M. Nicolet for his constant encouragement and to Dr. M. Ackerman for the many helpful discussions. We are also indebted to Mr. Dekoker and the technical staff of ETCA for the construction of part of the electronics, as well as to Dr. Forth of Leybold (Köln) and Dr. Ir. K. Buchheit of Siemens (München) for the construction of the cryopump and the molecular leak, respectively.

REFERENCES

1. C.Y. JOHNSON, E.B. MEADOWS and J.C. HOLMES, Ions of the arctic ionosphere, J. Geophys. Res., 63, 443 (1958).

2. C.Y. JOHNSON, Aeronomic Parameters from mass spectrometry, Ann. Geophys., 17, 100 (1961).

3. V.G. ISTOMIN, Mass spectrometer measurements of atmospheric composition in the USSR, Space Res. III, Proc. Intern. Space Sci. Symp. 3rd., 209 (1963).

4. V.G. ISTOMIN and A.A. POKHUNOV, Ions of Extra-terrestrial origin in the Earth's Ionosphere, Space Res. III, Proc. Intern. Space Sci. Symp. 3rd., 117, (1963).

5. R.S. NARCISSI and A.D. BAILEY, Mass Spectrometric Measurements of Positive Ions at Altitudes from 63 to 112 Kilometers, J. Geophys. Res., 70, 3687 (1965).

6. R.S. NARCISSI, A.D. BAILEY, L.E. WLODYKA and C.R. PHILBRICK, Ion composition measurements in the lower ionosphere during the November 1966 and March 1970 solar eclipses, J. Atmos. Terr. Phys., 34, 647 (1972).

7. L.C. HALE, A probe assembly for the direct measurement of ionospheric parameters, Scientific Report No 223 (E), Ionosphere Res. Lab., Pennsylvania State University (1964).

8. L.C. HALE, D.P. HOULT and D.C. BAKER, A summary of blunt probe theory and experimental results, Final Report, Ionosphere Res. Lab., Pennsylvania State Univ. (1967).

9. J.D. MITCHELL, An experimental investigation of mesospheric ionization, Scientific report No 416, Ionospheric Res. Lab., Pennsylvania State Univ. (1973).

10. A. PEDERSEN and J.A. KANE, Rocket measurements of ion and electron densities in the D-region during sunrise, Mesospheric Models and Related Experiments, 274, Fiocco (ed.), Reidel Publ. Co., Dordrecht.

11. R. JAESCHKE and A. PEDERSEN, Ion densities in the lower D-region measured with a parachute probe, Mesospheric Models and Related Experiments, 279, Fiocco (ed.), Reidel Publ. Co., Dordrecht.

12. I.A. BRAGIN, Direct measurements of ion and electron concentration in the stratosphere and mesosphere, Space Res. VII, 391, North Holland Publ. Co, Amsterdam.

13. I.A. BRAGIN, A.D. DANILOV and O.K. KOSTKO, Interpretation of charged particle concentration at the heights of 10-60 km, Space Research VIII, 355, North Holland Publ. Co, Amsterdam.

14. D. KRANKOWSKY and F. ARNOLD, Cluster Ions in the Stratosphere : A mass spectrometric measurement, Symposium on methods of measurement and results of lower ionospheric structure, p. 89, Konstanz, 1973.

15. M. ACKERMAN, A. DROWART, J.P. DE KEERSMAKER, D. FRIMOUT, S. SCHADECK, E. VAN RANSBEECK, Spectrométrie de masse ionosphérique par ballon. - Avant projet de construction de Nacelle, Aeronomica Acta C nr. 24.

16. M. AILLIET, M. ACKERMAN and F. BIAUME, Large Conductance Molecular Leak for Gas Sampling at High Pressure, J. Sci. Instr. (J. Phys. E) 2, 622 (1969).

17. E. ARIJS, Effusion of ions through small holes, to be published (Aeronomica Acta A nr. 124).

18. W. PAUL, H.P. REINHARD and U. VON ZAHN, Das Elektrische Massenfilter als Massenspektrometer und Isotopentrenner, Z. Phys., 152, 143 (1958).

19. D. NEVEJANS and E. ARIJS, A programmed Control Unit for a Balloon Borne Quadrupole mass Spectrometer, to be published (Aeronomica Acta A nr. 125).