A BALLOON BORNE QUADRUPOLE MASS SPECTOMETER FOR THE DETERMINATION OF THE IONIC COMPOSITION OF THE STRATOSPHERE

by

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ABSTRACT

A system combining a quadrupole mass spectrometer with a helium cooled cryopump has been developped for the measurement of the iron composition above 35 km altitude. The characteristics of the instrument are discussed.

RESUME

Un système comprenant un spectomètre 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.

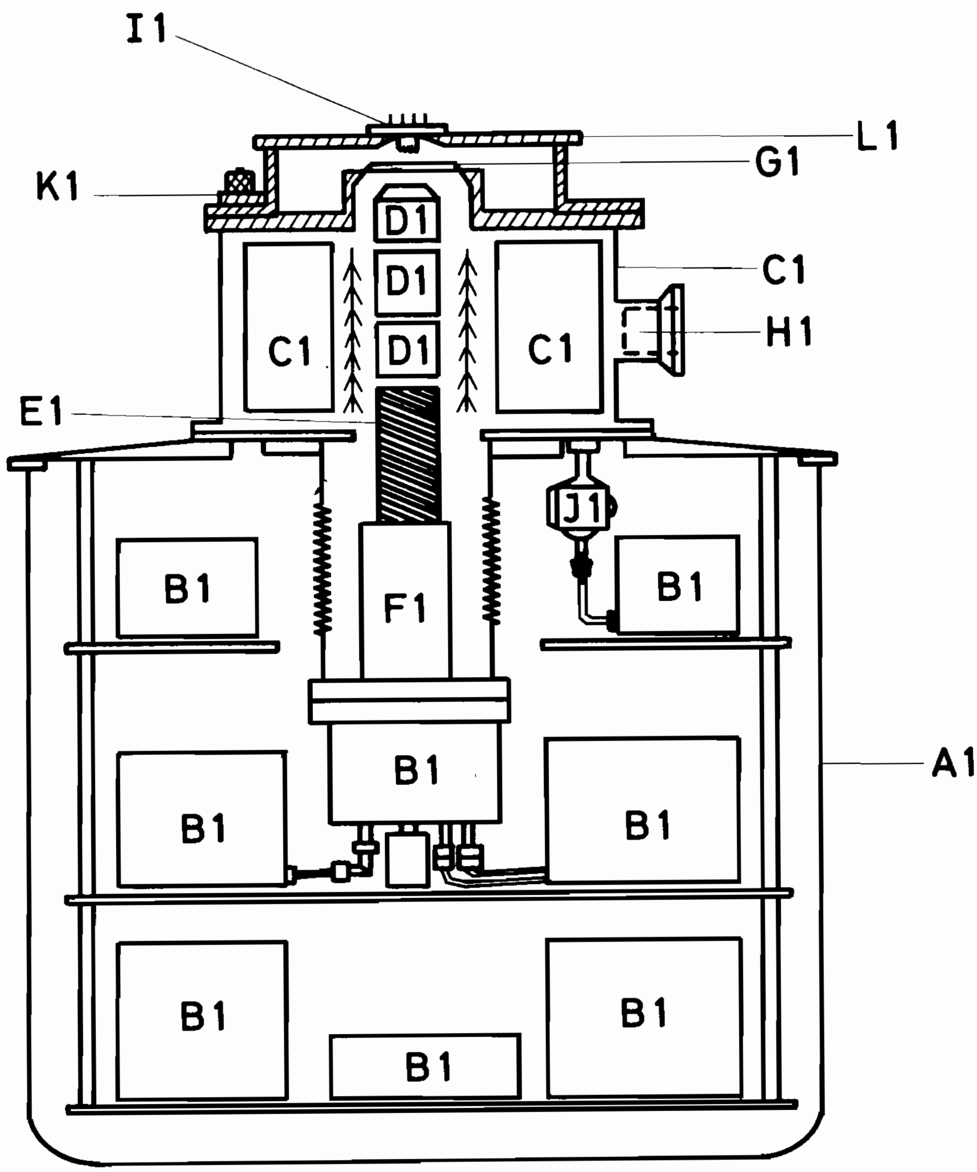

Fig. 1

Figure 1. General Experimental Arrangement

A1.- Light weight pressurized aluminium vessel; B1.- Electronics Boxes ; C1.- Cryopump ; D1.- Ion lens ; E1.- Quadrupole; F1.- Electron Multiplier ; G1.- Molecular leak ; H1.- Isolation valve ; K1.- By-pass valve ; I1.- Ion source for testing; J1.- Penning gauge; L1.- Protective cap.

1. Introduction

The ion composition of the upper atmosphere has been the subject of many experiments. Thus far however, identification of the stratospheric ions by means of a mass spectrometer has only been made at altitudes greater than 60 km. For lower altitudes only global ion densities have been measured using Guerdian condenser and blunt probe techniques (6-13). In order to determine the ion composition of the stratosphere at an altitude of about 40 km, a balloon borne quadrupole mass spectrometer has been built at our Institute. The experiment basically consists of sampling ions from a pressure region of a few Torr, namely the stratosphere, into an evacuated vessel. The ions are focussed by an appropriate electrostatic lens system into a quadrupole mass filter and after being filtered according to their mass, they reach an electron multiplier, the signals of which are counted by pulse counting techniques. The technological aspects of the mass spectrometer will be discussed during this short talk.

2. General experimental arrangement and measuring procedure

A general view of the instrument is given on fig. 1. The gondola is divided into 2 different sections. The first one is a light weight aluminium vessel, which is pressurized and which contains most of the electronic modules. The second part is the mass spectrometer housing itself, which is evacuated by a cryopump and which is shown in more detail on fig. 2. This cryopump is a superinsulated one, with a liquid helium content of 1,6 liter and a holding time of approximately 7 hours. It contains the ion focusing lens, the electric quadrupole mass filter and the electron multiplier. On top of the cryopump a molecular leak with a conductance of about 5 $ml.sec^{-1}$ is mounted. This leak consists of a laser beam perforated platinum sheet of 12 microns thickness and can withstand an overpressure of 10 Torr at maximum (14-15). Therefore the leak remains protected by an ejectable cap as long as outside pressure stays above this pressure limit. Evacuation of the space between the protective cap and the platinum sheet is possible by means of a bypass valve.

Before launching the system is pumped down by a separate rotary and diffusion pump group. When a pressure of 10^{-5} Torr is reached the cryopump is filled with liquid helium and the by-pass valve is closed. The separate pumping unit is then disconnected and the instrument is sealed off by a valve. The gondolla is then ready to be launched.

During the flight the pressure is measured by means of a Penning gauge. When the balloon has reached the altitude of flight (which has to be at least 37 km), the protective cap is ejected. At that moment the pressure in the mass spectrometer compartment is determined by the conductance of the molecular leak, the ambient pressure and the pumping speed of the cryopump. With typical values for the pumping speed of 500 liter/sec, the leak rate 5 ml/sec and the ambient pressure 3 Torr, the internal pressure is approximately 3.10^{-5} Torr, which is a reasonable working pressure for the quadrupole and the electron-multiplier. Once the protective cap is ejected, the atmospheric ions can effuse through the leak in the mass spectrometer region, where they are focussed by the ion lens into the quadrupole. They are then filtered according to their mass and subsequently reach the electron multiplier, which is of the spiraltron type. Each ion reaching the spiraltron gives rise to a pulse which is sent to a pulse counting system.

Since most measurements of global ion densities indicate an ion density of the order of 10^3 cm^{-3}, a very low pulse counting rate can be expected if the ions are filtered according to their mass to charge ratio. Therefore a

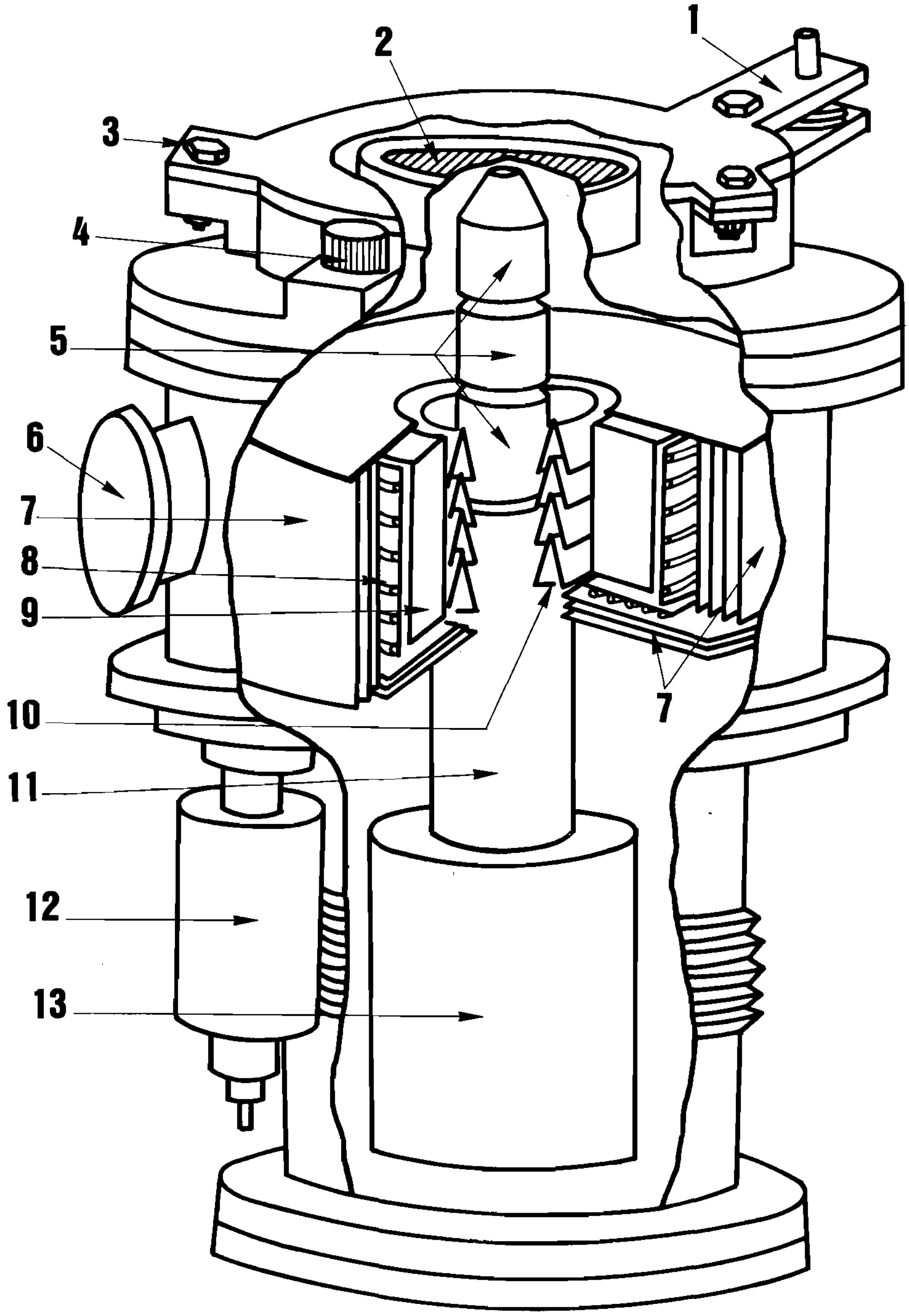

Fig. 2

Figure 2. Scetch of the ion sampling system, cryopump and mass filter

1. Protective cap; 2. Molecular leak; 3. Explosive bolts; 4. Bypass-valve; 5. Ion lens; 6. Isolation valve; 7. Superisolation of cryopump; 8. Cold gas exhaust spiral; 9. Liquid helium reservoir; 10. Chevron baffles; 11. Quadrupole mass filter; 12. Penning gauge; 13. Electron multiplier housing.

procedure has been choosen, which consists of measuring thy ion counting rate in mass domains rather than at definite mass peaks. In case of extremely low counting rate, the platinum sheet can be biased from 0 to - 20 volt in steps of approximately 2 volts by means of remote control. Care however must be taken in this case because breaking up of heavy ions, such as water clusters may become a problem.

The various modules located in the pressurized part of the gondolla are the following. First, immediately below the mass spectrometer housing, there is the quadrupole power supply which produces the RF and DC voltages required to drive the quadrupole rods. Secondly, at the same level we find the reprogrammable control unit which is the center for controlling and monitoring the operation of the system. Its major functions are: generation of the DC voltages controlling the mass domain setting of the quadrupole supply, ion pulse counting, measuring time counting, PCM signal generation and program storage. Besides these 2 units there are a 4 kV high voltage supply for the Penning pressure gauge an electron multiplier power supply ajustable from -1,5 to -3 kV, a lens voltage power supply which delivers -400 volt and a pulse amplifier. All units, except the control unit and the pulse amplifier, are connected to a + 28 volt bus powered by a switching regulator. This booster, together with the battery power pack (Ag-Zn batteries) is located at the bottom level of the vessel.

3. Telemetry and remote control

Our ion mass spectrometer package is further equipped with a data transmission system of the SITTEL type, which is commonly used on balloon borne experiments launched by the CNES. The SITTEL unit, consisting of a 9 channel FM/PM telemetry with frequency division multiplexing (IRIG standards), a remote control feature with 8 bistable relays and a localization system, is hanging below the experiment at a distance of approximately 5 m. It is connected to our experiment through two cables carrying the telemetry and remote control signals and entering the pressurized vessel at its upper flange via two hermetic connectors.

The remote control capabilities of SITTEL are fully exploited to control the state of the experiment. In the first places one bistable relay is used for cutting battery power just prior to separation between the package and the stratospheric balloon. This is necessary because otherwise pressure rise in the mass filter area will cause breakdown in the high voltage supply, the spiraltron and the pulse amplifier. A second relay is used to command the ejection of the protective cap, normally covering the ion inlet aperture. This command should be executed when the ambient pressure becomes lower than the limit of 3 Torr (4 millibar). The 6 remaing bistable relays are dedicated to the programmable controller. Two contacts are reserved for the two possible models of interrupt and the last 4 contacts are forming a 4-bit reference address, which offers the selection of preprogrammed measurement jobs.

Four SITTEL telemetry channels are being used in the following way. IRIG channel 7 is occupied by a low speed time-division multiplexer transmitting such parameters of technological importance as there are : internal pressure, internal temperature, ion gauge current (- pressure of the mass filter area), membrane bias voltage and state of the ion sampling orifice (open or closed). Further, IRIG channels 8 and 9 are monitoring the control voltages of the quadrupole power supply. Finally, IRIG channel E, which has the largest band-with, is used to transmit the PCM signals generated in the reprogrammable control unit. The PCM code is bipolar : logic "true" and

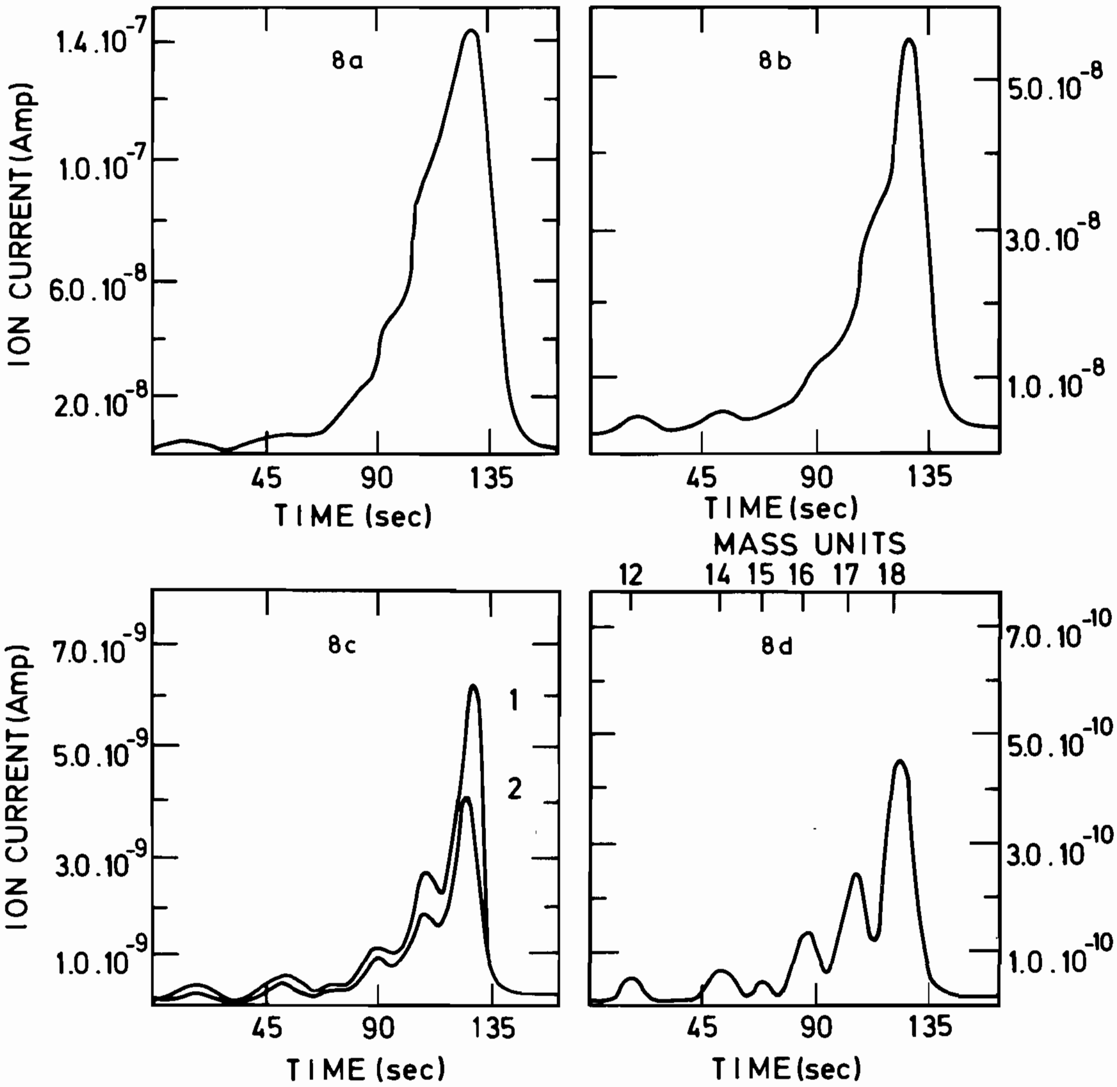

Fig. 3

Figure 3. Some typical spectra obtained during testing.

logic "false" are being represented by pulses of opposite level while the base line stays at half full scale or 1 volt.

4. Real time data handling

The availibility of real time data is of great importance in this experiment. As measuring time is strongly limited by the liquid helium supply, the ground borne crew should be able to keep track of the actual mass domain he is investigating. In order to solve this problem a small computer aided data handling system was built based on a Hewlett-Packard minicomputer. It is further composed of a CRT-keyboard console, a paper tape program input and a simple PCM signal conditioner-decommutator built at our Institute.

During flight the user of the system gets a table on the CRT informing him of the already executed measurements together with the corresponding collected ion counts. At the same moment ellapsed time and time to spent are shown, so that the experimenter can decide when to change or when to interrupt a program by remote control.

The same system will also be used to analyse data while replaying flight recordings. An even more sofisticated software package will be written in the future to allow the plotting of complete mass scannings in real time.

5. Performance of the system

The system has been thouroughly tested in the laboratory. To do so, some slight modifications were introduced, such as : external power supplies, installation of an electron impact ion source above the molecular leak, simulation of the remote control by a set of switches and replacement of the ion counting system by an electrometer and a strip chart recorder.

Some typical spectra obtained with this arrangement are shown in fig. 3, which picture a scanning from 11 to 21 a.m.u., each time with a different resolution. The resolution, as well as the mass domain were set by reprogramming the memories of the reprogrammable control unit. A more detailed description of this testing procedure would be beyond the scope of this paper and will be published elsewhere (16).

The cryopump has been tested separately and its performance was satisfactory in every respect. The experiment was flown in May 1974 from the CNES balloon launching base in Aire-sur-l'Adour but because of a balloon failure no usefull data could be obtained.

A second flight took place in May 1975 and was partially successful in so far that the telemetry and remote control worked perfectly as well as the cryopump system. The protective cap however, was not completely ejected because of a failure of the pyrotechnical system, so that no ions could be detected.

At present our efforts are concentrating on a more reliable device replacing the actual protective cap design.

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QUESTIONS POSEES A M. NEVEJANS PAR LES PARTICIPANTS
QUESTIONS ASKED TO MR. NEVEJANS BY THE PARTICIPANTS

QUESTION de M. A. SOUFFLOT
Question Laboratoire de Physique Stellaire et Planétaire

Connaissez-vous la pression au niveau du détecteur et ne pensez-vous pas qu'une meilleure pression dans la gamme 10^{-6} T ou inférieure ne serait pas souhaitable ?

REPONSE
Reply

The pressure in the immediate vicinity of the spiraltron multiplier is not known. However, the pressure is measured by a Penning gauge at the bottom of the Cryopump (as can be seen on figure 1). It is assumed that the pressure is of the same order of magnitude in the vicinity of the spiraltron. This pressure is of the order of 10^{-5} Torr. In order however to make a better discrimination between noise and real signal pulses a pressure of 10^{-6} Torr or better would be more convenient. This however would require a cryopump with a higher pumping speed. The construction of such a pump is planned for future experiments.