Outer Planets Atmospheric Entry Probes: Science Objectives and Payloads

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The scientific objectives of atmospheric entry probes are to characterize the physical structure of the atmosphere and to determine its chemical composition. The structural properties of the atmosphere are determined with a combination of triaxial accelerometers and temperature and pressure gages. The atmospheric thermal balance is measured with a net flux radiometer. The identity and relative abundance of the chemical constituents of the atmosphere are obtained by a mass spectrometer and a gas chromatograph. The cloud layers are located with a nephelometer. The operating characteristics of these instruments are described and the use of the data to increase our knowledge of the outer planets is indicated.

Introduction

THE complement of scientific instruments for outer planets atmospheric entry probes makes measurements in a region that is critical to the total characterization of these planets, but is inaccessible to remote sensing from flybys and orbiters. Information on the outermost portions of the atmospheres are derived from Earth-based spectroscopy, stellar occultations and increasingly from spacecraft infrared, ultraviolet, and radio occulation experiments. The cores of the outer planets, especially Jupiter and Saturn, are being studied in terms of the statistical mechanics of liquid metallic hydrogen-helium mixtures, laboratory experiments on hydrogen at megabar pressures, and the analysis of the Pioneer 10 and 11 gravity data. However, the very deep atmospheres of the outer planets rapidly become opaque at optical and microwave frequencies, and the interior modeling requires an independent determination of temperature and composition below 1 bar in order to construct an adiabat connecting the outer atmosphere to the inner core. Therefore the region between the tropopause and the 30 bar level is a critical link joining the outer atmosphere and the deep interior. The direct measurement of the physical and chemical properties of this atmospheric region, by entry probe instruments will provide the data necessary for a more complete description of the outer planets.

The outer planets atmospheric entry probe then has two very basic science objectives. One is the determination of atmospheric structure and the other is the determination of atmospheric composition. The instruments that provide these determinations are described in this paper and the use of these data to augment our present knowledge of the outer planets is described.

Atmospheric Structure

Of all of the outer planets, Jupiter has been the most extensively studied, both from the ground and from spacecraft. Therefore, the description of atmospheric experiments is presented in the context of what is known and what we still seek to know about Jupiter's atmosphere.

Our present knowledge of the atmospheric structure of Jupiter is based on analyses of the radiative processes, such as by Wallace, et al.,[1] and Pioneer 10 and 11 infrared radiometer[2,3] and radio occultation[4,5] measurements. The Pioneer radiometer data have been analyzed by Orton[6] and found to be consistent with the radiative theory when identical assumptions are employed. Orton concluded that the infrared emission is sensitive to Jupiter's temperature profile only in the 0.1 to 1 bar pressure region. The existence of a thermal inversion above 0.1 bar and the presence of a cloud layer near 1 bar in the tropical zones could not be established unambiguously from the radiometer data. The thermal inversion is detectable in the Pioneer radio occultation data[7] and when taken together the radiometer and occultation data show good consistency. However, to a great extent the interpretation of atmospheric structure from remote sensor measurements is model dependent. Direct measurements with an entry probe can help resolve the ambiguities in the remote data and permit a choice between competing models.

The measurement of atmospheric parameters with the entry probe consists of measuring density with accelerometers and pressure and temperature with pressure and temperature gages.[8] The concept was proved valid in the Planetary Atmospheric Experiment Test (PAET) Program.[9] It is being implemented on the Viking mission to Mars,[10] and the Pioneer Venus Program.[11] The Russians used a similar procedure in their exploration of Venus.[12]

The thermal structure of upper portions of the outer planet atmospheres is determined by the balance between radiative heating and cooling mechanisms. The location of the sources and sinks of radiative energy within the atmospheres is revealed by net flux radiometer measurements from the entry probe.

Accelerometer

The objective of the accelerometer experiment is the measurement of the aerodynamically induced deceleration of the entry probe by the planetary atmosphere. The aerodynamic deceleration is directly proportional to the ambient atmospheric density. The density, ρ, is determined from the component of acceleration along the flight path, a_s

$$\rho = -\frac{2}{V^2}\frac{M}{C_D A}a_s$$

where M, V and C_DA are the mass, velocity and aerodynamic drag area of the probe.

In the upper atmosphere, atmospheric data are available only from the accelerometer measurements. In the lower atmosphere the accelerometer measurements are enhanced by direct measurements of atmospheric temperatures and pressures. The independent data on temperature, pressure and density are combined statistically with probe trajectory data to yield the best estimate of atmospheric structure profiles.[13]

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Accelerometer data are required from the beginning of the sensible atmosphere to the end of the mission within the troposphere. The minimum interpretable value from the accelerometer is $10^{-4}\ g_E$, which for an entry probe occurs in the vicinity of 700 km above 1 bar level for the nominal atmospheric models of the outer planets. The probe traverses the upper atmosphere at relative velocities up to 47 km/sec; therefore, a high sampling rate is required to trace out the density profile. The analog output of each accelerometer transducer is sampled at the rate of 5 samples/sec. After peak deceleration, when the probe has slowed to subsonic velocities, the accelerometer sampling rate is reduced to 0.02 samples/sec.

The accelerometer unit is a self-contained package that consists of three orthogonally mounted accelerometers and their suporting electronics (see Fig. 1). The Bell Aerospace Company design illustrated in the figure incorporates a fourth accelerometer to serve as a g-switch. Each transducer is a single-axis, pendulous proofmass transducer which uses a capacitive bridge pickoff to detect the acceleration forces acting on the proofmass. The electromagnetic force required to maintain the proofmass in its null position is a direct measure of the aerodynamic forces exerted on the probe by the atmosphere. This type of accelerometer can measure acceleration in the desired range of -0.001 to $-800\ g_E$.

The characteristics of the accelerometer package are listed in Table 1. The accelerometers are aligned orthogonally and assumbled in a rigid structure. The package is mounted so that the longitudinal accelerometer lies along the center line of the probe with its proofmass as close as possible to the probe's center of gravity.

The accelerometers are energized on command of the data handling subsystem programmer about 40 min. before the anticipated occurrence of $-0.01\ g_E$ acceleration. The analog output of the accelerometers are sampled at 5 samples/sec until the probe experiences $-2\ g_E$ acceleration after peak deceleration. From the $-2\ g_E$ level to the end of the mission, the data is sampled at 0.02 samples/sec. In order to attain a high level of precision in the upper atmosphere density measurements, the longitudinal accelerometer is provided with three range scales; 0 to $-0.1\ g_E$, 0 to $-10\ g_E$, and 0 to $-800\ g_E$. Range switching is activated by the accelerometer electronics. Two bilevel outputs are included in the data stream to indicate when a range change has occurred.

The outputs of the accelerometer are 0 to 5 VDC analog signals, which are digitized by the probe data processor. The longitudinal signal is quantized into 10 bit words, the lateral signals into 7 bit words per axis. The upper atmosphere data are stored and are transmitted (interleaved with real-time science and engineering data) after radio frequency blackout.

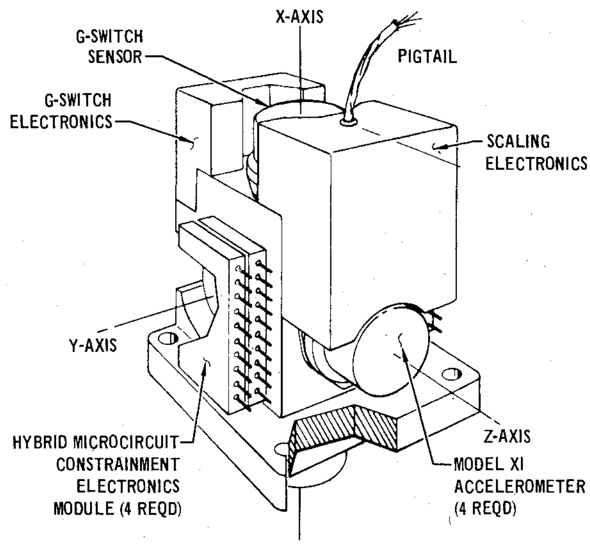

Fig. 1 Bell Aerospace Company design of the accelerometer/g-switch assembly.

Pressure Gage

The objective of the pressure gage measurements is to obtain atmospheric pressure profiles in the tropospheres of the outer planets. The pressure measurements are made at the stagnation region of the probe. The thermal limit of the sensor restricts the pressure measurements to the lower atmosphere where the probe velocity is subsonic. At the beginning of the measurement regime, the ambient and dynamic pressure contribute almost equally to the total pressure measured by the sensor:

$$P_T = P_\infty + 1/2\rho_\infty V_\infty^2$$

where P_∞ is atmospheric pressure, ρ_∞ is ambient density, and V_∞ is velocity. Therefore, accelerometer data are needed to determine probe velocities and ambient densities in this region in order to reduce the gage data. As the probe approaches its terminal velocity, the dynamic pressure correction to the measurement becomes very small and is neglected.

The properties of the pressure gage are given in Table 2. A capacitive type of sensor is employed because it responds to a wide range of pressure in a single instrument. The pressure gage is a single unit that contains four pressure transducers and a common electronics package. The transducers are in the form of pressure sensing capsules; each capsule is sensitive to a different pressure range. The full-scale values of each capsule are 0.1, 5, 10 and 40 bar, respectively. Automatic range switching occurs from one capsule to another as the pressure profile is traversed.

The inlet port of the pressure gage is collocated within the mass spectrometer inlet probe assembly in the sampling tube of mass spectrometer system. Pressure measurements are initiated at $-2\ g_E$ (after peak deceleration) with deployment of the mass spectrometer sampling tube. The output of the pressure gage is an analog signal in the 0 to 5 VDC range. The output signal is sampled once every 50 sec and is digitized into 10 bit words by the probe data processor.

Table 1 Accelerometer

RANGE:	LONGITUDINAL 0 TO $-0.1\ g_E$, 0 TO $-10 g_E$, 0 TO $-800\ g_E$		
	LATERAL +10 TO $-10 g_E$		
ACCURACY:	0.01% OF READING		
SIZE:	7.5 x 4.5 x 4.5 CM (SENSORS PLUS ELECTRONICS)		
VOLUME:	152 CM^3, (9.2 IN^3) (SENSORS PLUS ELECTRONICS)		
WEIGHT:	0.3 KG, (0.66 LB) (SENSORS PLUS ELECTRONICS)		
POWER:	PEAK 8.2W FOR 20 SEC; AVERAGE 2W		
DATA OUTPUT:	0–5 VDC DIGITIZED BY PROBE DATA HANDLING SUBSYSTEM		
DATA RATE:	WORD SIZE (BITS/WORD)	SAMPLE RATE (WORDS/SEC)	DATA RATE (BITS/SEC)
HIGH RATE			
LONGITUDINAL	10	5	50
LATERAL	7	5	35
LOW RATE			
LONGITUDINAL	10	0.02	0.2
LATERAL	7	0.02	0.14

Table 2 Pressure gage

RANGE:	0 TO 40 BAR IN FOUR RANGE SCALES WITH FULL-SCALE VALUES OF 0.1, 5, 10 AND 40 BAR RESPECTIVELY		
ACCURACY:	0.5% OF READING		
SIZE:	3.8 CM DIA x 16 CM (SENSOR PLUS ELECTRONICS)		
VOLUME:	181 CM^3, (11.1 IN^3)		
WEIGHT:	0.2 KG, (0.44 LB)		
POWER:	1.2W AVERAGE		
DATA OUTPUT:	0–5 VDC DIGITIZED BY PROBE DATA HANDLING SUBSYSTEM		
DATA RATE:	WORD SIZE (BITS/WORD)	SAMPLE RATE (WORDS/SEC)	DATA RATE (BITS/SEC)
	10	0.02	0.2

Table 3 Temperature gage

RANGE:	50° TO 600°K		
ACCURACY:	± 0.5°K		
SIZE:	SENSOR	1.25 DIA x 10 CM	
	ELECTRONICS	2.5 x 3 x 7 CM	
VOLUME:	SENSOR	12.3 CM^3 (0.75 IN^3)	
	ELECTRONICS	52.5 CM^3 (3.2 IN^3)	
WEIGHT:	SENSOR	0.2 KG (0.44 LB)	
	ELECTRONICS	0.15 KG (0.33 LB)	
POWER:	1 W		
DATA OUTPUT:	0–2.5 VDC, 0–5 VDC, DIGITIZED BY DATA HANDLING SUBSYSTEM		
DATA RATE:	WORD SIZE (BITS/WORD)	SAMPLE RATE (WORDS/SEC)	DATA RATE (BITS/SEC)
	10	0.02	0.2

Temperature Gage

The objective of the temperature measurement is the determination of atmospheric temperature profiles in the tropospheres of outer planets. The atmospheric temperature measurements are made by deploying the temperature gage directly into the probe flowfield. The measurement regime is therefore limited to the lower atmosphere, where local flowfield conditions do not exceed the thermal limit of the gage.

The sensing element of the temperature gage is a platinum resistance wire. To provide sensor redundancy, the temperature gage contains two platinum elements in a single housing. The two elements are connected in parallel to one resistance bridge. The circuitry is designed so that, when both platinum elements are operational, a 0 to 2.5 VDC output range is obtained. Should one element open, the output voltage range immediately goes to 0 to 5 VDC and the voltage output for a given temperature jumps to twice the previous value. In order to determine the appropriate scale factor, the data handling programmer sends a command to the temperature gage immediately after sensor deployment which introduces a calibrated bridge resistance in parallel with sensing elements. The change in output signal identifies the scale factor to be used in data reduction. Experimental data from similar total temperature sensors have produced a maximum response time of 0.5 sec. The response is dependent on Mach number and pressure, the lag time decreasing as atmospheric pressure increases.

The temperature gage consists of two components, the deployable sensor unit and the electronics package, and is typical of platinum wire sensors used in many space applications except for the deployment mechanism. The physical properties of the gage are given in Table 3. Before deployment, the sensor unit is positioned behind the forward heat shield in the vicinity of the probe maximum diameter. The gage deployment is accomplished by means of a preloaded spring, which is released on command of the probe data processor when the probe attains the $-2\ g_E$ level (after peak deceleration). Upon deployment, the sensor unit is located in a region of high local dynamic pressure within the flowfield. The sensor is extended approximately three centimeters beyond the probe boundary layer.

The output of the temperature gage is an analog signal in the 0 to 2.5 VDC range (or in the 0 to 5 VDC range on the failure of one sensor element) which is sampled once every 50 sec. The analog signal is digitized into 10 bit words by the probe data processor prior to transmission.

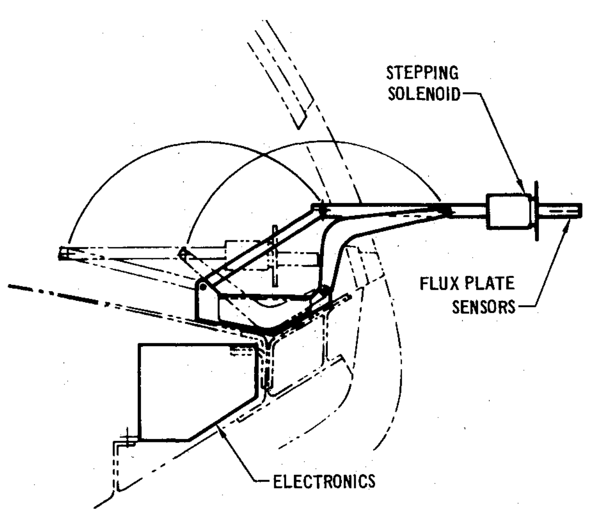

Fig. 2 Net flux radiometer.

Net Flux Radiometer

The objective of the net flux radiometer equipment is to determine the vertical distribution of radiative sources and sinks with the atmosphere. The sensor is a flat plate, known as the flux plate, which is deployed outside of the entry probe, perpendicular to the probe axis of symmetry. The sensing element detects the difference in the flux of radiant energy incident to the two sides of the flux plate. This flux difference produces differential heating within the flux plate, and is measured by a thermopile within the plate.

The net flux radiometer for the outer planets entry probe is based on the instrument developed by V. E. Suomi[11] for the Pioneer Venus probes. The flux plate consists of a section of glass 0.04 in. thick by 0.318 in. square. Around the parallel edges of the plate are wound 15 turns of 0.002 in. constantan wire. Each turn of wire is electroplated half way around with copper to form the equivalent of 15 different thermocouples in series. The two flat sides of the flux plate are covered by windows, which serve as a wide bandpass filters as well as protecting the plate from convection.

In the outer planets application of the net flux radiometer, simultaneous independent measurements are made in two spectral regions. Flux measurements in the 0.2 to 4μ region provide a profile of the deposition of solar energy within the atmosphere. Measurements in the 4 to 40μ region provide a profile of the atmospheric radiation of absorbed thermal energy. The two measurements are obtained by using two separate flux plates, each its own spectral response. For the solar flux the windows are IRTRAN, infrared transparent glass. The two flux plates are mounted on a single boom that is deployed byond the flowfield of the entry probe. In order to eliminate any effects arising from possible asymmetries between the two sides of the flux plate, the sensors are rotated 180° once per sec.

The analog output of the thermopile in each flux is differenced by passing it to a voltage-controlled osilllator and then to a counter. The accumulated difference count after eight cycles is proportional to the average net flux for a 16 sec sampling interval. This average represents the net flux data per sensor and yields 8 bits every 16 sec. In addition, a second channel per sensor produces 16 bits of temperature data every 80 sec. The dual sensor nex flux radiometer yields 112 bits each 80 sec. The data are transmitted to the probe data processor at the rate of 1.4 bps.

The properties of the net flux radiometer are summarized in Table 4; radiometer is illustrated in Fig. 2.

Atmospheric Composition

The high value that is placed on atmospheric composition measurements derives in great part from the use of the data characterizing the composition of the outer planets as a whole. The insight into planetary composition that is provided by the composition measurements can be indicated by comparing the various models for the interiors of Jupiter and Saturn.

The discovery by Low[14] that Jupiter emits twice the radiative energy it receives from the Sun prompted Hubbard[15] to model the interior of Jupiter in analogy to a low

Table 4 Net flux radiometer

SIZE:	SENSOR ASSEMBLY	2.6 CM DIA x 15 CM	
	ELECTRONICS	5 x 5 x 7.8 CM	
VOLUME:	SENSOR ASSEMBLY	80 CM^3 (4.9 IN^3)	
	ELECTRONICS	195 CM^3 (12 IN^3)	
WEIGHT:	SENSOR ASSEMBLY	0.4 Kg (1.0 LB)	
	ELECTRONICS	0.5 Kg (1.1 LB)	
POWER:	2.2W		
DATA OUTPUT:	2 CHANNELS OF FLUX DATA 2 X 40 BITS		
	2 CHANNELS OF TEMPERATURES 2 x 16 BITS		
DATA DIGITIZED INTO A SINGLE BIT STREAM BY THE INSTRUMENT'S DATA PROCESSOR.			
DATA RATE:	SAMPLE SIZE (BITS/SAMPLE)	SAMPLE RATE (SAMPLE/SEC)	DATA RATE (BITS/SEC)
	112	0.0125	1.4

mass star. Jupiter is assumed to have a fully convective structure, a liquid metallic core, a molecular hydrogen envelope, and a uniform hydrogen-helium ratio throughout the planet. For this model to agree with Jupiter's average density, the hydrogen-to-helium ratio must be about 1.6 by mass, or 6.5 by number.

On the other hand Podolak and Cameron[16] consider the cores of Jupiter and Saturn to have formed out of grains of silicates and metals from the primative solar nebula. The grains accumulated into a rocky core, which eventually became large enough to capture an atmosphere of hydrogen, helium, water, ammonia and methane from the surrounding nebula. The water may have initially condensed into a layer of ice around the rocky core. The subsequent inflall of captured gas vaporized this ice, enhancing the atmospheric content of water above the solar ratio. Podolak and Cameron therefore predict that the atmospheres of Jupiter and Saturn have a solar hydrogen-to-helium ratio (about 3.5 by mass, 14 by number), solar proportions of ammonia and methane, and an abundance of water of about 7.5 times the solar value.

Taking a third approach, Smoluchowski[17] stresses that helium has a limited solubility in liquid hydrogen. The cores of Jupiter and Saturn would therefore be deficient in helium compared to the planetary average, and the atmospheres would contain an excess of helium. A measurement of the hydrogen-to-helium ratio in the atmosphere would yield a value different from that predicted by models based on a uniform composition or those based on solar composition.

Thus, we have three different theories for the interiors of Jupiter and Saturn arrived at from different starting points. What is significant in terms of atmospheric measurements is that these competing theories predict differing values for the hydrogen-to-helium ratio and the relative abundances of the main atmospheric constituents. To provide a rigorous test of the interior models, Hubbard[18] recommends that the hydrogen-to-helium ratio be measured with a precision of 1%.

The basic composition measurements on the atmospheric entry probe are made by a mass spectrometer and a gas chromatograph, each instrument operating independently of the other. The mass spectrometer identifies the constituents in an atmospheric sample by means of their molecular masses. The instrument has the sensitivity to detect atmospheric constituents at the ppm level and the unique capability of determining significant isotopic ratios, such as D/H, $^3He/^4He$, $^{16}O/^{17}O/^{18}O$ and $^{36}Ar/^{38}/Ar/^{40}Ar$. A drawback to the mass spectrometer is that in the process of mass sorting, the instrument fragments the constituent molecules into molecular ions. The gas chromatograph, on the other hand, separates the components of an atmospheric sample wihtout altering the chemical identity of the constituents. Furthermore the instrument can determine the hydrogen-to-helium ratio to an estimated 3% accuracy, a higher accuracy than the mass spectrometer determination. By an innovative combination of chromatographic columns and detectors, the gas chromatograph can be made responsive to atmospheric trace

Table 5 Mass spectrometer

RANGE:	1 TO 46 ATOMIC MASS UNITS		
VOLUME:	8,200 CM^3 (500 $IN.^3$)		
WEIGHT:	6.4 Kg (14 lb)		
POWER:	10 W		
DATA OUTPUT:	MASS SPECTRUM	39 x 10 BITS	
	INSTRUMENT STATUS	100 BITS	
DATA DIGITIZED INTO A SINGLE STREAM BY THE INSTRUMENT'S DATA PROCESSOR			
DATE RATE:	SAMPLE SIZE (BITS/SAMPLE)	SAMPLE RATE (SAMPLE/SEC)	DATA RATE (BITS/SEC)
	490	0.0245	12

constituents in the parts-per-billion range, but at the expense of increased instrument complexity, weight and volume. The mass spectrometer and gas chromatograph are viewed as complementary instruments, each instrument providing ambiguities in the data from each instrument can be resolved and the composition of outer planet atmospheres more fully determined.

The addition of a nephelometer to the science payload of the entry probe provides a means for locating the cloud layers in the outer planet atmospheres. The light scattering properties of the cloud condensates is utilized to detect the presence of the clouds. Through a correlation with the pressure-temperature measurements obtained with the atmospheric structure experiment, the validity of cloud models, such as those of J. S. Lewis,[19] can be tested.

Mass Spectrometer

The mass spectrometer analyzes atmospheric samples by ionizing the constituent gas molecules and sorting out the resultant ions by electromagnetic fields generated within the instrument. The ions produced in the atmospheric sample are identified by their characteristic mass-to-charge ratios, as exhibited by their position on a spectrum of mass numbers. The abundance of the atmospheric constituents is derived from the peak heights of the mass spectrum.

The mass spectrometer experiment is contained in an integrated mass spectrometer package that consists of three major elements, the sampling system, the mass spectrometer, and the data control system. The function of these elements is described in the paragraphs that follow, and the physical properties of the package are listed in Table 5.

The sampling system of the mass spectrometer is illustrated in Fig. 3. The atmospheric gas samples are obtained through a 1.5 cm diam tube which is deployed by a pyro pin-puller device which releases a preloaded metal bellows. The thrust from the bellows causes the sampling tube to push a plug out of the forward heat shield and extend 6 cm beyond the mold line into the flowfield. In addition, the bellows prevent sample contamination from pyro-gases. The atmospheric sample flows through the sampling tube into the mass spectrometer plenum.

It is imperative that only atmospheric gases enter the atmospheric sampling tube and that none of the outgassing products from the charred heat shield are ingested. To evaluate the sampling concept, an experimental program was undertaken to scale the key flowfield features in a transonic wind tunnel.[20] A 10.2 cm (4 in.) diam scale model was used in the tests. Representative contaminant gases were injected into the boundary layer through the porous forebody of the model to simulate heat shield outgassing. The level of contamination gases entrained into the sampling tube was measured with a gas chromatograph at a sensitivity of 20 ppm. The experimental results indicate that, when the sampling tube length is greater than the boundary-layer thickness, the contamination level is zero.

Two alternate techniques have been developed for delivering atmospheric samples from the plenum to the mass

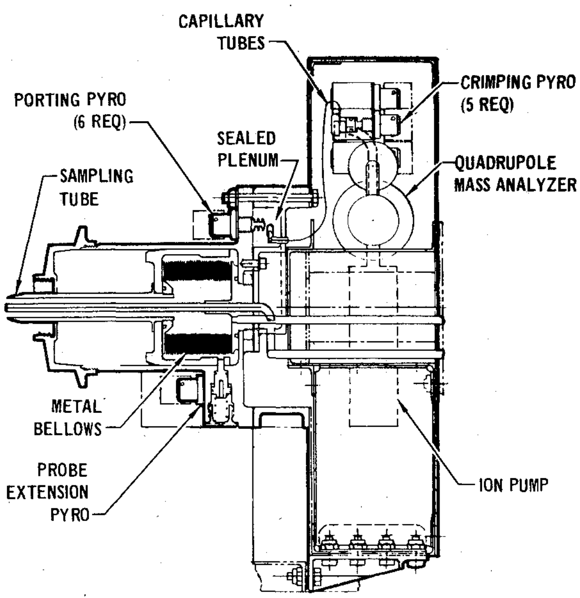

Fig. 3 Mass spectrometer sampling system.

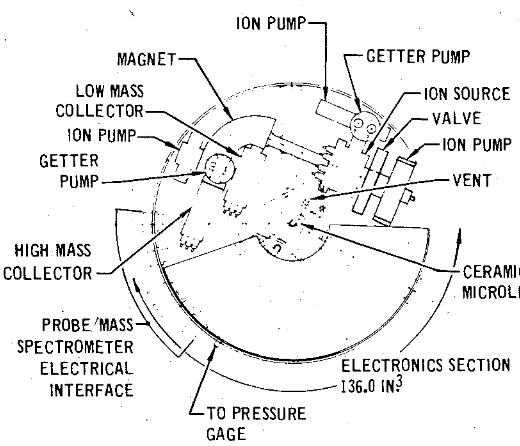

Fig. 4 Magnetic deflection mass spectrometer.

spectrometer. N. W. Spencer has designed a batch sampling system involving a number of separate inlet tubes for emitting atmospheric samples into the mass spectrometer. The inlets are opened and closed in sequence by porting and crimping pyros, so that at each sampling interval a new sample is delivered to the instrument. The delivery system developed by J. H. Hoffman[21] utilizes a ceramic microleak. This inlet provides a single step reduction of pressure from ambient to 10^{-5} Torr. The low pressure level in the mass spectrometer is maintained by a pnumatically controlled variable conductance valve leading to an ion pump. Either sample delivery system can be accommodated into the integrated mass spectrometer package. The porting and crimping mechanisms of the batch sampling system are indicated in Fig. 3. Figure 4 illustrates a layout of mass spectrometer components based on Hoffman's continuous sampling technique.

Two types of mass analyzers are used in atmospheric mass spectrometer experiments. In the quadrupole mass spectrometer, a quadrupole electric field is established between four rod shaped electrodes. At a given rf voltage, only ions of a single mass-to-charge ratio undergo stable oscillations, traverse the field, and impact on the ion collector. Ions of other mass-to-charge ratios undergo unstable oscillations and do not reach the collector. Sweeping the rf voltage yields a spectrum of masses. In the studies of mass spectrometer accommodation, it was determined that quadrupole analyzers with rods up to 15.2 cm can be positioned in the atmospheric entry probe.

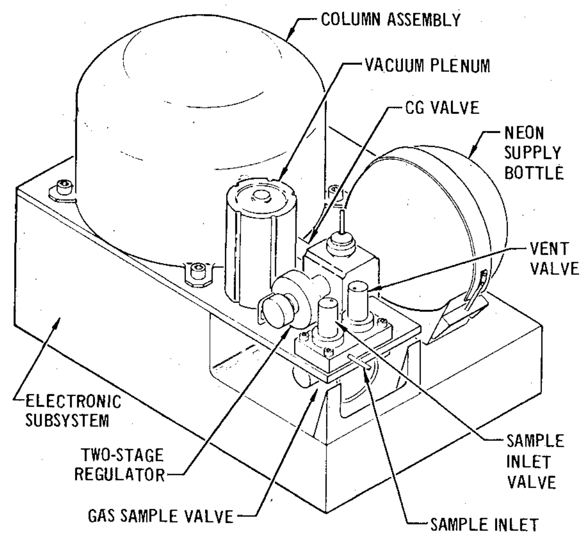

Fig. 5 TRW Inc. design of the gas chromatograph.

The magnetic deflection mass spectrometer carries out the mass sorting of ions in two stages. First, in the electrostatic sector, ions are sorted with respect to kinetic energy and directed into the magnetic sector, where the ions are sorted with respect to momentum. At a given accelerating voltage, only ions of a given mass-to-charge ratio traverse both sectors and arrive at the ion collector. Sweeping the accelerating voltage yields a spectrum of masses. Figure 4 presents a layout of an magnetic deflection mass spectrometer based on a feasibility study by J. H. Hoffman.[21] We conclude that the components and sampling interface specified by Hoffman can be accommodated into the instrument package.

The mass spectrometer data control system controls the sequencing of atmospheric sampling events and the scanning of the mass spectrum. The programmer is energized by an enabling signal from the probe data processor five sec after the deployment of the atmospheric sampling probe at the $-2\ g_E$ level. The mass spectrum is canned by stepping the mass analyzer from peak to peak through a preselected set of mass peaks. For the mass range of 1 to 46 amu, 39 peaks are monitored. Alloting a 10-bit word for each peak height, 390 bits are required per mass scan. With an allowance of 100 bits per scan for instrument performance data, 490 bits are utilized in obtaining a mass spectrum of the atmosphere. Setting the mass spectrometer data rate at 12 bits per sec, the mass range is scanned in 41 sec. If a total of 45 min is available for mass spectrometer sampling, 65 mass spectra are obtained.

Gas Chromatograph

In the gas chromatograph the constituent molecules of an atmospheric sample are separated by passing the sample through a length of small diameter tubing filled with a packing material such as porous polystyrene beads. The sample is conveyed through the column by a chemically inert carrier gas. The constituents of the sample are separated by their relative affinity for the column packing material, the constituent with the least affinity traverses the column first, followed in succession by gases of increasing affinity for the packing material. As each constituent is removed from the column, its presence in the carrier gas stream affects the physical properties of the carrier gas. A detector such as a thermistor, which responds to changes in the thermal conductivity of the gas stream, indicates the presence of the atmospheric constituent. The column retention time identifies the separated constituent; the extent of the change in the physical property of the carrier gas determines the amount of the constituent in the atmospheric sample.

Table 6 Gas chromatograph

VOLUME:	3940 CM^3 (240 IN.^{3})		
WEIGHT:	2.6 Kg (5.7 LB)		
POWER:	9 W		
DATA OUTPUT:	3 SAMPLES x 300 BITS/SAMPLE		
DATA DIGITIZED INTO A SINGLE STREAM BY THE INSTRUMENT'S DATA PROCESSOR			
DATE RATE:	SAMPLE SIZE (BITS/SAMPLE)	SAMPLE RATE (SAMPLE/SEC)	DATA RATE (BITS/SEC)
	300	0.0017	0.5

The design of a gas chromatograph for the outer planets atmospheres is being undertaken by V. I. Oyama. A system level study by TRW Incorporated is part of this effort, and the instrument description is drawn from that study.[22] The basic gas chromatograph has for its objective the detection of hydrogen, helium, oxygen, carbon monoxide, methane, argon, and krypton at concentrations above 0.1% and a measurement of the hydrogen-to-helium ratio with a precision of 1%. This gas chromatograph is illustrated in Fig. 5.

The atmospheric sample for the gas chromatograph comes from the plenum of the mass spectrometer and flows through the gas sample valve of the chromatograph. This component consists of a sample loop enclosed by solenoid valves. At the appropriate time for a chromatographic analysis, the valves are closed, trapping an atmospheric sample in the loop. The sample is transferred to the chromatograph column by sweeping the carrier gas through the sample loop. The carrier gas, which is neon, is stored in a 3 liter pressure bottle.

The gas chromatographic column consists of a 15m length of small diameter tubing packed with polystyrene beads. The tubing is coiled on a cylindrical aluminum spool. The column assembly also contains a thermal conductivity detector along with heaters and insulation to closely control the column temperature.

The basic gas chromatograph weighs 2.6 kg and has a volume of 3940 cm^3 (see Table 6). The capability of the instrument is extended to detect simple organic molecules, water, ammonia, hydrogen sulfide, phosphine, and hydrogen cyanide with the addition of a second, short column with an electron capture detector. This configuration is estimated to weigh 3.2 kg. A further enhancement in instrument sensitivity is achieved by employing an ionization detector in series with the electron capture detector. The sensitivity for the detection hydrocarbons is increased to the parts-per-billion level, but the instrument weight is now 4.1 kg. Additional design studies are being undertaken to increase the capability of the gas chromatograph while reducing its weight, size and analysis time.

Table 7 Backscattering nephelometer

VOLUME:	983 CM^3 (60 IN.^{3})		
WEIGHT:	0.9 Kg (1.9 LB)		
POWER:	2 W AVERAGE		
DATA OUTPUT:	1 BACKSCATTER OUTPUT 1 x 10 BITS		
	2 BACKGROUND LEVEL 2 x 10 BITS		
	3 INSTRUMENT STATUS 3 x 6 BITS		
DATA DIGITIZED INTO A SINGLE STREAM BY THE INSTRUMENT'S DATA PROCESSOR			
DATE RATE:	SAMPLE SIZE (BITS/SAMPLE)	SAMPLE RATE (SAMPLE/SEC)	DATA RATE (BITS/SEC)
	48	0.033	1.6

Nephelometer

The objective of the nephelometer experiment is the detection of cloud layers in the atmospheres of the outer planets. The light-scattering characteristics of the cloud condensates are exploited to detect the presence of the cloud layers. The condensates scatter a beam of light from the nephelometer. A portion of the scattered light is intercepted by the nephelometer collector lens.

The backscattering nephelometer consists of a light source, lenses and optical detectors. The operation of the instrument is shown in Fig. 6. The source is a light emitting diode, which illuminates the atmosphere with 9000 Å light. Three photodetectors are used, one to measure the backscattering of the incident light by the cloud condensates. The other two detectors monitor the background scattering of sunlight at two wavelengths, 3500 and 5300 Å. These components together with the power supply and the data processing electronics are packaged into a single unit. The physical properties of the back scattering nephelometer given in Table 7 are for the instrument designed by B. Ragent and J. Balmont for the Pioneer Venus mission.[11]

The nephelometer is mounted on the aft equipment cover of the entry probe and looks out perpendicularly to the probe axis of symmetry. The nephelometer is recessed within the probe to prevent the accumulation of atmospheric condensation on the windows. A view port is opened in the heat shield at $-2g_E$ (after peak deceleration) just prior to the initiation of the nephelometer measurements.

The data output from the nephelometer consists of three channels of photodetector data at 10 bits/word and three channels of instrument status data at 6 bits/word. The analog output of the detectors is sampled once every 30 sec. A data processor within the instrument digitizes these data and transfers them to the probe data processor at 1.4 bits/sec using a clock signal furnished by the probe.

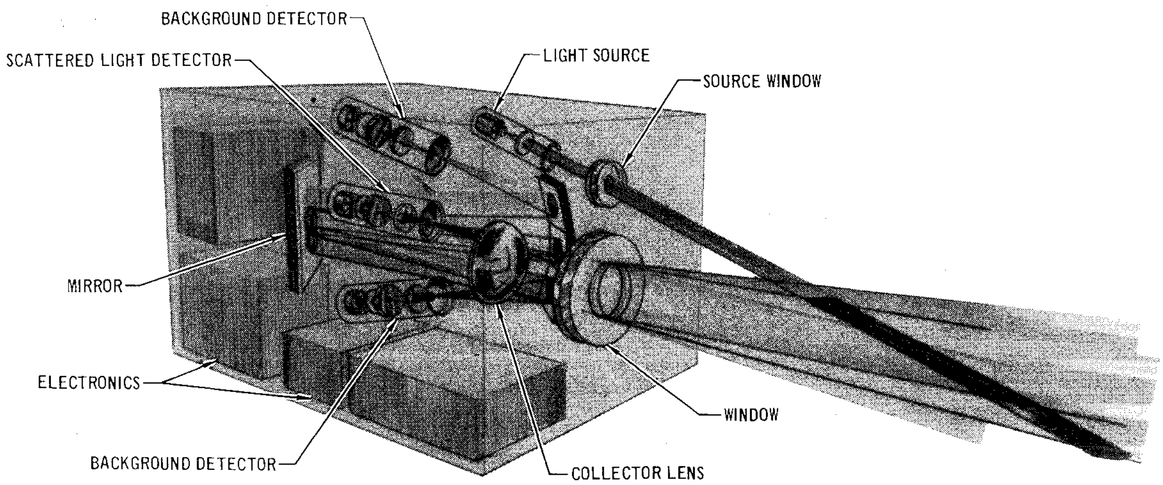

Fig. 6 Backscattering nephelometer.

Summary

The basic complement of seven entry probe instruments make independent measurements of temperature, pressure, density, thermal balance and composition directly within the atmospheres of the outer planets. These measurements are free of the model dependency that is necessary in the interpretation of flyby and orbiter measurements of an atmosphere. Since the entry probe provides a detailed characterization of a very localized region of an atmosphere, while a global view of the atmosphere is obtained from the parent spacecraft, the two vehicles perform complementary scientific functions. The data from the in situ and remote measurements will then be enfolded to yield a comprehensive description of the outer planets and their atmospheres. This philosophy will be implemented in the recently announced Outer Planets Oribter/Probe (Jupiter) mission.

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