



CHEMICAL COMPOSITION MEASUREMENTS OF THE ATMOSPHERE OF JUPITER WITH THE GALILEO PROBE MASS SPECTROMETER

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ABSTRACT

The Galileo Probe entered the atmosphere of Jupiter on December 7, 1995. Measurements of the chemical and isotopic composition of the Jovian atmosphere were obtained by the mass spectrometer during the descent over the 0.5 to 21 bar pressure region over a time period of approximately 1 hour. The sampling was either of atmospheric gases directly introduced into the ion source of the mass spectrometer through capillary leaks or of gas, which had been chemically processed to enhance the sensitivity of the measurement to trace species or noble gases. The analysis of this data set continues to be refined based on supporting laboratory studies on an engineering unit. The mixing ratios of the major constituents of the atmosphere hydrogen and helium have been determined as well as mixing ratios or upper limits for several less abundant species including: methane, water, ammonia, ethane, ethylene, propane, hydrogen sulfide, neon, argon, krypton, and xenon. Analysis also suggests the presence of trace levels of other 3 and 4 carbon hydrocarbons, or carbon and nitrogen containing species, phosphine, hydrogen chloride, and of benzene. The data set also allows upper limits to be set for many species of interest which were not detected. Isotope ratios were measured for $^3\text{He}/^4\text{He}$, D/H, $^{13}\text{C}/^{12}\text{C}$, $^{20}\text{Ne}/^{22}\text{Ne}$, $^{38}\text{Ar}/^{36}\text{Ar}$ and for isotopes of both Kr and Xe.

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INTRODUCTION

The determination of the composition of Jupiter's atmosphere and the comparison with solar abundances is of interest from the point of view of understanding both the nature of the formation of this planet through mechanisms such as direct capture of nebular gas or infusion of icy planetesimals and the subsequent evolution of its atmosphere by precipitation of constituents into the interior. Although remote sensing from Voyager and other spacecraft and from ground based observations had constrained the relative abundance to hydrogen of helium, methane, water, ammonia, and other species prior to the Galileo Probe entry, sampling below the cloud layers was only possible for many species with the in situ measurements enabled by the Probe. Isotopic determinations which had been obtained by earth based

spectroscopy for some species such as deuterium [Smith, *et al.*, 1989, Carlson *et al.*, 1993] could be measured for a broad range of species with an insitu mass spectrometer measurement.

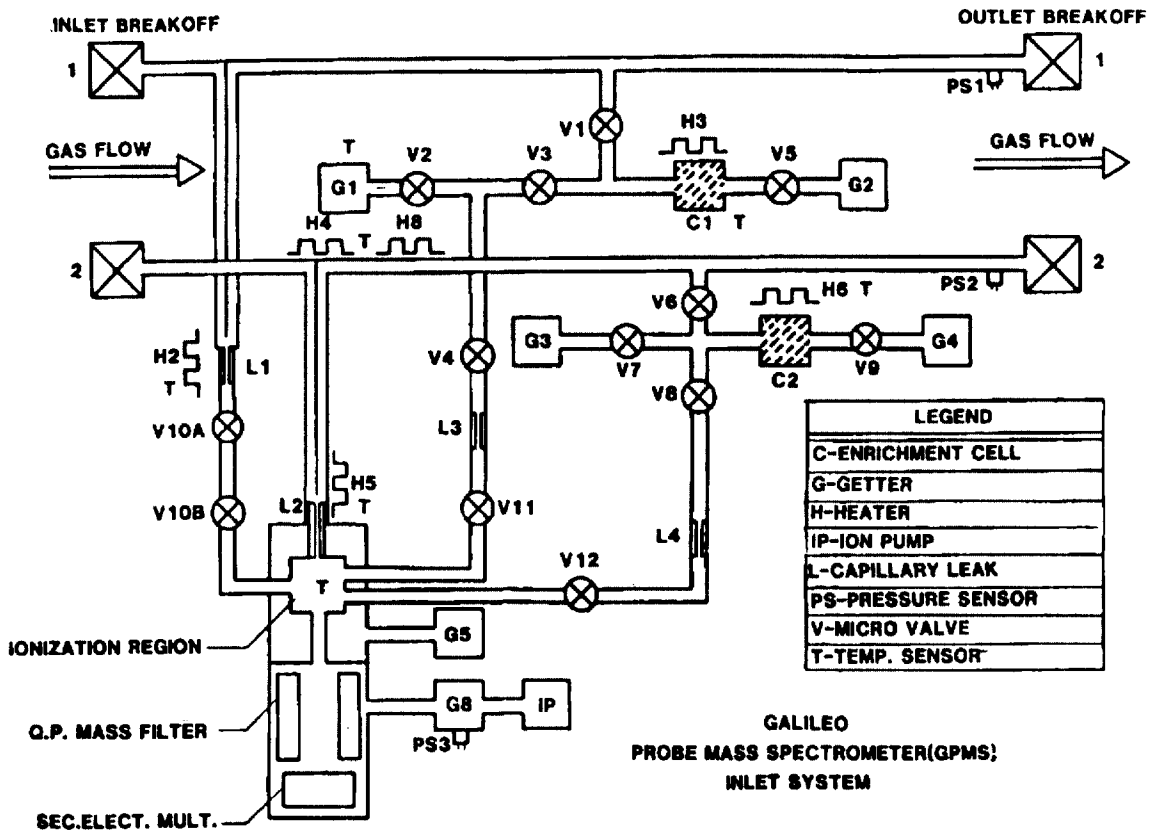


Fig. 1. The GPMS inlet lines, enrichment cells, capillary leaks, micro valves and other instrument elements are schematically illustrated. From [Niemann *et al.*, 1992].

Preliminary analysis of the Galileo Probe Neutral Mass Spectrometer (GPMS) data [Niemann *et al.*, 1996] gave isotope ratios for the noble gases, D/H, and $^{13}\text{C}/^{12}\text{C}$, and abundance ratios to hydrogen for helium, methane, neon, argon, and hydrogen sulfide as well as upper limits to the mixing ratio for water, ammonia, hydrogen chloride, krypton, and xenon in the 9 to 12 bar region of the atmosphere. Continuing analysis of the GPMS data since this preliminary report has established the presence of the additional species ethane, ethylene, and propane, suggested the presence of benzene, as well as carbon and nitrogen containing species, and demonstrated an unexpected and substantial increase in the abundance of water, hydrogen sulfide, ethane and other species with increasing depth into the atmosphere over the 8 bar to 21 bar pressure regime. It has been suggested [Atreya *et al.*, 1996, Neimann *et al.*, 1996, Owen *et al.*, 1996] that this increase with depth may be due to the probe entry into the down welling side of a vertical Hadley type atmospheric circulation cell - a large downdraft which has an atypical abundance of many species compared to their global average. The observed depletion of the volatiles below their respective condensation levels in the Probe region is attributed to condensation followed by precipitation, and subsequent saturation at the colder temperatures, as the gases move upward in the adjacent member of the circulation cell.

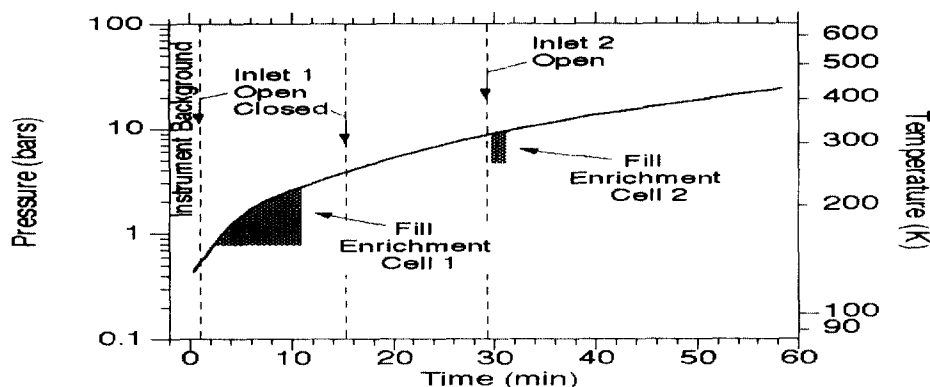


Fig. 2. The sequencing of the 2 separate inlets and the enrichment cell sampling times are illustrated on a plot of atmospheric pressure vs. time.

EXPERIMENT DESCRIPTION

Instrument Description

The instrument has been described [Niemann et al., 1992]. The instrument consists of a quadrupole analyzer mass spectrometer with a mass range 2 to 150 amu. The ion source had a magnetically confined electron beam emitted from a hot filament. The electron energy was nominally 75 eV with occasional 25 eV and 15 eV measurements. The ion detector was an electron multiplier operated in a pulse counting mode. The ion source and analyzer volumes were continuously pumped by a miniature sputter ion pump and by chemical getters. The gas sampling system allowed gas from one of two direct leaks (DL1 or DL2) or from enrichment cells (EC1 or EC2) to be introduced into the ionization region of the mass spectrometer. The operation of one of the enrichment cells was optimized for the detection of rare gases (RG). Several background spectra were taken. The gas sampling system and other instrument elements are shown schematically in Figure 1.

Figure 2 illustrates the time sequencing of the direct atmospheric measurements, the first background measurement, and the sampling of the atmosphere by the enrichment cells over the pressure and temperature ranges encountered by the probe. The gas sampling system allowed atmospheric gas flowing through one of two inlet lines to be sampled directly or after chemical processing by one of two enrichment cells. The later measurements were designed to provide a cleaner noble gas measurement and an increased signal to noise level for trace species. In addition background measurements were taken at 3 intervals during the descent sequence. The measurement sequence over the 6863 integration steps during which data was transmitted and the estimated effect on the pressure in the mass spectrometer ion source is illustrated in Figure 3.

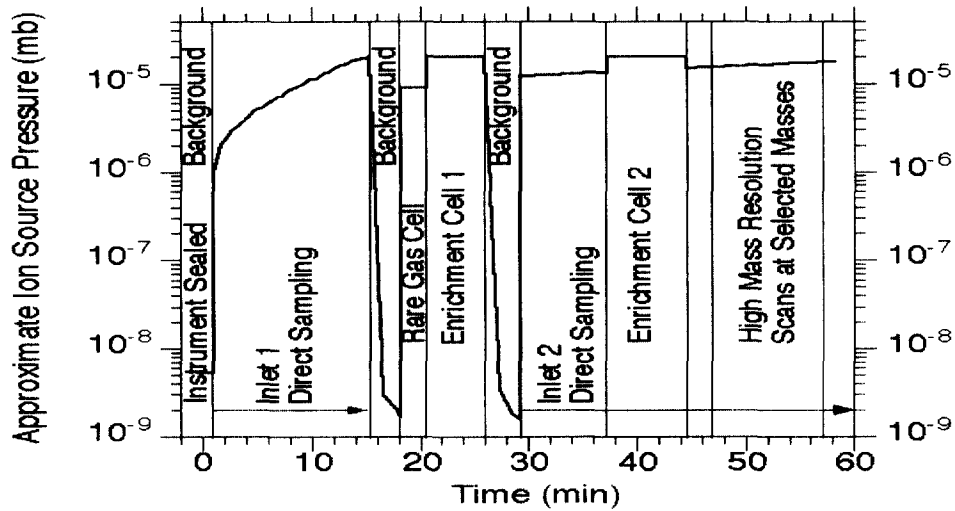


Fig. 3. The descent sequence is illustrated by showing the approximate ion source pressure at various periods during the descent. Background measurement periods and enrichment cell periods are also illustrated

The detailed step number and the time at which each sequence was initiated is summarized in Table 1 together with the approximate temperature and pressure at the start of the sequence as derived from the Atmospheric Structure Experiment [Sief, *et al.*, 1996].

Table 1. Galileo Probe Mass Spectrometer Descent Sequence					
measurement period	step	time (sec)	T (K)	P (bar)	notes on instrument state
B0 (background 0)	0	12	---	---	instrument background
DL1 (direct leak 1)	84	54	130	0.4	V10A and V10B open
B1 (background 1)	1811	917	251	3.8	all source inlet valves closed
RG (rare gas)	2161	1092	268	4.6	V11 open; V2, V3 closed; V4 open
EC1 (enrichment cell 1)	2452	1238	281	5.4	V11 open; V1, V2, V5 closed; H3 on; V3, V4 open
B2 (background 2)	3097	1561	306	7.3	all source inlet valves closed
DL 2a (direct leak 2a)	3482	1753	321	8.6	inlet 2 open; all other source inlet valves closed
EC2 (enrichment cell 2)	4442	2233	353	12.1	V8, V12 open; V7, V9 closed; C2 heated by H6; signal through L4 is added to that from L2 which has no shut off valve
DL2b (direct leak 2b)	5331	2677	381	15.7	V8, V12 closed

Instrument Performance

Although several of the probe experiments were affected by the greater than expected thermal coupling to the probe interior of the Jovian atmosphere [Young et al., 1996], the data set from the mass spectrometer was impacted relatively little. This was due, in part, to the protection of thermal inertia of the internal pressurized housing which had been implemented to avoid electrical discharge at certain pressure levels during the descent. Temperatures in the instrument electronics varied from approximately -10 C several minutes into the descent to approximately 70 C near the end of the probe mission.

The response of the detector to changes in the sampling system for several selected masses over the course of the descent is illustrated in Figure 4. The signal levels during the background measurement periods and the enrichment cell periods indicated that valves and heaters performed as expected

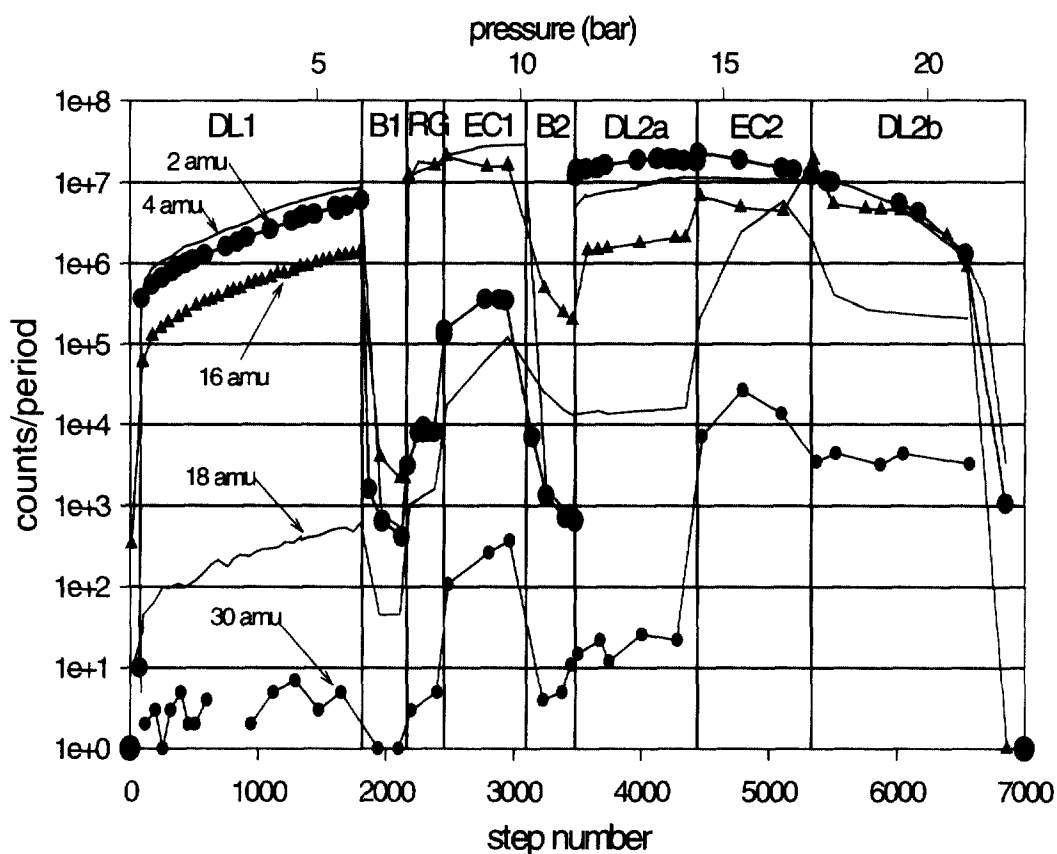


Fig. 4. Detector counts for selected mass values are shown over the entire descent sequence. The primary contributions to masses 2, 4, 16, 18, and 30 are from hydrogen, helium, methane, water, and ethane respectively. Relatively large increases in the count rate at masses 18 and 30 after EC2 are evident.

The counts plotted in Figure 4 have been corrected for detector dead time effects. These corrections are valid over the entire descent for the counts shown at 30 amu, 18 amu, and 16 amu. However, in the later portion of the DL2a region, the EC2 region and the DL2b region the detector is nearly saturated at 2 and 4 amu and for these measurements the form of this correction is not valid. The variation in ratios of the counts/period in the DL1 and the DL2 region for the different masses illustrate the need for independent calibrations for the two capillary leaks. This is true, in general, for each separate species. DL2 introduces the gas into the ionization region in a direct beam path from the end of the capillary leak and a portion of this gas is ionized before it thermalizes with the walls of the chamber. The path to the ionization region from DL1 is more indirect because of the requirement to close valves V10a and V10b after the first segment of the measurement is complete.

COMPOSITIONAL ANALYSIS

Summary of Previous Results and New Findings

Niemann *et al.* [1996] have previously reported abundances of 0.156 ± 0.006 for ^4He , $(2.1 \pm 0.15) \times 10^{-3}$ for CH_4 , $(7.7 \pm 0.5) \times 10^{-5}$ for H_2S and upper limits of $(3.7 \pm 0.35) \times 10^{-4}$ for H_2O , $(3.5 \pm 0.3) \times 10^{-3}$ for NH_3 , $(2.3 \pm 0.25) \times 10^{-5}$ for ^{20}Ne , $(1.0 \pm 0.4) \times 10^{-5}$ for ^{36}Ar , $(8.5 \pm 4) \times 10^{-9}$ for ^{84}Kr , and $(5 \pm 2.5) \times 10^{-9}$ for ^{132}Xe . The helium to hydrogen ratio is in excellent agreement with the value derived from another Probe instrument the Helium Abundance Detector [Von Zahn, *et al.*, 1996]. Methane abundances were derived from measurements in both the DL1 and DL2a region. The minimal interference at mass 17 in the DL1 region allows the $^{13}\text{C}/^{12}\text{C}$ ratio to be established at (0.0108 ± 0.005) [Niemann *et al.*, 1996], identical to the solar value.

The upper limit of 3.7×10^{-4} for water previously reported [Niemann, *et al.*, 1996] was derived from the region just below 12 bar (prior to step 4442 where the enrichment cell measurement was initiated). This value represents a limit of 0.2 times the solar value. However, the data shown in Figure 2 shows that the water abundance increased by the time the enrichment cell experiment EC2 had been completed and direct sampling of the atmosphere resumed at 15.7 bar. This rapid increase in mixing ratio is also observed for several other species and is consistent with the view that atmospheric circulation effects created a large region substantially depleted in condensable species at the higher altitude regions of the probe entry site. Another example is the variation in mass 30 counts with step number, also shown in Figure 2.

The DL2b sequence provides data from the deepest part of the atmosphere sampled before the instrument began to degrade due to the extreme conditions. High quality data was obtained during the DL2b sequence over the pressure range from 15.7 bar to approximately 21 bar. This region shows the greatest number of chemical species in the spectra. In addition to the species listed above we have identified ethane, ethylene, and propane in the spectra. Our preliminary analysis also suggests the presence of trace levels of other 3 and 4 carbon hydrocarbons, of carbon and nitrogen containing species, of phosphine, hydrogen chloride, and of benzene.

Post Encounter Laboratory Calibration

The calibration of the flight unit in 1985 sampled a variety of chemical species postulated to be present in Jupiter's atmosphere. Several of the species identified in the GPMS data were not included in these calibration experiments and we are presently continuing these experiments with a spare GPMS unit. This calibration is necessary for quantification of mixing ratios since the sensitivity of the instrument to different gases varies considerably from species to species due to the gas inlet and pumping systems.

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