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# PLANETARY ATMOSPHERE MASS SPECTROMETRY

N. W. SPENCER

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For presentation at American Astronautical Society meeting, Advance Space Experiments, Ann Arbor, Michigan, September 1968.

# PLANETARY ATMOSPHERE MASS SPECTROMETRY

N. W. Spencer

The present capability for Earth atmosphere composition determination by mass spectrometry makes possible in situ qualitative and quantitative measurements of the constituents of the atmospheres of the two nearest planets, Mars and Venus. Neutral particles mass ranges which are expected to extend from hydrogen to carbon dioxide in the case of Venus, and from hydrogen to krypton for Mars, are well within the capabilities of existing instruments. Available techniques allow measurements over a large pressure range, which may be as high as 125 atmospheres at the Venus surface, to the present limit of detectability, about $10^{-9}$ torr, several hundreds of kilometers above the surfaces of both planets. Ion spectrometer systems, also providing new knowledge of the thermal ion properties of the Earth's magnetosphere, can be used in planetary atmospheres studies to resolve pressing questions regarding the nature of the ions in those atmospheres.

Advanced digital techniques now permit low data-rate systems which search the full mass range, then measure and record only those masses that exceed the in situ-determined noise level by a fixed amount. Thus the systems make very efficient use of data systems, adapting instrument operation to the composition of the atmosphere. Systems appropriate to Mars and Venus are now being prepared for flight tests. The instruments weigh about 10 pounds, require about 10 watts and are sterilizable.

## INTRODUCTION

Of fundamental importance in the study of a planet, its evolution, and the physics of its interaction with the sun's radiation, is knowledge of the planet's atmosphere. Key parameters are the constitution of the neutral particle atmosphere – that is, the composition of the gas with which the incident solar radiation reacts – and the constitution of the ionized component. Also important for understanding the dominant energy transfer processes in the atmosphere are the temperatures of all the constituents – the neutrals, the electrons, and the ions – which may be inferred from their altitude profiles. Knowledge of these properties permits estimation of biological and evolutionary aspects of the planet, all pertinent to study of the origin of the solar system.

The present state of space exploration technology and research is sufficiently advanced to allow qualitative and quantitative measurements, in situ, of the atmospheric constituents for the two nearest planets, Mars and Venus. This has been clearly demonstrated by Venera 4, the successful Russian entry probe, which greatly advanced our knowledge of Venus. A considerably greater understanding of these planets can be gained with the more definitive atmosphere measurements that are possible with mass spectrometer systems, in contrast to the rather crude but partly effective devices employed on Venera 4. This paper describes the conceptual basis for and the details of two systems, representative of the existing instrumental technology in atmospheric composition determination, which can be applied to this problem.

Earth atmosphere studies embodying in situ measurements, which have now passed from the exploratory to the research phase, provide a background of experience on which we can draw in exploring planetary atmospheres. Direct measurement of the qualitative composition of Earth's upper atmosphere is an accomplished fact; and quantitative evaluation of key constituent concentrations, for example of atomic oxygen and ozone, is beginning to be realized. Similar measurements are required in the planets' atmospheres. Other factors clearly essential to planetary exploration are launch vehicle capability, communication data rate, and matters of systems and subsystems reliability; and all have been demonstrated to be attainable. An example is a particularly striking and significant technological advance in the data-rate achieved for Mariner '69, to be launched in February 1969 to Mars, as compared to that of Mariner IV; 16 kilobits per second are realizable today in contrast to 8 bits per second 4 years ago.

## Present Knowledge of the Venus Atmosphere as it Applies to Spectrometer Design

Information from the U.S.S.R. Venera 4, the U.S. Mariner 5, Earth based radar, microwave radiometry, and IR observations permits a new level of confidence in our concept of the Venus atmosphere.[1,2] A year ago, before Venera 4 and Mariner 5, estimates of the surface pressure ranged from a few to a few hundred Earth atmospheres, and the composition was considered on the basis of Earth based observations to be dominated by $CO_2$. Venera 4, apparently the first successful entry probe, was at first thought to have reached the planet's surface. It indicated the surface pressure to be about 18 atmospheres, the corresponding temperature to be 550°K, and the composition to be more than 90% $CO_2$. Mariner 5 however, though mainly confirming these results, raised a question through analysis of its trajectory that the altitudes assigned to the Venera 4,data were not correct and thus that the spacecraft did not transmit all the way to the planet's surface. At this writing, new analyses of Earth based radar-determined radii of Venus seem to confirm this belief. Thus there remains little doubt that the surface pressure is considerably higher than the last value measured by Venera 4, and it may be as high as 120 atmospheres. The corresponding temperature at the surface, based on the measured lapse rate, would be about 750°K, in reasonably good agreement with the early microwave indications. No additional data relative to the lower atmosphere composition were obtained by Mariner 5; thus the Venera 4 results confirming the presence of $CO_2$ are still the most recent and also are generally accepted. These results are summarized and discussed in a recent paper by Jastrow[3] and will not be further considered here, except as summarized in Table 1.

Regarding potential planetary atmosphere mass spectrometry, however, one may now choose, with reasonable confidence, realistic system design parameters. $CO_2$ is taken as the overwhelmingly predominant component of the lower atmosphere, and also as the most massive except for possible volatiles associated with cloud material, which could represent significant minor constituents. It was claimed that Venera 4 also indicated measurable concentrations of water vapor and oxygen, and nitrogen although the latter was not "measured." One can only accept the data regarding gases other than $CO_2$ with skepticism, and thus mass spectrometers for use in the lower atmosphere of Venus must be designed to measure $CO_2$ and other possible gases. The upper mass limit can be taken as $CO_2$ for the "nominal" atmosphere, but can conceivably extend to masses of 200-300 amu, depending upon estimates of cloud material. For example, mercuric chloride (278 amu) has been suggested as a cloud constituent.

With respect to the upper atmosphere, Venera 4 and Mariner 5 indicated measurable quantities of only $CO_2$ and hydrogen; oxygen was not detected. This was surprising because of the anticipated dissociation of $CO_2$ which would produce significant quantities of CO and O. For this reason, mass spectrometer systems intended for Venus (and the Martian upper atmosphere where the same result may be obtained), should be arranged to indicate the presence of all masses from 1 amu (H) to at least 44 amu ($CO_2$), to support or contradict these results.

Thus, in summary, the following design parameters for mass spectrometer systems for use in the Venusian atmosphere are selected:

Table 1

VENUS ATMOSPHERE PARAMETERS FOR MASS SPECTROMETER DESIGN PURPOSES

Lower Atmosphere

Surface to 100 km ($10^{-1}$ torr)

| | | |
|---|---|---|
| Pressure Range: | 120 atmospheres | – $10^{-1}$ torr |
| Temperature Range: | 750°K | – 200°K |
| Mass Range: | $H_2$ | – $CO_2$ (2-44 amu) |

Upper Atmosphere

100 km ($10^{-1}$ torr) to exosphere

| | | |
|---|---|---|
| Pressure Range: | $10^{-1}$ | – $10^{-9}$ torr* partial pressure |
| Temperature Range: | 250°K | – 1000°K |
| Mass Range: | H | – $CO_2$ (1-44 amu) |

---

*Estimated limit of detectability

## Present Knowledge of the Mars Atmosphere as it Applies to Spectrometer Design

There have been many estimates of the Martian surface pressure during the past few years ranging from a few millibars to a few hundred. However, recent spectrographic determinations[4], and the Mariner 4 occultation experiment[5] indicated the surface pressure to be about 10 mb, a value accepted until additional measurements can be made. In this case, the dynamic range demands for measuring composition are substantially less severe than in the case of Venus. $CO_2$ is the dominant lower atmosphere constituent as shown on several occasions by spectrographic observations, and by Mariner 4 data. There are gross uncertainties regarding other constituents, none of whose presence has been confirmed. It is generally assumed that $N_2$ makes up most of the balance of the lower atmosphere, if it is not nearly all $CO_2$. Planetary evolution processes suggest that several other gases such as $H_2O$, $CH_4$, $A_r$, Ne and Kr may also be present. There is a suggestion also that higher order hydrocarbons are present, although again not qualitatively confirmed.[6] Possible contributions from cloud material corresponding to mass numbers above 90 are not considered here.

Thus, in summary, the following design parameters for mass spectrometers for use in the Martian atmosphere are selected as shown in Table 2.

Table 2

MARS ATMOSPHERE PARAMETERS FOR MASS SPECTROMETER DESIGN PURPOSES

Lower Atmosphere

Surface to 40 km ($10^{-1}$ torr)

Pressure Range: 25 mb – $10^{-1}$ torr
Temperature Range: 300°K – 150°K(?)
Mass Range: $H_2$ – Kr (2–90 amu)

Upper Atmosphere

40 km ($10^{-1}$ torr) to exosphere

Pressure Range: $10^{-1}$ torr – $10^{-9}$ torr*
Temperature Range: 150°K(?) – 1000°K
Mass Range: H – $CO_2$ (1–44 amu)

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*Estimated limit of detectability

## Pressure Range Considerations in the Use of Mass Spectrometers

All mass spectrometers identify particular gases by a sorting process that depends upon the charge-to-mass ratio of the gaseous ions. Since the gases are handled on a particle basis, the density of the ions being sorted must always be sufficiently low to avoid significant interaction among ions or between ions and neutral particles. Thus, the analyzer section of the spectrometer is always maintained at a low pressure, regardless of the density of the atmosphere being sampled. For regions of the atmosphere where the pressure is about a $10^{-3}$ torr or less, no pressure reducing elements are necessary. For higher densities however, various techniques can be used to provide the necessary reduction.

The following summary indicates typical pressure requirement and techniques that can be used to achieve the required density reduction:

(a) $10^{-4}$ torr to limit of sensitivity: corresponds to the thermosphere and higher regions of a planetary atmosphere where no reduction is required.

(b) $10^{-1}$ torr to $10^{-4}$ torr: corresponds to the Martian atmosphere from about 40 to 100 km. Ionizing sources can operate throughout this range, but pressure reduction in the form of a very small orifice or slit between the source and the analyzer is required. Analyzer pumping is required for long-time operation.

(c) 10 atmospheres to $10^{-1}$ torr: this range includes the lower atmosphere of Mars and possibly that of Venus from altitudes of tens of kilometers upward. A "leak" in the form of sintered stainless steel or a small (microns size) hole in a diaphragm can effect the necessary reduction between the atmosphere sampling port and the ion source.

(d) High pressure (~100 atm) to 10 atm: corresponds possibly to the lower atmosphere of Venus. Conventional pressure reducing valves can be used, in conjunction with the "leaks" noted above.

## Possible Missions for Ion and Neutral Spectrometers

The need to know the ion constituents is, at least for the present, confined primarily to the upper atmospheres of the planets. Ion spectrometers at present in use in Earth atmosphere studies can answer the more pressing questions about the planetary ionospheres. They are applicable for measurements in orbiters and probes or on any vehicle which penetrates the charged particle (thermal energies) regions about the planets.

Because of the greater sensitivity of ion spectrometers (neutral particle instruments must ionize the particles before detection and are thus generally less sensitive by about a factor of at least 100), ion spectrometers are useful for measuring much lower particle densities. Typical sensitivities for ion spectrometers without multipliers can be as high as 1 - 10 ions per cc, a value which can be increased by electron multipliers. Enhancement of the sensitivity is possible also by use of negative "drawing-in" electrodes around the spectrometer inlet.

Neutral particle instruments, although less sensitive, are also available and suitable now for in situ measurements, and can be adapted to orbiters, probes and landers. Instruments appropriate to atmosphere measurements on Earth or planetary spacecraft can uniquely identify the presence of major constituents and minor constituents in concentrations as low as 1 part in $10^5$ or $10^6$. Typical sensitivities of developed systems without multipliers are about $10^{-5}$ ampere per torr; this corresponds to a detectability limit of about $10^7$ particles per cc which, a suitable electron multiplier may increase to possibly $10^2$ particles per cc. This sensitivity is adequate for measurements at altitudes of several hundreds of kilometers above Mars or Venus. Because the neutral atmospheres of these planets are probably in diffusive equilibrium, measurement of the neutral particle concentrations over an altitude range of tens to hundreds of kilometers can provide a description of the nature of the planet's entire thermosphere-exosphere.

Thus, both ion and neutral concentrations can be determined in the upper atmospheres of both Mars and Venus from altitudes of about 100 km to at least several hundred kilometers, by mass spectrometric techniques. Orbiters (and of course fly-by's) at suitably greater altitudes, and atmosphere-entry probes provide satisfactory platforms; here, however, many technological requirements must be considered, including instrument pointing direction, velocity, data rate, etc., all strongly influencing the measurement systems' design.

For the lower atmosphere (defined as the region below altitudes where the local particle mean-free-path exceeds the particle-sensitive major dimensions of the measuring instrument by perhaps a factor of 10 - 100), mass spectrometers offer equally useful and probably unique capabilities. Additional features are required to insure that the gas particle density in the ion source has been reduced to a suitably low value, by some means such as a "leak." As noted above, a "leak" can take the form of a very small (micron size) hole in a diaphragm, or a filter arrangement using sintered stainless steel; both of these have been developed.

## Present Spectrometer System Characteristics

Although there have been spectacular advances in all regards in the capabilities of space vehicles launched to the planets, the present designs still pose demanding and challenging problems for the mass spectrometrist and the electronic system designer. Weight, power, data transmission, reliability, and the wide dynamic range necessary in an uncertain environment set compelling and challenging limits. Sterilization requirements are still imposed by firm international agreement to avoid possible contamination of a planet by organisms by Earthly origin. However, this is less problematical now than a few years ago, because of reduced requirements and improved components. Also, the advent of solid state microcircuits and new concepts for timing, voltage, and control circuits philosophy, all hand-in-hand with the growth of digital techniques, have made possible new system approaches in which we can have high confidence.

A number of years of spectrometer system development effort at Goddard Space Flight Center and the Jet Propulsion Laboratory, and other laboratories have accompanied these advances. These efforts have led to potentially very useful instruments whose general characteristics can be summarized as follows:

## Weight

Because launch vehicle and spacecraft capability for planetary missions have advanced rapidly, extensive effort has not been expended to reduce spectrometer system weight. Nevertheless, the weight for a planetary mass spectrometer system, including the spectrometer tube and associated electronics, has been reduced to about 10 pounds. This does not include, for example, the weight of devices required to reduce the gas density at the Venus surface to a value acceptable for mass spectrometry. The addition of that capability may add an additional 2 pounds to the system weight. Mars instruments would not require pressure reducers.

## Power

Spectrometer systems generally require about 10 watts when operating. In the case of neutral particle systems using hot-filament electron sources, about half of this can be attributed to filament heating. Smaller, less power-consuming filaments (0.001 inch in diameter, using about 4 watts including regulator) are reducing this power requirement. Logic and control power are not decreasing greatly because of increases in logic and control complexity that parallel the growth of system sophistication.

## Data Rate Requirement

Substantial reductions in the data rate needed to transmit useful composition data have come about relatively recently. This major advance, taken with the equally substantial increase in spacecraft communication system data rate noted above, has largely solved a most pressing problem that once precluded adequate quantitative measurements of atmosphere composition. These advances have been made possible by the remarkable improvements in electronic data handling and logic systems, coupled with the vastly reduced power requirements of those systems. The stability now achievable in frequency and voltage levels, and the great flexibility and simplicity made possible by digital advances too, have provided systems unattainable a number of years ago.

In data rate terms, systems which scan and transmit the mass spectrum and so require a continuous and substantial data rate can, while clearly making possible the largest dynamic range, be sacrificed in favor of low data-rate techniques. These low data rate systems are arranged to search for measurable mass peaks, evaluate the peak maxima and then form appropriate digital words for transmission when called for. The former approach demands, usually, a rate of thousands of bits per second, while the latter now requires only a few hundred bits per second. This significant advance is being enhanced daily as a direct result of continuing advances in digital electronics.

## Dynamic Range

A less dramatic yet substantial improvement has been realized in sensitivity and the signal-to-noise ratio in spectrometer systems. This leads to greater dynamic range, and compensates for the inherent loss in sensitivity experienced in using peak-reading systems as discussed above. These gains have been possible largely as a result of advances in digital current measurement and data handling systems; with the addition of electron multipliers and pulse counters, such systems now permit detection of a very small number of individual ions, thus extending the low pressure limit. The development of high pressure ionizing sources and leaks has extended the high pressure limit. Present systems thus have adequate dynamic range to permit (a) measurements from the surface of Mars and/or, with pressure reducers, Venus, to altitudes well into the thermosphere where diffusive equilibrium is assumed to hold; and (b) detection of possibly significant minor constituents.

## Example of Mass Spectrometer Systems: Neutral Particle System

The spectrometer system under development at Goddard Space Flight Center* for quantitative analysis of the Mars and Venus atmospheres employs a quadrupole electrostatic analyzer. Four parallel rod-electrodes, usually circular in cross-section, but having a hyperbolic surface (in this case) for improved resolution, (Fig. 1) comprise an ion-filter when appropriate rf and dc voltages are applied. That is, the electrostatic field established causes the electrode arrangement to pass essentially all ions of a particular e/m ratio, while inhibiting the passage of and providing a sink for ions of other charge-to-mass ratios. Adjustment of these voltages permits selection of the particular ion mass to be measured. The literature provides a number of referenced articles which discuss the properties of quadrupole mass filters.[7]

The addition of an ion-source, in this case employing an electron beam to ionize the gas sample neutral particles – and an electron multiplier, complete the sensor system as shown in block diagram form in the upper left corner of Fig. 2. Fig. 3 illustrates the electrode arrangement of the ion source which permits measurement of high densities – in this case corresponding to a pressure of $10^{-1}$ torr, several orders of magnitude higher than conventional sources. Its output current/source pressure characteristic is shown in Fig. 4. Small dimensions, and particularly a very small ion exit aperture (0.004 × 0.005 inches) between the source and the analyzer, a small (0.002 × 0.002 inches) electron entrance aperture, and relatively high electrode voltages, make this improvement possible.

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*System developed by members of Aeronomy Branch, and Experiment Engineering Branch, Laboratory for Atmospheric and Biological Sciences.

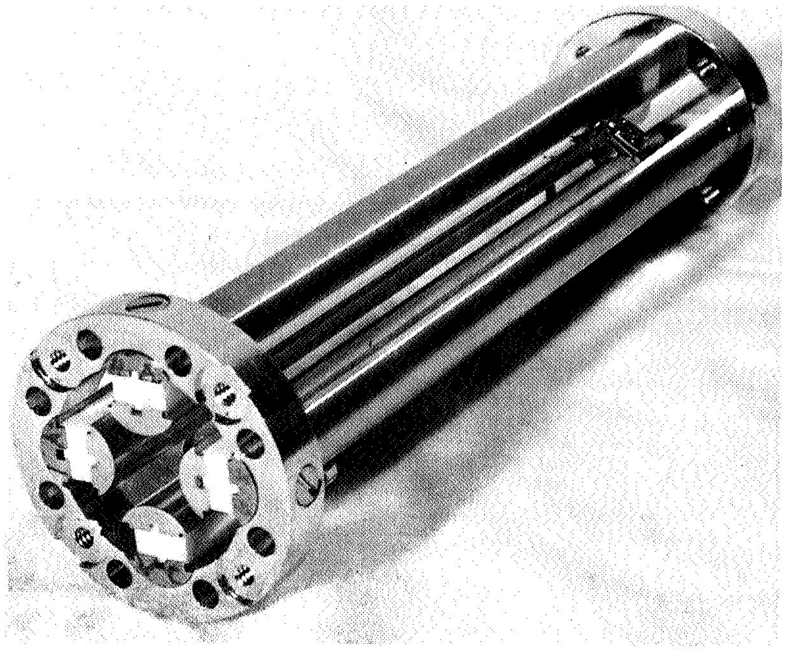

Fig. 1 Photograph of the analyzer section of a planetary quadrupole mass spectrometer instrument. The inner surfaces of the 4 rod-electrodes have hyperbolic surfaces to enhance the resolving power of the instrument.

Quadrupole spectrometer systems used in Earth atmosphere studies vary rf and dc power sources so that the useful mass range of the instrument (20-50 amu) can be scanned in time. A multirange linear electrometer, or a log amplifier, together with a pulse-counting device*, or a combination of these, convert the electron multiplier output current to a voltage suitable for telemetry. The electrometer output constitutes the telemetry signal; during a mass range scan it contains signal, noise or both, requiring in any case a continuous channel, often with a high data rate.

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*(counts as pulses groups of electrons produced at the output of an electron multiplier as a result of an individual ion arriving at the entrance dynode of the multiplier.)

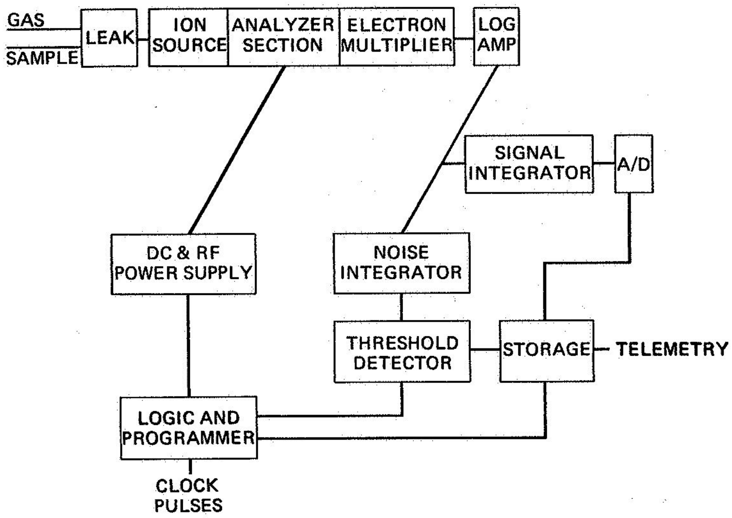

Fig. 2 Block diagram illustration of the Goddard Space Flight Center planetary quadrupole mass spectrometer system. The system employs a crystal-controlled digital rf oscillator system and an adaptive-scan logic and control system.

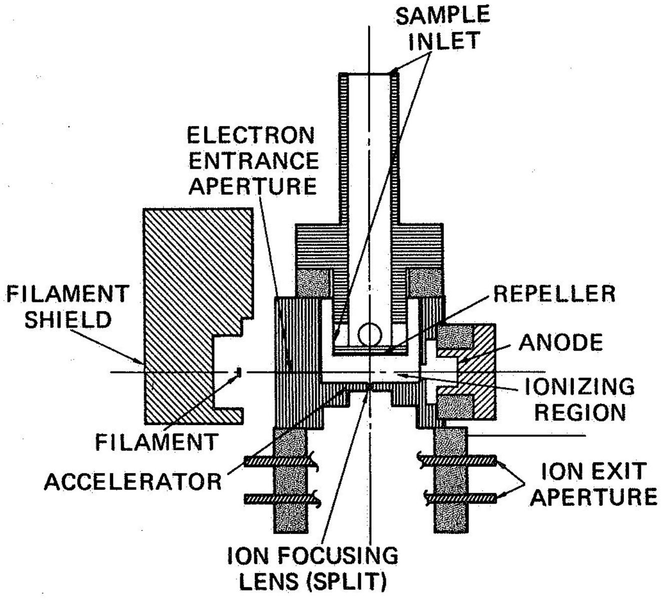

Fig. 3 Drawing of a "high pressure" ion source useful for ionizing gases with pressures as high as $10^{-1}$ torr.

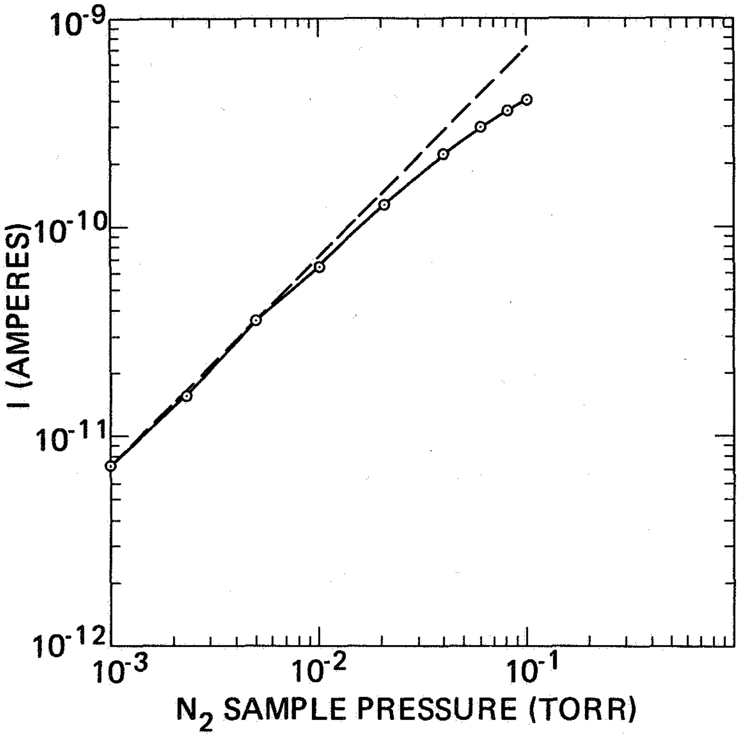

Fig. 4 Sample pressure/ion current characteristic of "high pressure" ion source.

Recent advances now permit systems with much lower data rates, whose performance in terms of minimum detectable signal closely approximates that of the more conventional systems. These advances seem to make it clearly preferable to use non-magnetic mass spectrometer systems, such as the quadrupole, in which mass separation is effected by electric rather than magnetic fields. In effect, one can trade the difficulty of mechanical and magnetic design, and attaining magnetic field stability for circuit complexity, which can be more readily and satisfactorily dealt with. In other words, the rapidly advancing electronics technology is accelerating the learning curve for spectrometer systems using electrostatic analyzer arrangements such as the quadrupole; in contrast, leveling appears to be the trend in magnetic systems.

The quadrupole system discussed here, which reflects these concepts, has been developed to optimize data systems capability. It employs the adaptive scan approach, that is, is searches for a mass of sufficient concentration to provide a useful measurable output signal and then measures and stores the magnitude of the output signal using only a single digital word. It also records the identity of the mass of the gas measured. During a scan of the mass range however, the system automatically "by-passes" masses that are indistinguishable from noise to use the data channel most efficiently. Thus the system measures and records only those signals (gases) which have a preselected and useful S/N ratio.

Figure 2 illustrates the overall system in block diagram form. The power supply provides both dc and ac voltages generated by a multiple-crystal-controlled oscillator. These, under control of the logic, establish a series of discrete, sequential rod voltages for each integral mass from 1-90 amu. The cycle starts at a mass number known to correspond to a gas not present in the atmosphere sample, for example, amu 10. This permits evaluation of the threshold or noise level of the system, by the noise integrator. Although both the noise and signal integrator detect the noise output of the log electrometer, the noise integrator provides, in 3 milliseconds an integrated level to the logic, which is multiplied by 20, stored and used as a reference for comparison with the output of the signal integrator. If the signal integrator output does not contain a sufficient signal component to exceed the noise integrator output, the logic steps the rod voltages for the next mass number, and resets the signal integrator, permitting the procedure to be repeated. When the system steps to a mass number where the signal integrator output is significant, i.e., exceeds by 20X the noise integrator output, the electrometer output is integrated for 30 ms, converted to digital form by the A/D converter and stored, this provides in the memory, a measure of the detected gas for transmission to Earth.

This process is repeated for every mass number, but only those producing significant outputs as compared with the integrated noise level reference are converted to digital form and stored for telemetering. Thus, the system searches sequentially through all masses at a rapid rate, slowing the scan rate only to measure those exceeding a preselected level which is referenced to the system noise level. The integrated noise level is updated several times during each mass range cycle, insuring that the reference optimally reflects the threshold S/N ratio independently of electrometer and electron multiplier drifts; such drifts cannot adequately be anticipated, but usually occur.

A system of this nature, in which a single data word suffices for quantitative measurement of a mass peak, is feasible only because of the readily attainable 100% transmission, or flat-topped peak, and stable characteristic of the quadrupole. Thus one can "program" discreet rod voltages, mass by mass in any desired order, or the system can be 'tuned' to a particular mass, confident that maximum ion transmission will be realized and that output signals proportional to the sample gas density will be measured. The data rate required by this system is a function of the number of masses existing in the sampled atmosphere, and the spectrum location identification. The time required to scan the predetermined total mass range is thus determined by the number of gases present in the atmosphere being measured, and varies in length accordingly.

## Ion Mass Spectrometer System

For the quantitative detection and measurement of the positive-ion constitution of planetary atmospheres, a system using a Bennett ion spectrometer sensor has been derived from systems in use in Earth satellites*, such as the OGO and the Atmosphere Explorer series. The planetary design, like the neutral spectrometer discussed above also employs a data system optimization scheme. In this case, however, flat-topped peaks

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*Developed by members of the Aeronomy Branch, Laboratory for Atmospheric and Biological Sciences.

are not possible and thus the output signal maximum is measured by a "peak-detecting" device.

Fig. 5 is a block diagram of the system and Fig. 6 is a photograph of the rf spectrometer tube employed. The tube is simple in concept, using a series of insulated parallel grids carefully spaced and held in place by a (brazed) ceramic structure. It has a very large entrance aperture as compared with most spectrometers which affords high sensitivity in spite of the relatively low ion-transmission efficiency (5-10%). The mass selection capability of the tube derives from the coincidence of the drift time of ions of a particular mass between groups of grid triplets and the period of a suitable rf voltage applied to the grids as described in the references. No ion source is required, as the purpose is to detect and measure ambient atmospheric ions. An electron multiplier is not usually employed, for conventional electrometer systems lead to overall system sensitivities, in atmospheric terms, of the order of 1-10 ions per cc. The ions of a particular charge-to-mass ratio reaching the collector of the sensor comprise a current which is measured by several linear electrometers of sensitivities differing by a factor of 10 which together provide a dynamic range of 3-5 orders of magnitude as required.

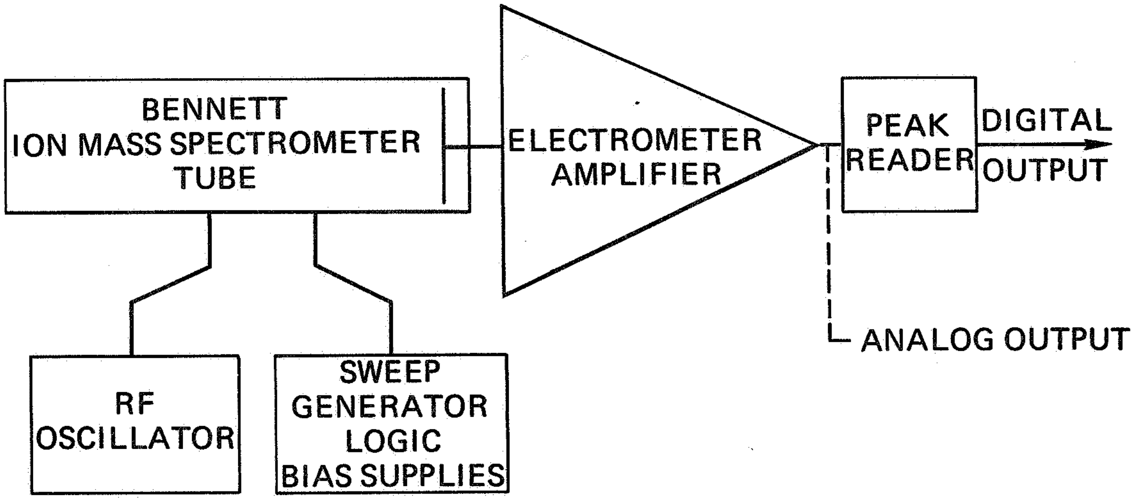


Fig. 5 Block diagram illustration of positive-ion mass spectrometer system.

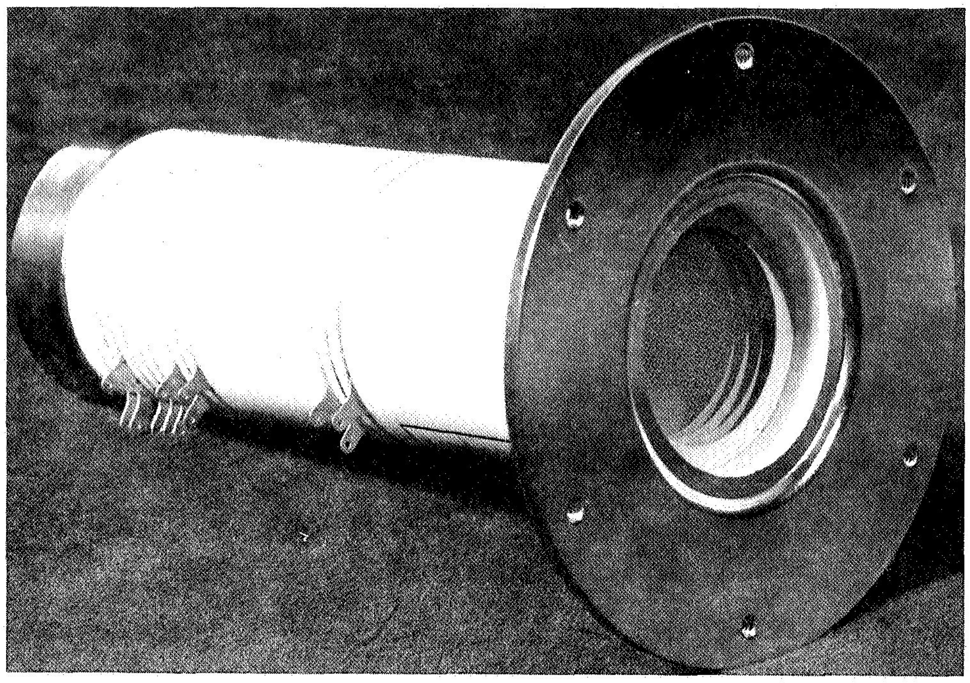


Fig. 6 Photograph of Bennett ceramic ion spectrometer sensor showing grid assemblies.

The peak-detecting system searches among the electrometer outputs and selects that which is on-scale. It then periodically (100 times/second) converts the output signal to digital form, and compares this value to a previous digitized value. If the most recently digitized value exceeds the reference value, the value is replaced in the interim-storage register. This procedure continues, (while the system is mass-number scanning) the magnitude of the value in interim-storage continuously being replaced, provided the newly digitized value exceeds the stored value by 3 db. When the maximum of the ion current peak has been attained (a subsequent value reflecting a decrease of 3 db) the value in the interim-storage is transferred to regular storage, where it remains until called for by the logic/ telemetry system of the spacecraft.

Fig. 7, a photograph of a telemetry record of a test flight of this system, illustrates the technique. The lower three traces are the outputs of 3 electrometers whose sensitivities differ by factors of 10 as noted. The

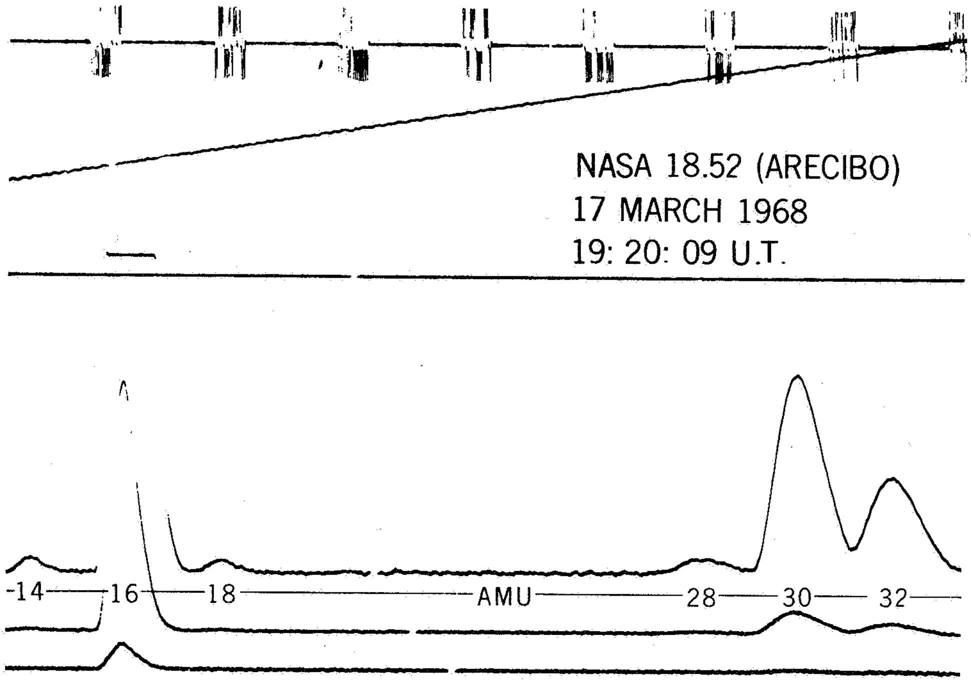


Fig. 7 Photograph of a portion of a telemetry record from an Earth atmosphere flight. The lower 3 traces represent the outputs of 3 electrometers with sensitivities differing by factors of ten. The upper trace conveys, in analog form, digital representations of peak heights and mass identification.

next trace is a reference level, and the next represents the linear sweep rate of the system. The top trace contains the digital output, corresponding to mass peak magnitude and identification, provided by the peak detecting system.

Fig. 8 shows oxygen ion densities, measured in the Earth's upper atmosphere, during a flight test. The two sets of data points shown were obtained from both the peak reading system, and the usual technique of measuring peak deflections on the analog telemetry record. It can be seen that the results of the two techniques agree rather well. Reference to Fig. 7 demonstrates that a dramatic savings in data rate has been accomplished by the peak reading device.

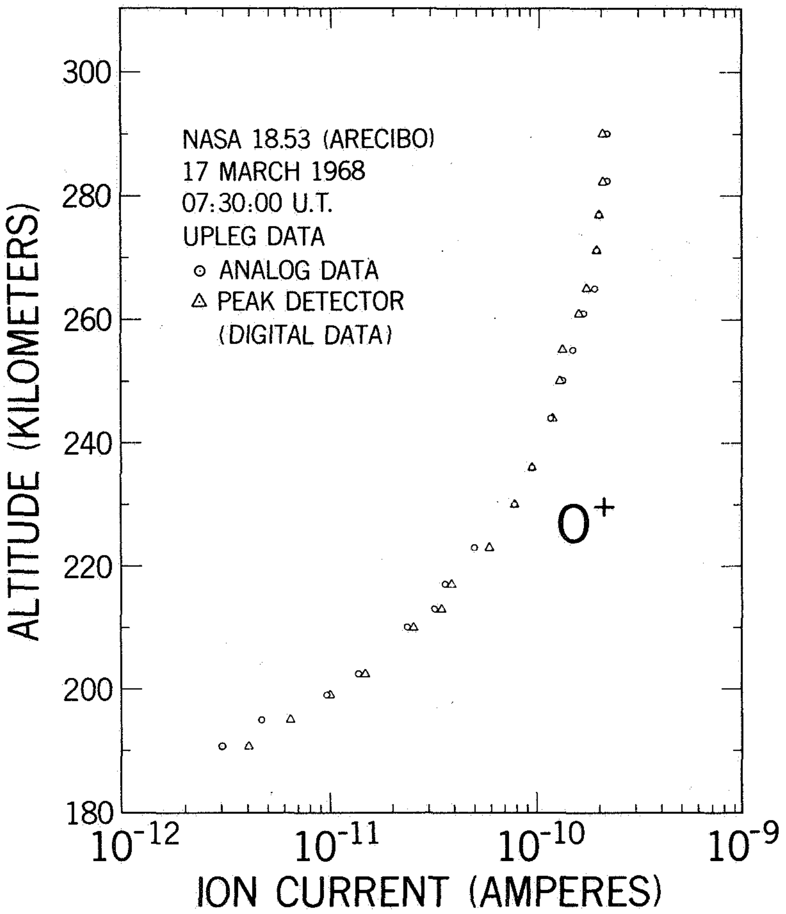


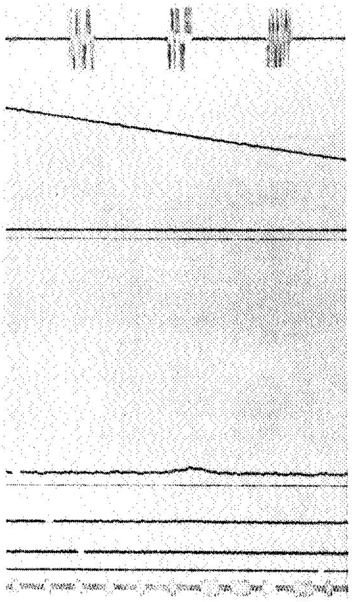
Fig. 8 Earth atmosphere atomic oxygen ion profiles obtained from a test flight. Results from both a typical analog telemetry system and a peak detecting digital system are shown for comparison.

Finally, Fig. 9, similar to Fig. 7, but showing a portion of the flight where the signal-to-noise level was much less, illustrates the present limiting signal-to-noise ratio capability of the system. This example corresponds to a sensitivity of about 10 ions per cc.

The overall characteristics of the system are shown in Table 3.

## SUMMARY

Mass spectrometer systems suited to in-situ measurements of both neutral and charged particles are available and offer a unique capability for study of planetary atmospheres. Although two specific types intended for Mars



NASA 18.53 (ARECIBO)
17 MARCH 1968
07:30:00 U.T.

FLIGHT TELEMETRY RECORD SHOWING ANALOG PEAK AND CORRESPONDING DIGITAL READOUT OF $O^+$ ION CURRENT NEAR THE LIMITING SENSITIVITY OF THE INSTRUMENT

Fig. 9 Photograph of a portion of an ion spectrometer test flight telemetry record illustrating a near-limiting sensitivity case. The digital peak detecting system operates satisfactorily at this signal-to-noise level, which is also easily detectable in analog form.

Table 3

SUMMARY CHART OF POSITIVE-ION MASS SPECTROMETER CHARACTERISTICS

| | |
|---|---|
| DYNAMIC RANGE (1-45 AMU) | ION CURRENT: $1\times10^{-14}$ TO $5\times10^{-9}$ AMPERES<br>ION CONCENTRATION: 1 TO $1\times10^{5}$ IONS/CM$^3$ |
| WEIGHT | 8 POUNDS ± 10% |
| SIZE | 6 IN. × 6 IN. ×10 IN. |
| POWER PROFILE | 4 WATTS, ± 10%, FULL ON IN ALL MODES |
| DATA RATE | 10 BITS PER SECOND |
| COMMANDS | NONE |
| TEMPERATURE ENVIRONMENT | FUNCTIONAL: 0° TO 50°C<br>STORAGE: -10° TO 60°C |
| SPATIAL RESOLUTION (ALONG ORBIT) | 50-100 KILOMETERS |

and Venus use, have been chosen for development at Goddard Space Flight Center, and are discussed in this paper, it should be recognized that there are many other possibilities. Magnetic deflection instruments, both single and double focussing, and monopoles can be employed for both ion and neutral measurements. Quadrupoles can also be used for ion measurements as well as neutral particles.

Continued development of both quadrupole and magnetic systems is desirable, and should be encouraged, to improve the already substantial usefulness of the existing instruments.

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