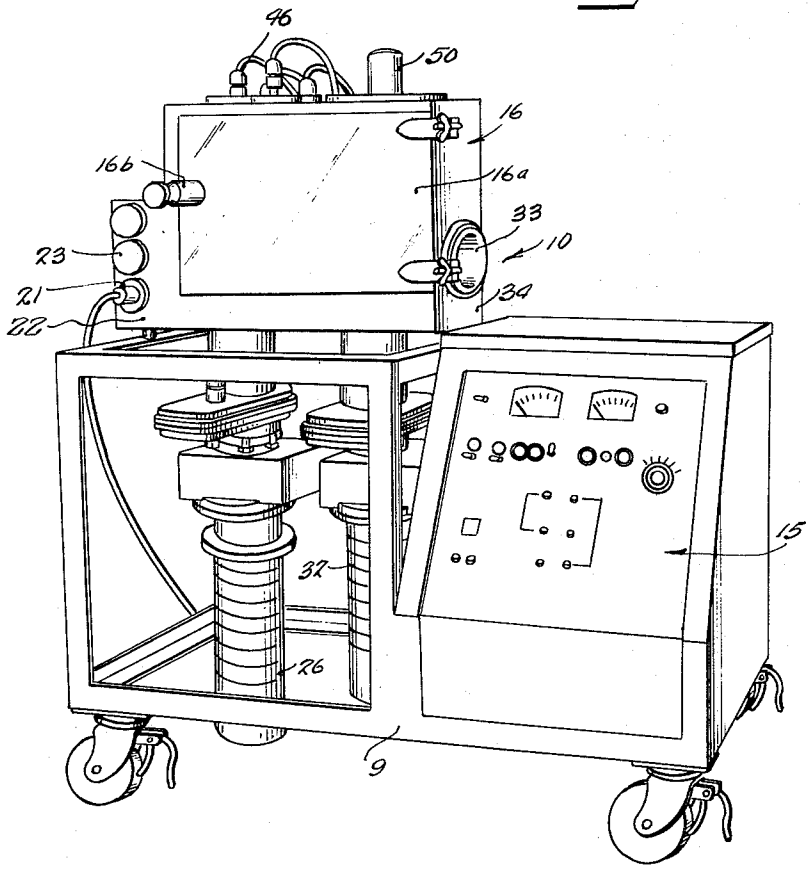
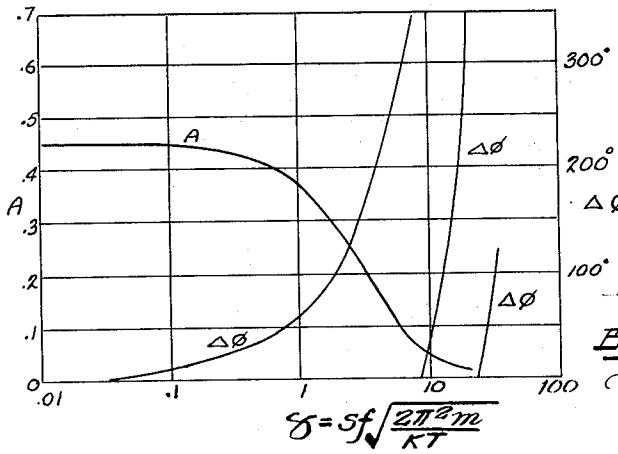
March 15, 1966 W. L. FITE ETAL 3,240,927

GAS ANALYSIS MODULATED BEAM APPARATUS

Filed Aug. 1, 1962 5 Sheets-Sheet 1

Fig. 1





$$\gamma = 5f\sqrt{\frac{2\pi^2 m}{KT}}$$

Fig 7

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GAS ANALYSIS MODULATED BEAM APPARATUS

Filed Aug. 1, 1962 5 Sheets-Sheet 2

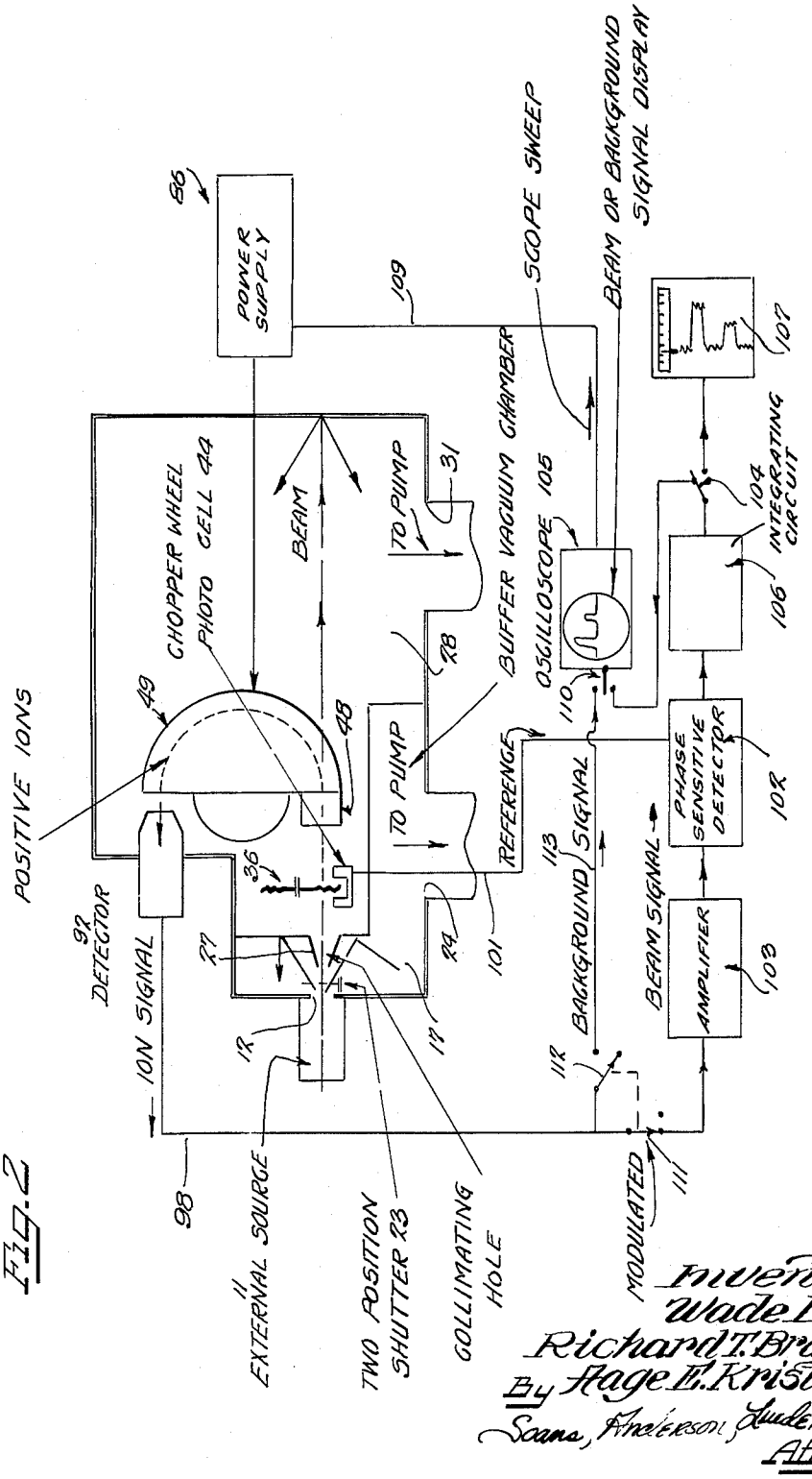


FIG. 2

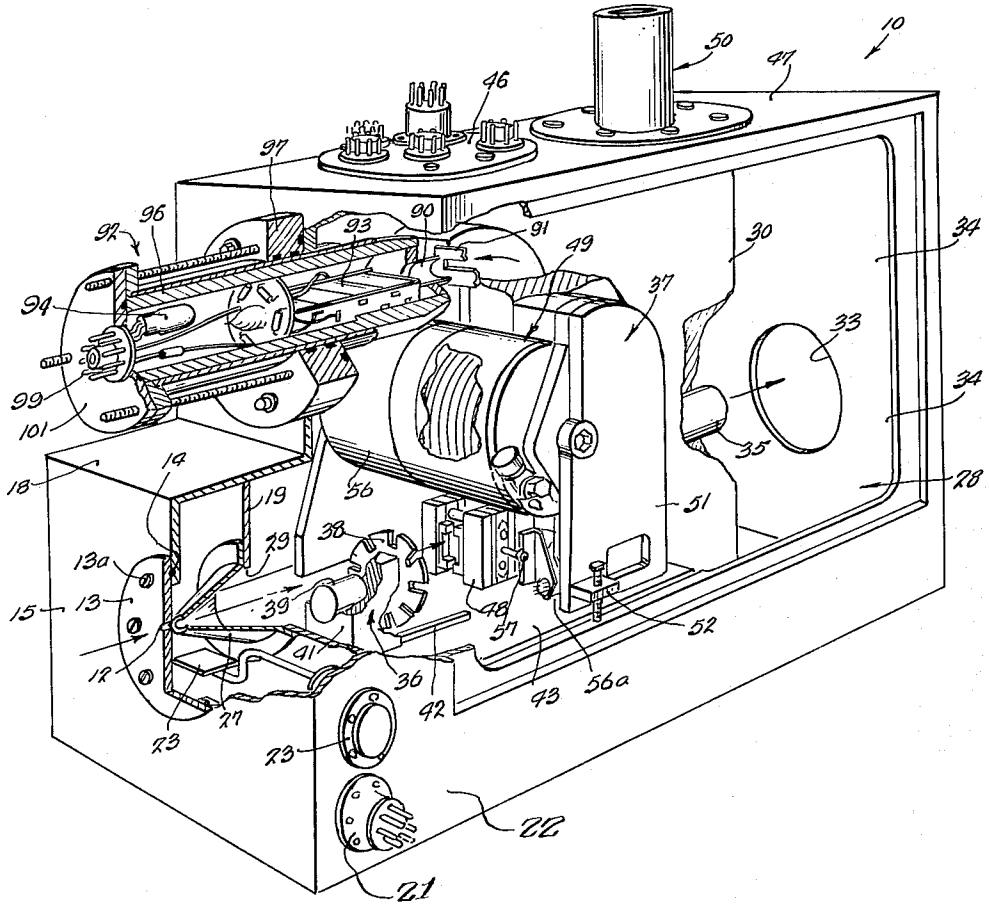
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GAS ANALYSIS MODULATED BEAM APPARATUS

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Fig. 3



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GAS ANALYSIS MODULATED BEAM APPARATUS

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Fig. 5

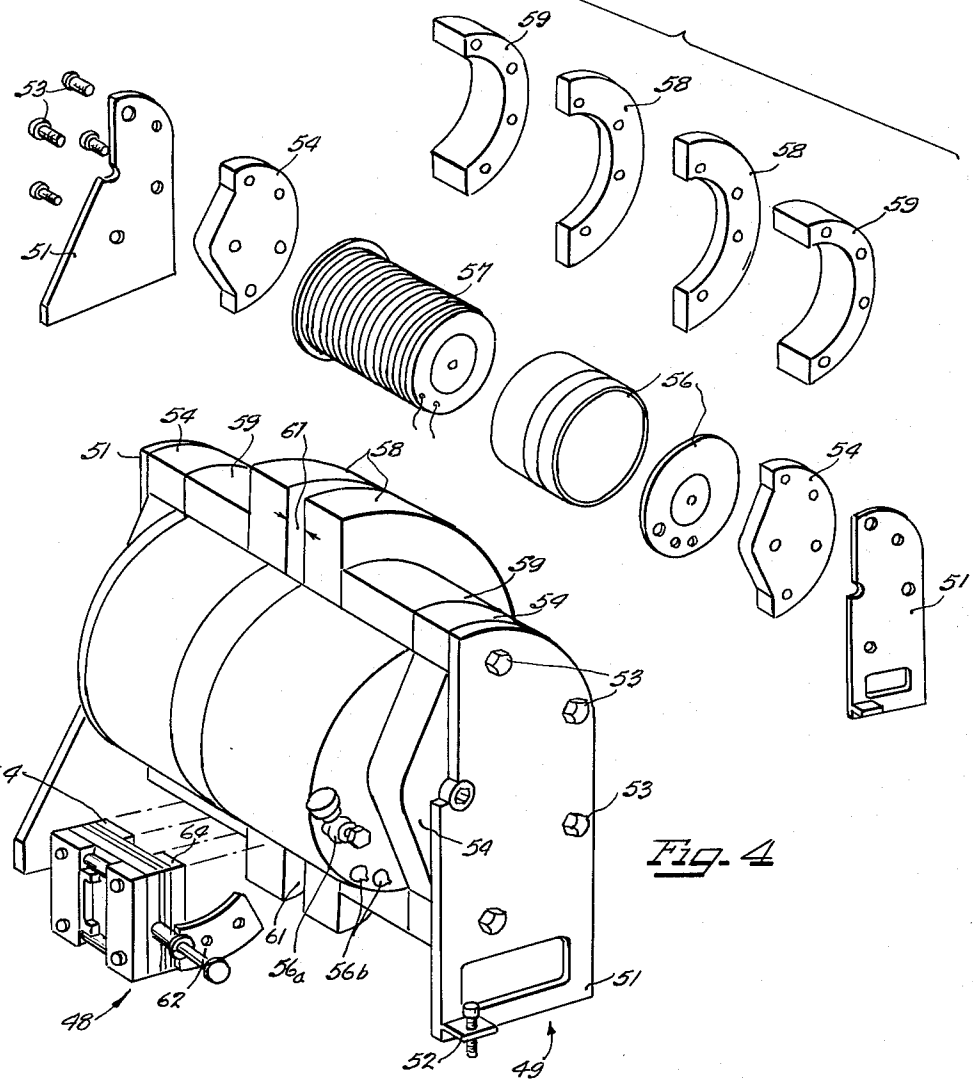


Fig. 4

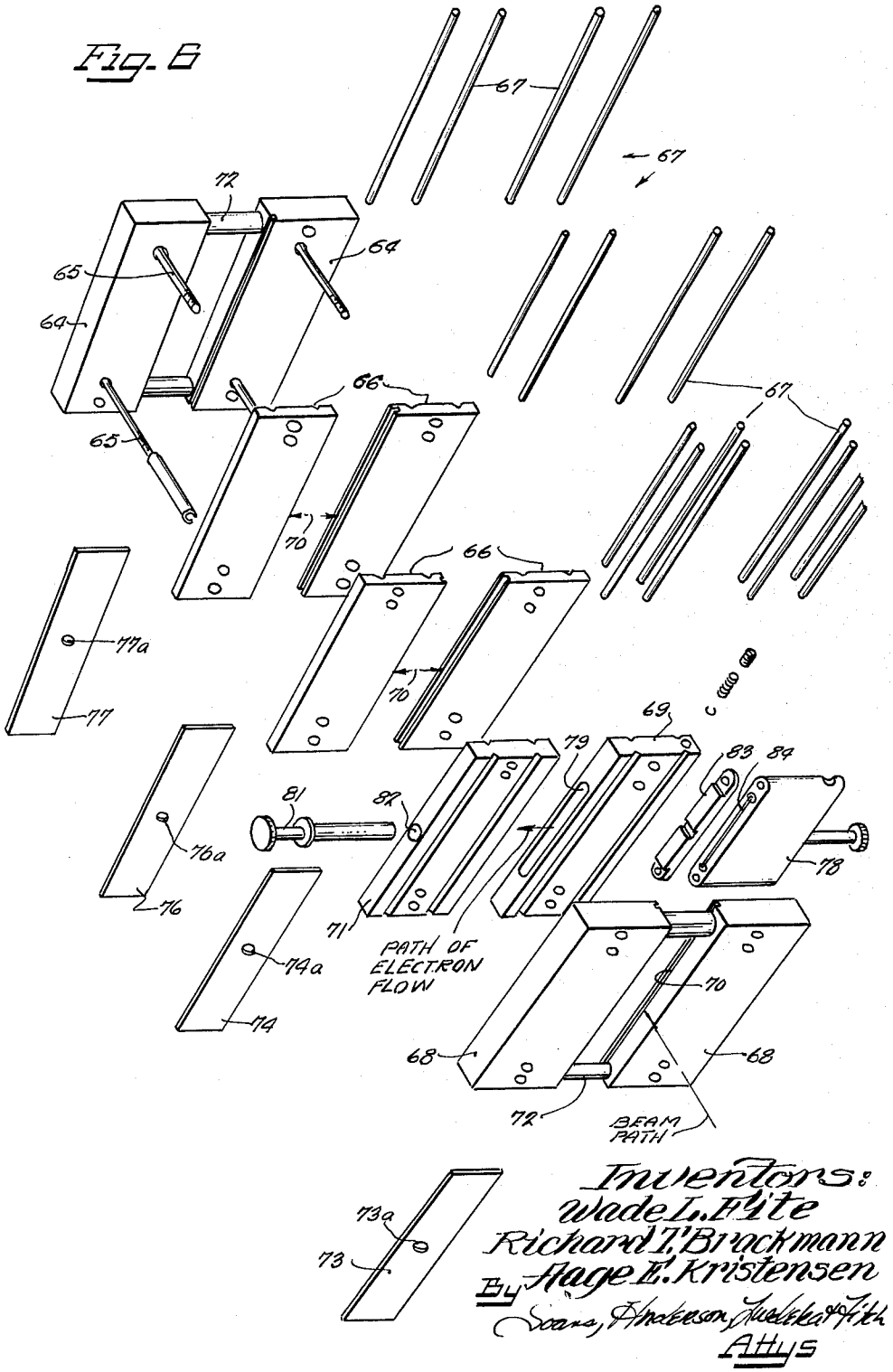
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GAS ANALYSIS MODULATED BEAM APPARATUS

Filed Aug. 1, 1962 5 Sheets-Sheet 5

Fig. 6



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3,240,927

GAS ANALYSIS MODULATED BEAM APPARATUS

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Filed Aug. 1, 1962, Ser. No. 214,060
9 Claims. (Cl. 250—41.9)

This invention relates to apparatus for analyzing matter and more particularly, to apparatus for effecting the analysis of gases over extremely broad temperature and pressure ranges.

Various devices have been developed in the past for effecting gas analysis through the utilization of various forms of the well-known mass spectrometer. Substantial limitations have been imposed both on the versatility and reliability of many of these devices due to the fact that their use is normally confined to relatively moderate temperature and/or pressure ranges and background signals created in the devices distort the output signals corresponding to the characteristics of the gas under investigation. In addition, devices of this type that function satisfactorily as conventional D.C. mass spectrometers or those which employ the principle of beam modulation are generally limited to this single application so that it is extremely difficult to analyze both stable gases and those containing free radicals with a single unit.

Accordingly, it is the prime object of the present invention to provide a new and improved apparatus for analyzing both chemically stable gases and those containing free radicals.

A further object of the present invention resides in the provision of an improved apparatus for analyzing gases employing a beam modulation technique whereby electrical signals corresponding to the source under investigation are readily separated from spurious background signals.

Still another object of the present invention resides in the provision of apparatus for analyzing both stable gases and those containing free radicals which are derived from a wide variety of sources having temperatures which vary from near absolute zero to several thousand degrees Kelvin and pressures from less than 10^{-3} mm. Hg up to one atmosphere.

A further object of the present invention is the provision of apparatus which is sufficiently versatile so that it can be readily adapted to effect the analysis and study of flames and rocket exhaust, can be applied to research related to both condensable and non-condensable gases, can be utilized to effect the analysis of gases containing free radicals and normal species, and can be applied to conventional use as a mass spectrometer.

Another object of the present invention is the provision of such apparatus in which part of the gas being analyzed is formed into a collimated beam which is passed into an ionizer and mass analyzer, the ionizer and mass analyzer providing a substantially unimpeded path for the unionized portion of the beam in order that particles in the beam not be scattered and combine to form new particles, not in the original beam, which would interfere with the mass analysis of the original beam.

Other objects and advantages of the present invention will become apparent from the following detailed description of one preferred embodiment thereof when considered in conjunction with the accompanying drawings wherein:

FIGURE 1 is a perspective view of a preferred embodiment of the gas analyzing apparatus of the present

invention including various control instrumentalities utilized in conjunction therewith;

FIGURE 2 is a diagrammatic illustration of the essential components of the gas analyzing apparatus illustrated in FIGURE 1;

FIGURE 3 is an enlarged perspective view of part of the apparatus illustrated in FIGURE 1 with various portions thereof broken away to illustrate the component features thereof;

FIGURE 4 is an enlarged perspective view of an ionizer unit and mass spectrometer assembly incorporated in the structure depicted in FIGURE 3;

FIGURE 5 is an exploded view of the mass spectrometer assembly illustrated in FIGURE 4;

FIGURE 6 is an exploded view of the ionizer unit utilized in conjunction with the mass spectrometer assembly illustrated in FIGURES 3–5; and

FIGURE 7 is a graphical representation of parameter values which are utilized to yield useable information from results of measurements effected by the analyzing apparatus illustrated in FIGURES 1–6.

In general, a gas analyzing apparatus in accordance with the present invention, one preferred embodiment of which is illustrated in the accompanying drawings, is designed to effect the analysis of both stable gases and those containing free radicals through the utilization of a beam modulation technique so that such gases can be readily analyzed without substantially distorting the characteristics of the system being studied. As shown in the accompanying drawings, the analyzer includes a confining enclosure which is designed to be attached to an external source which is to be studied. Gaseous particles from the system being investigated are directed into the analyzer through a small orifice in one wall of the enclosure.

Upon entering the enclosure, the gas expands into a first differentially pumped vacuum chamber and a narrow beam of particles is selected and formed from the expanding gas by a collimating aperture assembly which is mounted in a wall which separates the first differentially pumped vacuum chamber from a main experimental chamber. The collimated beam is directed along a substantially line of sight path into the main chamber wherein further collimation thereof is effected. Means provided within the main or experimental chamber and disposed along the line of sight path of travel of the beam effect the periodic interruption thereof so that the beam is effectively modulated at a preselected frequency. A portion of the modulated beam is subjected to ionization by a separately created electron beam that is directed substantially perpendicular to the line of sight path of travel of the collimated beam. The ions formed by the collision of the beam particles with the electrons are accelerated into a mass spectrometer wherein selective magnetic analysis is effected. Narrow band amplification and detecting circuitry are employed to measure the modulated ion current signals resulting from the analysis of the ionized particles.

Referring in particular to FIGS. 1–3, gaseous particles derived from an external source **11** pass into the analyzer **10** through a suitably proportioned entrance orifice **12** that is formed in a plate **13**. The plate **13** is removably secured in gas tight relation by suitable fastener **13***a* and a conventional O ring assembly **14** to a forwardmost wall portion **15** of a gas tight housing or assembly confining enclosure **16**. The entire analyzer assembly confined within the enclosure **16** is suitably mounted on a movable support table **9** (FIG. 1) which also includes a housing **15** for various control instrumentalities associated with the analyzer.

The support structure is readily movable from location

to location as is an electronics rack panel (not shown) which houses various other conventional power supply and control units utilized with the analyzer, as hereinafter described. As shown, the assembly confining enclosure **16** is provided with a hinged door **16***a* which can be secured to the side wall of the enclosure by a locking element **16***b* so as to completely cover an access opening in the side wall. By pivoting the hinged door **16***a* away from the side wall of the enclosure **16**, ready access can be had to the internal portion thereof so that cleaning, replacement of components, etc. can be readily effected.

The gaseous particles passing through the entrance orifice **12** expand into a first vacuum chamber **17** which is preferably maintained at a pressure sufficiently low to allow the particles entering from the source **11** to have a mean free path greater than the path of travel of the particles therein. In this connection, the size of the entrance orifice **12** that is formed in the plate **13** will depend directly upon the existing pressure differential between the external source and the first vacuum chamber **17**. Preferably, for a source at atmospheric pressure the entrance orifice has a diameter of approximately .001 inch. When external sources are studied that have lower pressures the entrance orifice is made correspondingly larger.

As illustrated in FIGURES 2 and 3, the first vacuum chamber **17** is defined by a step-like projecting wall portion **18** of the assembly defining enclosure **16** and by a chamber defining inner wall **19**. The wall portion **18** surrounding the first vacuum chamber **17** is provided with a plurality of suitably proportioned ports or apertures, one of which accommodates the plate **13** that contains the entrance orifice **12**. In addition, an ion gauge (not shown) and a thermocouple gauge **21** extend though a side wall portion **22** of the enclosure **16** with the base portions thereof mounted in gas tight sealing relation with the apertures provided in the wall portion. A manually operable beam interrupter or shutter assembly **23** is also mounted in gas tight relation within another of the apertures provided in the wall portion **22**, and is utilized, as hereinafter described, to selectively block the particles passing into the chamber **17** from the external source **11**.

Additional communication with the first vacuum chamber **17** provided through a suitably proportioned exhaust port **24** provided in the lower wall of the enclosure **16**. The exhaust port **24** communicates with a conventional pump assembly **26** (FIG. 1) which effects the maintenance of the desired low pressure within the chamber **17**. In a conventional manner, the vacuum pump assembly **26** includes the pump, trap and valve components that are necessary to insure the proper removal of undesired gaseous constituents from the first vacuum chamber **17**.

Finally a conically shaped beam collimating assembly **27** also communicates with the first vacuum chamber **17** and defines the entrance to a second vacuum chamber **28** wherein the major components of the analyzing assembly are situated and whereto a portion of the gaseous particles pass immediately after entering the device from the external source **11**. The collimating assembly **27** is secured to the chamber defining inner wall portion **19** so as to encompass a suitably proportioned aperture **29** which is provided therein.

The second vacuum chamber **28**, hereinafter referred to as the experimental chamber, has a suitably proportioned exhaust port **31** located in the lower wall portion of the confining enclosure **16**. As described, in conjunction with the first vacuum chamber **17** the exhaust port communicates with a vacuum pump assembly **32** which is similar to the vacuum pump assembly **26** and also includes the desired pump, trap and valve components necessary to insure the removal of undesirable gaseous particles and the maintenance of the desired low pressure within the experimental chamber. A large liquid nitrogen trap **30** is also removably mounted within the main experimental chamber **28**. The trap **30** provides additional low temperature baffling for the chamber **28** and a large trapping surface for condensable vapors.

To facilitate a complete understanding of the operation of the device and the manner in which spurious background signals are readily differentiated from the signals representing the modulated beam derived from the external source **11**, a distinction should be made between the modulated beam and the undesirable background gases which normally will give rise to spurious background signals. In this connection, the group of particles derived from the external source and formed into the collimated beam are hereinafter referred to as the "beam." The source particles which are subjected to numerous collisions prior to randomly entering the experimental chamber **28** from the first vacuum chamber will be referred to as the "background flow." The gases present in the high vacuum background of the experimental chamber are designated as the "background" and represent the summation of the residual gas in the experimental chamber, the gas from the beam that suffers one or more collisions with a surface, and the aforementioned background flow which enters the experimental chamber from the first vacuum chamber **17** and suffers one or more collisions with a surface in the experimental chamber.

The beam particles passing from the first vacuum chamber **17** through the beam forming or collimating assembly **27** are directed along a substantially line of sight path of travel toward a suitably sealed observation port **33** which is provided in the rear wall portion **34** of the enclosure **16**. The line of sight path is in part defined by a cylindrical sighting tube **35** that extends through and is mounted within the removal trap **30**.

More particularly, a relatively small portion of the particles entering the first vacuum chamber **17** will be formed into a collimated beam by the assembly **27** and, as shown particularly in FIGURES 2 and 3, will be directed past a beam modulating assembly **36** and through a mass analyzer unit **37**. In this connection, a toothed chopper wheel **38**, which is driven by a small synchronous motor **39** of a conventional type, has a side portion of the toothed or slotted periphery thereof disposed along the line of sight path of travel of the collimated beam passing through the assembly **27**. The toothed wheel **38** and synchronous driving motor **39** are mounted on a metal supporting block **41** which is secured for relative movement on a track **42**. The track **42** is positioned on a main support plate **43**, which serves as the mounting structure for the analyzing assembly **37** and the various components associated therewith, adjacent the line of sight path of travel of the beam.

As diagrammatically illustrated in FIGURE 2, a photosensitive cell and light source assembly **44** are also secured to the metal supporting block **41**. The cell and light source are mounted on opposite sides of the toothed chopper wheel **38** adjacent the track **42** so that during the rotation of the wheel under the control of the synchronous motor **39** the periodic interruption of the passage of light from the source to the cell is effected.

The synchronous motor **39** is driven at a preselected speed so that the collimated beam of gaseous particles passing through the analyzer assembly **37** toward the rearwardmost portion of the enclosure **16** is selectively interrupted or modulated. At the same time a synchronizing signal is derived from the photocell which has the light energy normally supplied thereto interrupted at the same frequency as the collimated beam. In one preferred embodiment of the invention, the synchronous motor **39** drives the chopper wheel **38** at a rate such that the beam is interrupted to produce an ion output signal having a frequency of 1440 cycles per second.

In a conventional manner electrical power for the synchronous motor **39** and the photocell-light source as-

sembly 44 is provided through conductors which pass into the experimental chamber through a conventional electrical flange 46 that is disposed in gas tight relation about a suitably proportioned aperture in the upper wall 47 of the enclosure 16. The electrical flange 46 is situated adjacent an upwardly extending filling port 50 for the auxiliary trap 30. The port 50 extends through another aperture in the wall 47 and is situated in gas tight relation therein.

The analyzer assembly 37 (FIG. 4) includes an improved beam ionizer unit 48 and a 180° mass spectrometer 49. The ionizer unit 48 is designed to continuously ionize beam particles directed through the ionizing region and to effect the acceleration of the resulting positive ions into the 180° mass spectrometer 49 in a nearly monoenergetic beam. An important aspect of the analyzer assembly 37 that results from the manner in which the ionizer unit and mass spectrometer are constructed, is that the beam particles are directed through the assembly on a line of sight path without suffering any wall collisions or the like. Accordingly, undesirable trapping and the possibility of recombination of species in the ionizing region does not result. This is extremely important when analyzing free radicals inasmuch as collision and trapping of the gas gives rise to ions formed from products of the free radicals. It should be obvious that only ions from the primary beam of radicals are desired to be analyzed so that reliable information as to the characteristics of the external source 11 is obtained.

The analyzer assembly 37, which includes the 180° mass spectrometer 49, is mounted on the main supporting plate 43 within the experimental chamber 28. Although the embodiment of the analyzer assembly 37 will be hereinafter described as employing the 180° mass spectrometer 49 it should be understood that various other forms of analyzing apparatus including the more conventional forms of mass spectrometers might also be employed in the analyzer assembly.

Referring to FIGURE 3, a pair of vertically extending supporting brackets 51 are secured by suitable fasteners 52 to the support plate 43. The brackets 51 are designed to receive a plurality of fasteners 53 which maintain a pair of mounting members 54 in fixed relation relative to a vacuum tight container 56 that serves to confine an electromagnetic coil 57. The container 56 is pumped to approximately 1 mm. Hg pressure during assembly through the valve element 56*a* that is located adjacent gas tight coupling elements 56*b* which hold the conductors that supply current to the coil 57.

A pair of semicircular pole pieces 58 are mounted in coaxial relation with the electromagnetic coil adjacent the outer surface of the vacuum tight container 56. The pole pieces 58 are secured to and supported by a pair of semicircular pole piece mounting brackets 59 that are, in turn, supported on the brackets 51 through the mounting members 54 by fasteners 53.

The pole pieces 58 are mounted about the container 56 so that the inner faces thereof, which are preferably plated with a material such as gold to provide charge free surfaces, define a slit or passageway 61 having a width of approximately ½ inch. The lower extremities of the poles 58 that extend downwardly beneath the container 56 define the entrance to the slit 61. The ionizer unit 48 is secured to the lower ends of the pole pieces 58 at this location by an arcuate bracket 62 that is secured to and extends from one of the mounting blocks 64 of the ionizer unit (FIGS. 4 and 6).

The ionizer unit 48 is constructed from a plurality of relatively thin blocks preferably formed of a material such as iron which are arranged in a stacked array so as to form an extension of the pole pieces 58. Suitable insulating elements such as sapphire rods 67 are utilized to insulate adjacent supporting blocks 66 and the rearward and forwardmost mounting blocks 64 and 68, respectively. A filament insert holder 69 and collector rod holder 71 are positioned between the forwardmost mounting blocks 68 and the first pair of supporting blocks 66. As illustrated in FIGURE 6, the supporting blocks 66, and holders 69 and 71 are secured by suitable fasteners 65 to the mounting blocks 64 and 68 so that a vertically extending rectangular passageway 70 is provided wherein a plurality of suitably apertured rectangular plates 73, 74, 76 and 77 are removably positioned.

More particularly, the forwardmost mounting blocks 68, which are joined by a pair of cylindrical separating elements 72 as are the mounting blocks 64, have aligned slotted guideways formed therein that are designed to receive an apertured repeller plate 73. Similarly, the first pair of supporting blocks 66 have aligned slotted guideways provided therein which are proportioned to receive an extractor plate 74 that is provided with an aperture 74*a* having somewhat larger diameter than the aperture 73*a* provided in the repeller plate 73. Likewise, the second pair of supporting blocks 66 and the rearwardmost mounting blocks 64 are provided with suitably proportioned guideways wherein an apertured focusing plate 76 and ground plate 77 are positioned. As illustrated in FIGURE 6, the aperture 76*a* in the focusing plate is of larger diameter than that of either the repeller or extractor plates and the aperture 77*a* in the ground plate 77 is again somewhat larger. The apertured plates 73, 74, 76 and 77, which are preferably formed of a material such as nonmagnetic stainless steel define the path of travel for the collimated beam through the ionizer unit to the spectrometer 49.

A filament insert 78, which can readily be removed from the ionizer so that filament replacement can be effected without disassembly of the ionizer unit, supplies the necessary electron flow to effect ionization of the beam passing through the ionizer. The insert 78 is proportioned so as to slideably fit within a suitably proportioned aperture 79 formed in the filament holder 69. Similarly, a collector rod 81 is proportioned so as to freely pass into a cylindrical aperture 82 provided in the collector rod holder 71. As shown, a cover 83, preferably formed of a material such as stainless steel, is secured to the surface of the filament insert whereto a replaceable filament 84 is secured.

The cover 83 serves to collimate a portion of a supply of electrons that is generated by the filament 84 and directs the collimated electron flow toward the collector rod along a path that is perpendicular to the path of travel of the beam through the ionizer. A conventional filament regulator (not shown) supplies the necessary D.C. heater current to the filament 84 through suitable conductors (not shown). The magnitude of the heater current supplied to the filament is dictated by a conventional control circuit which responds to the magnitude of electron current striking the collector 81. Preferably this heater current is held substantially constant so that a controlled amount of ionizing current is derived from the filament 84.

As the emitted electrons traverse the beam path, continuous ionization of beam particles is effected and the resulting ions are directed to the spectrometer 49. In this connection, the field established in the ionizer, as a result of the different potentials established on the repeller, extractor, focusing and ground plates from a convenional power supply 86 (FIG. 2), draws the ions into the region between the extractor and focusing plates. The potential on the ground plate 77 causes the ions to be accelerated outwardly from the ionizer device through the aperture 77*a* and into the region between the pole pieces 58 of the mass spectrometer 49.

By properly adjusting the various potential differences between the plates 73, 74, 76 and 77 and the electron current produced by the filament 84, a diverging substantially monoenergetic flow of ions emerges from the aperture 77*a* in the ground plate 77 and is injected into the field established by the mass spectrometer.

The aperture 77*a* formed in the ground plate 77 serves as a virtual slit which has a width slightly larger than the beam width of the ionizing electrons that are directed normal to the path of travel of the beam. A virtual slit rather than an actual slit is formed in the ground plate to insure a line of sight clearance hole through the ionizer unit 48 for those gaseous particles of the beam which are not subjected to ionization during their passage through the ionizer and, subsequently, without diversion through the slit defined between the lower extremities of the pole pieces 58.

More particularly, the portion of the beam which is unaffected by the ionizing flow of electrons passes through the passageway defined in the mass spectrometer, strikes the rearwardmost portion of the experimental chamber 28 and a substantial portion thereof is evacuated under the influence of pump 32. The clearance provided by the suitably proportioned apertures 73*a*, 74*a*, 76*a*, and 77*a* insures that the modulated beam is not subjected to entrapment and is not impeded in any way, thus precluding alteration of chemically unstable species prior to ionization.

The 180° mass spectrometer 49 provides a substantially uniform magnetic field path having a radius of approximately 10.5 centimeters for the ions injected from the ionizer unit 48. The spectrometer can be tuned to a particular mass or swept across a range to be investigated by suitable settings of the ion energy and magnetic field intensity controls utilized with the analyzer. The power supply 86 preferably includes conventional circuit and control means for the mass spectrometer 49.

Approximately 60° beyond the entrance to the spectrometer, a slit assembly (not shown) is mounted to collect ions that are diverging out of the magnetic field. The slit assembly also functions to collect ions having masses to which the spectrometer is not tuned. The positioning and size of the slit assembly is readily adjustable to suit various requirements in resolution. Conventionally it is situated as set forth above, and has a slit width of approximately 2 centimeters located centrally between the pole pieces 58.

Referring to FIGURES 2 and 3, an exit slit 91 is secured to the end faces of the pole pieces 58 so that the ions emerging from the spectrometer are directed toward a compact shielded detector unit 92. The detector unit 92 includes a modified form of photomultiplier tube 93 (FIG. 3) and a preamplifier 94 mounted within a shielding container 96. The container 96 extends through a suitable O ring seal 97 that is mounted in the wall of the housing 16 and proportioned to receive the container in gas tight relation. The photomultiplier tube 93 is preferably of an end window type that communicates with the spectrometer 49 through a small cylindrical hollow shield 90. The shield 90 is situated within the apertured end portion of the container 96 so as to provide a shielded path for ions emanating from the exit slit 91 and passing to the end window of the photomultiplier.

More particularly, the photomultiplier tube 93, which produces an electrical signal proportional to the composite ion output signal of the mass spectrometer, is a modified form of a conventional end window multiplier. In this connection, the multiplier has the glass shielding thereof removed to the bottom seal and is disposed within the shielding container 96 so that the seal bears against the inner peripheral surface thereof. In addition, minor modifications are made in the positioning of the dynode rails and the conductors which lead from the dynodes to the base so that the possibility of shorts and the like is eliminated, while at the same time a compact shielded detector is provided. The output from the photomultiplier is fed to the preamplifier tube 94 which supplies an output signal via a conductor 98 to external measuring instrumentalities. In this connection, a single tube socket 99 is mounted within an aperture provided in a removable cover plate 101 for the shielding container 96. The single tube socket 99 serves to supply the necessary operating potential to the photomultiplier 93 and preamplifier 94 and provides the means whereby the output signal is derived from the preamplifier.

In operation of the device, an external source 11 is suitably coupled to the input of the first vacuum chamber 17 through the aperture 12. A portion of the gaseous particles entering the first vacuum chamber are thereafter coupled through the beam collimating assembly 27 and directed along the line of the sight path through the second vacuum chamber 28. Thereafter, the beam is selectively interrupted by the action of the beam modulating assembly 36, and the photocell light source assembly 44 simultaneously effects the production of synchronizing signal which is fed via a conductor 101 to a conventional phase sensitive detector circuit 102.

The modulated beam is directed through the ionizer 48 wherein a portion of the beam particles are bombarded by a flow of electrons supplied from the filament 84. The positive ions produced by the action of the ionizer are injected into the mass spectrometer 49, which is selectively operated in either a D.C. mode or a sweep mode as established by the power supply 86. The ions passing through the mass spectrometer 49 (i.e. the ions having masses to which the spectrometer is tuned) are passed through the exit slit 91 and are detected by the photomultiplier 93 which produces an output signal corresponding thereto. The output signal from the photomultiplier is fed through the preamplifier 94 and through the signal carrying conductor 98 to a conventional narrow band, push-pull amplifier 103. The amplifier 103, which is tuned to a frequency corresponding to the modulating frequency rate of the beam modulating assembly 36, i.e. 1440 cycles per second supplies a low impedance, push-pull output to the detector circuit 102.

If the mass spectrometer is tuned to a mass which is present in the beam, in the background, and in the background flow, the composite ion signal derived from the photomultiplier consists of several components. In this connection, the detected ion signal contains a direct current component corresponding to the ions produced from the background gas, an alternating current component corresponding to the modulated beam, as well as an alternating current component which represents the modulated background flow. When the composite signal is fed to the amplifier, the fundamental frequency of the composite alternating current signal is amplified, and the direct current and other extraneous signal components are eliminated.

Since the modulated beam must traverse the distance between the chopper wheel 38 and the input to the ionizer 48 the phase of the ion signal supplied from the detector differs in phase from the synchronizing signal derived from the photocell light source assembly 44. Accordingly, the push-pull output from the amplifier 103 is phase sensitively rectified by the action of the detector 102. To accomplish this, the detector 102, which amplifies the synchronizing signal, effects a selective variation in the phase thereof at the input to the rectifier through the utilization of a conventional selsyn device which yields a measurable indication of the phase variation. The phase shifted synchronizing signal is thereafter utilized to drive a conventional vibrator that includes an untuned vibrating reed (not shown) functioning as a single pole, double throw switch.

More particularly, a pair of fixed contacts of the vibrator are connected to the output terminals of the tuned amplifier 103. When the phase and frequency of the vibrating reed, as dictated by the phase shifted synchronizing signal, correspond to the frequency and phase of the output signal from the push-pull amplifier 103, a pulsating D.C. voltage is produced at the output of the detector that corresponds to the output signal of the amplifier. Extraneous 1440 cycles per second signals resulting from background noise and the like do not corre-

spond in phase to the synchronizing signal fed to the vibrator so that any D.C. output signal from the detector **102** resulting therefrom is negligible and is cancelled out by the section of an integrating circuit **106**.

As shown in FIGURE 2, the output from the detector **102** is selectively fed through the integrating circuit **106** and a switch **104** to either an oscilloscope **105** or a conventional recorder **107**. The integrating circuit **106** acting on the output signal from the detector **102** effects the production of the D.C. output signal that is proportional to the amplitude of the detector output signal averaged over the time constant of the integrating circuit.

Accordingly, the integrating circuit provides an output signal which represents the mean amplitude of the in-phase ion signal supplied to the photomultiplier in the detector assembly **92** averaged over a known time constant absent any extraneous signals due to noise, etc. This in-phase ion signal is proportional to the neutral beam density of the mass species to which the spectrometer is tuned and is displayed either on the oscilloscope or the recorder **107**, as dictated by the position of the switch **104**.

Assuming that the output signal is fed to the oscilloscope **105** through the switch **104** and a switch **110**, the observable trace represents the ion current signal derived from the mass spectrometer, which is a composite of the background flow and beam signals. Since the background flow signal is usually quite small compared to the beam signal, the effects of the background flow component of the composite signal derived from the integrating circuit can normally be ignored without substantially effecting the reliability of the measurements effected by the analyzer.

However, the analyzer includes means for compensating for such signals. As previously described, the first vacuum chamber includes a manually operable beam interrupter or shutter assembly **23** which can be selectively positioned to block the beam particles passing into the experimental chamber from the external source **11**. When the shutter assemby is moved to a blocking position, the ion signal represents only the background flow so that the output from the detector circuit **102** is proportional only to the background flow density. By observing the output signal produced at the oscilloscope with the shutter assembly **23** in the blocking and unblocking positions, the magnitude of the background flow signal can be readily determined and the measured results can be modified to yield an accurate indication of the beam component.

As illustrated in FIGURE 2, a conductor **109** electrically connects the oscilloscope **105** to the ionizer and mass spectrometer control circuit and power supply **86**. The conductor **109** is connected between the spectrometer sweep control and the horizontal sweep of the oscilloscope so that the output from the detector circuit **102** can be readily observed on the vertical axis of the oscilloscope as the spectrometer **49** is operating in the sweep mode over a selected mass range.

The foregoing description of one preferred embodiment of the analyzer has been confined generally to the utilization thereof when employing beam modulation. However, the device can also be employed to examine a mass spectrum of all the gases present in the ionizing region without regard to modulation. The utlization of the analyzer in this manner as a more conventional mass spectrometer is effected by actuating the ganged switch contacts **111** and **112** so that the amplifier **103**, detector circuit **102** and integrating circuit **106** are shunted by a conductor **113** which is selectively connected to the vertical sweep input of the oscilloscope **105** by the actuation of the switch **110**. Accordingly, as the mass spectrometer is swept over a selected mass range with the horizontal sweep of the oscilloscope **105** synchronized therewith, a spectrum of the background gas in the ionizer unit **48** is presented on the horizontal axis of the oscilloscope.

In addition to the information derived from the device with respect to spectral analysis of gaseous particles derived from an external source **11**, the analyzer can also be utilized to yield information as to the temperature of the collimated beam of these particles.

As previously described, the collimated beam of gaseous particles after being selectively interrupted by the chopper wheel **38** must traverse the distance between the chopper wheel and the ionizer **48**. Since the mounting structure for the motor driven chopper wheel is selectively movable along the track **42** the wheel can be positioned a selected measurable distance from the ionizer. Assuming that all of the gaseous particles in the beam have the same velocity, the time that it takes the beam to traverse the distance between the chopper wheel and the ionizer is given by:

$$t=\frac{s}{c} \tag{1}$$

where:

t=the time required for the beam to pass from the chopper wheel to the ionizer
s=the preselected distance between the chopper wheel and the ionizer
c=the beam velocity

By repositioning the mounting structure along the track so that the chopper wheel is positioned at a new location a selected distance s' from the ionizer. A second time value t' is given by:

$$t'=\frac{s'}{c} \tag{2}$$

Combining Equations 1 and 2, the velocity of the beam is given by:

$$c=\frac{s-s'}{t-t'} \tag{3}$$

or:

$$c=\frac{\Delta s}{\Delta t} \tag{4}$$

Accordingly, if the chopper wheel assembly is moved a selected distance Δs and the time interval Δt is measured, the velocity of the beam is obtained from Equation 4. In this connection, the time interval Δt is derived from the phase difference between the two signals produced by the analyzer with the chopper wheel **38** at the distances s and s' from the ionizer **49**. The detector circuit **102** is ideally suited for yielding this phase difference as previously described.

With the phase difference determined the time differential Δt is given by:

$$\Delta t=\frac{\Delta\theta}{360^\circ}\frac{1}{f} \tag{5}$$

where:

$\Delta\theta$=the measured phase variation
f=the modulating frequency (e.g. 1440 cycles per second)

Relating this to Equation 4, beam velocity, c, can be determined by the following relationship:

$$c=\Delta sf\frac{360^\circ}{\Delta\theta} \tag{6}$$

Thus obtaining the beam velocity, the beam temperature T can be obtained from the following:

$$T=\frac{m}{3k}c^2 \tag{7}$$

where:

m=the mass of the beam particles.
k=Boltzmann's constant.

For the more realistic case where the particles in the beam do not all have the same speed but have a distribu-

tion of speeds given by the Maxwell-Boltzmann distribution, the analysis is more complicated than that given above. For the case of a Maxwellian beam, FIGURE 7 graphically represents the relationship between a parameter

$$\gamma = sf\sqrt{\frac{2\pi^2 m}{KT}}$$

and the phase shift $\Delta\theta$.

FIGURE 7 also shows the amplitude "A" of the modulated signals as a function of the parameter γ. The amplitude changes with distance (and therefore γ) because with increased drift distance, the slower particles in a given beam pulse are overtaken by the faster particles in the succeeding beam pulse and the modulated character of the beam is lost with increasing distance.

In order to obtain the temperature of particles of mass in the beam it is necessary only to note the phase of the signal observed and determine the corresponding value of γ. From knowledge of the particle mass (given by the analyzer directly) and the distance from the chopper wheel and the ionizing electron beam, algebraic solution from the definition of γ gives the absolute temperature directly.

A somewhat similar analysis can be utilized to derive a relationship which is useful in obtaining relative temperature measurements between beams emitted from certain sources, i.e. a low pressure furnace. Such an analysis yields the following relationship:

$$T = (S_0/S)^{2T_0} \quad (8)$$

where:

S_0=the modulated output signal detected by the analyzer as described above at a measurable temperature

T_0=the measurable temperature

S=the beam signal obtained from the analyzer at the unknown temperature T.

From the foregoing description of one preferred embodiment of the analyzer, it should be apparent that the device permits an effective instrument for yielding information related to the characteristics of gases containing both normal species and free radicals from a wide variety of sources. The employment of the beam modulation technique insures the separation of the beam signal from spurious background signals and minimizes the possibility of the alteration of species under investigation prior to analysis. Moreover, the employment of the beam technique permits thermal decoupling between the analyzer and the external source so that gases having temperatures which vary over a range between near absolute zero and several thousand degrees Kelvin can be readily analyzed. Furthermore, the structural characteristics of the analyzer are such that various inlet orifices **12** can be employed to accommodate inlet gas pressures which vary over a range of between 10^{-3} mm. Hg. to 1 atmosphere. Finally, the unit can be employed as a conventional mass spectrometer which yields the additional advantage of versatility.

It should be understood that various conventional control elements and circuit components are utilized in conjunction with the analyzer as previously described, the details of which do not form an essential part of the invention. Moreover, various modifications in the analyzer as previously described can be devised by those skilled in the art without deviating from the invention, various features of which are set forth in the following claims.

What is claimed is:

1. A device for analyzing a gas which comprises means forming a collimated beam of gas particles within a vacuum system, means disposed in the path of travel of the collimated beam of particles for effecting the modulation thereof at a preselected frequency, a mass analyzer disposed adjacent said modulating means in the direction of travel of said beam, means located adjacent the entrance of said mass analyzer for effecting the ionization of at least a portion of said collimated beam without substantial diversion of said beam so that said partially ionized beam travels directly into said mass analyzer, detecting means mounted adjacent the exit of said mass analyzer for producing a modulated output signal having a frequency corresponding to the preselected frequency at which said beam is modulated by said beam modulating means, said ionizing means and said mass analyzer providing a substantially unimpeded path for the passage of the unionized portion of said collimated beam in order that particles in the beam not be scattered and combine to form new particles not in the original beam, and means responsive to the output signal from said detecting means for producing output information related to the characteristics of said modulated beam of gas particles.

2. A device for detecting free radical and other gaseous constituents whereby analysis of a gas can be effected, which device comprises a first vacuum chamber including means for forming a collimated beam of particles of the gas to be analyzed and for directing said beam along a relatively straight path of travel, a second vacuum chamber whereto said collimated beam is directed and including means disposed in the path of travel of the collimated beam of particles for effecting the periodic interruption of said beam, means monitoring the rate at whcih the periodic interruption of said beam is effected and for producing a synchronizing signal having a frequency related thereto, a mass analyzer disposed within said vacuum chamber adjacent said beam interrupting means in the direction of travel of said beam, an ionizer unit located adjacent the entrance of said mass analyzer for producing a stream of electrons directed substantially perpendicular to said collimated beam so that a portion of said beam is ionized, the ionized portion of the collimated beam being injected into said mass analyzer, said ionizer unit and mass analyzer providing a substantially unimpeded path for the passage of the un-ionized portion of said collimated beam in order that particles in the beam not be scattered and combine to form new particles not in the original beam, detecting means mounted adjacent the exit of said mass analyzer for producing a modulated output signal having a frequency corresponding to the frequency at which the said beam is periodically interrupted by said beam interrupting means, and circuit means connected to said monitoring means and said detecting means for producing output information related to the characteristics of said modulated beam of gas particles.

3. A device for analyzing a gas supplied thereto from an external source, which device comprises a gas tight housing that defines a first and a second vacuum chamber, means mounted within said housing between said first and second vacuum chambers for forming a collimated beam of particles of the gas derived from the external source and for directing said beam from said first vacuum chamber along a line of sight path into and through said second vacuum chamber in order that particles in the beam not be scattered and combine to form new particles not in the original beam, means mounted within said second vacuum chamber in the path of travel of said collimated beam for effecting the interruption thereof at a preselected frequency, a mass spectrometer disposed adjacent said interrupting means in the direction of travel of said beam, an ionizer unit located adjacent the entrance of said mass spectrometer, said ionizer unit includng a stacked array of mutually insulated apertured members that define a portion of the line of sight path of travel of said beam, a filament element removably mounted within said ionizer unit for effecting the production of a flow of electrons which ionizes a portion of said collimated beam, means supplying said apertured members of said ionizer with potentials having a magnitude such as to produce an accelerating field for the ionized beam particles that is directed toward said mass spectrom-

eter so that the ionized portion of the collimated beam is injected into said mass spectrometer while the remaining portion thereof travels directly therethrough, detecting means mounted adjacent the exit of said mass spectrometer for producing a modulated output signal having a frequency corresponding to the preselected frequency at which said beam is interrupted by said beam interrupting means, and means responsive to the output signal from said detecting means for producing output information related to the characteristics of said beam of gas particles.

4. A device for analyzing a gas supplied thereto from an external source, which device comprises a gas tight housing that defines a first and a second vacuum chamber, means effecting the evacuation of said first and second vacuum chambers to respective pressure levels, means mounted within said housing between said first and second vacuum chambers for forming a collimated beam of particles of the gas from the external source and for directiong said beam from said first vacuum chamber along a line of sight path into and through said second vacuum chamber in order that particles in the beam not be scattered and combine to form new particles not in the original beam, means mounted within said second vacuum chamber in the path of travel of said collimated beam for effecting the interruption thereof at a preselected frequency, means monitoring the rate at which the periodic interruption of said beam is effected and for producing a synchronizing signal related thereto, a mass spectrometer disposed adjacent said beam interrupting means in the direction of travel of said beam, an ionizer unit located adjacent the entrance of said mass spectrometer, said ionizer unit including a stacked array of mutually insulated apertured members that define a portion of the line of sight path of travel of said periodically interrupted beam, a filament element removably mounted within said ionizer unit for effecting the production of a flow of electrons substantially perpendicular to the line of sight path of travel of said collimated beam which ionizes a portion thereof, means supplying said apertured members of said ionizer with potentials having a magnitude such as to produce an accelerating field for the ionized beam particles that is directed toward said mass spectrometer so that the ionized portion of the collimated beam is injected into said mass spectrometer while the remaining portion thereof travels directly therethrough, detecting means mounted adjacent the exit of said mass spectrometer for producing a modulated output signal having a frequency corresponding to the preselected frequency at which said beam is interrupted by said beam interrupting means, a phase sensitive circuit connected to the output of said monitoring means and said detecting means for producing an output signal related to the characteristics of said beam of gaseous particles derived from said external source, and means connected to said phase sensitive circuit for recording said output signal.

5. A device for analyzing a gas supplied thereto from an external source, which device comprises a gas tight housing that defines a first and a second vacuum chamber, means effecting the evacuation of said first and second vacuum chambers to respective pressure levels, means mounted within said housing between said first and second vacuum chambers for forming a collimated beam of particles of the gas from the external source and for directing said beam from said first vacuum chamber along a line of sight path into and through said second vacuum chamber in order that particles in the beam not be scattered and combine to form new particles not in the original beam, a motor driven chopper wheel assembly mounted within said second vacuum chamber in the path of travel of said collimated beam for effecting the interruption thereof at a preselected frequency, means monitoring the rate at which the periodic interruption of said beam is effected and for producing a synchronizing signal related thereto, a mass spectrometer disposed adjacent said chopper wheel assembly in the direction of travel of said beam, an ionizer unit located adjacent the entrance of said mass spectrometer, said ionizer unit including a stacked array of mutually insulated apertured members that define a portion of the line of sight path of travel of said periodically interrupted beam, a filament element removably mounted within said ionizer unit for effecting the production of a flow of electrons substantially perpendicular to the line of sight path of travel of said collimated beam which ionizes a portion thereof, means supplying said apertured members of said ionizer with potentials having a magnitude such as to produce an accelerating field for the ionized beam particles that is directed toward said mass spectrometer so that the ionized portion of the collimated beam is injected into said mass spectrometer while the remaining portion thereof travels directly therethrough, detecting means mounted adjacent the exit of said mass spectrometer for producing a modulated output signal having a frequency corresponding to the preselected frequency at which said beam is interrupted by said chopper wheel assembly but differing in phase from said synchronizing signal in direct proportion to the distance between said movable chopper wheel assembly and said ionizer unit, a phase sensitive circuit connected to the output of said monitoring means and said detecting means for producing an output signal related to the characteristics of said beam of gaseous particles derived from said external source, and means connected to said phase sensitive circuit for recording said output signal.

6. A device for analyzing a gas supplied thereto from an external source, which device comprises a gas tight housing that defines a first and a second vacuum chamber, said housing including means for allowing selective access to said first and second vacuum chambers, means effecting the evacuation of said first and second vacuum chambers to respective pressure levels, means mounted within said housing between said first and second vacuum chambers for forming a collimated beam of particles of the gas from the external source and for directing said beam from said first vacuum chamber along a line of sight path into and through said second vacuum chamber in order that particles in the beam not be scattered and combine to form new particles not in the originial beam, means mounted within said second vacuum chamber in the path of travel of said collimated beam for effecting the interruption thereof at a preselected frequency, means monitoring the rate at which the periodic interruption of said beam is effected and for producing a synchronizing signal related thereto, a mass spectrometer disposed adjacent said beam interrupting means in the direction of travel of said beam, an ionizer unit located adjacent the entrance of said mass spectrometer, said ionizer unit including a stacked array of mutually insulated apertured members that define a portion of the line of sight path of travel of said periodically interrupted beam, a filament element removably mounted within said ionizer unit for effecting the production of a flow of electrons substantially perpendicular to the line of sight path of travel of said collimated beam which ionizes a portion thereof, means supplying said apertured members of said ionizer with potentials having a magnitude such as to produce an accelerating field for the ionized beam particles that is directed toward said mass spectrometer so that the ionized portion of the collimated beam is injected into said mass spectrometer while the remaining portion thereof travels directly therethrough, detecting means mounted adjacent the exit of said mass spectrometer for producing a modulated output signal having a frequency corresponding to the preselected frequency at which said beam is interrupted by said beam interrupting means, a phase sensitive circuit connected to the output of said monitoring means and said detecting means for producing an output signal related to the characteristics of said beam of gaseous particles derived from said external source, and means connected to said phase sensitive circuit for recording said output signal.

7. A portable device for analyzing a gas supplied thereto from an external source which device comprises a gas tight enclosure mounted on a movable support table for movement therewith, said enclosure having a substantially rectangular configuration and having external and internal wall members proportioned to define a first and a second vacuum chamber, one of said wall members being apertured to allow ready access to said first and second vacuum chambers, a door member secured to said apertured wall member so that said door member can be selectively moved out of and into gas tight sealing relationship with said aperture, means effecting the evacuation of said first and second vacuum chambers to respective pressure levels, means mounted within said enclosure between said first and second vacuum chambers for forming a collimated beam of particles of the gas from the external source and for directing said beam into said second vacuum chamber, means mounted in said second vacuum chamber in the path of travel of the collimated beam of particles for effecting the modulation thereof at a preselected frequency, a mass analyzer disposed adjacent said modulating means in the direction of travel of said beam, means adjacent the entrance of said mass analyzer for effecting the ionization of at least a portion of said collimated beam without substantial diversion of said beam so that said partially ionized beam travels directly into said mass analyzer, detecting means mounted adjacent the exit of said mass analyzer for producing a modulated output signal having a frequency corresponding to the preselected frequency at which said beam is modulated by said beam modulating means, said ionizing means and mass analyzer providing a substantially unimpeded path for the passage of the un-ionized portion of said collimated beam in order that particles in the beam not be scattered and combine to form new particles not in the original beam, and means responsive to the output signal from said detecting means for producing output information related to the characteristics of said modulated beam of gas particles.

8. A device for analyzing a gas supplied thereto from an external source, which device comprises a gas tight housing, first and second vacuum chambers within said housing, said first chamber including means defining an entrance orifice for admitting gas to be analyzed, means within said first chamber for selectively blocking said orifice to block the admission of gas to said first chamber, means effecting the evacuation of said first and second vacuum chambers to respective pressure levels, means mounted within said housing between said first and second vacuum chambers for forming a collimated beam of particles of the gas from the external source and for directing said beam from said first vacuum chamber along a line of sight path into and through said second vacum chamber in order that particles in the beam not be scattered and combine to form new particles not in the original beam, means mounted within said second vacuum chamber in the path of travel of said collimated beam for effecting the interruption thereof at a preselected frequency, means monitoring the rate at which the periodic interruption of said beam is effected and for producing a synchronizing signal related thereto, a mass analyzer disposed within said second vacuum chamber adjacent said beam interrupting means in the direction of travel of said beams, an ionizer unit secured to the entrance of said mass analyzer for producing a stream of electrons directed substantially perpendicular to said collimated beam so that at least a portion of said beam is ionized, the ionized portion of the collimated beam being injected into said mass analyzer, said ionizer unit providing a substantially unimpeded path for the passage of the unionized portion of said collimated beam, detecting means mounted adjacent the exit of said mass analyzer for producing a modulated output signal having a frequency corresponding to the frequency at which the said beam is periodically interrupted by said beam interrupting means, and circuit means connected to said monitoring means and said detecting means for producing output information related to the characteristics of said modulated beam of gas particles.

9. A device for analyzing a gas supplied thereto from an external source, which device comprises a gas tight housing, first and second vacuum chambers within said housing, means effecting the evacuation of said first and second vacuum chambers to respective pressure levels, means mounted within said housing between said first and second vacuum chambers for forming a collimated beam of particles of the gas from the external source and for directing said beam from said first vacuum chamber along a line of sight path into and through said second vacuum chamber in order that particles in the beam not be scattered and combine to form new particles not in the original beam, a periodic beam chopper mounted within said second vacuum chamber in the path of travel of said collimated beam for effecting the interruption thereof at a preselected frequency, means monitoring the rate at which the periodic interruption of said beam is effected and for producing a synchronizing signal related thereto, a mass spectometer disposed after said chopper in the direction of travel of said beam, an ionizer secured to the entrance of said mass spectrometer and spaced a predetermined distance from said chopper, and means for ionizing a portion of the particles in said beam and injecting the ionized particles into said mass spectrometer while the remaining portion of the beam travels directly through the ionizer, detecting means mounted adjacent the exit of said mass spectrometer for producing a modulated output signal having a frequency corresponding to the preselected frequency at which said beam is interrupted by said chopper but differing in phase from said synchronizing signal in direct linear relation to the time necessary for particles to move from said chopper to said ionizer, a phase sensitive circuit connected to the outputs of said monitoring means and said detecting means for producing an output signal related to the difference in the phase of the two outputs and indicative of beam velocity.

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