THE UNIVERSITY OF MICHIGAN
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MEASUREMENTS OF ATMOSPHERIC PRESSURE, TEMPERATURE, DENSITY, AND COMPOSITION AT VERY HIGH ALTITUDES

Prepared for the project by

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1.0 INTRODUCTION

This report is the fifth in a series which outlines a research effort oriented toward development of a system employing a small mass-spectrometer-type device in the measurement of pressure, temperature, and density of the atmosphere at altitudes where the mean free path of the neutral particles is long in comparison with the dimensions of the measuring object.

As noted in previous reports, the effort is devoted in general to several tasks:

(a) a theoretical study of the general measurement problem, and several associated problems;

(b) development of suitable sensors;

(c) development of associated instrumentation to permit fruitful employment of the sensors; and

(d) the development of an ultra-high-vacuum system capable of achieving pressures as low as the state of the art permits, with the final objective of sensor calibration and testing.

The following sections of the report will summarize the work during the interval in these regards.

2.0 THEORETICAL STUDY

Previous reports have discussed in detail the nature of the pressure variation one would expect to observe in a small chamber located in a rocket-launched rolling sphere at high altitudes, under the influence of stream velocity at least comparable to the mean thermal velocity of neutral particles. The significant factor was shown to be the normal component of the vector velocity which results in a significant increase in the pressure when positive, and a decrease when negative. The effects are summarized by the following equations:

$$P_i = P_o \sqrt{\frac{T_i}{T_o}}\, f(s)$$

where:

P_i = internal pressure

P_o = external pressure (ambient)

T_i = internal temperature

T_o = external temperature (ambient)

$$f(s) = e^{-s^2} + \sqrt{\pi}\, s(1 + \text{erf } s) \qquad (1)$$

$$s = \frac{V_s}{V_g} \qquad (2)$$

$$V_g = \sqrt{\frac{2kT_o}{m}} \qquad (3)$$

m = mass of gas being measured

V_s = normal component of vector velocity

k = Boltzmann's constant

It is of historical interest to note that an experiment based upon this concept was attempted using the V-2 rocket as early as 1946, and on several subsequent launchings.[19] The results were essentially inconclusive, however, because of insufficient altitude, and hence velocity. More recently the method has been employed rather successfully by Lagow and others[20]* employing Aerobee

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*Most recent of several papers published over many years.

rockets; the chief difficulties were associated with rocket out-gassing and other problems involving the vehicle.

Thus in the present research, it was concluded that the next logical and essential step required separation of the measurement devices from the rocket, and in addition prior out-gassing of the instruments to enable a substantial reduction of the background gas level, a notably serious limitation in the recent experiments (see first quarterly report GQ-1, November, 1958).

To define the limits which one should expect to encounter in the proposed initial experiment of the present research, an estimate has been made of the expected payload for the Aerobee 150 rocket to be used, and a corresponding peak altitude of 145 miles assumed. This conveniently corresponds to a Churchill flight (NN3.11F) which carried Lagow's experiment. Thus it will eventually be possible to make an interesting comparison of results. The immediate benefit, however, is the adoption of the measured trajectory of NN3.11F for use in planning of the present experiment.

Two aspects of the measurement are of interest. The first, considered by the writer to be the major developmental aspect of the system, involves a determination of the variation of pressure with roll angle of the sphere and hence with the normal component of the vector velocity. A satisfactory measurement of this quantity will yield the velocity distribution function of the gas and hence the kinetic temperature. The second point of major interest involves measuring the maximum and minimum pressure during a roll period, and the pressure when the normal component of the vector velocity is zero, the latter pressure being the ambient pressure. In regard to the maximum and minimum, if one employs Eq. (1) and permits s to have its maximum and minimum values, then, as has been shown:

$$\Delta P = P_{i\ max} - P_{i\ min} = nV_s \sqrt{2\pi k m T_i} \qquad (4)$$

where

n = number density of ambient gas.

This can be rearranged, letting the density

$$nm = \rho = \frac{\Delta P}{V_g \sqrt{\pi}\ V_s} \qquad (5)$$

This is the form employed by Horowitz and Lagow.[19]

Except for the upper 20-30 miles of a suitable rocket trajectory, the minimum pressure can be neglected, without significant error, and thus under this condition,

$$\rho = \frac{P_{max}}{V_g \sqrt{\pi}\, V_s} \qquad (6)$$

To establish the limits for the expected initial experiment, typical values of pressure based upon the most recent standard[21] and the estimated peak altitude (145 miles) have been computed, and plotted as shown in the accompanying figures.

Three separate plots are included: (a) pressure vs. time from peak altitude (Fig. 2.1), (b) pressures vs. altitude in feet (Fig. 2.2), and (c) normalized pressure vs. rotational angle of the sphere for 3 times during the flight: 40, 100, and 160 seconds before or after peak time (Fig. 2.3). In the first two figures, the maximum and minimum pressures and the ambient pressure are shown. In Fig. 2.2, the difference is also plotted. It is clear from these curves that it is feasible to measure both maximum and minimum only when their difference is relatively small, when, in fact, it becomes important.

The curves shown are computed on the basis of air assuming ground-level composition. For the experiment planned, the omegatron will be used as a single-gas ionization gage, that is, will be adjusted to measure N_2 pressure only and thus the magnitudes indicated on the curves must be reduced roughly by the ratio of N_2 to air concentration. The advantage in using N_2 is clear. The molecular weight is known and dissociation is probably negligible to the expected altitude.

On the basis of the studies that have been made, including the above, the general outline of the proposed experiment is now as follows:

(1) Located on a great circle of the 13-in. sphere, in a plane normal to the axis of rotation:

  (a) 3 omegatrons tuned to N_2, spaced 90° apart;

  (b) 1 Bayard Alpert thermionic ionization gage located 90° from the omegatrons to measure total pressure;

(2) 1 Bayard Alpert thermionic ionization gage located at the end of the spin axis (90° from plane of other gages) to measure total pressure (ambient).

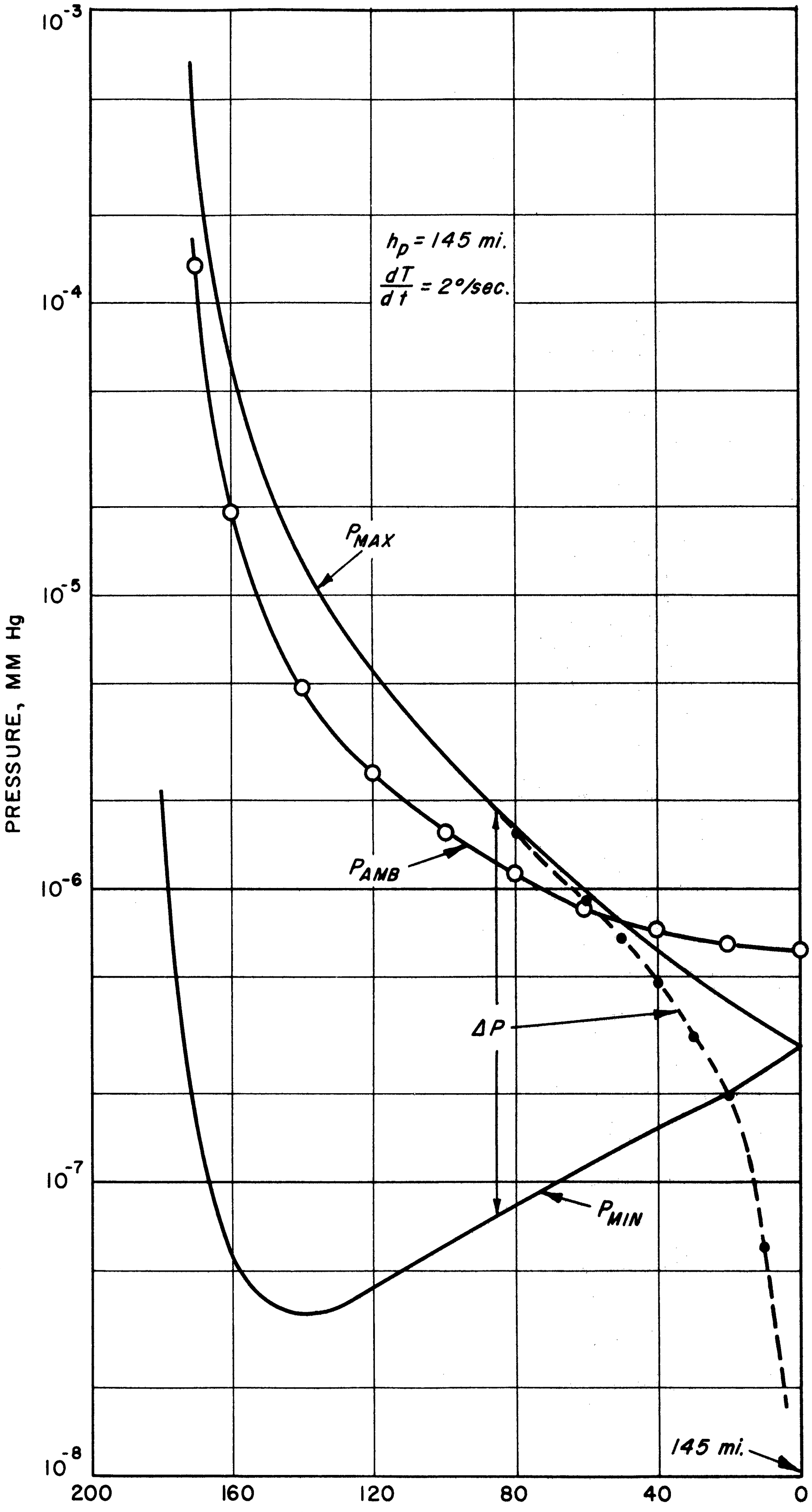

Fig. 2.1. Pressure vs. time from peak.

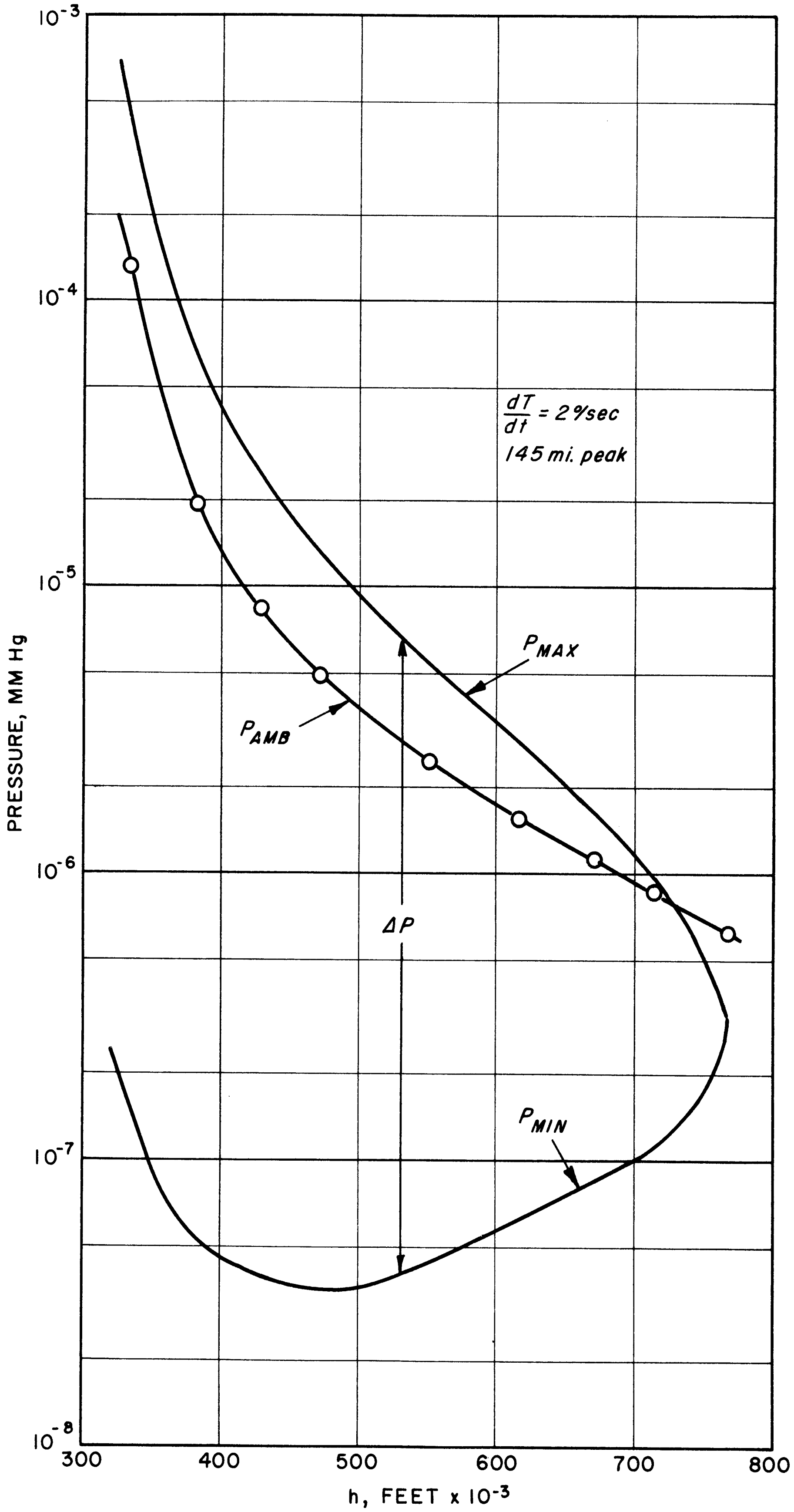

Fig. 2.2. Pressure vs. altitude.

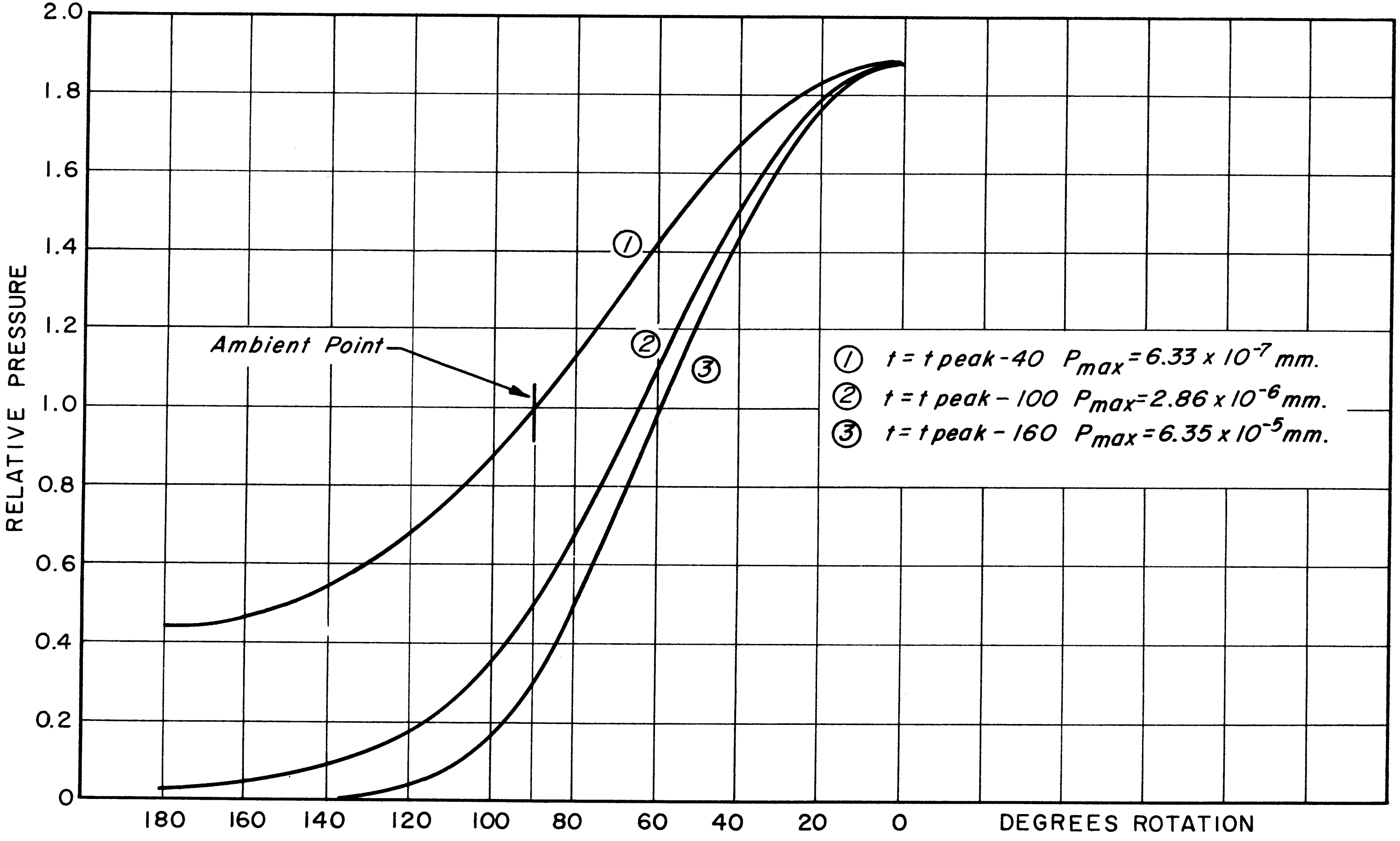

Fig. 2.3. Relative pressure with spin. Three cases—145-mile peak.

3.0 SENSOR DEVELOPMENT

The last report indicated the construction of two new "test" tubes, serial Nos. 5 and 6, which were built primarily (a) to evaluate the possibility of using an electron multiplier to improve sensitivity and (b) to provide a more uniform rf field to indicate the relative importance of this parameter.

Additional studies involving a previously built tube were continued while Nos. 5 and 6 were being assembled, and the results were of sufficient promise to indicate that there was little need at present to pursue either the multiplier or more uniform field investigations. The newer results indicated that with existing, proven techniques employed with other experiments being pursued in the laboratory, there was adequate sensitivity for the pressures anticipated in the first flight.

Thus the effort at present in regard to sensor development is directed toward the construction of models suitable for flight. Many changes are necessary to achieve a tube adequate for dependable operation in the rocket. For this design an appropriate permanent magnet has been chosen that weighs approximately 8 pounds, has a gap length of 7/8 inch, and a diameter of 1-1/4 inches. The flux obtainable with this magnet is about 3800 gauss, an appropriate value for the tube desired.

Because of the desirability of vacuum cleanliness, it is planned to make the tube envelope an integral part of the sphere skin, thus enabling a nearly ideal orifice. This is illustrated in Fig. 3.1. The tube elements will be assembled on a bottom plate which will close the chamber. Present efforts are directed forward fabricating the tube elements from stainless-steel etched mesh to provide cleanliness and free particle movement.

The present design contemplates assembly on sapphire rods, with the rods external to the action volume to prevent perturbing, localized field irregularities.

The magnetic field and polarizing potentials will be such that the ion-orbit length will be relatively short to minimize the effects of initial velocity and consequent loss of ions.

In addition to laboratory checks of the omegatron, the "Diatron," discussed in previous reports, has been tested. The results indicate that it is not suitable for use in this experiment for the following reasons; (a) its sensitivity is low, (b) its structure is relatively complicated, and (c) it is not well suited to adequate flow equilibrium. Thus the "Diatron" on hand will not be flown but will be retained for spectrometer purposes on the laboratory vacuum system.

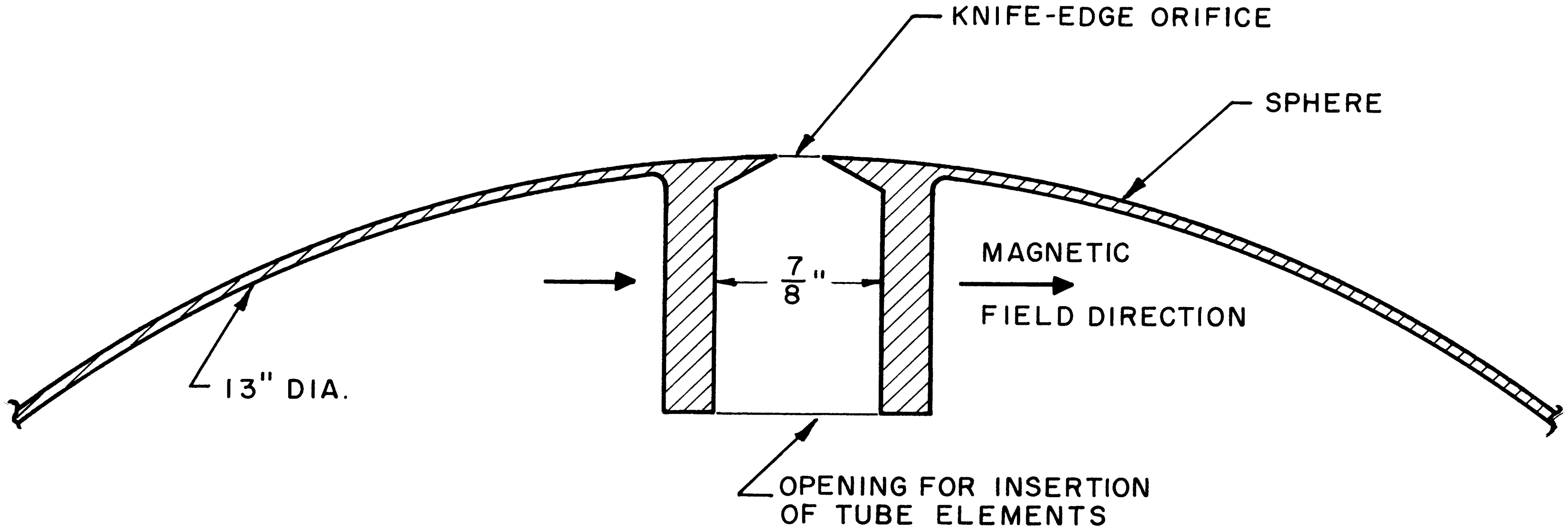

Fig. 3.1. Outline of omegatron chamber designed as an integral part of sphere.

4.0 INSTRUMENTATION

4.1 SPHERE

Modest financial resources available for this research as well as desirable economies have indicated the adaptation of circuits developed for other experiments being conducted by this laboratory to the sensors planned for the omegatron-sphere experiment. Thus a considerable effort already underway can be applied directly to this work. In this regard, electrometer systems necessary to convert the d-c output current of the omegatrons and ionization gages to useful voltages for telemetry are already being developed and nearing final form, and will thus be available soon for this purpose. These circuits comprise a significant fraction of the necessary electronics required.

Other, less complicated circuits are required and are being developed. These include (a) filament emission regulators, (b) rf generators, (c) minor voltage supplies, etc.

A final decision regarding the specific telemeter has not been made; however, it appears at this time that either a Bendix TXV-13 with appropriate subcarrier oscillators developed in this laboratory or a NASA-built unit patterned after the DKT-7 will be employed.

Two stainless-steel spheres 13 in. in diameter comprised of spun hemispheres have been fabricated for the experiment. One set of these has been completed in regard to assembly and vacuum-sealing details, and is ready for further work such as installation of the chambers, orifices, brackets, etc. These latter installations will not be made until flyable models of the omegatrons have been satisfactorily completed.

4.2 ROCKET NOSE CONE

As noted in previous reports, proper functioning of the experiment requires that the sphere be ejected from the rocket in a particular fashion to enable rotation in a particular fashion. Specifically, it is desired that the sphere, upon ejection, spin at about a 1-rps rate with its spin axis lying in a plane parallel to an earth-tangent plane. To be assured of such motion, one would need a stable platform from which to launch the sphere, and some stabilizing means once launched. These provisions are clearly beyond the resources of the program, at least at present, and thus a compromise has been made. Experience with the Aerobee indicates that, with a suitable roll rate gross launching weight, and a proper stability factor, the rocket can be expected, without malfunction, to remain essentially upright as it passses the 100-125-km level. It can thus be considered to be a quasi-stable platform of several degrees deviation except that it will be rolling about 2 rps. To offset the roll, it is expected to rotate the sphere inside the vacuum chamber just opposite to the rocket roll using a roll gyro as sensor.

Ejection will be effected by spring force as is the custom with other experiments underway in the laboratory. It is planned to use a lanyard to impart the necessary spin to the sphere upon ejection; however, to maintain the proper axis of rotation, it will be necessary to provide a maximum moment of inertia about the desired spin axis. Fortunately, the necessary location of the permanent magnets and other heavy items required for the measurements corresponds with the desired location insofar as the moment of inertia is concerned and thus the required conditions can be achieved. It is felt that the likelihood of attaining the desired sphere motion within acceptable limits is quite high.

5.0 ULTRA-HIGH-VACUUM SYSTEM

No further effort has been devoted to the UHV system. It has been demonstrated that the apparent ultimate pressure of the system, $\sim 5 \times 10^{-11}$ mm Hg, can be readily attained with a "cold finger," and thus the system will be available when needed.

6.0 FUTURE WORK

The contract covering this work has been extended without additional funds, and thus the work will continue toward the stated objective. It will be necessary to extend the period again, at least to the summer of 1960, to permit preparation for the test launching. The effort will be directed toward preparation of the instrumentation for flight.

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