A Gas Density Detector for Use in Space

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We have investigated the suitability of radioactively-induced currents in ionization chambers and proportional counters and of breakdown currents in glow tubes as a monitor of gas density for use in meteoroid detection in space. The ionization chamber using an alpha source of moderate activity ($\lesssim$1 mCi) has a small maximum current $\lesssim$1 μamp at a few hundred volts. However, the dependence of current on gas density is approximately linear at intermediate densities ($\sim$1 to 760 torr at 25°C), and thus the ionization chamber might find application as a hole size detector. The proportional counter using a similar source provides currents up to 100 μamp at $\sim$1 kv, but the dependence of current on gas density is not monotonic, which complicates the interpretation of these readings. The glow tube gives currents $\sim$1 mamp at moderate voltages ($\sim$200 v) and thus is a promising "on-off" gas detector. Optimum parameters for construction of a coaxial glow tube were found and temperature and mechanical stability tests were conducted.

Introduction

A POSSIBLE meteoroid detection device is a gas-filled, thin-walled cell which evacuates when punctured. Such a detector can be operated in two modes. As an "on-off" gage, it indicates a puncture if the gas density falls below a preset threshold. As a hole size gage, it measures the time rate of change of the gas density. We have constructed an on-off gage in which a radioactive source produces particles that ionize the gas between two electrodes of a gas detector (Fig. 1). The resulting current, detected in an external circuit, is a complicated function of the gas density and the other parameters. This device must be rugged, small, and light, with rapid response, have no moving parts, and have a relatively large current output when filled with gas and negligible current when evacuated. Here we describe the theory and construction of such a device operating in the ionization chamber, proportional counter, and glow tube modes.

Theory

When a charged particle from a radioactive source loses all its kinetic energy by collisions in a gas, it comes to rest. The total distance it has traveled in coming to rest is called the range R, and is obtained by integrating the differential energy loss $-dE/dx$ of the particle in the material[1]

$$R = \int_0^E \frac{dE}{(-dE/dx)} \tag{1}$$

If R is less than the interelectrode spacing d of a gas detector, then the number of ion pairs n_I produced in the detector volume will be the same for all values of R regardless of variations in the gas density. However, if $R > d$, the n_I produced by the charged particle along its path will be

$$n_I = \frac{1}{w}\int_0^d \left(-\frac{dE}{dx}\right) dx \tag{2}$$

where w is the average energy loss per ion pair. The dependence of n_I on the density N of the detector gas is in general complicated for $R > d$, but is approximately linear under some circumstances. Since the detector current of ionization chambers and proportional counters is a function of n_I, we see that the current varies with detector gas density only when $R > d$. This observation is irrelevant for glow tubes, because their running current does not depend on n_I. The values of $(-dE/dx)$ and n_I for alpha particles are typically several orders of magnitude greater than for beta particles under otherwise identical conditions.[2] Gamma emitters are not of interest for our purposes since the probability of photons interacting with matter is small compared to charged particles.

The positive ions and electrons recombine at a rate given by

$$dn_e/dt = dn_+/dt = -\alpha n_+ n_e \propto N^2 \tag{3}$$

where n_+ and n_e are the number per unit volume of positive ions and electrons, respectively, and α is the coefficient of recombination. Since n_+ and n_e are both proportional to n_I, their rates are proportional to N^2 if n_I is a linear function of N.

After their creation, positive and negative atomic ions thermalize locally (in space) with a temperature close to that of the surrounding neutral gas atoms. An electric field ϵ superimposes on their fast random thermal motions a slow drift velocity $v_\pm$ toward their complementary electrodes, given by

$$v_\pm = \mu_\pm \epsilon/P \tag{4}$$

where $\mu_\pm$ is the mobility of positive and negative atomic ions, respectively, and depends on the charge and mass of the ion and on the nature of the host gas, and P is the gas pressure at standard temperature.

Free electrons lose their kinetic energy primarily in collisions that excite gas atoms. The energies of the lowest-lying excited states of monatomic (i.e., rare) gas atoms are typically $\sim$10 ev, so that free electrons quickly thermalize to an average "agitation energy" E_a of 10 ev. However, the electrons do not attain a velocity distribution which is Maxwellian. Note that the free electrons will be much "hotter" than the atomic ions or gas molecules (for which $kT \sim 0.025$ ev at room temperature).

Superimposed upon the agitation motion of the electrons is a drift velocity v_e about 10^3 larger than that for atomic ions. By a simple theory,[3] $v_e = e\tau\epsilon/m$, where τ is the mean free time between collisions. Assuming that all electrons have the same rms agitation velocity $u = (2E_a/m)^{1/2}$, and recalling that their mean free path λ_e is $u\tau$, we obtain

$$v_e = e\lambda_e\epsilon/mu = e\lambda_e\epsilon/(2mE_a)^{1/2} \tag{5}$$

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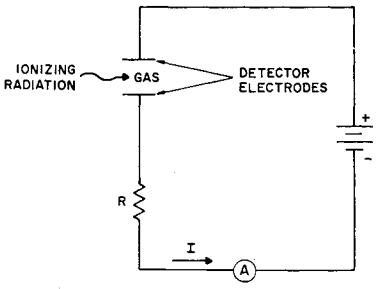

Fig. 1 Schematic diagram of the basic gas detector.

One can decrease E_a, and thus increase v_e, by roughly a factor of ten in rare gas detectors by adding a few percent of a polyatomic gas which has excited rotational and vibrational states $\sim$1 ev above its ground state. Also, λ_e is increased by the addition of such a polyatomic impurity, because a quantum mechanical phenomenon called the Ramsauer effect,[4] which causes the total cross section for the scattering of electrons by rare gas atoms to have a minimum at $\sim$1 ev. Preferred polyatomic gases are N_2, CO_2, and CH_4. (In contrast, O_2, H_2O, NH_3, HCl, or SiF_4 could capture an electron and drastically reduce its drift velocity.)[4]

Operational Modes

The various operational modes associated with the current-voltage characteristics of the basic gas detector (Fig. 1) are depicted in Fig. 2 (Ref. 5). The ionization chamber and proportional counter modes are not self-maintaining (current ceases in the absence of ionizing radiation), but in the other modes radiation is needed only to initiate the electric discharge and an external resistor (R in Fig. 1) is used to limit the current. In what follows, we discuss the three modes which appear to be best suited for use as a gas density detector to be flown on a spacecraft.

Ionization Chamber Mode

The ionization chamber[3,4] is a low-current, low-voltage device that has been utilized in commercial radioactive ionization pressure gauges. The mechanical construction usually employs a parallel plate geometry (Fig. 3). The guard ring makes the electric field between the electrodes more homogeneous by minimizing edge effects, and it allows one to ignore leakage currents through the insulators. In the ionization chamber mode, the only ion pairs present in the gas are produced by the bombarding radiation. The region 0 to B of Fig. 2 describes the direct current (dc) operation in this mode with a radioactive source of constant activity. From 0 to A, not all the ion pairs are collected, because the small v_e and v_+ allow many ions to recombine or diffuse out of the sensitive region before reaching an electrode. In the saturation region, A to B, all the ion pairs are collected by the electrodes, as v_e is sufficiently large to make recombination negligible. Space charge effects are not always negligible.[3]

The expected current of an ionization chamber is easily estimated. For a 1-mCi alpha source whose energy is 5 Mev, we assume that 2.5 Mev is lost on the average by each alpha particle in the sensitive region of the chamber and that w is always on the order of 30 ev. Then the number of ion pairs produced is 3×10^{12} sec^{-1}. Since each ion pair contributes one electronic charge to the external current in steady state dc operation at saturation, the resulting saturation current I_{SAT} is 4.8×10^{-7} amp for a given gas density, independent of the kind of gas used. For alpha sources of 5 Mev energy with activities <1 mCi, the currents will typically be $\lesssim 10^{-6}$ amp. It is difficult to obtain physically small alpha sources with activities of 1 mCi, and our experimental maximum current was $\sim 3 \times 10^{-7}$ amp, which would be difficult to detect under the constraints of flight conditions.

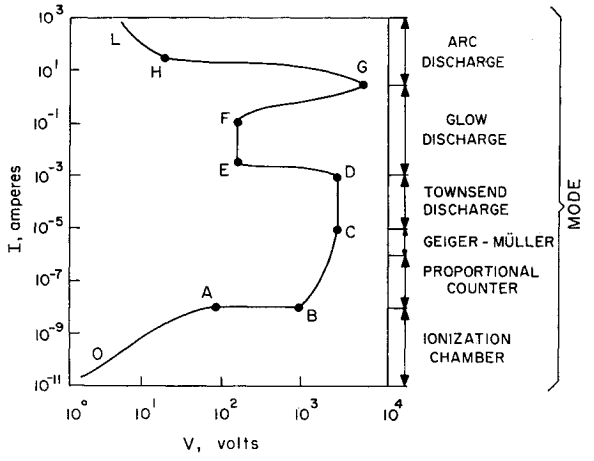

Fig. 2 Typical current vs voltage characteristics of a gas detector at fixed gas density.

Proportional Counter Mode

Proportional counters[3] are usually designed with a coaxial geometry, to take advantage of the large fields near the central electrode. The magnitude of the electric field ϵ_r at a distance r from the axis of the counter is

$$\epsilon_r = V/r \ln(b/a) \tag{6}$$

where a is the outside radius of the inner conductor wire, b is the inner radius of the outside cylindrical conductor, and V is the voltage across the counter. Cylindrical guard rings are often used with this geometry. Close to the center electrode, which is maintained at a positive polarity, ϵ_r becomes large, and electrons produced by the ionizing radiation can themselves attain sufficient energy between collisions to ionize gas molecules. The many photons given off in an avalanche process can in turn eject electrons from the container walls and gas molecules. If $\gamma(\ll 1)$ is the average number of photoelectrons produced by one ion pair in the gas, then the initial avalanche due to one primary electron produces $n\gamma$ photoelectrons, and the latter multiply by the factor n before collection at the anode to give a total of $n^2\gamma$ electrons. These electrons then produce $n^2\gamma^2$ photoelectrons which multiply by n to give $n^3\gamma^2$ total electrons before collection, and so on. Hence the total multiplication M is

$$M = n + n^2\gamma + n^3\gamma^2 + \ldots = n/(1 - n\gamma) \tag{7}$$

if $n\gamma < 1$. In the limit that $n\gamma \ll 1$, we see that $M = n$. Thus, the condition for a "proportional" counter is that the output current of the counter is proportional to the number of primary electrons produced by the ionizing radiation if photoelectron production is negligible. We have ignored recombination, electron attachment losses, and space charge effects, which is legitimate for large electric field, small ionizing radiation activity and n not too large. As $n\gamma \to 1$, M becomes very large and the counter becomes nonproportional. At $n\gamma = 1$, $M = \infty$, and a self-maintaining discharge is established (e.g., Geiger-Müller mode, glow tube mode, etc.). This depends not only on the nature of the gas (on n) but also on the photo-

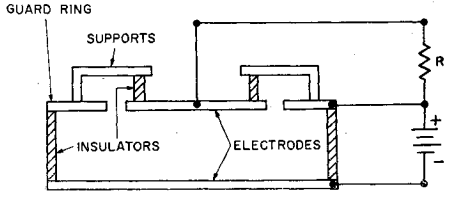

Fig. 3 Typical parallel plate ionization chamber.

electric properties of the electrodes (on γ). Values of M up to 10^4 can be obtained, but operation becomes unstable when $n\gamma \to 1$, i.e., when n is large.

The current-voltage characteristics with fixed gas density and constant radiation activity in the dc operation of the proportional counter mode are shown in Fig. 2. The current is the product of the equivalent ionization chamber saturation current and the multiplication factor. If the applied voltage V is sufficiently large, M, and therefore I, is an exponential function of V, which is approximately proportional to N.[3] At $N \simeq 1$ torr, where λ_e is large, n is large, and M varies rapidly with both V and N. The addition of a small amount of CO_2 or CH_4 to a rare gas in the counter smooths out these variations by lowering E_a. Since multiplications of 10^2 to 10^3 are reasonable in proportional counters, and since typical ionization chamber saturation currents go up to 10^{-7} amp, proportional counters give currents up to 10^{-4} amp at voltages $\gtrsim 1000$.

Glow Tube Mode

The cold cathode glow tube[6,7] is usually constructed with a coaxial geometry or with two parallel conducting rods. The device typically has a low current ($\ll 1$ mamp) due to residual ionization at low voltages, but breaks down to give currents ~ 1 mamp at some striking voltage V_s. The tube is usually operated in the normal glow discharge regime (E to F in Fig. 2) at a running voltage V_r somewhat less than V_s. Cosmic rays are a natural contributor to the residual ionization necessary to start (but not sustain) breakdown, but external light and radioactive sources are much more effective. Small amounts (~ 1 μCi) of ^3H or ^{85}Kr are sometimes added to glow tubes so that their characteristics will be maintained when operated in the dark. To be self-maintaining, the glow tube must produce new ion pairs in the gas at the same rate that they are collected at the electrodes. The chief mechanism occurs when positive ions reach the cathode and neutralize by combining with an electron: the ions eject extra electrons from the cathode surface which then contribute to the electron avalanche and interelectrode current. This process depends on the properties of the cathode material and surface as well as those of the gas, and is usually stronger than photoelectron production.

The glow tube has a large space charge such that most of the voltage drop occurs in a small region near the cathode occupied by relatively many positive ions and few electrons; the rest of the interelectrode space has roughly equal numbers of positive atomic ions and electrons. The current density J (current per unit area of cathode surface) in the normal glow discharge regime is approximately a constant. Referring to Fig. 2, the amount of glow spreads from a small part of the cathode (at E) until the entire length of the cathode is glowing (at F); the glowing region has a fixed J ($J \propto N^2$),[6] and the unglowing region, negligible current. Thus, the area of the cathode covered by the glow is proportional to the total current through the tube.

An approximate rule, Paschen's Law, states that at fixed temperature and with parallel plates, V_s is a function of $P \cdot d$ for a given gas and cathode material and surface. (For variable temperatures, one reads "gas density" for P.) V_s is large at both high and low gas densities, passing through a minimum in between. At high densities, λ_e is small, and electrons do not usually acquire enough energy between collisions to ionize gas atoms and produce an electron avalanche. At low densities, the paucity of gas atoms makes the production of an electron avalanche improbable.

V_s and V_r are reduced in so-called Penning mixtures, in which a small amount of impurity gas is admixed to the host. The impurity gas is chosen so that it is energetically possible for a collision between a metastable host atom and an impurity atom to return the host atom to its ground state and to ionize the impurity atom, thus increasing the ionization in comparison with a pure host gas sample. The more nearly equal the two energies, the more probable it is that this transfer reaction occurs. This reaction is possible in an electron avalanche because the atoms, in addition to being ionized, are excited to metastable atomic states which have a long lifetime ($\sim 10^{-2}$ to 10^{-4} sec) compared with the mean time between atomic collisions ($\sim 10^{-10}$ sec) or the mean time for radiative de-excitation ($\sim 10^{-7}$ to 10^{-10} sec). A Ne (99.5%)–A(0.5%) mixture satisfies the aforementioned requirement, since the energy of metastable neon is 16.6 ev, while the ionization energy of argon is 15.8 ev. This effect is also observed in a He (99.5%)–A(0.5%) mixture because the energy of metastable helium is 19.8 ev, but is most pronounced in the Ne-A mixture, where a minimum in V_s and V_r occurs with argon concentrations between 0.1 and 1%. At lower concentrations there are too few argon atoms, whereas with higher concentrations, electrons begin to ionize directly so that the tube behaves more like an argon device.

The effect of the cathode material and surface are also important. Acton and Swift[6] report the variation of minimum running voltages $V_r^{\min}$ for Ne (99.5%)–A(0.5%) mixtures with various cathode materials: $BaCO_3$ (55 v), evaporated potassium (62 v), evaporated magnesium (79 v), sputtered molybdenum (84 v), sputtered nickel (113 v), and unsputtered nickel (136 v). The results for He (99.5%)–A(0.5%) are roughly 20% higher for each material. The minimum striking voltage $V_s^{\min}$ is about 20v higher than $V_r^{\min}$ for both Penning mixtures. The dependence of V_r and V_s on the cathode material is not as noticeable at high gas densities (Pd $\gtrsim$ 500 torr-cm at room temperature). They report that high purity gases, careful construction, and diligent out-gassing techniques are critical in obtaining stable, optimum performance.

The positive ions bombarding the cathode can eject atoms as well as electrons, causing the deposition of cathode material on the walls of the devices (sputtering). The rate of sputtering is roughly proportional to N^{-5} (Ref. 6). Furthermore, sputtered atoms tend to absorb gas molecules (even the rare gases, but at a slower rate) on their way from the cathode to the walls, thus reducing N, speeding up the sputtering, and eventually destroying the tube. However, at low sputtering rates, these processes are beneficial because they clean the cathode surface and preferentially absorb impurities in a rare gas glow tube. Many commercial glow tubes are "pre-aged"[7] by running them 24 hr in the abnormal glow discharge region (F to G in Fig. 2) at twice their normal glow current density, and then 24 hr at the rated normal glow current density. Tubes with the cathodes and gases thus cleaned up have more stable operational characteristics. It is worth noting here that Al, Mg, and Ba do not sputter as readily as do Mo, Ta, Ni, Cu, and Ag.[6]

Experimental Procedure and Results

The voltages ($\pm 10\%$ accuracy), currents ($\pm 5\%$ accuracy), and pressures ($\pm 0.1\%$ accuracy) reported here were produced and measured with standard electrical and vacuum equipment. For the ionization chamber mode, we used a parallel plate configuration that allowed variation of d and A (electrode cross-sectional area). A radioactive foil was fastened to an electrode by sandwiching it between the flat side of the plate and a thin ($\sim \frac{1}{16}$ in.) annular brass piece (cutout area $\lesssim$ area of the foil) screwed flush to the electrode. The coaxial proportional counter consisted of a copper wire central electrode along the axis of a brass tube, the wire being supported at each end of the tube by a glass-to-metal seal with a tubular inner conductor to which the wire was soldered. A conformed radioactive foil was held against the interior wall of the outer electrode by a small wire spring clip. Two kinds of glow tube electrodes were used. Commercial neon glow lamps were stripped down to their two, parallel, cylindrical, barium-strontium surface electrodes. Coaxial devices similar to the proportional counter design were also constructed. The vacuum

chamber was flushed several times before filling with the test gas. The impurity gas was admitted first to a low pressure, and then the main constituent gas was admitted to a high pressure, the ratio of the two pressures giving the relative amounts of the two gases.

For the radioactive source, α particle emitters produce several orders of magnitude more ion pairs than do β or γ emitters of the same activity, and radiation shielding problems are minimized since the range of alphas is much smaller. The radioactive source should have 1) sufficiently high energy so that its range exceeds the interelectrode distance, 2) a half life $T_{1/2}$ long enough to provide adequate activity throughout the duration of the spacecraft's mission (~2 yr), 3) a half-life short enough so that great amounts of material or excessively large surface areas are not needed to get an adequate activity, 4) a daughter nucleus that is stable so that a unique activity is present, 5) sufficiently low penetrating power so that a minimum external radiation hazard exists, and 6) availability in a form which can be easily inserted into the detector. For detectors with $d \lesssim 1$ cm, 5 Mev alphas satisfy condition 1 at gas densities less than that of STP.[2] Conditions 2 and 3 require that $2 < T_{1/2} < 10^4$ yr. A foil source is the most convenient form to place inside the detector.

We have chosen ^{241}Am, a readily available foil source which has energetic alphas (5.44 and 5.49 Mev), a 458-yr half-life, and reasonable specific activities (~250 μCi per cm^2). ^{226}Ra has gaseous decay products, a lower specific activity (since $T_{1/2}$ = 1600 years), and β and γ activity which is hard to shield. ^{148}Gd and ^{209}Po have acceptable properties but are not readily available in any form. ^{238}Pu foils are acceptable, but are not in commercial production. We also considered the use of ^{39}A or ^{85}Kr as a combined β source-detector gas. This would avoid the problem of mounting the radioactive source in the detector, but the radiation hazard is not negligible. One cm^3 of ^{39}A (^{85}Kr) at STP has an activity of 70 mCi (1.5 Ci), which yields a specific ionization roughly equivalent to a 200-μCi (5-mCi) alpha source.

Radiation in some form (e.g., light, radioactivity, etc.) is necessary for the most effective firing of a glow tube. Because the detector is light-tight, the inclusion of a weak radioactive source is helpful, but one need not worry about aforementioned conditions 1 and 3. A small amount (~1 μCi) of ^{39}A or ^{85}Kr could be added to the glow tube gas, or a small piece (~1 μCi) of radioactive metal like ^{60}Co or ^{63}Ni could be soldered into the detector.

Ionization Chamber Mode

Parallel plate ionization chambers were tested by varying the gas, gas density, voltage, radioactive source activity, electrode area, and interelectrode distance. Figure 4 shows $I(V)$ data for a A-He mixture at three pressures with a 250 μCi ^{241}Am foil source. The onset of saturation occurs at higher V's as P is increased. Figure 4 also shows $I(P)$ data for the A-He mixture and air at 175 v under otherwise identical conditions. The curve is linear in the middle and begins to bend over slightly at higher pressures because of the onset of recombination. At low pressures there is a residual current which is not conducted via the gas, but is caused by electrons and other ions produced at the walls and electrodes by the ionizing particles. Figure 4 shows that the dc operation of ionization chambers is insensitive to the gas used, a fact further documented in Table 1. The saturation current I_{SAT} is the constant value of I for saturation of the ionization chamber at a given pressure, and the saturation voltage V_{SAT} is defined as the lowest voltage at which the chamber is still saturated at a given pressure. Note that all the gases used in Table I have identical characteristics within a factor of 4 under the same conditions.

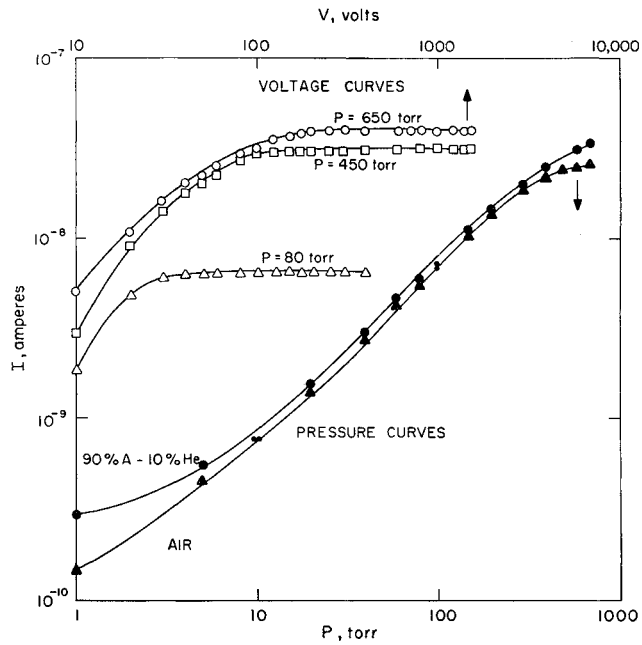

Fig. 4 Ionization current vs voltage at three pressures and ionization current vs pressure at 175 v for A(90%)-He(10%) at room temperature. I vs P is also shown for air at 175 v. Configuration was two circular parallel plate electrodes (each 1 in. diam) spaced 5/16 in. apart. Source was a single 250 μCi ^{241}Am foil mounted on one electrode.

Numerous measurements were made by varying these conditions, from which we learned 1) the guard ring was unnecessary, 2) there was no dramatic change in I when we varied A or d (at constant electric field and N, the n_I produced by the radiation was approximately proportional to the volume of gas between the two electrodes), and 3) the variation of current with different ^{241}Am source activities was roughly proportional to the source activity. To determine the maximum current obtainable under relatively optimum conditions, two 1 mCi ^{241}Am foils were attached to each of two large electrodes, one 2.88-in. diam and the other 3.38-in. diam. Our maximum measured current was 2.8×10^{-7} A for pure argon at 1 atm and 300 v with a 1 in. spacing. This is in fair agreement with the predicted value, and gives a practical upper limit for this type of device with moderate source strengths.

Table 1 Data taken at room temperature with the configuration and source of Fig. 4[a]

	I, 10^{-9} amp		I_{SAT}, 10^{-9} amp			V_{SAT}, v		
Gas	P, torr: 700[b]	1	650	450	80	650	450	80
A	41	0.22	40.5	34	7.3	250	250	125
A(90%)–CH_4(10%)	40	~0.1	40	34	7.4	200	180	125
A(90%)–CO_2(10%)	40	0.28	40.5	34	7.5	250	150	80
A(90%)–He(10%)	38.5	0.3	39	31	6.5	250	150	125
He	10.8	0.15	10.2	7.3	1.5	100	50	40
Air	28	0.15	...	...	...	...	...	...

[a] Values for N_2, H_2 and CH_3 are ~30, ~10, and ~40 (10^{-9} amp), respectively.
[b] Measurements of I were taken at 174 v. I_{SAT} and V_{SAT} are defined in the text.

Proportional Counter Mode

Measurements were made on a coaxial device having a copper wire central electrode (0.005-in. diam) supported at both ends by glass-to-metal seals in a 7/16-in.-i.d. brass tube 2 in. long. A 100 μCi ^{241}Am was clipped to the inside of the tube. Guard rings were determined experimentally to be unnecessary. Figure 5 shows data for pure argon: at voltages below 100–200 v we note the familiar ionization chamber behavior; at ~200 v, multiplication effects cause I to rise sharply, attaining $M > 10^4$ at higher voltages. No attempt was made to determine the quantitative dependence of I on V and P. An

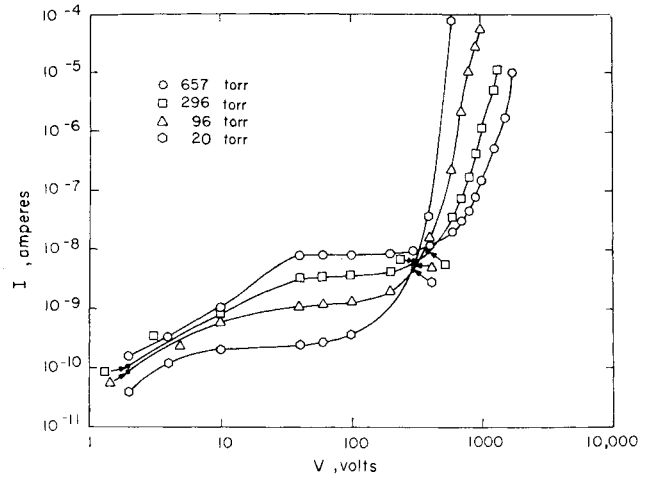

Fig. 5 Current vs voltage for pure argon at room temperature. Configuration (see text) was coaxial with a 100 μCi ^{241}Am foil source.

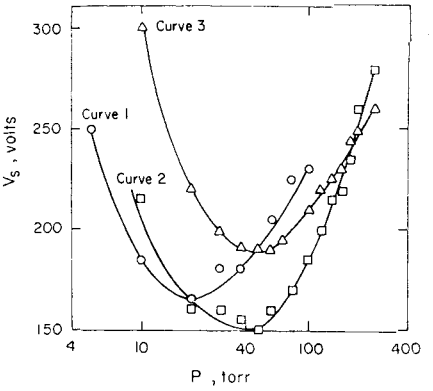

Fig. 7 Striking voltage vs pressure at room temperature. Curve 1: two parallel, cylindrical electrodes from a commercial glow tube, using He(99%)-A(1%). Curve 2: coaxial device (see text) with the central wire negative, using He. Curve 3: same gas and configuration as curve 2 except that the central wire was positive.

important observation is the cross-over of the four curves between 300 and 500 v. This indicates that above 500 v the current I *increases* as P *decreases* from 657 torr to 20 torr; at still lower P, I will decrease. Since the variation of I with N at high voltages is *not* monotonic, the readings from such a gas density detector could lead to ambiguity unless it were carefully calibrated.

Figure 6 shows data using pure argon taken at lower voltages, where there is no apparent multiplication at pressures ~700 torr. Note the current maximum near 4 torr at 400 v, caused by multiplication at lower gas densities where λ_e becomes large. This effect was drastically reduced when 10% CO_2 was added to the argon, because E_a was lowered. However, there was still some low-pressure multiplication above 300 v. We did not investigate the effect on the current of variations in the tube geometry and the foil activity.

Glow Tube Mode

Extensive tests were made in order to determine the optimum design for a glow tube gas detector. Preliminary data on some prototype detectors are shown in Fig. 7. Here two parallel, cylindrical electrodes ($\frac{1}{32}$-in. diam and $\frac{5}{16}$-in. long, spaced ~$\frac{1}{16}$-in. apart) with a barium-strontium surface were inserted into a He (99%)–A(1%) mixture and tested for breakdown as a function of pressure. In curve 1 in Fig. 7 note that V_s^{min} is 165 v at 20 torr, which was very near the value measured for pure argon (V_s^{min} = 160 v) at 20 torr.

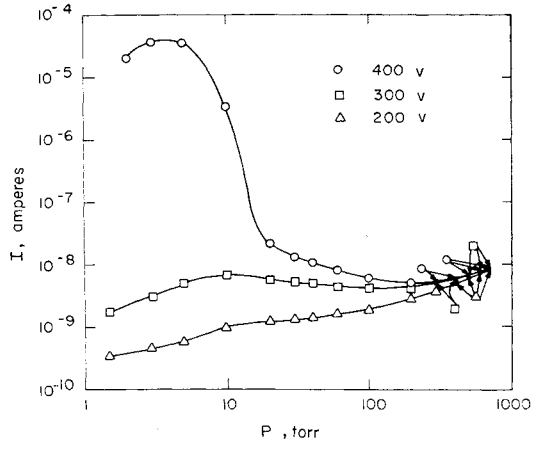

Fig. 6 Current vs pressure for pure argon at room temperature. Same configuration and source as in Fig. 5.

The other tests were performed with coaxial devices using a brass tube ($\frac{1}{8}$-in. i.d. and $\frac{3}{32}$-in. o.d.) and a nickel wire central electrode supported along the axis of the tube by a glass-to-metal seal at one end. Curves 2 and 3 in Fig. 7 show data for a device 1 in. long with a 0.020 in. diam Ni wire, operating in pure He. The central electrode is negative in curve 2, and positive in curve 3. Curve 3 crosses curve 2 at ~185 torr. The lower V_s values for the positive central electrode at $P >$ 185 torr suggest that photoelectron production predominates over electron production by positive ion bombardment of the cathode, a fact which might be of use at high filling pressures. We did not observe any difference in the behavior of coaxial devices containing helium and a He (99%)–A(1%) Penning mixture, probably because of gas contamination.

By varying the dimensions in order to minimize V_s, consistent with minimum size and weight, we made numerous tests which led to the final design for the prototype gas detector, shown in Fig. 8. The Electrical Industries, Murray Hill, N.J., Type 4AS-40T-SX, compression-type, glass-to-metal seal used there has a 0.025-in.-diam Ni wire passing through its tubular central conductor to which it is soldered. Some ^{59}Co foils (~$\frac{1}{8}$ in. square by 0.005 in. thick and weighing 6 mg) were irradiated with thermal neutrons in the VPI reactor to produce ^{60}Co. Each foil had a measured activity between 0.32 and 0.37 μCi after irradiation. ^{60}Co has a half-life of 5.3 yr, and decays by emitting a β particle (314 kev maximum kinetic energy) and two γ rays (1.173 and 1.332 Mev). After a foil was installed in a detector, the measured radiation outside was 3 to 4 mrem/hr (a luminescent wrist watch dial ~1–2 mrem/hr). The cobalt foils were too large to fit in the $\frac{3}{32}$-in.-i.d. brass tube, so a $\frac{1}{8}$-in.-i.d. brass sleeve was used in combination with the brass plug to hold the foil in. The sleeve is not a necessary feature. All joints were soldered with pure tin solder. After construction each unit was care-

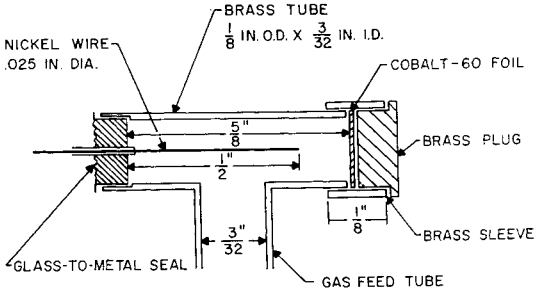

Fig. 8 Final glow tube design.

Table 2 Striking voltage and current at various pressures using pure helium. A 46 kilohm resistor was in series with each tube[a]

	Unit 1				Unit 2		Unit 3							
	(+ Polarity)		(− Polarity)		(−Polarity)		100°C		22°C		0°C		−195°C	
P, torr	V_s, v	I, ma	V_s, v	I, ma	V_s, v	I, ma	V_s, v	I, ma	V_s, v	I, ma	V_s, v	I, ma	V_s, v	I, ma
200	300	2.4	270	2.1	250	1.8	270	1.2	270	2.0	260	1.6	340	1.8
175	280	2.0	260	1.7	230	1.4	240	1.0	260	1.8	230	1.1	300	0.90
150	270	1.6	250	1.6	210	1.1	235	0.90	250	1.5	210	0.80	310	1.2
125	230	1.0	210	1.0	...	...	...	...	...	...	...	...	...	...
100	200	0.52	200	0.80	200	1.0	210	0.50	220	0.80	190	0.45	300	0.90
75	210	0.60	190	0.40	170	0.60	...	...	...	...	...	...	...	...
50	180	0.28	180	0.54	180	0.80	250	0.60	210	0.60	210	0.50	280	0.70
25	230	0.60	180	0.24	...	...	...	...	...	...	...	...	...	...

[a] Units 1 and 2 were tested at room temperature; the polarity is that of the central wire electrode. Unit 3 was tested at four temperatures; the central wire electrode had negative polarity.

fully cleaned and washed (both inside and outside) successively with dilute nitric acid, distilled water and acetone.

Calibration data for three units constructed in our final design are given in Table 2. The units, designated 1, 2, and 3, were not heated and outgassed at high vacuum before testing in our bell jar system (unlike commercially-produced glow lamps). The measurements for unit 3 show that there was no great variation of V_s between 0° and 100°C, but that V_s did rise by 50 to 100 v at liquid air temperature (−195°C) compared to room temperature. Comparison of the data at room temperature for the three units gives an idea of the variation in characteristics from unit to unit. If the applied voltage was kept constant and the helium pressure was slowly lowered (at fixed temperature), the current remained constant within a factor of 2 or 3 from 200 torr to 20 torr, and then dropped fairly rapidly to an extremely low value at $\lesssim$15 torr.

Mechanical stability tests were conducted on unit 1. It was installed in a calibrated vibrator and subjected to oscillatory vibrations for 5 min with each of the following maximum accelerations (frequencies): 3 g (18 Hz), 34 g (500 Hz), 14 g (1000 Hz), 1 g (10,000 Hz), and 1 g (20,000 Hz), where g is the acceleration caused by gravity. The performance of this unit showed no operational effects resulting from these tests.

One device was constructed exactly like unit 1, except without the ^{60}Co foil. With the central electrode negative, V_s was 50–100 v higher than in unit 1 at helium pressures between 25 and 100 torr at room temperature, but was the same at 150 torr. The striking voltage rose if the unit was left in the bell jar at a given gas pressure. The rise was ~40 v in 4 hr and ~100 v in 10 hr for the unit without a ^{60}Co foil, whereas the unit with a ^{60}Co source showed a rise of only 40 v in 10 hr.

Unit 2 was tested with pure neon and gave similar characteristics to helium: V_s was 190–200 v for neon pressures between 25 and 100 torr at room temperature. Hence our devices have roughly the same characteristics for helium, neon, and He (99%)–A(1%), in disagreement with theory. This result may have been caused by outgassing from the walls of our vacuum system.

Concluding Remarks

Our theoretical arguments and experimental results for ionization chambers are in agreement in giving maximum saturation currents ~10^{-7}–10^{-6} amp for reasonable radioactive source activities (~1 mCi alpha source) at several hundred volts. Since such low currents are difficult to detect for a gas cell under flight conditions in space, we cannot recommend ionization chambers for gas density detection. However, we draw attention to the approximate linear dependence of the current on gas density at intermediate densities, a fact which could be of use in a hole-size detector if such small currents could be easily measured in space.

Proportional counters provide currents up to 10^{-5}–10^{-4} amp at voltages ~1000 v, both of which compare unfavorably with typical glow tube characteristics. The proportional counter is the least attractive candidate for gas density detection in space.

The most promising detector operates in the glow tube mode. Currents ~1 mamp at voltages ~200 v are attainable using helium at filling pressures of 50 to 100 torr at room temperature. These devices can function at temperatures between −195° and 100°C, but their striking voltage is 50% larger at −195° than at room temperature. They withstand well the strains from vibrations. This device appears to be useful as an "on-off" type gage, but may be applicable for use in hole-size detection. L. McMaster of NASA Langley Research Center, Hampton, Va., has informed us that a hole-size detector based on the variation of V_s with gas density is feasible, and that laboratory prototypes are operational. However, calibration for this latter application would be complicated unless one could eliminate the change of the glow tube characteristics in time which we observed. Our striking voltages increased 20% to 50% if the device sat in a bell jar chamber for 10 hr. More careful cleaning and outgassing of these devices may help solve this problem; addition of a ^{60}Co foil source (0.34 μCi activity) reduced the effect in our work.

Finally, we indicate some possible improvements. Ceramic seals having better vibration and temperature characteristics than glass-to-metal seals may be better suited to the rigors of a launched space environment. If an easy means of welding or soldering molybdenum can be found, this material may prove to be superior to nickel for the central electrode. A 0.006- or 0.008-in.-thick Ni or Mo tube should prove to be a better material for the outer electrode than the thicker brass tube used in our prototype glow tube device.

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