Review of Scientific Instruments

Extension of the Low Pressure Range of the Ionization Gauge

Cite as: Review of Scientific Instruments **21**, 571 (1950); https://doi.org/10.1063/1.1745653
Submitted: 13 April 1950 . Published Online: 20 December 2004

Robert T. Bayard, and Daniel Alpert

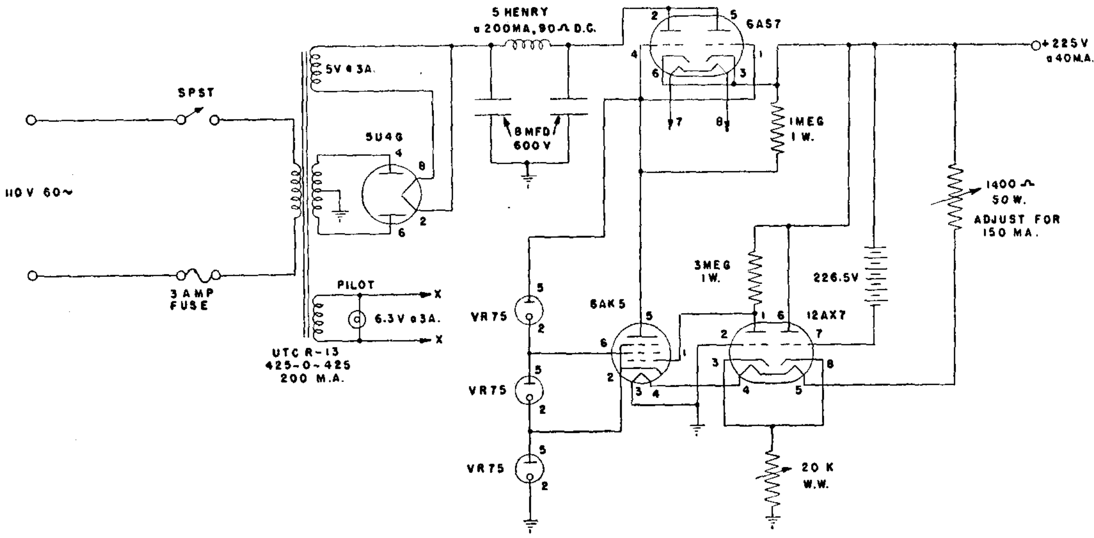

FIG. 1.

necessary to adjust the 20,000-ohm rheostat in the cathode circuit of the 12AX7 to set the voltage between the ground and the right-hand grid to a value between 1.5 and 2.0 volts. Direct current heating of the filaments of the 12AX7 and the 6AK5 improves the performance by a factor of two. The direct current amplifier, for whose power requirements the present circuit was designed, uses 150 milliamperes for filament heaters and 40 milliamperes for plate supply. When used in this connection, the 1400-ohm potentiometer is replaced by the series heaters in the amplifier and a much smaller resistance with which the current is adjusted to 150 milliamperes.

Data on the performance of the power supply follow. A change of input voltage from 108 to 135 volts results in a 10-millivolt change in output; a change from 93 to 135 volts results in a 20-millivolt shift. At 118 volts input, a change in load from 0 to 190 milliamperes results in a 20-millivolt shift in output voltage. Ripple is less than 1 millivolt between 93 and 135 volts.

In order to determine the expected operating characteristics of the power supply in the spectrometer, it was fed from a Sola constant voltage transformer, and the output was bucked by a set of batteries. A load drawing 150 milliamperes was supplied. The difference between the bucked potential and ground was then measured on a 4.5-second Brown Electronik Recorder with a full scale deflection of 10 millivolts. Since the input impedance of the Brown recorder is not high and is a function of the position of the carriage on the slide wire in the recorder, the current drawn from the batteries is not constant and a balance must be achieved between charging and discharging the batteries. This balance is critical and extends over a very narrow range; either side of balance the system rapidly becomes unstable. It will be seen from Fig. 2 that when a balance is achieved, the output voltage is stable to better than 50 microvolts. Any fast fluctuations do not, of course, appear. Standardization pips in the recorder account for the large apparent shifts in voltage; it can be seen

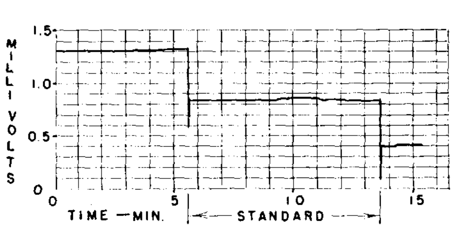

FIG. 2.

that the battery-recorder system does not return to the same position after this momentary disconnection in the circuit.

The author wishes to express his thanks to Mr. David Caton for his most valuable assistance. This work has been supported in part by the AEC.

[1] A. O. C. Nier, Rev. Sci. Inst. 18, 398 (1947).

Extension of the Low Pressure Range of the Ionization Gauge

ROBERT T. BAYARD AND DANIEL ALPERT
Westinghouse Research Laboratories, and Physics Department, University of Pittsburgh, Pittsburgh, Pennsylvania
April 13, 1950

THE ionization gauge[1] has been generally considered useful for the measurement of gas pressures ranging down to 10^{-8} mm Hg.[2] This low pressure limit is not the lowest pressure attainable with modern vacuum techniques, but has been shown to be a limitation of the conventional ionization gauge itself. An investigation made in this laboratory to determine the cause of this limitation has resulted in a new ionization gauge whose range has been considerably extended. The new gauge has been used to measure pressures of the order of 10^{-10} mm Hg.

The conventional ionization gauge resembles structurally the triode vacuum tube. The grid, however, serves as anode and is operated at a positive potential (100 to 250 v), while the plate is negative (10 to 50 v), both with respect to the cathode. Electrons from the cathode, before being collected at the grid, can create positive ions by collision with gas molecules. The number of ionizing collisions for a given electron current is considered to be proportional to the gas density. The current to the ion collector, or plate, is thus a measure of the pressure.

Dushman[3] has shown that the ion current for a given electron emission is indeed linearly related to the pressure between 3×10^{-6} mm Hg and 10^{-3} mm Hg. On the assumption that this relation continues to hold true, ionization gauges have been used to measure lower pressures. Workers in the field today, however, agree that while currents less than that corresponding to 10^{-8} mm Hg[4] could easily be measured, they are not observed. On the other hand many investigators[5] have had indications that considerably lower pressures than 10^{-8} mm Hg have actually been attained. This suggests the existence of a residual current to the ion collector which is independent of pressure. Nottingham[6] has suggested that this residual current is due to soft x-rays which release photo-electrons from the ion collector, the x-rays being created at the grid by the incidence of the thermionic electrons.

Independent evidence for the existence of a residual current comes from the observed characteristics of the ionization gauge itself. If for a given pressure and electron current, the ion collector current i_c is measured as a function of grid potential v_g, the plot of i_c *vs.* v_g, shown in Fig. 1a, has a characteristic shape for pressures above 10^{-7} mm Hg. The gas ionization curve shown (upper line) is typical of data taken on RCA type 1949 gauges. Note that i_c rises rapidly with v_g up to 200 volts and varies slowly with potential above this value. When the pressure is considerably lowered (ion gauge reading 10^{-8} mm Hg) the curve of i_c *vs.* v_g is radically different as shown (lower line). This residual curve continues to rise with grid potential, the slope on a log-log plot being between 1.5 and 2. In the intermediate range of pressures (10^{-7}–10^{-8} mm Hg) the characteristic corresponds to a superposition of the "gas ionization" curve and the "residual" curve. These results, obtained independently in this laboratory, are in agreement with data published in 1931 by Jaycox and Weinhart[7] and with unpublished findings of W. B. Nottingham.

With the explicit purpose of examining the hypothesis that this residual current is due to x-rays, a design was sought for an ion gauge which would operate in the usual manner but whose ion collector would intercept only a small fraction of the x-rays produced at the grid. The ionization gauge which evolved from these considerations is shown in Fig. 2. The new gauge has the usual three elements, but is inverted from the conventional arrangement; the filament A is outside the cylindrical grid B, while the ion collector C, consisting of a fine wire, is suspended within the grid. The volume enclosed by the grid is made comparable to that between the grid and plate of the ordinary ionization gauge. The positive potential on the grid forms a barrier to the ions formed inside the grid-enclosed volume so that they are eventually collected at the center wire. The ion collection efficiency is thus comparable to that of the conventional ionization gauge. On the other hand, the geometrical cross section of the ion collector to radiation from the grid is approximately one hundred times smaller than that of the conventional cylindrical collector.

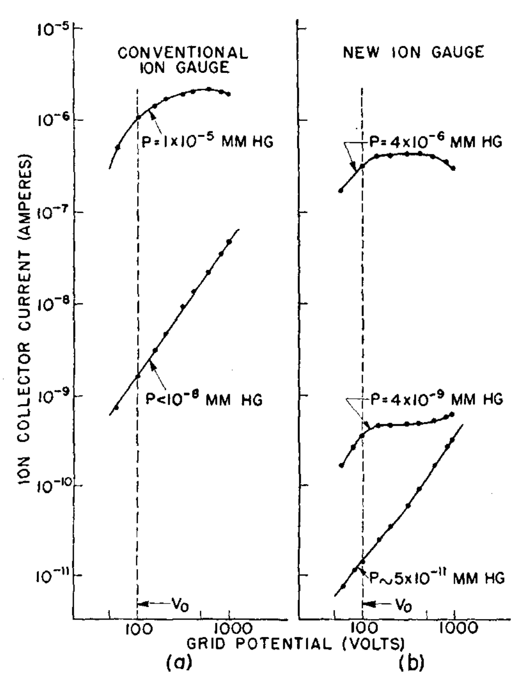

FIG. 1. (a) Typical data for RCA type 1949 gauge. (b) Typical data for the new type gauge. V_0 is the normal operating voltage.

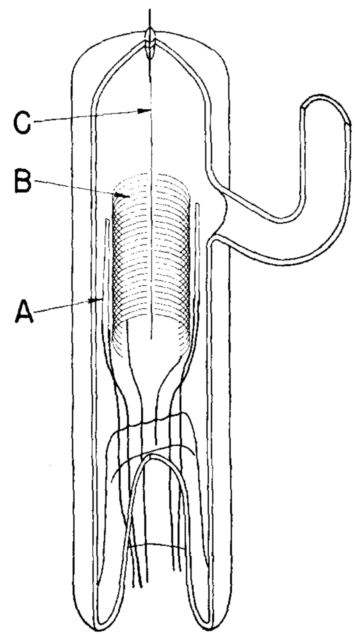

FIG. 2. Cutaway view of the new gauge showing filament A (an auxiliary filament is also shown), grid B, and ion collector C.

The properties of the new ionization gauge are shown by the curves of Fig. 1b. At higher pressures the characteristics of the new gauge are very similar to those of the RCA gauge, but it is evident that the new tube continues to have typical "gas ionization" characteristics at much lower pressures. At 4×10^{-9} mm Hg the collector current is predominantly due to gas ionization, and it is not until the pressure is less than 10^{-10} mm Hg that the residual current predominates.[8] Note that the slope of the residual curve is the same as that for the RCA gauge. On the other hand the value of the collector current for the new gauge, at a given grid voltage, is one hundred times lower than that for the RCA gauge. This ratio of residual currents for the two types of ion gauges is the same as the ratio of their geometrical cross sections to radiation mentioned above. These general characteristics of the new gauge clearly substantiate the x-ray hypothesis and indicate that ionization gauges can be built to measure even lower pressures.

The sensitivity of the new ionization gauge has been measured by calibration with a McLeod gauge at nitrogen pressures in the neighborhood of 10^{-4} mm Hg and by comparison with a standard ionization gauge at various pressures between 10^{-5} and 10^{-7} mm Hg. As seen from the typical curves in Fig. 1, the sensitivities of the two types of ionization gauges are essentially the same. The new gauge gives indication of pressures at least 100 times lower than the standard ion gauge. It has a minimum of metal surface, is easily outgassed, and is operated on a standard power supply. These characteristics make the gauge a useful tool for studies in the field of high vacuum.

[1] For a complete discussion of ion gauges see for example S. Dushman, *Scientific Foundations of Vacuum Techniques* (John Wiley and Sons, Inc., New York, 1949), p. 332–366.

[2] Pressures mentioned in this letter are equivalent nitrogen pressures.

[3] S. Dushman, Phys. Rev. **17**, 7 (1921).

[4] This current is usually of the order of 10^{-9} ampere for 0.010 ampere electron current and 100–150 v grid potential.

[5] (a) P. Anderson, Phys. Rev. **47**, 958 (1935). (b) W. B. Nottingham, J. App. Phys. **8**, 762 (1937). (c) I. R. Senitsky, Phys. Rev. **78**, 331 (1950). (d) The so-called flash filament method of L. Apker, whereby pressures are estimated from measurements on the rate of accumulation of gas on a clean wire, has been used by several investigators including the author to measure pressures of the order of 10^{-10} mm Hg. (e) The mass spectrometer group in our laboratory has had indications that in a well-baked out spectrometer tube the residual gas pressure is 10^{-9} mm Hg or less.

[6] Reference 1, p. 359.

[7] E. K. Jaycox and H. W. Weinhart, Rev. Sci. Inst. **2**, 401 (1931).

[8] The pressure represented by the lowest curve, as judged by the deviation of the lower portion from a straight line, is estimated to be of the order of 5×10^{-11} mm Hg.