Title
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Publication Date
1982-08-01

LBL-14596 c.2
Preprint

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

Submitted to Review of Scientific Instruments

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Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

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LBL-14596
EEB-L-82-07
L-66

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This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Equipment Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Measurement of UV Radiation in a Low-Pressure Vapor-Discharge Tube with Mercury Isotopes

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ABSTRACT

Natural mercury has seven stable isotopes that will, when excited in a low-pressure gas-discharge tube, generate UV lines due to transitions from the 6^3P_1 state to the ground state at slightly different wavelengths. Wishing to investigate the increase of UV radiation (254 nanometers) for different mixtures of Hg isotopes that would lead to improvements in the efficacy of fluorescent lamps, we prepared an experimental setup for a specially designed discharge tube that will be used repeatedly to test various isotopes. The test lamp is designed to obtain reproducible data in order to compare Hg isotope mixes. The tube is provided with a heat pump unit to control the cold-spot temperature of the mercury sample and a vacuum-pump aggregate to regulate the rare-gas pressure of argon inside the tube. The tube, made of quartz, is enclosed in a plastic box that

is flushed continuously with nitrogen or argon gas to prevent the generation of ozone and to absorb UV radiation. The current through the discharge tube is controlled by a power supply that can provide different voltages and loads and can maintain a sinusoidal waveform for its positive column current. The wall of the tube is maintained at a temperature that is constant and higher than the temperature of the mercury sample, which determines the mercury vapor pressure inside the tube.

PACS numbers: 52.80. Dy, 51.50. tv, 31.30.Gs

INTRODUCTION

In a fluorescent lamp, the UV radiation from mercury is converted to visible light through the excitation of a phosphor coating on the inside of the tube wall. The predominant UV radiation is the 253.7-nanometer (nm) line that generates light, while the radiation of a 184.9-nanometer (nm) line is unwelcome for the standard cool white phosphors because it poisons the phosphor. Natural mercury has seven stable isotopes[1] that will generate different UV lines within a low-pressure discharge tube due to transitions from the 6^3P_1 state at slightly different wavelengths.[2] The imprisonment of resonance radiation caused by the emission and reabsorption of resonance quantum by the same isotopes,[3] or by the overlapping of hyperfine structure among isotopes,[4] reduces the amount of useful radiation produced. Resonance radiation in low-pressure mercury vapor has been examined by many authors.[5-18] Except in a few cases, natural mercury was used in previous experiments on low-pressure gas-discharge lamps. We are interested in studying resonance radiation as a function of different parameters of the various stable isotopes of mercury. Based upon an understanding of the behavior of individual isotopes, it should be possible to analyze the output of a mercury sample having a mix of isotopes, such as natural mercury or a sample prescribed and prepared artificially. The practical application of this research is to find an optimum mercury isotope mixture for improving the energy-efficacy of fluorescent lamps.

THE DISCHARGE TUBE

We designed a gas-discharge tube to transmit UV radiation (254-nm and 185-nm lines); we used a quartz tube about 122 cm in length and with an inside diameter of 3.8 cm. The length and diameter are similar to those of a commonly used F40 T-12 lamp. At the ends of the tube are two removable filament-mounting supporters in an upright position so as to prevent excessive mercury drops from contacting the supporters. The filaments are separated by a constant distance and can easily be replaced after each experiment by a new pair made of the same materials. At almost the center of the tube is a small fingerlike vessel that holds the mercury sample. The temperature of this vessel is controlled by a unit that operates on the Peltier effect. By serving as the coldest point along the discharge tube, the central vessel determines the vapor pressure of the mercury after the equilibrium state has been reached. The rest of the tube, heated with heating tape, remains at a higher temperature. The mercury vapor pressure is determined by the temperature.

At one end of the discharge tube we built a pumping outlet, which has a high-vacuum and high-temperature valve (HVHT) in line to cut off the pumping system that is connected immediately after the valve. The removable filament supporters are connected to the discharge tube through an O-ring adapter, the O-ring being made of Vitron, which will not contaminate the gas inside the tube. The argon gas used in the tube has a grade of 99.999%, which is acceptable for our purposes.

With the filament supporters and the HTHV valve closed, the tube can retain a vacuum down to about 10^{-7} Torr for as long as several weeks. The cold-spot temperature (i.e., the Hg vapor pressure) and the rare-gas pressure can be regulated independently.

The discharge tube is placed inside a long box made of plastic sheeting that completely attenuates the ultraviolet radiation. This box completely seals off the discharge tube from the laboratory environment and is continuously flushed, through an inlet and an outlet hole, with inert gases such as nitrogen or argon, thereby maintaining an oxygenfree interior. The outlet pipe is submerged in water to prevent outside air from entering the box. Thus, the box serves three purposes: to stop penetration of the strong UV radiation, to eliminate production of ozone, and to provide an absorption-free path to the detector of the 185-nm and 254-nm radiation. Thermocouples and thermistor cables are brought into the box, along with the power supply lines for the discharge tube and for the heating tapes. The heating tapes are wrapped around the outside of the tube to keep the wall temperature somewhat higher than that of the cold spot. The active element of the temperature-control unit for the mercury sample is a thermoelectric module. This module relies on the Peltier effect of a semiconducting material to absorb or generate heat; thus it can serve as either a refrigerating device or a heater. Figure 1 shows the general setup of the discharge tube.

THE TEMPERATURE-CONTROL UNIT

The thermoelectric module manufactured by Marton is constructed with thermoelectric semiconductors located between a top and a bottom ceramic plate. A small metallic cup (filled with thermal paste of good heat conductivity), which will hold the sample vessel in the gas-discharge tube, is soldered on the surface of the top ceramic plate. The bottom ceramic plate is attached to a heat sink of water connected to a water reservoir, a water pump, and a fan radiator outside the plastic box. The temperature-control unit is located in the center of the enclosing box, with its electrical supply line and water pipe brought out through the wall of the box. Figure 2 shows the schematic construction and arrangement of the temperature-control unit with reservoir, water pump, and fan radiator in circuit. The temperature can be regulated from $-15^{o}C$ to $90^{o}C$.

THE POWER SUPPLY

The power supply for the gas-discharge tube was designed to have a variable AC supply voltage of 60 Hz, and either a resistive or reactive load impedance in series with the positive column of the discharge tube. The indicator meters for the thermocouples located at different places along the enclosed tube are mounted on the power supply unit so they can be read easily. Load resistance in series with the discharge column can be changed in steps from a few hundred to three thousand ohms, while the load reactance is adjustable to two, four, and six henries of inductance. The purpose of using large inductances in circuit is to maintain a sinusoidal waveform for the positive column current. All measurements are taken with sinusoidal current waveforms. In the power supply unit, a number of output terminals provide accurate measurement of the rms values of current and voltage and the power consumption of the discharge tube. The filament power is taken independently from two step-down transformers having voltages that can be regulated. The heart of the power supply is a rotary switch with 10 settings. The arrangement of the wire connections is such that the current through the tube will not exceed a value of about 400 mA even when it might be necessary to use high voltage for testing a discharge tube under special conditions. The supply unit is well grounded to protect the operator from high-tension hazards. A circuit diagram is shown in Figure 3.

THE VACUUM-PUMP AGGREGATE

A vacuum-pump aggregate is designed and constructed to have a roughing pump in series with an oil-diffusion pump. A liquid nitrogen cold trap made of stainless steel is situated immediately after a regulatable high-vacuum main valve connected to the inlet pipe line of the discharge tube. The inlet pipe line of the system is provided with four high-vacuum needle valves--labeled 1, 2, 3, and 4 in Figure 4. Valve 1 is the input valve of an argon gas cylinder; valve 2 connects to a glass passage having a volume approximately equal to that of the discharge tube. The passage and the tube are joined through the HVHT valve mentioned previously. The glass passage prevents the discharge tube from grounding through the pumping aggregate, which may happen when the applied voltage is high. Valves 3 and 4 are each connected to a glass vessel having the same volume as the discharge tube. The glass tubing has the same volume as the discharge tube so that the gas pressure inside the main tube can be reduced incrementally with the opening of valves 2, 3, or 4 in sequence. Thus the pressure can be 1/2, 1/3, or 1/4 the original gas pressure, while the main valve is closed to cut off pumping. The vacuum aggregate is capable of bringing the entire system down to a pressure of 10^{-7} Torr.

High vacuum pressure is measured with a Varian ionization gauge that ranges down to 10^{-8} Torr, while the rare-gas pressure, normally a few Torr in magnitude, is measured with two Veeco thermocouple gauge-control instruments: Model TG-70 for 1 to 1,000 millitorr and Model TG-270 for 0 to 20 Torr. Figure 4 shows a schematic diagram of the pumping system. To reduce outgassing and contamination by gas molecules within the pump system, all parts of the vacuum pump are made of stainless steel. Vitron O-rings are necessary to create the proper seals. Brass parts are not used inside the pumping circuit.

SIGNAL MONITORING

At the middle of one length of the enclosure box is attached a square box, also made of UV-attenuating plexiglass sheeting, which holds the device that measures the intensity of the UV radiation. This box is sealed with silicon-rubber tape and also flushed with inert gas discharged through a water filter. Between the square box and the main box, an opening made of quartz allows transmission of the UV radiation. A radiometer (International Light #118) equipped with photodetectors and filters calibrated for the UV 185-nm and 254-nm lines is used to measure the radiation intensity in watts/cm^2. Other monitoring devices can also be mounted inside the attached instrument box, e.g., a photomultiplier tube or an EG&G monochrometer controlled by a Hewlett-Packard desk computer that records the spectral data and plots the spectral power distribution curve automatically. The EG&G monochrometer is used to measure the radiation in the visible spectrum, 380 nm to 780 nm.

TEMPERATURE MEASUREMENT

The temperature of the mercury sample will be measured simultaneously by a thermocouple and a thermistor inserted through small holes at the bottom and in the center of the sample vessel. The output signals of these measuring devices become the input of a control computer that can regulate the input current to the Peltier element to maintain the temperature of the mercury sample at $\pm 0.1^{\circ}C$.

To keep the wall temperature higher than that of the mercury sample, electrical heating tapes are wrapped around the length of the discharge tube. Their temperatures will be measured with thermocouples along the discharge tube and regulated by variacs stationed outside the main box. Heating tapes with glass fiber insulation can be used to bake the tube to a temperature as high as 400°C, which is necessary after a pair of new filaments have been put in and the tube is ready for evacuation. The supporters of the discharge tube inside the box are two metallic plates with V-shaped grooves, which are able to sustain temperatures as high as several hundred degrees. Because there are only point contacts between the metallic supporters and the tube, very little heat can transfer through the plates to damage the plastic box.

PRELIMINARY EXPERIMENT AND RESULTS

In the preliminary experiment, the UV output of natural mercury was measured as a function of one of the following parameters while the other parameters were held constant: (1) the mercury sample's temperature, T(Hg); (2) the argon pressure, p(Ar); (3) the positive column current intensity, I; or (4) the wall temperature, T(W). Throughout the measurement, only the power consumed by the positive column is taken into account, without considering the power supplied to the filament or the series load impedance. Because the experimental results are analyzed in terms of UV radiation per watt, which is to some extent equivalent to the efficacy of a fluorescent lamp, they can easily be compared with the results published previously on the low-pressure gas-discharge lamp. In our experiment, all the samples were tested in the same discharge tube; therefore, the diameter of the tube and the length of the arc are not variables. Meanwhile, we can adjust the primary parameters T(Hg), p(Ar), I, and T(W) independently in order to control all conditions and produce consistent results within a very limited tolerance.

CONCLUSION AND SUGGESTIONS

In the study of UV radiation of the positive column of low-pressure mercury vapor, the most useful parameters are the pressures of the mercury vapor and the argon. In the past, the discharge tube usually was submerged in a temperature-controlled bath so that the mercury vapor pressure would be determined by the wall temperature. However, in such a setup the argon pressure within the tube would also change. In the experimental setup described here, the pressures of the mercury and the argon can be controlled independently.

In our experiments, the inside wall of the discharge tube is not coated with fluorescent phosphor for generating visible light; therefore, the output of UV radiation is measured in terms of radiant exitance (or radiant emittance) in watts/cm^2 instead of visible luminance. To apply the experimental data to a fluorescent lamp having the same inside diameter and length as the discharge tube, it could be assumed that the efficacy of output of visible light is approximately proportional to the radiant exitance of the UV-254 line. A mercury sample containing a mixture of isotopes in proper proportions could increase the generation of UV-254 to a maximum value under normal operating conditions of lamps. In addition to performing experiments on individual mercury isotopes, testing various mercury mixtures is one of the main goals of our investigation.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Rudy Verderber and Sam Berman for their encouragement and support.

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Equipment Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

REFERENCES

1. R.C. Weast and M.J. Astle, eds. Table of the Isotopes, in Handbook of Chemistry and Physics, 61st ed. (CRC Press, Inc., Boca Raton, Florida, 1980-81), pp. B316-B317.

2. J. F. Waymouth, Electric Discharge Lamps (MIT Press, Cambridge, Massachusetts, 1971), p. 24.

3. T. Holstein, Phys. Rev. 72 (12), 1212-1233 (1947).

4. T. Holstein, D. Alpert, and A.O. McCoubney, Phys. Rev. 85 (6), 985-992 (1952).

5. C. Kenty, J. Appl. Phys. 21, 1309-1318 (1950).

6. J.F. Waymouth and F. Bitter J. Appl. Phys. 27 (2), 122-131 (1956).

7. K. T. Compton, Phys. Rev. 20 (4), 283-299 (1922).

8. T. B. Read, Br. J. Appl. Phys. 15, 837-841 (1964).

9. M. A. Cayless, Br. J. Appl. Phys. 14, 863-869 (1963).

10. M. Koedam, A.A. Kruithof, and J. Riemens, Physica 29, 565-584. (1963).

11. F. Bitter et al., Phys. Rev. 96 (6), 1531-1539 (1954).

12. M.W. Zemansky, Phys. Rev. 36, 219-238 (1930).

13. G. Meister and T. H. Heine, Ill. Eng. November, 681-686 (1949); March, 159-164 (1952); and December, 660-665 (1952).

14. B. T. Barnes, J. Appl. Phys. 31 (5), 852-854 (1960).

15. T. J. Hammond and C. F. Gallo, Appl. Opt. 10 (1), 5864 (1971).

16. W.L. Lama et al., Appl. Opt. 21 (10), 1801-1811 (1982).

17. C.W. Jerome, Ill. Eng. 51, 205 (1956).

18. R. E. Drullinger, M.M. Hessel, and E.W. Smith, Analysis of Optically Excited Mercury Molecules, National Bureau of Standards Monograph 143 (U.S. Government Printing Office, Washington, D.C., 1975).

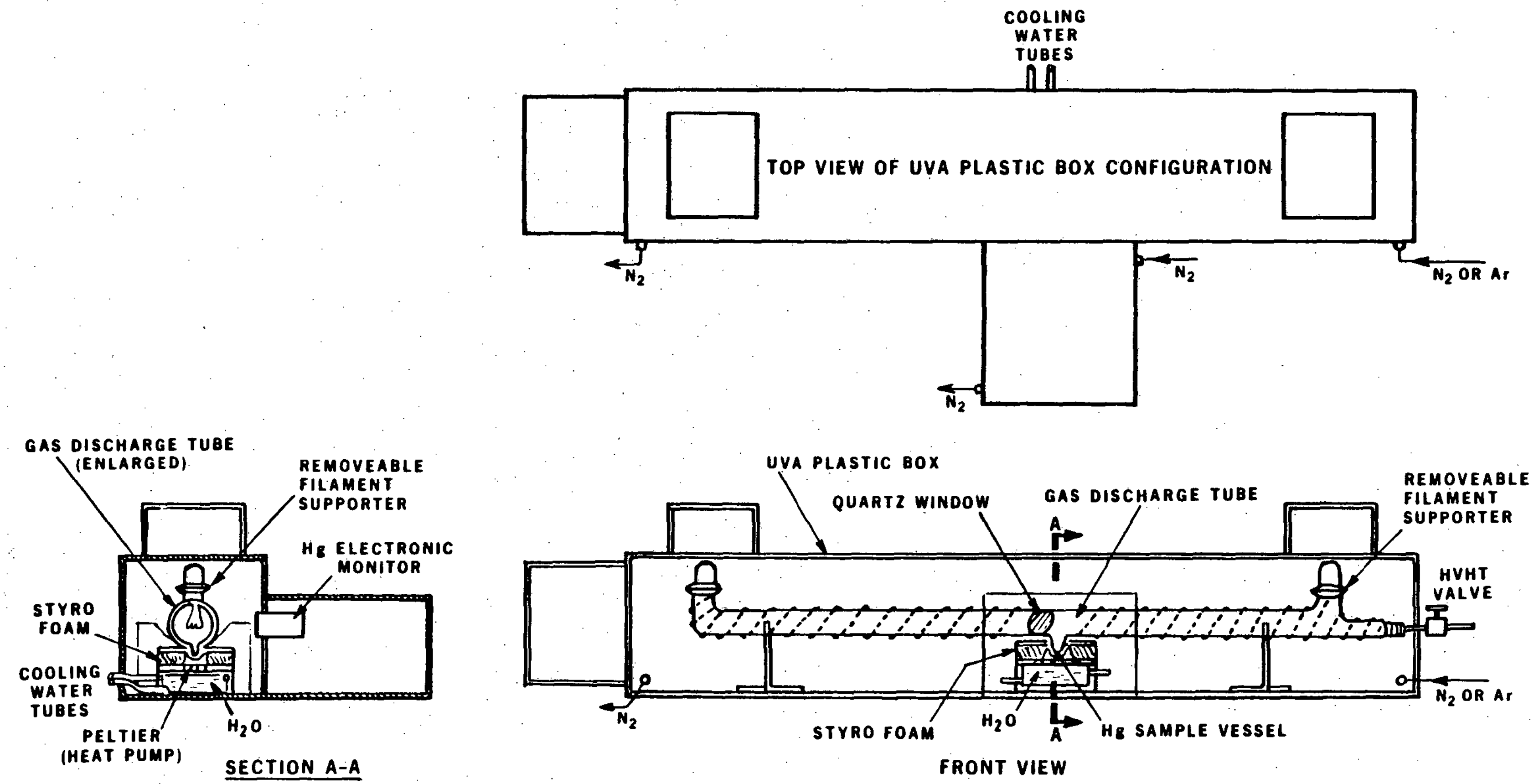

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Figure 1. Setup for testing the gas-discharge tube.

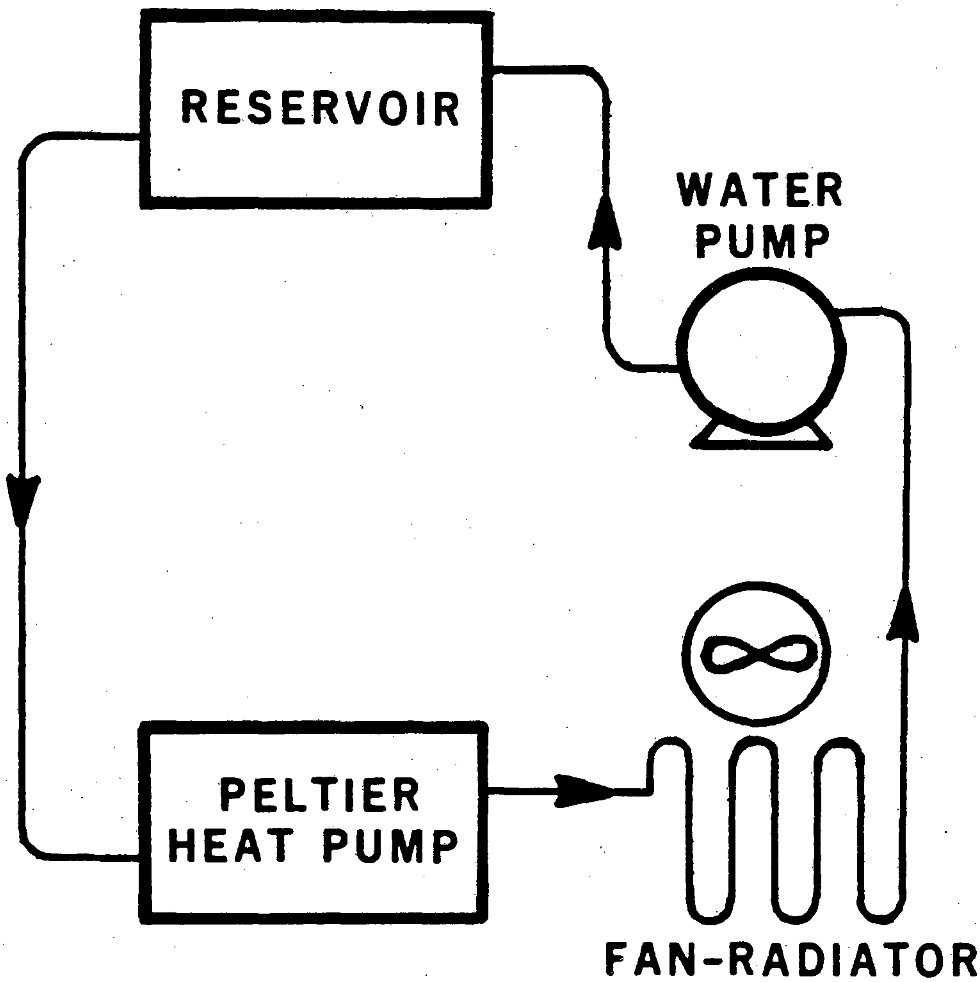

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Figure 2. Schematic diagram of the temperature-control unit.

DISCHARGE TUBE POWER SUPPLY

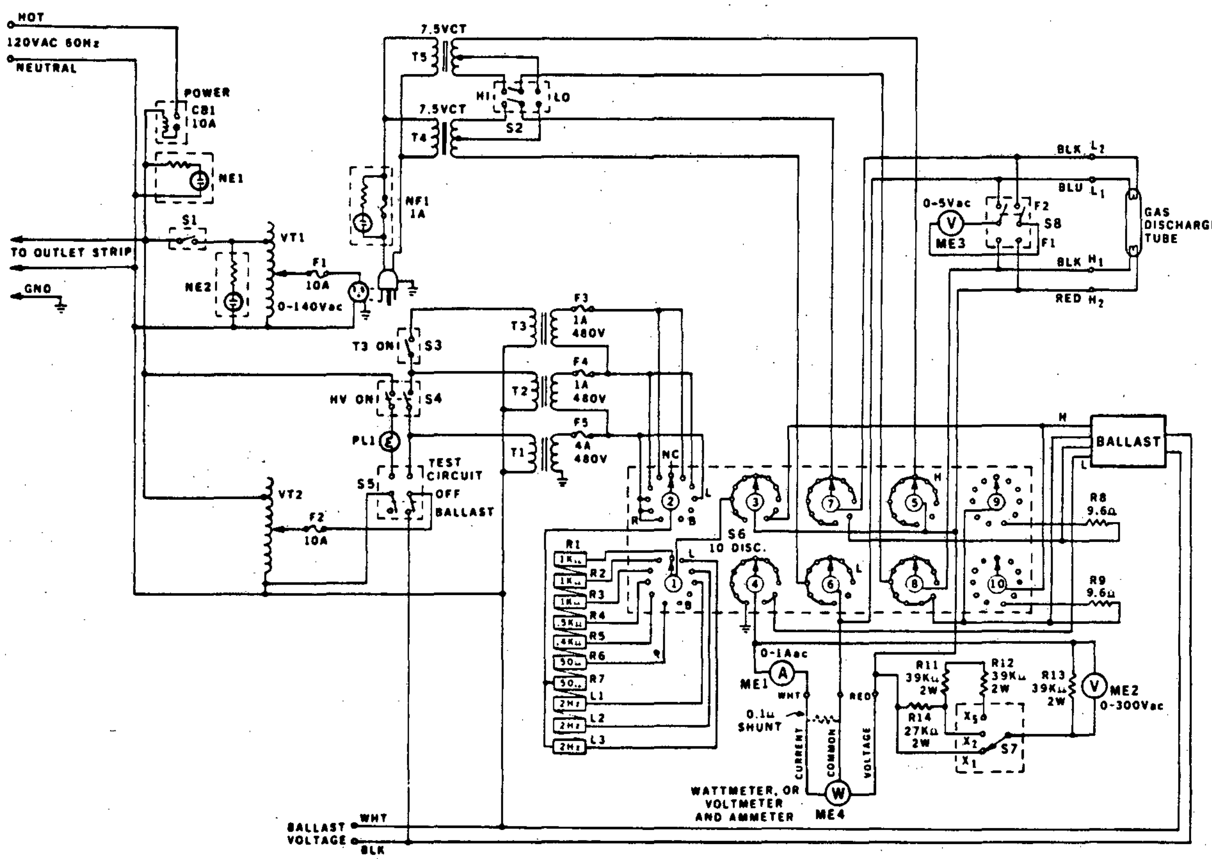

Figure 3. Circuit diagram of the power supply for the gas-discharge tube.

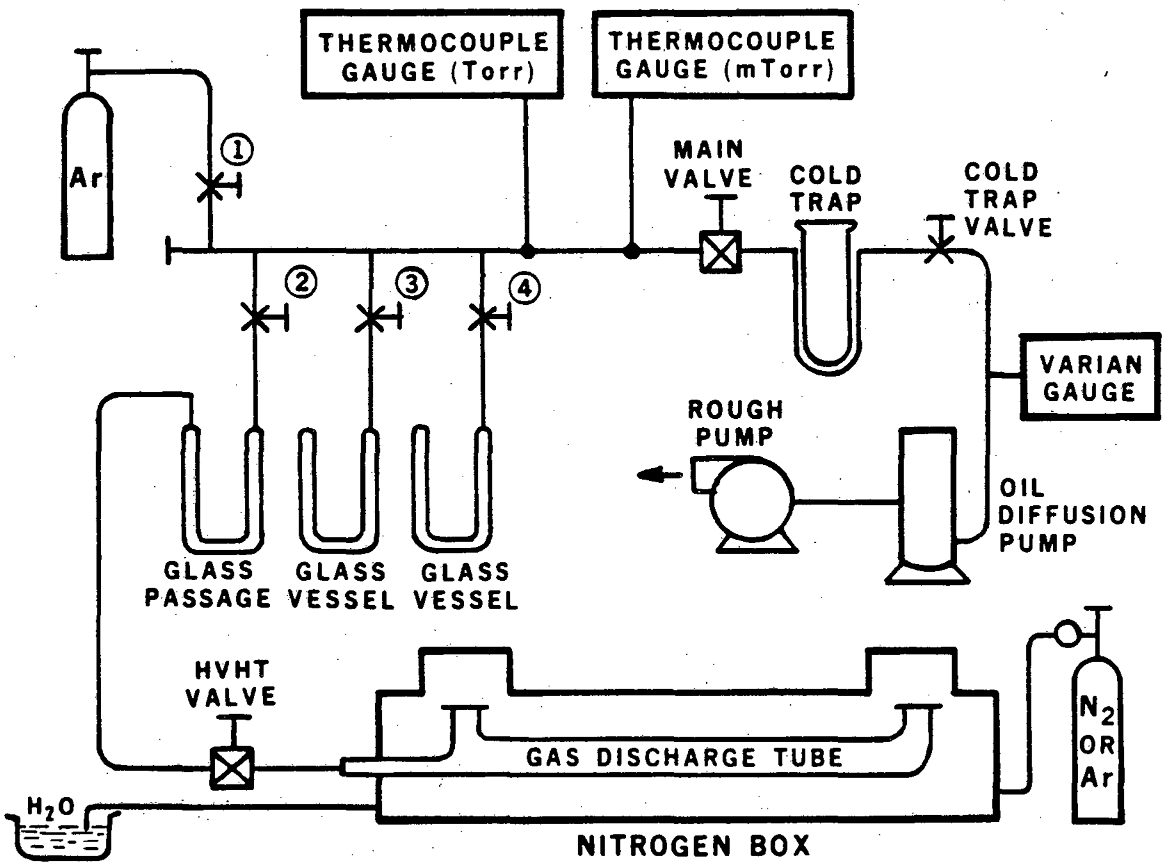

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Figure 4. Schematic diagram of the vacuum system.

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