Session 1526

Demonstrations and Experiments in Plasma Physics

David M. Hata
Portland Community College

Abstract

Portland Community College, through a grant from the Advanced Technological Education Program at the National Science Foundation, has implemented a suite of demonstrations and experiments in plasma physics. These activities, which focus on the optical and electrical characteristics of gas plasmas, have been classroom-tested at Portland Community College in PCC's associate of applied science degree program in Microelectronics Technology.

The demonstrations and experiment range from low-cost experiments based on NE-2 neon bulbs to more sophisticated studies using fiberoptic spectrometers and Langmuir probes. This paper will describe experimental activities in plasma physics and describe how these activities are integrated into a technician-level course in RF Plasma Systems.

Introduction

For the purpose of this paper, "plasma" refers to an ionized gas. It is often referred to as the "fourth state of matter." In this state of matter, plasmas exist when enough energy is supplied to a gas to sustain the continuous creation of positively charged and free electrons. It is the creation of charged particles that makes the plasma useful in manufacturing processes, e.g. etching, sputtering, and deposition.

Plasma technology is one of several enabling technologies that makes manufacturing at the nanoscale possible today. It is absolutely essential in the manufacture of integrated circuits as well as a variety of surface coating applications.

We benefit from gas plasmas everyday. Gas plasmas produce the visible light in our universe, including our sun. In our offices, fluorescent lighting is based on producing a gas plasma within a coated glass tube. We seldom think of the variety of materials coated by a plasma deposition process, e.g. our eyeglasses with anti-reflective coatings.

Gas plasmas are briefly mentioned in chemistry courses, but students enrolling in engineering technology programs lack an understanding of gas plasmas. The laboratory activities described in this paper are designed to provide a basic understanding of the electrical and optical properties of gas plasmas. They range from inexpensive demonstrations and experiments to more sophisticated studies using a Langmuir Probe.

"Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition

They have been tested in the laboratory at Portland Community College in PCC's MT 240 RF Plasma Systems course.

Demonstrations

Structure of a DC Glow Discharge in a Long Tube

The equipment for this demonstration can be purchased from scientific supply companies, e.g. Fisher Scientific. The experimental set up is shown in Figure 1.

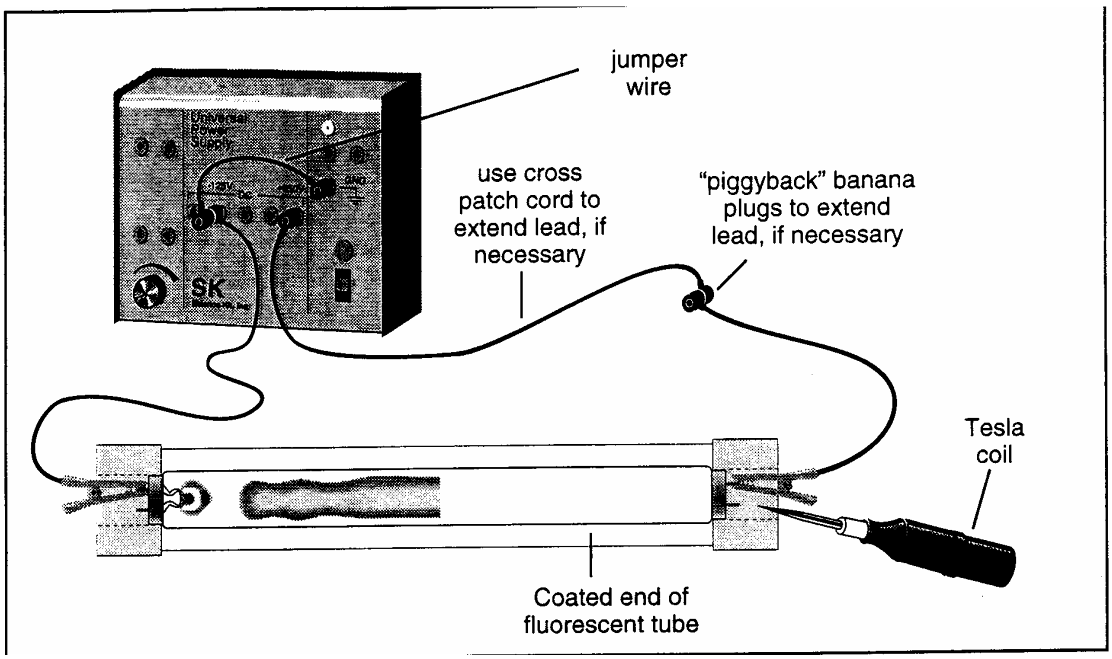

Figure 1. Experimental apparatus to study the structure of a DC glow discharge in a long tube.

A DC voltage in the range of 250 volts is applied to the terminals of a fluorescent tube. The tube is half-coated to allow viewing of the plasma inside the tube. The uncoated end should be connected to the negative terminal of the power supply and the terminal at this end will serve as the cathode. A Tesla coil is used to initiate, or strike, the plasma.

The plasma produced by excitation of the argon-mercury gas mixture in the tube produces a visible structure. At the cathode, the cathode glow is visible followed by the Crooke's dark space, negative glow, Faraday dark space, and positive column. The Aston dark space is covered by the cathode glow and the anode glow and anode dark space are behind the coating at the other end of the tube.

The demonstration is static in that no parameters can be varied, e.g. excitation voltage. A modification that was made replaced the fixed output DC voltage source with a variable high voltage source, e.g. PS-310 High Voltage Power Supply manufactured by Stanford Research Systems. Use of PS-310 requires a 50 kΩ limiting resistor in series with the power supply. The PS-310 produces output voltages with a one-volt resolution.

Spectral Studies Using Gas Discharge Tubes

Gas plasmas emit light as a result of the excitation-relaxation processes in the gas plasma. Specific wavelengths of light emitted by an excited gas provide a characteristic fingerprint for a given gas. Spectrum tubes for common gases, e.g. nitrogen, helium, argon, and neon, are relatively inexpensive, but require a spectrum tube power supply to produce an excitation voltage of 5000 volts @ 10 mA.

Traditionally, the spectra for a given gas plasma is viewed by students using a hand-held spectroscope, having an accuracy of $\pm$ 50 Angstroms. However, some students and instructors have difficulty viewing the colored lines produced by the diffraction grating. A suitable alternative is to use a fiberoptic spectrometer, e.g. Ocean Optics USB-2000 Spectrometer, to produce a graph of "Intensity versus Wavelength" on a computer monitor.

Experiments

NE-2 Neon Lamp Experiment

The NE-2 neon lamp is a low-cost plasma chamber that can be used to study the breakdown, conduction, and turn-off characteristics of a simple gas plasma. The experiment requires a variable DC power supply with an output voltage range of 0 volts to 120 volts DC. A suitable DC power supply is the Agilent E3612A.

Using the E2612A, a 200 k Ω series limiting resistor, NE-2 neon lamp, and two standard multimeters, data can be taken to construct an I-V characteristic curve for the NE-2 neon lamp. The experimental set-up is shown in Figure 2. The breakdown voltage is in the range of 65 – 75 volts. Conduction ceases when the voltage across the lamp drops below 55 volts.

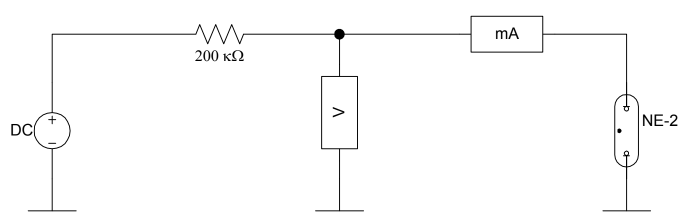

Figure 2. Experimental set-up for obtaining the I-V for a NE-2 neon lamp.

The current measuring limitations of general-purpose multimeters limit measurements to the glow discharge region. Currents in the dark discharge region are too small to be measured by general-purpose multimeters, and current levels at the high end are limited so that the arc discharge region is not reached.

The two circuit applications, shown in Figure 3, provide opportunities for students to apply their knowledge of the electrical properties of gas plasmas. The single-lamp flasher circuit produces an output in the range of 3 Hz while the dual-lamp circuit oscillates at a frequency in the range of 1 Hz. It is instructive to view the capacitor charge-discharge waveforms. For this measurement, it is recommended that a digital-storage oscilloscope be used since the signal frequency is very slow.

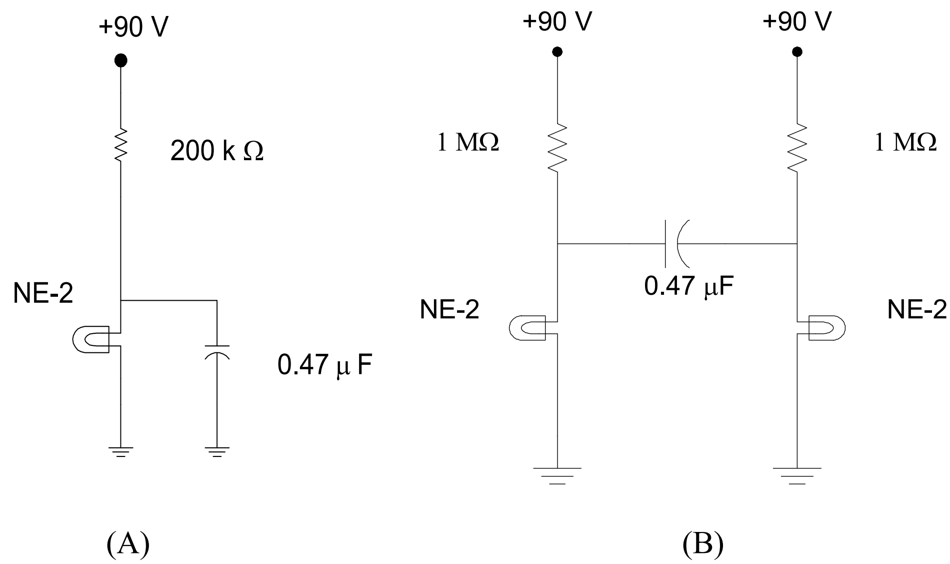

Figure 3. Circuit applications for a NE-2 neon lamp. (A) Single-lamp flasher circuit. (B) Dual-lamp flasher circuit.

DC Breakdown of Gases: Paschen Curves

The "neon lamp" experiment provides data for one gas at one pressure in a chamber with fixed physical dimensions. The apparatus for this experiment allows for variation of chamber pressure and electrode spacing. The schematic for the Paschen Curve apparatus is shown in Figure 4.[1] The chamber consists for a stationary electrode and a moveable electrode, whose position is controlled by a rotary feedthrough. A high-voltage DC power supply is connected to the electrodes through a 25 kΩ ballast resistor. Chamber pressure is established using a roughing pump capable of pumping the chamber down to the range of 1 millitorr. A throttle valve in the roughing line can provide a means of adjusting the chamber pressure. Gases enter the chamber through a high precision leak valve from gas bottles or gas manifold. A milliameter is inserted in series with the ballast resistor to measure the plasma current.

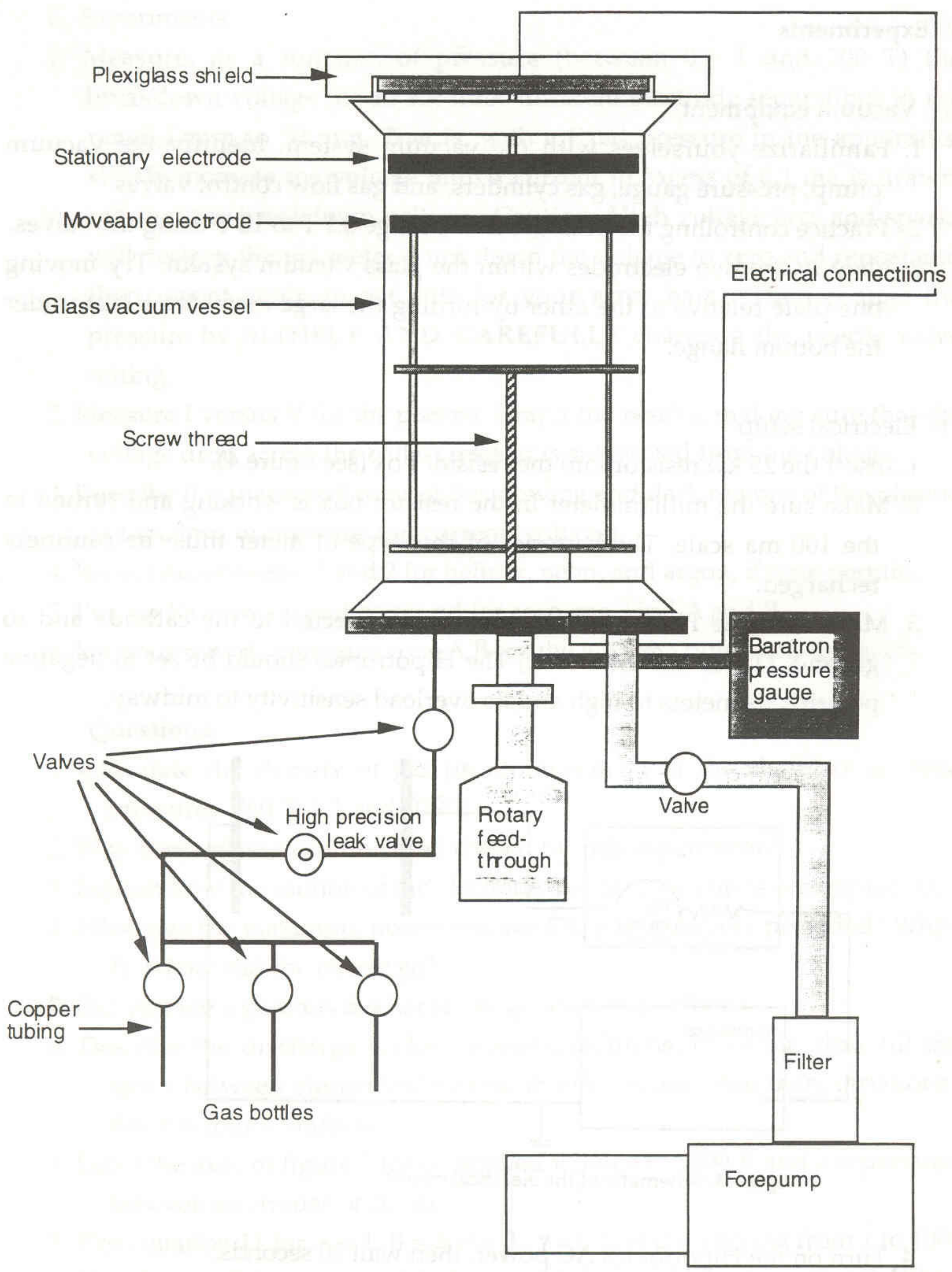

Figure 4. Experimental set-up for determining the Paschen curve for a gas.[1]

Using this apparatus, the breakdown voltage as a function of pressure can be determined for a specific gas for electrode separations in the range of 1 mm to 50 mm. For a given electrode spacing and gas, the chamber pressure can be set and the applied voltage increased until a current in excess of 0.1 ma is drawn. The minimum voltage at which this occurs is the breakdown voltage. After recording the breakdown voltage, the applied voltage is reduced to zero, the pressure is set to the next value, and the applied voltage increased to the breakdown voltage. Repeating this process, data points to plot a graph of breakdown voltage versus pressure can be obtained for the gas being used at the given electrode spacing. The experimental procedure can be repeated for a different electrode spacing or different gas.

Langmuir Probe Studies of a Gas Plasma

The Langmuir probe consists of a thin cylindrical conducting wire, which is inserted into the bulk plasma. A variable voltage is applied across the probe tip and the resultant current through the tip is measured. The data can then be used to construct a current-voltage graph, which can then be analyzed to yield the following plasma parameters: plasma floating potential, plasma potential, electron temperature, electron number density, ion number density, electron energy distribution, and debye length. A simple probe circuit is shown in Figure 5.

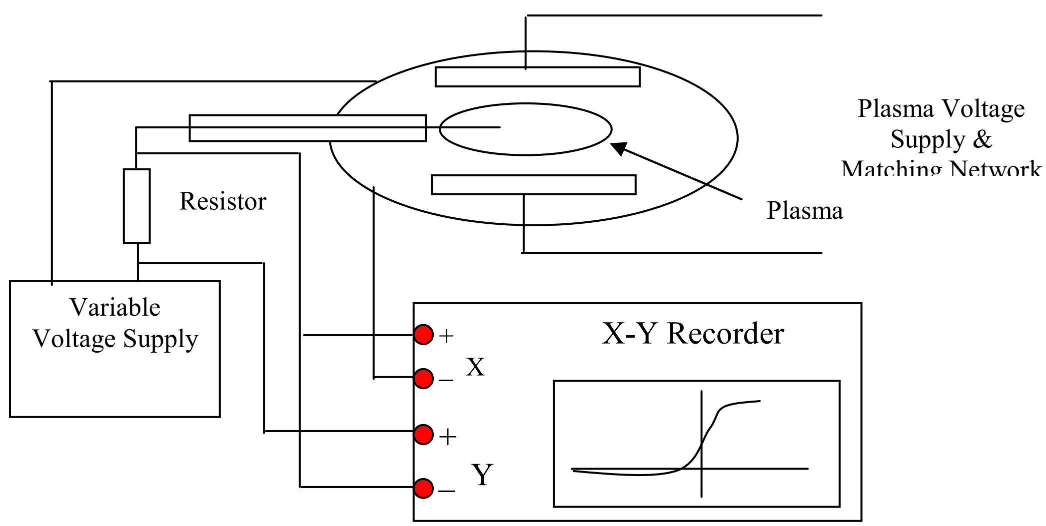

Figure 5. A simple probe circuit.

Making your own Langmuir probe takes patience and a good machine shop. Unfortunately, most community colleges do not have adequate facilities to make there probes. An alternative, albeit expensive, is to purchase a commercial Langmuir probe such as the SmartProbe from Scientific Systems. The SmartProbe configuration shown in Figure 6 consists of a Langmuir probe, acquisition unit, gating electronics, and user interface to a host PC. The acquisition electronics unit contains the variable power supply to bias the probe tip. The standard unit can measure current levels up to 250 mA with 18-bit resolution.

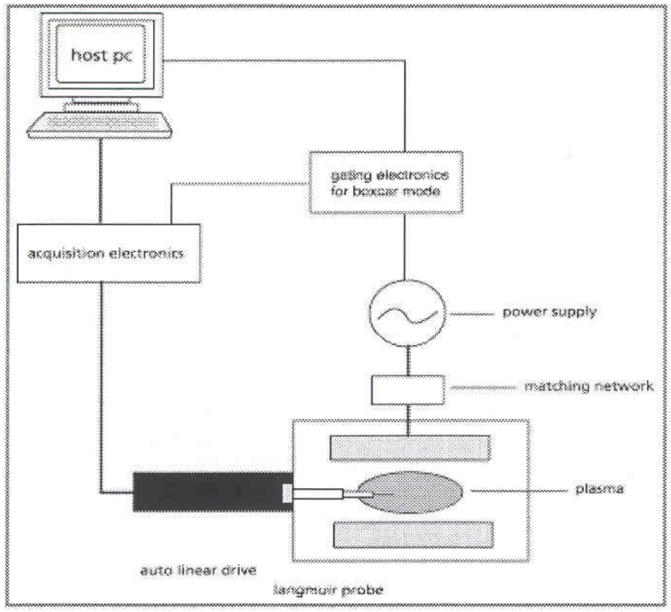

Figure 6. SmartProbe configuration for plasma measurements.[2]

A typical I-V characteristic curve measured using SmartSoft is shown in Figure 7. The I-V characteristic can be divided into three main regions: The electron saturation region, the electron retardation region, and the ion saturation region. Two analysis routines are available in SmartSoft that calculate the plasma potential Vp, the floating potential V_f, the electron temperature kT_e, the electron density n, and the debye length λ_d.

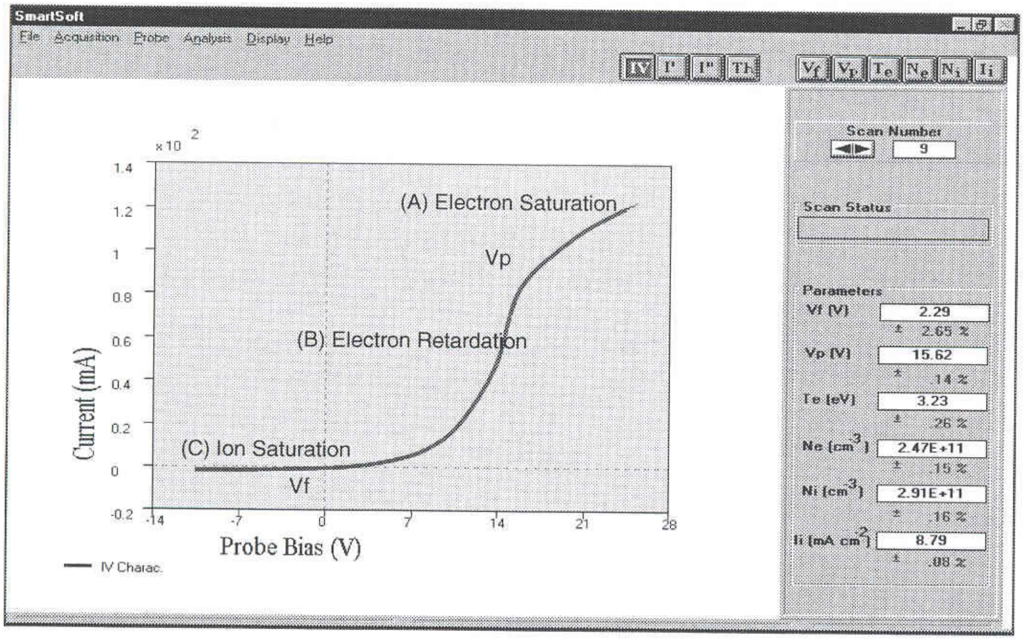

Figure 7. Typical SmartProbe I-V Characteristic display.

Implementation

Setting up and implementing the plasma demonstrations is relatively easy to do. However, they are only demonstrations and do not require any more than observation on the part of students. Modifying the DC glow discharge demonstration to allow the applied voltage to be varied and inserting a milliammeter in series with the supply will allow some quantitative data to be collected. Remember that using a variable DC supply will most likely require a ballast resistor to limit the current flowing through the milliammeter.

Optical studies using the Ocean Optics spectrometer do effectively show the differences in the spectra of various gases. Students will want hard copies of the spectra so print capability should be provided in the laboratory.

The NE-2 neon lamp experiment is also relatively low-cost and for the time spent, it provides a relatively high cost-benefit ratio. Besides applying the concepts of breakdown and off characteristics for a plasma device, the experiment reinforces the charge-discharge characteristics of capacitors studies in basic electric circuits courses and requires students to use their skill in using a dual-trace oscilloscope to make waveform measurements. The breakdown voltage is approximately 70 volts and the lamp turns off at approximately 55 volts

The “DC Breakdown of Gases” experiment is a bit more complex to implement. It takes a plasma chamber with vacuum pumping, RF or DC power source, and gas supply. It is a logical extension of the NE-2 neon lamp experiment, but requires several orders in magnitude to fund this activity. Most colleges would be able to afford one system at most.

Similarly, Langmuir probe experiments are high-cost activities, but provide the most quantitative data. Probes such as the SmartProbe from Scientific Systems cost on the order of $15,000. The cost-benefit ratio in a technician-level training program is questionable, and such systems will most likely be used at the graduate level.

Summary

The experiments presented in this paper provide an array of laboratory activities ranging from simple demonstrations using low-cost equipment from scientific supply companies to sophisticated Langmuir probe experiments using high-cost equipment from specialized equipment manufacturers. Faculty can implement lab activities in plasma physics according to their curriculum needs and as equipment budgets allow.

Bibliography

---, "Laboratory in Plasma Physics," Princeton Plasma Physics Laboratory, 1999.

----, "SmartProbe Product Overview," Scientific Systems, 2000.

Hata, David M. Introduction to Plasma Technology: A Technician's Perspective, Module 2 Introduction to Plasma Physics, 2004.

Biographical Information

DAVID M. HATA
Mr. Hata retired in 2003 after 32 years of teaching at Portland Community College in Portland, OR. During his tenure at PCC, he taught in the EET and Microelectronics Technology programs and served as Principal Investigator for seven National Science Foundation grants. He is a past recipient of ASEE's Chester F. Carlson Award and Robert G. Quinn Awards and past Chair of the Two-Year College Division.