PHY170: VACUUM PHYSICS

INTRODUCTORY REMARKS

In Vacuum Physics you will learn about the creation of vacuum with mechanical and diffusion pumps. This will include interfacing an analog-to-digital (i.e. A/D) converter, measuring the pumping speed of the pumps, and studying a thermocouple pressure gauge. You will have to read various books and manuals.

Open secrets: a) If the measured value of a certain quantity is very different from the expected value, it is best to stop and think about it; then consult with an instructor if you are stumped.
b) When you have accumulated a reasonable amount of data, it is a good idea to summarize the results in the form of tables and/or graphs in your notebook. This impresses the instructor at the time of grading.

EXPERIMENTS

The following gives you a general guideline on the ***minimum*** number of experiments that we expect you to perform in the VACUUM PHYSICS section of this course. We encourage you to be creative and propose an experiment. Your instructors are always interested in seeing you try new experiments once you have developed some expertise.

Advice: It takes about a half hour for the diffusion pump to warm up and work properly. Therefore, you need to plan ahead in order to make good use of each 3-hour lab period. You will have to be “awake” before you open any valve, so that you don’t expose the **hot** diffusion pump to atmospheric pressure.

Note: become familiar with the various pressure units in use. Find out how to convert Torr in mbar and Pascal.

I. VACUUM SYSTEM

1) **Learn the purpose and safe operation of ALL components on the Vacuum Cart before turning ON the pumps**:
   a) Mechanical and Diffusion pumps.
   b) Pirani and Penning gauges
   c) Valves, Quick Connects, Mist Filter, etc. and how to operate the system safely.

   In your notebook, describe (& make drawings/photographs) how the pumps and gauges work and how the whole vacuum system fits together --we love to ask “how do certain things work” questions at the end of term.

2) Do a pump down, recording in your notebook pressure vs. time for the mechanical pump. For the diffusion pump, start recording pressure vs. time with the pump cold and see what happens as it heats up. (Note that choosing Channel 4 on the vacuum gauge controller will "Autorange" between the various pressure ranges so you won't have to change the range by hand.) Make graphs of pressure vs. time using the computer. After you have done this, you will really appreciate letting the computer take the data for you!

II. INTERFACING

Here you will interface the pressure gauge controllers (and later the output of a thermocouple gauge) to the computer, which communicates with an analog/digital (A/D) converter box through a USB connection. Few important points to think about during this part are:

- Why is it useful?
- How do you make the connections?
- What is the best rate of data taking (data points per second?) in your experiment?

III. PRESSURE VERSUS TIME

Have the mechanical and the diffusion pumps running, but don't open the valves to the vacuum chamber initially. How does the pressure P vary with time t after you

1) Start pumping the chamber with the mechanical pump?
2) Cross over to the diffusion pump for $P \leq 100$ mTorr?
3) Cool a surface inside the vacuum chamber to very low temperature using liquid nitrogen for $P \leq 10^{-6}$ Torr.

IV. PUMPING RATE

- How can you convert $P(t)$ into pumping rate using the ideal gas law, $PV = nRT$?
- Compare your measured rates with the specifications given by the manufacturer for the mechanical pump and the diffusion pump.

V. MASS DISTRIBUTION OF RESIDUAL GASSES IN A VACUUM

Is this mass distribution just like our atmosphere: ~80% N_2, ~20% O_2, etc.? If not, what is happening to cause a different distribution? To answer these questions, use our Residual Gas Analyzer ($4,000!) that is mounted on a separate pumping station. See what happens to the mass distribution when you cool a surface inside the vacuum chamber with liquid nitrogen or when you let small amounts of gas into the chamber. (See separate instructions)

VI. Cooling of a heated wire

One kind of pressure gauge that works at moderate vacuum is a THERMOCOUPLE gauge. In this device a voltage of thermocouple junction (V_{th}) is measured that is proportional to the temperature rise of two very fine heated wires. This temperature rise is a measure of the pressure because the temperature of the wires results from a competition between the heating rate of the wires and the rate at which surrounding gas molecules remove the heat by collision with the wires. If you suddenly turn off the heat, the wires will cool. Question: will it cool more quickly at high or low pressure?

1) Learn how a thermocouple works.
2) Devise an experiment to measure V_{th} as function of heater power and pressure. **Warning! You must keep the heater current below ~0.25 A to avoid burning out thermocouple gauge.** To avoid this problem, place a resistor in your heater-current circuit--you will have to figure out what value of resistance is needed.
3) Learn how to use the Fluke-45 Digital Voltmeter and also how to connect V_{th} directly to the A/D converter. To get a better signal, there is a special preamplifier (×250 gain) that is built in the A/D converter box prior to the A/D converter to pull the level of signal to achieve better digitization.
4) **Advice**: do these two types of measurements first at 1 atm.
    a. Now do the experiment you devised. At least three (or more) widely separated pressures (1 atm., ≈0.2 Torr & < 10^{-4} Torr), measure **V_{th} vs heater power** (using Fluke-45 DVM) for both orientations of the thermocouple. If you can reasonably justify how both orientations would not matter at the lowest pressure then you can skip one orientation. How do you expect the V_{th} to depend on power? Can V_{th} be used to measure the actual junction temperature?
    b. Do the **V_{th} vs time** experiment at each pressure (after you suddenly shut off the heater power & using the preamp-A/D converter). Isaac Newton had something to say about how the temperature drops with time after the heating of an object is stopped.

5) Now measure V_{th} vs pressure for several constant heater currents (using the A/D converter) to determine the range of pressures over which the THERMOCOUPLE gauge works best as a pressure-measuring device.

VII. OPTIONAL EXPERIMENTS

Ask us about an improved measurement of the pumping speed and other advanced experiments.

Think about your own vacuum projects.