
VACUUM TECHNIQUES

A good vacuum is essential to many experimental physics applications especially those at the physical extremes of low temperature and high energy. It is quite likely that, in the course of your future studies, you will at some point have to use a vacuum system. In this lab you have the opportunity to gain experience with vacuum techniques and equipment by creating a vacuum and measuring its pressure. At the end of this lab, you will get a chance to apply your understanding of vacuum systems to create a simple optical device, an interference filter, by using a vacuum environment to deposit thin films on glass. Evaporative deposition techniques, such as the one you will experiment with, have made vacuum technology crucial in the development of solid-state microelectronic and micromechanical devices.

Introduction: Vacuum Quality and Pump Speed

A perfect vacuum is a region of space which is free of all matter. How perfect a real vacuum is can be quantified in terms of the absolute pressure inside a chamber. The lower the pressure, the "better" or "higher" the vacuum.

STOP! Write down six different units of pressure in your lab book and relate each one to at least one other. *For the units of pressure consult [Guthrie, 1963 #8] pg. 4.*

Although a vacuum is always described in terms of pressure, it is not always best to measure it by measuring a force over an area. This is especially true for very high vacuums (i.e., low pressures).

Think! Why? How else might you make the measurement?

The most common way of creating a vacuum is to pump the gas out of a vessel that is initially at atmospheric pressure. There are many different ways of pumping on a vessel, but all of them have a limiting pressure below which they

are ineffective. The lowest possible pressure achievable by a particular pump is called the *ultimate pressure* of the pump. In mechanical pumps the main problem which limits pressure is the contamination of the pump oil. In the compression cycle of a mechanical pump some of the gases being extracted will condense into the pump oil. This problem can be remedied by employing a pump with ballast which admits dry gases (ones which won't condense into the pump oil) to reduce condensation. The admission of gas, however, increases leakage back into the system and causes increased limiting pressures.

Some pumps also have a limiting pressure (< 1 atm) above which they are ineffective. The use of those pumps must be preceded by another pump, called a "forepump" or a "roughing pump", which brings the pressure in the vessel within their working range. Usually pumps which require a forepump require a backing pump as well. The *backing pump* is used to extract residual gases from the main pump to keep it at low enough pressure to operate. The pressure of the backing pump is called the *backing pressure*.

As one might guess, different pumps will evacuate a given vessel in different amounts of time. The time required for a pump to achieve its ultimate pressure depends not only on the kind of pump, but also on the volume of the vessel to be evacuated and the size of the conduit or tubing which connects the pump to the vessel. The *pump down speed*, S , of a complete vacuum system (pump + conduit + vessel) is defined by

$$S = Q/P \quad (1)$$

where Q is the volume of gas leaving the system in a unit of time and P is the pressure of the system. To define the speed of a pump we could then write

$$S_p = Q_p/P_p \quad (2)$$

In practice the speed of the pump can be determined by pumping on a blank. A *blank* is a flat piece of metal which covers the intake of the pump.

After measuring the pump with a blank it is sensible to connect tubing to the pump and watch its effect on the pump speed. A wide tube might not restrict gas flow or pump speed while a narrow tube might. It is useful to introduce the

conductance, F , of a tube which is the gas throughput of the tube divided by the difference in pressure of the two ends of the tube. This is written as

$$F = Q/(P_1 - P_2) \quad (3)$$

where P_1 and P_2 are the pressures at the two ends of the tubing. For a more thorough development see [Melissinos, 1966 #9] pg. 126. For an analogy with the electric circuit see [Guthrie, 1963 #8] pg. 28.

Exercise 1a: Suppose one had a pump connected to a vessel by some tubing. The flow of gas out of the vessel is Q_v . How is this related to the flow in the pump, Q_p ? Why?

Exercise 1b: Melissinos derives the result

$$\frac{1}{S} = \frac{1}{S_p} + \frac{1}{F} \quad (4)$$

Derive this result yourself. Does it make sense? Why or why not? (Hint: consider fast/slow pumps and tubes with high/low conductance)

Exercise 2: Consider a pump that has worked on a vessel for a long time so that most of the gas is evacuated from the vessel. Is the pump more efficient at these lower pressures than it was near atmosphere? Why or why not? Is the pump speed increased or decreased as the pressure goes down? Explain.

Exercise 3: How would you classify a vacuum system operating at 10^{-4} mm Hg. Is it low vacuum, high vacuum, very high vacuum, or ultra-high vacuum? What about a system at 10^{-7} Torr?

Introduction: Gaseous Flow and Mean Free Path

Consider a system comprised of a vessel that is connected by a tube to a pump. The pressure at the pump is lower than the pressure in the chamber. On average, gas molecules flow from the higher pressure region into the lower pressure region.

Think! This may seem obvious, but take the time to think it through. Ask yourself: Why is this? Is it more appropriate to describe the gas as being pushed or pulled by the pressure gradient? See Figure 1.

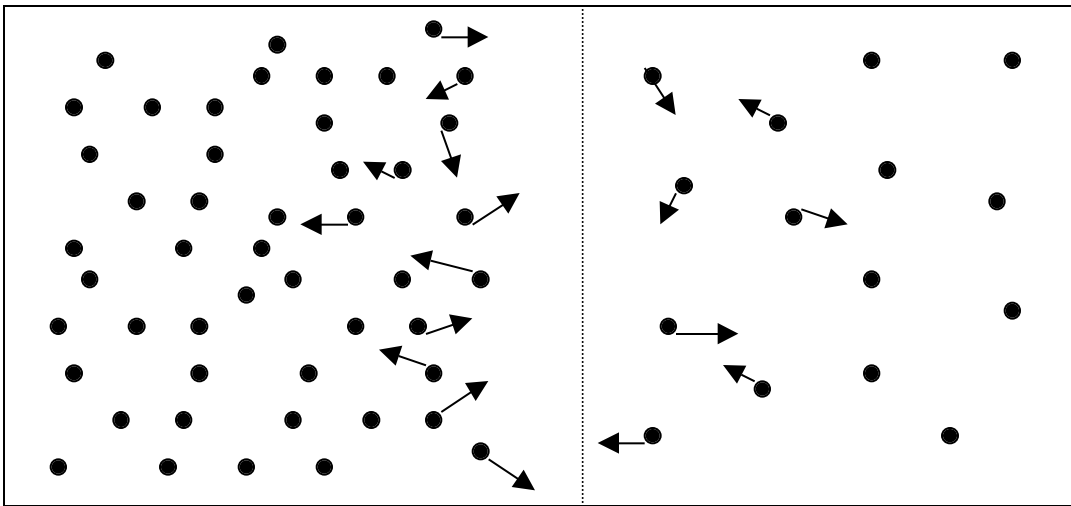


Figure 1. The gas molecules in the left half of the box are at higher pressure while those on the right are at lower pressure. On average there will not be enough collisions from the right side to keep molecules from the left side from coming over. Thus a net transport of gas from left to right (or high pressure to low pressure occurs).

The way in which gas flows in response to an enclosed pressure gradient depends on both the relative and the absolute pressures involved. There are two types of gas flow possible when evacuating a vacuum chamber: *viscous flow* and *molecular flow*. The word viscous might bring to mind the drag force due to air on a projectile. In that instance the collisions of the air molecules with the

projectile impedes its movement. In viscous flow, the collisions of the gas molecules with each other impedes the flow of the gas itself. In molecular flow, on the other hand, the gas molecules are more likely to run into the walls of the tubing and chamber than they are to encounter each other. There is no sharp transition between these two types of flow.

Think! Why not? If you had to define a transition point, what would be the natural choice? Which type of flow should dominate at high pressures? Which should dominate at low pressures? Which type of type of flow evacuates a chamber faster?

Flows which are not entirely viscous or molecular are defined as *transitional flows*. For more discussion see [Dushman, 1962 #10] pg. 80.

To determine which type of flow will take place in a given system (i.e., whether a gas molecule is more likely to collide with a wall or with another gas molecule) one must introduce the notion of the *mean free path* in the system. The *mean free path* (MFP) is defined as the average distance a gas molecule goes before a collision with another gas molecule. If the MFP is very short then a molecule will collide many times with other molecules before running into of the the vessel walls. If the MFP is very long then a molecule will bounce off the walls many times before hitting another gas molecule.

STOP! When the MFP is short what type of flow will occur? Is MFP short at high pressures or at low pressures? How are pressure and MFP related?

To make the above statements more quantitative, consider gas flowing through a long tube. Compare the MFP, given by L , to the radius of the tube, a . If the ratio L/a is small, then molecules hit each other many times before hitting the walls (*what type of flow?*). If L/a is large the molecules hit the wall several times before hitting each other (*what type of flow?*).

STOP! Read [Dushman, 1962 #10] pp. 80-81 to see specific numbers. In your lab book, describe the relationship between MFP and pressure (be sure to give units!). translates into a relationship between pressure and flow type.

Think! Does this relation hold for all gases and all temperatures? If not, for which gas(es) and/or what temperature(s) does it fail? Why?

Exercise 4a: For a tube of radius a , list the criteria for viscous, molecular, and

transition flows in terms of the pressure (i.e., $P=5a+3.4$)?

Exercise 4b: Explain why it is easier or harder to get molecular flow for a larger radius?

Exercise 4c: What is the cutoff for viscous flow in a tube of radius 1/4"? How about for molecular flow?

One of the chief characteristics of a system as it is being pumped down is its pressure as a function of time. A given system, initially at atmospheric pressure, approaches its ultimate pressure asymptotically.

STOP! In Exercise 2 you commented on the relation between pump speed and pressure. Using the information above, sketch a plot of pressure as a function of time.

Following [Melissinos, 1966 #9] pg. 127, the differential equation describing $P(t)$ is given by

$$-\frac{dP}{dt} = \frac{S}{C}(P - P_s) \quad (5)$$

where P is pressure, t is time, P_s is ultimate pressure, S is speed and C is the volume of the vessel that is being evacuated.

Exercise 5a: Solve this differential equation to get $P(t)$. Discuss what happens in the limit of high/low speed and large/small volume. (*Don't* confuse C with the conductance of the tubing, which is usually denoted by F !) Do these limits make sense?

Exercise 5b: Draw a sketch of $\ln(P)$ vs. time. From such a plot, how would you determine the speed (assume the volume is known)? Is this the speed of the pump or of the system? How could you find the other of the two?

Think! What is the problem with using the above derivation in practice? (Hint: consider **Exercise 2**.)

Materials and Methods:

To deposit aluminum one puts aluminum on a heating element in a vacuum chamber. The aluminum is then heated up until it vaporizes. This vapor stays in the chamber until it cools off and condenses back to metal. If the metal vapor touches a cold surface, such as a piece of glass in the vacuum chamber, it will immediately cool and solidify on the glass. After many vapor molecules do this a thin film of metal will condense on the glass. This technique is called vapor deposition and it is how mirrors are made. In high vacuums a thin film deposition will have fewer contaminants present to disrupt the growth of the film. Vacuums are important for storing materials as well as thin film deposition. When kept in a vacuum a material will not be as susceptible to oxidation or other reactions due to the absence of gas molecules.

In this lab, you will begin by experimenting with pumping on a vessel through different types of tubing to develop your understanding of how speed and conductance are affected by using different tubing. Then, you will evacuate an evaporation chamber and perform vapor deposition of aluminum onto a glass slide. For both parts you will need to use pumps and gauges. Those used in this lab are discussed briefly below. For more information on other types of pumps and gauges see [Guthrie, 1963 #8] chapters 3-6.

Materials and Methods: Pumps and Gauges

Mechanical Pumps

Rotary oil-sealed pumps are the most common type of mechanical pump. Gas from the vessel is allowed to enter a region of the pump. That region is then sealed, the gas inside it is compressed to a pressure >1 atm, and then it is expelled to the atmosphere. The region is again sealed, the gas inside it is expanded to a pressure below that in the vessel and the cycle is repeated. These pumps are effective in the range from atmospheric pressure down to 10^{-2} or 10^{-3} Torr. Mechanical pumps are often used as roughing pumps for other types of pumps, like diffusion pumps.

Diffusion Pumps

Diffusion pumps can achieve much higher vacuums than mechanical pumps but are only effective in the range of 10^{-4} to 10^{-7} Torr. In diffusion pumps, hot oil vapors are used to push gas molecules downwards, creating a pressure gradient at the bottom of a chamber. The gas at the very bottom has an increased pressure relative to the chamber and can be removed by a backing pump. It is common to use a mechanical "roughing" pump (to bring the pressure with the range of the diffusion pump) and then use the same mechanical pump as the "backing" pump for a diffusion pump. You can learn more about the diffusion pump by reading and consulting diagrams in [Guthrie, 1963 #8] chapter 4.

Thermocouple Gauge

A thermocouple is a junction between two metals whose work functions are so different that a detectable voltage ($\sim mV$) develops across the junction. The junction voltage depends linearly on temperature over a large range. If an electrical current is passed through a thermocouple, it may heat up, causing the

voltage drop across the junction to change. How much it heats up will depend on the rate at which it can dump heat into its environment. For a given amount of current, a thermocouple will get hotter at lower pressures since collisions with gas molecules are less frequent than at higher pressures. Alternatively, the amount of current that can be passed through a thermocouple without changing its temperature will be an indicator of the gas pressure in the chamber. This type of gauge can measure pressure from 0.5 to 500 mTorr but is inaccurate near atmospheric pressure.

Think! Why is a thermocouple gauge inaccurate above 500 mTorr? Why is it not useful below 0.5 mTorr?

Ionization Gauges

Positive ions produced by a hot filament will travel down a potential gradient and be collected at a negative electrode. The number of ions formed per unit time will depend on the density of gas molecules near the filament and therefore the current collected at the negative electrode is a measure of the gas pressure. This type of gauge is for gas pressures in the range 10^{-3} to 10^{-11} Torr.

STOP! Which two of the above four items should not be operated at atmospheric pressure?

Think! Don't operate them at atmospheric pressure.

Materials and Methods: Cleanliness

Cleanliness is of utmost importance in a vacuum system. So is dryness. Imagine a small spot of grease or water inside a vacuum chamber. At low pressures, most organic molecules, like water, will turn to vapor and contribute to the pressure in the chamber. The spots act like small gas reservoirs or leaks and

prevent the system from reaching high vacuum in a reasonable amount of time. **When working with a high vacuum system be very careful to keep things clean!** Vacuum grease is a special, high vapor pressure grease that is applied to assure a tight seal on the vacuum chamber, but if too much grease gets inside the chamber, it can poison the high vacuum and ruin the vapor deposition.

Think! Why should you wear gloves when taking materials in and out of the vacuum chamber?

Pumping Speed and Types of Flow

Procedure:

EVACUATING A TANK

- A. Connect the yellow cylindrical tank to the vacuum pump using the short metal adapter. Be sure to thoroughly clean all connections with Kimwipes. VERY LIGHTLY apply grease to surfaces to be sealed. REMEMBER: THINGS NEED TO BE CLEAN FOR VACUUMS. Connect the thermocouple gauges to their meters.
- B. Turn on the vacuum pump and in your lab notebook, track the pump pressure and the tank pressure as functions of time until the system reaches its ultimate pressure. (A table format works well.) Be sure to include notes on the absolute error in your measurement of t , P_{pump} , and P_{tank} . Then, make a graph of $\ln(P)$ vs. t for both P_{pump} and P_{tank} . Show error bars on the points.
- C. Replace the short adapter with a piece of 1/4" inner diameter (i.d.) hose. Repeat part B.
- D. Replace the 1/4" i.d. hose with a piece of 1/2" i.d. hose. Repeat part B.
- E. Replace the 1/2" i.d. hose with a blank. Repeat part B.

STOP! You are done "taking data", but there are several other characteristics of your system that you need to know (or measure) in order to interpret your results. What are they?

Pumping Speed and Types of Flow Analysis:

Questions you should be asking yourself and answering in your lab notebook include: Do your results make sense? (Think about your response to **Exercise 5**.) Are there any sources of error which you forgot to take into account? What type(s) of flow did you observe? How is this reflected in your data? What determines the pump speed of your system at a given pressure? What is the conductance of the tubes? (Think about your response to **Exercise 1**.) What is the error in the values of speed and conductance you deduce (it may be large)?

STOP! To determine the error in these numbers from the errors in your measurements, you may find it useful to refer to [Bevington, 1992 #12] chapter 6 (especially section 6.4). You might also find chapter 3 (especially section 3.2), on the propagation of error useful.

How do the conductances you measured compare with theory? (See [Scott, 1959 #11] section 6.6.) Are the values you found experimentally acceptable? Why or why not?

Vapor Deposition Procedure:

PREPARATION

- A. Figure 2 shows the various parts of the vapor deposition system. Read through the instructions below once quickly to get an idea of what you will be doing. Come back to this figure and talk yourself through the

procedure while looking at the diagram. Think about things like which valves will be open at which stage and ask yourself why. This is a good way to make sure you don't contaminate the system or destroy a gauge.

- B. The vacuum should be on to start. To open the chamber you will need to let some air in. Be sure the high vac, roughing, and backing valves are closed. **DO NOT CRANK ON THE VALVES TO MAKE SURE THEY ARE CLOSED** (this can cause future leaks). Open the vent valve. You should hear air entering the jar. **REMEMBER TO BE CLEAN!!!** As you will be lifting off the jar and getting inside the chamber you must remember to keep things clean or you will ruin your deposition. Gloves are required!!!
- C. Open the chamber by lifting the jar off and resting it on its special holder (behind and to the left of the chamber). Do you know why this is there? Look around the chamber. You should have some gloves on by now or be putting them on.
- D. With your **GLOVED HANDS** remove the evaporation shield. It is a cylindrical piece of metal with three rectangular holes on top. The holes are for holding glass slides. This prevents metal from being deposited all over the glass jar. You should see a viewing window on the side of the shield. This lets you look at the metal being evaporated inside the shield while you are doing the deposit.
- E. Put the material you are going to deposit in boats (probably Al and MgF_2). Remember to be handling things with gloves! Put the boats you will be using between the high current feedthroughs. You might want to make note of which feedthrough has which material.
- F. Put the evaporation shield back in place. You should note the location of the viewing window.

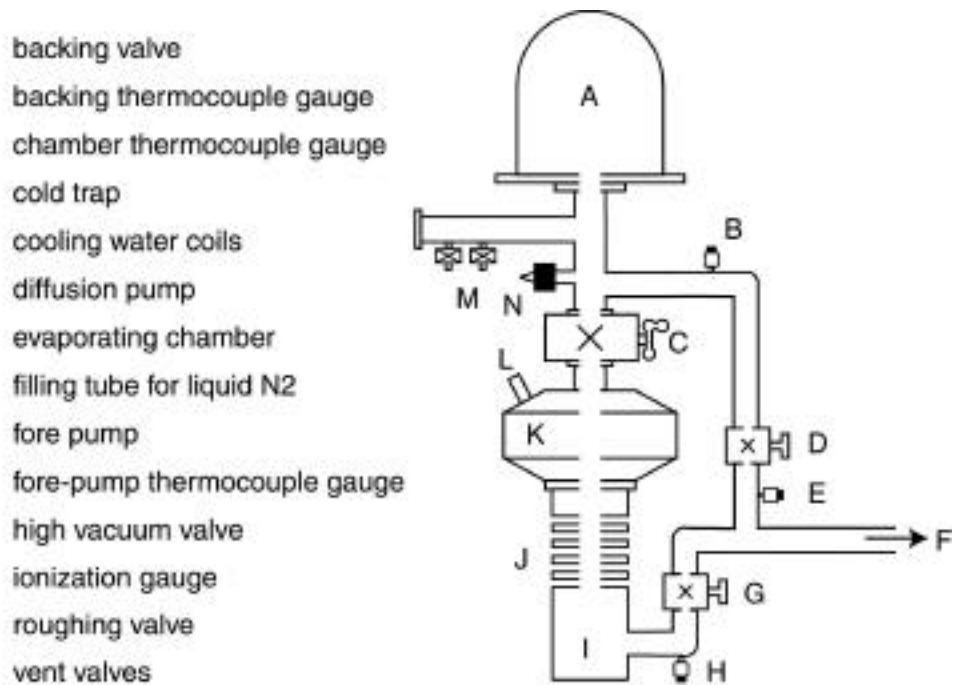


Figure 2. Schematic of the high vacuum system for vapor deposition. Write the appropriate letter next to each label on the figure.

- G. Clean three glass slides. While wearing rubber gloves wash the slides with lots of water and detergent by rubbing them with your gloved fingers. Rinse for AT LEAST 90 seconds in lots of water. Dry with Kimwipes. Finally, rub slides with a Kimwipe moistened by isopropyl alcohol or methane. This leaves a clean surface so metal will stick well. If available blow dry the samples to be sure they are free of particulate matter with an N₂ jet or Aeroduster.
- H. Load the clean slides into the holder on top of the evaporation shield.
- I. Clean the bell jar and the surface it touches. Leftover grease from the last run will destroy the possibility of high vacuum.
- J. Replace the bell jar. Be sure there is a LIGHT coating of grease (by using latex gloves and your finger) on the bottom of the jar. This is necessary for a high vacuum seal. Too much grease will prevent high

vacuum or take too long. Not enough will allow leaks into the chamber and prevent high vacuum.

- K. Close the vent valve. **BE CAREFUL WHEN SHUTTING VALVES.** Don't crank on a valve but be sure it cannot be turned further. If you crank on a valve its shape will deform and you will create a leaky valve. This raises the ultimate pressure of the system and may be a serious problem to fix.

COLD START

- A. Be sure all valves are closed. To get to high vacuum you will be using a liquid N₂ cold trap. Be sure you have several liters of ℓN₂.
- B. Turn Main Power on and Ionization Gauge POWER on. You should see the backing pressure gauge(to the right of the ionization gauge) come on. Be sure the thermocouple gauges (gauges on top of system next to bell jar) used to read the chamber's pressure and forepressure are plugged in and on.
- C. Turn on the mechanical pump. The switch is on the wall.
- D. Turn on the cooling water for the diffusion pump in the x-ray room.
- E. Wait until the forepressure reads 100 microns. Open the roughing valve and pump the chamber to less than 200 microns.
- F. Close the roughing valve and open the backing valve. Watch what happens to the pressure on all gauges.. Decrease the backing pressure to 100 microns. You may notice the chamber pressure go up. Close the backing valve and open the roughing valve again. Repeat E and F until both pressures are stable: backing at 100 microns, chamber at 200 microns.
- G. Double check to be sure the diffusion pump cooling water is running. Double check that you are at the pressures asked for in E and F.

Double check that the roughing valve is closed and the backing valve is open. Double check to be sure you have several liters of LN₂ for the cold trap. When checked turn on diffusion pump.

Think! Why shouldn't you turn on the diffusion pump until the backing pressure is at 300 microns or less? What would happen to the oil inside the pump?

- H. Fill the cold trap with liquid nitrogen.
- I. After about 15 minutes the diffusion pump will be hot. Be sure the roughing valve is closed and backing valve open. Then SLOWLY open the high vac valve. Keep the backing pressure below 300 microns.
- J. After the high vac valve is fully open and backing pressure is below 50 microns you may turn on the ionization gauge. To turn on the ionization gauge you should press and hold the START button.

DEPOSITION

- A. Be sure the thickness monitor is on and press STOP. Pressing STOP clears "P FAIL".
- B. Be sure the shutter on the evaporation shield is closed.
- C. Check the crystal with the test button. Under RATE the first digit should be a six. The second two digits indicate the remaining percentage of crystal life.
- D. Set the deposition parameters (TOOLING FACTOR=180.0, DENSITY and ACOUSTIC IMPEDENCE can be found in table 7.1 of the manual.

Think! What is the "tooling factor"? How can you find out what it is? Find out what it is.

- E. Press START on the thickness monitor.

- F. Check to be sure the chamber is below 50 microns on the ionization gauge. Turn on the evaporator(double check to be sure the shutter is closed before starting). Slowly apply current to the desired boat. Gently ramp the current up to approximately 30 Amps. Through the window on the side of the evaporation shield you should see the material start glowing and melting.
- G. After the material is melting you should open the shutter. Watch what happens to the thickness monitor. Note the rate at different times throughout your deposition in your lab book. Be sure to close the shutter after the appropriate amount of material has been deposited. See the PROJECTS section for the required thicknesses.
- H. After the appropriate thickness has been achieved and the shutter closed you should turn off the current. If you are going to deposit another film from another boat, wait a few minutes until the thickness monitor indicates deposition has stopped. Then repeat steps A-H.
- I. Turn off the ionization gauge (by flipping the power switch off then back on).

RECYCLING

Recycling means venting the chamber, in order to change boats or slides, while leaving the rest of the system under vacuum. It can save a lot of time since most of the system remains in high vacuum, but **YOU MUST BE VERY CAREFUL!** The ionization gauge and the diffusion pump should **NEVER** be operated at pressures over 300 microns: the gauge will burn out and the pump will spray oil over everything, requiring a long and painful clean up. You can isolate the two from the chamber by closing the high vac valve. **BE VERY SURE THE HIGH VAC VALVE IS CLOSED.** Also, **KEEP AN EYE ON THE BACKING PRESSURE.** If it gets too high, you should turn off the diffusion pump.

- A. Be sure the ionization gauge is off (by flipping the power switch off then back on).
- B. Close the high vac valve.
- C. VERY SLOWLY open the vent valve. We sometimes have problems with a leak in the high vac valve. Keep an eye on the backing pressure. If it starts getting too high ($>300 \mu\text{m}$), turn off the diffusion pump. Go to shutdown.
- D. Remove the bell jar and work inside as necessary. Remember your gloves and cleanliness!
- E. Replace the bell jar and guard. Don't forget the cleaning procedure(see Preparation section)!
- F. Close the vent valve.
- G. Close the backing valve and open the roughing valve.
- H. Watch the backing pressure closely (remember that the diffusion pump is still on and needs a low backing pressure). If the backing pressure exceeds 300 microns, quickly close the roughing valve, wait until the forepressure is less than 300 microns, and then open the backing valve. When the backing pressure is reduced to 50 microns go back to step G.
- I. When the chamber pressure is below 200 microns you are ready for step G from the Cold Start list.

PARTIAL SHUTDOWN (OVERNIGHT)

- A. Be sure the ionization gauge is off (by flipping the power switch off then back on). Be sure that the diffusion pump is off.
- B. If you are shutting down the bell jar must be on and evacuated.
REMEMBER THE CLEANING PROCEDURE TO REPLACE THE

JAR (see Preparation section). Replace the jar (after cleaning everything) and evacuate it.

- C. Close all valves.
- D. Complete parts E and F of Cold Start.
- E. When the appropriate pressures are reached you should end with the roughing valve closed and the backing valve open. The backing valve should be open and the mechanical pump running. This keeps water vapor out of the diffusion pump which is important.
- F. Turn off the power to the ionization gauge, diffusion pump, and evaporator.

SHUTDOWN

- A. Be sure the ionization gauge is off (flip the power switch off then back on).
- B. Be sure the diffusion pump is off.
- C. If the jar is off see parts B-D of Partial Shutdown.
- D. When system is evacuated to pressures listed in parts E and F of Cold Start you should close all valves. Be sure that vent, high vac, roughing and backing valves are closed.
- E. After closing all valves you may turn off the mechanical pump with the switch on the wall. Turn off power to the ionization gauge, diffusion pump, and evaporator as well as main power. Turn off the gauges by unplugging them.
- F. Turn off the cooling water.

Think! Why is the system left in an evacuated state for shut-off?

Vapor Deposition

Project 1:

The goal of the first vapor deposition project is to reduce the reflectance of glass by depositing a thin film overcoat. Transmission and reflection are discussed in [Hecht, 1987 #13] section 4.3.3 and anti-reflection coatings in [Hecht, 1987 #13] section 9.9.2. Anti-reflection coatings are used on many optical instruments to increase image brightness and decrease haziness due to internal light scattering. The images on page 376 of [Hecht, 1987 #13] provide an excellent illustration of the power of anti reflection coatings.

Every glass-air interface typically reflects ~4% of the incident light. If there is a thin film of dielectric at the interface (thickness= $\lambda_d/4=\lambda_{air}/4n_d$) whose index of refraction satisfies $n_d^2=n_g n_{air}$ then none of the light of wavelength λ will be reflected. MgF_2 has an index $n_d=1.38$, which does not quite satisfy the relation. Nonetheless, an MgF_2 overcoat will reduce the reflectance of glass (see **Exercise 6**). Using a HeNe laser (wavelength $\lambda_{air} = 632.8$ nm) and a photodetector, you can measure the transmission (or reflection) of various thin films.

Exercise 6: What index of refraction is needed to satisfy $n_d^2=n_g n_{air}$ (assume $n_g=1.5$)? Using equation 9.101 from [Hecht, 1987 #13] determine the reflectance of a MgF_2 overcoat.

Make three glass slides with different thicknesses of MgF_2 deposited on them. The thicknesses of the three layers should be $\lambda_{MgF_2}/8$, $\lambda_{MgF_2}/4$, and $\lambda_{MgF_2}/2$ of MgF_2 . All three can be made in the same chamber by partially closing the shutter of the evaporation shield during deposition.

Check the reflectance of each of the three films by first shining the laser directly on the photodiode intensity detector. Then place each of the slides between the detector and the laser and note the change in intensity. Write the raw data along with the calculated reflectance and estimated errors in your notebook (a tabular format works well). Take the $\lambda_{MgF_2}/4$ slide and place it in the transmission spectrometer. Measure the transmission as a function of wavelength and make a plot of your data with error bars.

Vapor Deposition

Project 1 Analysis:

Questions you should be asking yourself and answering in your lab notebook include: At what wavelength is the transmission minimized? What does this indicate about the thickness of the film? What experimental issues could account for differences between the observed and calculated thicknesses? How does this compare with the accuracy of the thickness monitor? Explain your data for reflectance of the three films. Is the reflectance the same across the entire film? What experimental issues would account for the variations? What can be done to improve the quality of the films or accuracy in the film thickness?

Vapor Deposition

Project 2:

The goal of the second vapor deposition project is to reduce the transmittance of glass by depositing a thin film overcoat. Transmission and reflection are discussed in [Hecht, 1987 #13] section 4.3.3 and anti-reflection coatings in [Hecht, 1987 #13] section 9.9.2. It is often advantageous to let only a partial amount of light pass through an optical instrument. Interferometers are a good example as they often employ partially silvered mirrors. In imaging the sun with telescopes it is important to only observe a tiny fraction of the sun's light to get good contrast.

Make three glass slides with different thicknesses of Al deposited on them. The thicknesses of the three layers should be 300Å, 500Å, and 800Å. All three can be made in the same chamber by partially closing the shutter of the evaporation shield during deposition.

Use a HeNe laser (wavelength $\lambda_{air} = 632.8$ nm) and a photodiode intensity detector to determine transmittance as mentioned in Project 1. Check the transmittance at about 10 different points on the film. Record the values of transmittance and approximate locations for each film.

Vapor Deposition

Project 2 Analysis:

Questions you should be asking yourself and answering in your lab notebook include: Does there appear to be a linear relationship between thickness and transmittance. Is the reflectance the same across the entire film? What experimental issues would account for the variations? What can be done to improve the quality of the films or accuracy?

REFERERENCES

1. A. Guthrie, 1963, Vacuum Technology, New York, John Wiley & Sons, Inc.
2. A. Melissinos, 1966, Experiments in Modern Physics, New York, Academic Press
3. S. Dushman, 1962, Scientific Foundations of Vacuum Technique, New York, John Wiley & Sons, Inc.
4. R. Scott, 1959, Cryogenic Engineering, Princeton, D. Van Nostrand Company, Inc.
5. P. Bevington and D. Robinson, 1992, Data Reduction and Error Analysis for the Physical Sciences, Boston, WCB/McGraw-Hill, Second Edition
6. E. Hecht, 1987, Optics, Reading, Addison-Wesley Publishing Company, Second Edition