
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.

I. 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.

Exercise 1: 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 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).

Exercise 2: Why? How else might you make this 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. 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 throughput, or 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 pg. 126. For an analogy with the electric circuit see Guthrie pg. 28.

Exercise 3a: 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 3b: Melissinos derives the result: $\frac{1}{S} = \frac{1}{S_p} + \frac{1}{F}$
Derive this result yourself. Does it make sense? Why or why not? (Hint: consider fast/slow pumps and tubes with high/low conductance)

Exercise 4: 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 5: 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?

II. 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.

Exercise 6: Why do molecules flow from the higher pressure region into the lower pressure region? Is it more appropriate to describe the gas as being pushed or pulled by the pressure gradient? See Figure 1.

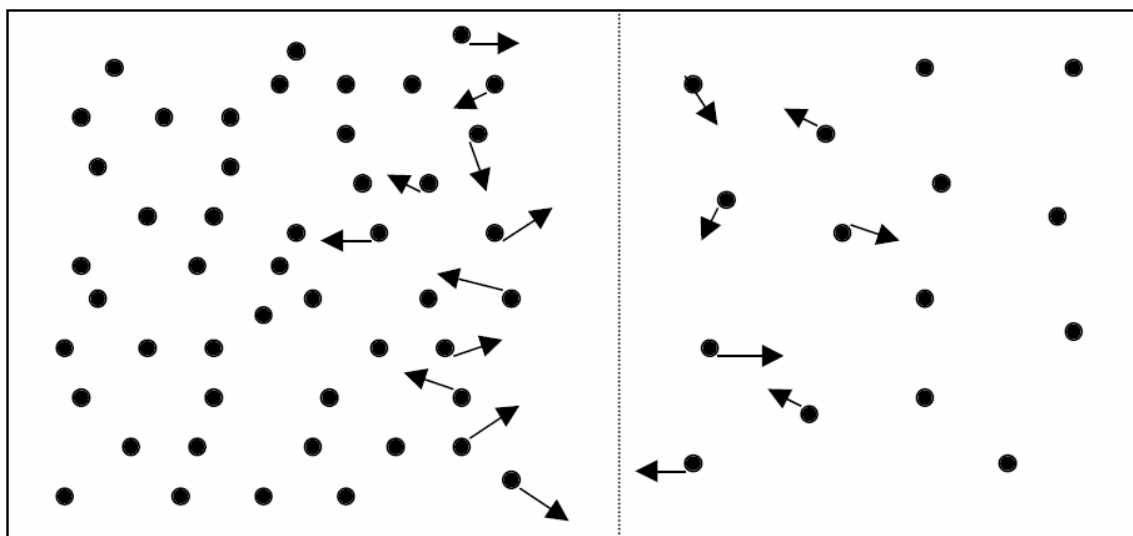


Figure 1 The gas molecules in the left half of the box are at higher pressure while those on the right are at lower pressure. On average there will not be enough collisions from the right side to keep molecules from the left side from coming over. Thus a net transport of gas from left to right (or high 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 impede its movement. In viscous flow, the collisions of the gas molecules with each other impede 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. Of course, there is no sharp transition between these two types of flow.

Exercise 7: Why aren't there any sharp transitions between the two flow types? If you had to define a transition point, what would be the natural choice?

Flows which are not entirely viscous or molecular are defined as *transitional flows*. For more discussion see Dushman pg. 80.

Exercise 8a: Which type of flow should dominate at high pressures? Which should dominate at low pressures? Explain each.

Exercise 8b: Which type of type of flow evacuates a chamber faster?

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 vessel walls. If the MFP is very long then a molecule will bounce off the walls many times before hitting another gas molecule.

Exercise 9: In **Exercise 8** you figured out at which pressures viscous or molecular flows dominate. Now ask yourself, 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?*).

Exercise 10: Read Dushman pgs 80-81 to see specific numbers. In your lab book, describe the relationship between MFP and pressure (be sure to give units!). Translate this into a relationship between pressure and flow type. 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 11a: 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 11b: Explain why it is easier or harder to get molecular flow for a larger radius?

Exercise 11c: 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.

Exercise 12: In Exercise 4 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 pg. 127, the differential equation describing $P(t)$ is given by

$$-\frac{dP}{dt} = \frac{S}{C}(P - P_s) \quad (4)$$

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 13a: 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 13b: 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?

Exercise 14: What is the problem with using the above derivation in practice?

III. Materials and Methods – General Introduction

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 a variety of materials 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.

IV. 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 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^{-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^{-3} 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 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.

Exercise 15: 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.

Exercise 16: Which two of the above four items should not be operated at atmospheric pressure? DO NOT OPERATE THEM AT ATMOSPHERIC PRESSURE!!

V. 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.

Exercise 17: Why should gloves be worn when taking materials in and out of the vacuum chamber?

VI. Pumping Speed and Types of Flow

PROCEDURE

- A. Connect the yellow cylindrical tank to the vacuum pump using one of the 3 provided tubes. The sizes of the tubes are labeled on the wall behind the apparatus. There is a large end and a small end to each of these tubes; the large end should be connected to the pump, the small end to the yellow tank. Be sure to thoroughly clean all connections with Kimwipes. VERY LIGHTLY apply grease to o-rings being sealed. REMEMBER: THINGS NEED TO BE CLEAN FOR VACUUMS. Turn on the thermocouple gauges (one has a switch, the other just plug into a power outlet).

- 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. It usually takes about 10 minutes for it to reach a moderate vacuum. 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. Repeat part B for each of the remaining tubes. To attach the short red tube, loosen the set screw on the rod connecting the tank to the table and rotate the tank downwards, then tighten the screw. Position the pump underneath the tank and connect it.

ANALYSIS

You should be asking yourself, and answering, the following questions in your lab notebook:

- Do your results make sense? (Think about your response to **Exercise 13**.)
- 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? How do your measurements compare with theory? (Think about your response to **Exercise 3** and see [Scott, 1959 #11] section 6.6.)
- What is the error in the values of speed and conductance you deduced (it may be large)? (Refer to [Devington, 1992 #12] chapter 6, section 6.4 and chapter 3, section 3.2)

VII. Vacuum and Vapor Deposition Procedures

In the following section we will perform a few vapor deposition experiments using the high vacuum apparatus. Vapor deposition works by placing the material to be vaporized on a heating element in a vacuum chamber. We will be using tungsten boats to hold our material. A current is applied across the boat to heat it up, thus heating the material until it liquefies, then 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 high quality 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.

Below is the procedure for preparing and evacuating the high vacuum system. The procedure to evacuate the chamber is the same for all of the vapor deposition projects, though there are variances in the materials being placed in the chamber as well as the heating techniques. Please read through this procedure and try to get a very good idea of what is being done in each step (refer to Figure 2 for a schematic of the system). Before starting anything also read through the deposition projects and complete any exercises required of you.

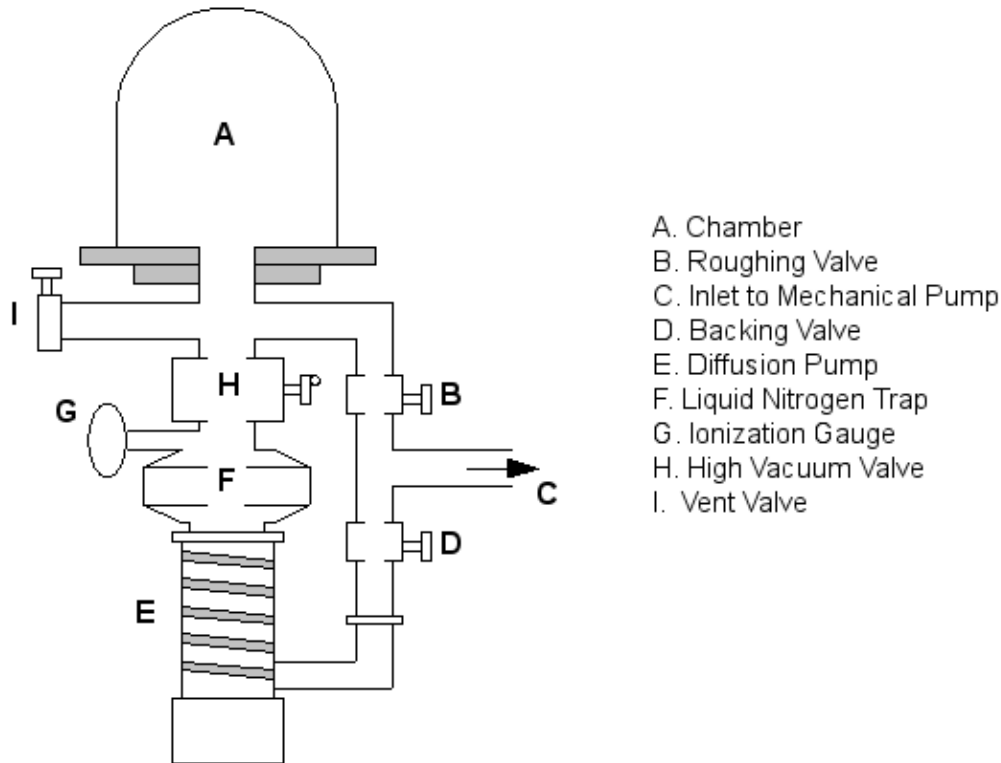


Figure 2 Schematic diagram of the High Vacuum System.

IMPORTANT: If you don't know what you are doing ask someone, opening the wrong valve at the wrong time can have catastrophic and unrecoverable effects on the system!

A TA will guide you through your first pump down until you are familiar with the procedure.

Note: When opening and closing valves, do not over open or over close. You will know when the valve is all the way open or all the way close. Do not give it an extra crank. Also, feel free to take your time between the steps. Nothing has to be rushed, except between steps F and G of vacuum start-up.

VACUUM START-UP

- A. Turn on the water in back office: Turn both orange valves counter-clockwise 90 degrees. They should be pointing inline with the pipes. Check that the water is flowing by observing the flow indicator connected to the tubing behind the vacuum system.
- B. Turn on the mechanical pump: Push the black START button on the box attached to the wall behind vacuum experiment.
- C. Turn on the Black ON button on front panel of vacuum apparatus. The thickness monitor should start blinking P-Failure. Press the stop button on the thickness monitor to stop this nuisance.
- D. When the Roughing Pressure Gauge reads 100 millitorr or less, slowly open Backing Valve.
- E. Start filling DEWAR with liquid nitrogen; when full proceed to the next step.
- F. Turn on Diffusion Pump Switch on front panel of vacuum apparatus. Diffusion Pump takes about 15min to warm up. Start filling the liquid nitrogen immediately after turning on diffusion pump.(go to step G).
- G. Slowly pour liquid nitrogen into the spout behind the glass chamber. If you pour too fast the nitrogen will boil up and squirt out of the chamber. You know you are done when gas is spreading along the floor (it's overflowing from underneath, falling onto the floor, and boiling).
- H. Calibrate TC1 only. Press CAL button once. TC1 is blinking now. Now Press Enter once. Do not press anything else until TC2 stops blinking. TC1 is now calibrated to atmospheric pressure. Actually it was calibrated to atmospheric pressure prior to nitrogen filling, but the cold nitrogen plays funny tricks on the gauge, making it think the pressure is dropping.

SAMPLE PREPARATION

- A. **Wear gloves at all times when handling the evaporation shield, metal boats and glass slides.** The gloves prevent your skin oil from getting on the boats. If oil gets on the boats, the oil burns and turns to soot during the heating phase, ruining your experiment and maybe ruining your next run as well. Get new boats and place them into the chamber beneath the washers and nuts. Secure them with the nuts. Do not over tighten. Turn nuts just tight enough so that boats do not move on their own. Over tightening causes stress which is increased when the current is turned on. Over tightening reduces life of boats, often causing failure on first attempt of vapor deposition
- B. When using magnesium fluoride (it's in a small tube in a labeled brown box on the shelf) pour MgF_2 onto entire thin area of each boat. Lightly pack down the powder with other side of MgF_2 tube. Add more MgF_2 on top of packed MgF_2 , repack slightly.
- C. When using Aluminum: use thicker 0.010 boats. First scrub and clean the first 3 inches of the aluminum roll, then cut two 1 inch pieces off of spool. Set both down in the middle of each boat.
- D. Be sure to adjust coefficients on thickness monitor. For example. Push MATL DENSITY button on thickness monitor. It should read 3.00 for MgF_2 . If not, then push Increase or Decrease button accordingly to adjust the monitor to the right values. Continue adjusting thickness monitor for ACCOUSTIC IMPEDENCE and TOOLING FACTOR. Note the different values on the white labels on the monitor for aluminum and MgF_2 when its time to use those materials.
- E. Be sure to prepare at least two boats with samples, preferably three boats. Often boats will break before vapor deposition occurs. With backups ready, you will not need to vent chamber to set up other samples and waste your time.
- F. Clean three glass slides with alcohol and Kimwipes found on shelves. Place slides in slots on top of metal holding tray. Be sure not to scratch the smooth metal surface where metal holding tray and glass dome sit. A scratch could allow a leak and vacuum will not occur. Very big problem when that surface is scratched.
- G. Check rubber bottom of glass dome. Is it shiny? If yes then there is vacuum grease on it. If no, add a little (found on shelves) and spread very thinly over bottom rubber surface. Wipe down smooth metal surface with Kimwipe to gather dirt/dust. Set glass dome down. **Set metal cage down over glass dome.**

CHAMBER PUMP-DOWN

- A. Close Backing Valve and then Open Roughing Valve. Now you are pumping down the chamber with the mechanical pump.
- B. When TC1 gets down to 75 mTorr (vacuum gauge reads 5.0 -2 Torr) close Roughing Valve and then open Backing Valve and then **SLOWLY** open High Vacuum Valve. It takes about one full crank until High Vac Valve actually begins to open. Do this slowly. As soon as you see TC1 begin to drop again stop turning High Vac Valve. Let it slowly pull pressure down. Every few seconds, slightly open the High Vac Valve more. Keep very slowly opening High Vac Valve until TC1 reads 40 MilliTorr. Once at 40 MilliTorr, feel free to open High Vac Valve all the way open.
- C. When TC1 reads 1.0 -3 push EMIS button on vacuum gauge. The high vacuum gauge is kicking in and in a few seconds it will show the approximate pressure of the chamber. TC1 is no longer accurate.
- D. Turn on Evaporator Switch on front panel of vacuum apparatus. Wait until Chamber pressure reaches ~2.0 -5 Torr or below to begin vapor deposition. Turn on boat 1, 2, or 3 using the big black switch on the front panel of the vacuum apparatus. Boat one is on far left and Boat 3 is on far right.

VAPOR DEPOSITION

- A. Melting MgF₂. Turn current up to 10. Let sample warm up for a minute. Notice the hole on the right side of slide stand. This lets you see the sample as it warms up. Turn current up to 15. Let it warm up for a minute. Slowly turn current up one notch at a time until 20-22. MgF₂ should start melting. Once it starts melting stop increasing current. If not melting yet, slowly continue increasing current. When MgF₂ is in liquid form, press Start on the Thickness Monitor. Slightly Increase or Decrease current to adjust the rate of deposition.
- B. Melting Aluminum: Set current to 15. Wait a minute. Set current to 20. Wait a minute. The boat should start glowing. Slowly increase current to 22-23, sit for one minute. Move to 25, the aluminum should start melting, if not, very slowly increase current. Once it starts melting, stop increasing current for a minute. Open the shutter and press Start on the thickness monitor. Continue to slowly increase current until 31-32. The aluminum should be in liquid form and you should be able to see it sort of bubbling. Slightly Increase or Decrease current to adjust the rate of deposition. The rate should be around 10-16 Å/sec.
- C. Adjust shutter to change thickness from one slide to the next. Close shutter completely when you have obtained desired thickness. Press stop on thickness monitor. Note that the thickness monitor continues to show an increase in thickness even though the shutter is closed.

VENTING

- A. Turn down current to zero and turn off boats with switch.
- B. **CLOSE THE HIGH VACUUM VALVE.** The Roughing valve should still be closed. Leave the backing valve open.
- C. Press EMIS button to turn off High Vacuum Gauge.
- D. Slowly open the Vent valve. After vented, close vent valve.
- E. You may now lift cage, evaporation shield, and bell jar to look at your samples. There may still be a small vacuum in the chamber so the Bell jar may be difficult to pull off. Simply twist a little as you pull the bell jar up.
- F. Return to **SAMPLE PREPARATION** to collect more samples.

SHUT DOWN

- A. Replace evaporation shield, bell jar, and cage. Turn off evaporator and diffusion pump switches. Press the red Off button on front panel of vacuum apparatus.
- B. Leave Mechanical pump ON, backing valve OPEN, and orange water pump valves OPEN. Because there is still liquid nitrogen in the diffusion pump, water will condense on the inside. We leave the mechanical pump on all night to pump out this water vapor. The water pump is left on to help cool the hot diffusion pump. A TA will turn off the pumps the next morning.

VIII. 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 $\sim 4\%$ 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 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 18**). Center the coating wavelength to that of laser light; use $\lambda_{air} = 632.8$ nm.

Exercise 18: 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.

Exercise 19: The thicknesses of the three layers of MgF_2 should be $\lambda_{MgF_2}/8$, $\lambda_{MgF_2}/4$, and $\lambda_{MgF_2}/2$. Calculate these thicknesses in Angstroms.

All three slides can be made in the same chamber by partially closing the shutter of the evaporation shield during deposition. (Open it all the way in the beginning then cover individual slides as you go up in thickness. You will have to hold the shutter in between slides, it will only hold itself completely open or closed).

Check the reflectance of each of the three films by inserting them into the Ocean Optics Spectrometer located in room 3215 (instructions on how to use the spectrometer are on top of the computer). Make printouts for all three slides, as well as an uncoated slide for use as a control.

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 transmission indicate about the thickness of the film?
- Is the reflectance the same across the entire film? What experimental issues would account for the variations?
- What experimental issues can account for differences between the observed and calculated thicknesses? How does this compare with the accuracy of the thickness monitor?
- What can be done to improve the accuracy in the film thickness?

IX. 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 300 Å, 500 Å, and 800 Å. All three can be made in the same chamber by partially closing the shutter of the evaporation shield during deposition.

Analyze your slides with the Ocean Optics Spectrometer.

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?

X. Vapor Deposition: Project 3

Due to time constraints involved with operating the vacuum system, Project 3 is not required, but is highly recommended if you have extra time.

The goal of the third vapor deposition project is to create interference filters. Interference filters allow only certain wavelengths of light to pass. They are used in a variety of optical applications such as astronomy and microscopy. The most simple interference filter consists of three layers. The first is a layer of semi transparent aluminum, the second is a $1/4\lambda$ layer of a dielectric, and the third is an identical layer of aluminum. In this experiment we will be using MgF_2 as the dielectric. A good description of the physics behind interference filters can be found at the hyperphysics website: <http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/intfilt.html>.

Deposit a 30% transmission layer of Al (approx 425\AA , use your results from Project 2 to estimate this number) on all three glass slides. Next deposit a layer of MgF_2 . You can choose how thick you want the MgF_2 layers, but remember that we are looking at visible light and that there is a physical limit to the amount of MgF_2 that we can put in a boat. This will place the upper and lower bounds of the MgF_2 layer at approx 800\AA - 1500\AA . The last layer is aluminum and is identical to the first. You should be able to do all three layers in one pump down by having 2 boats of Al and 1 boat of MgF_2 . Don't forget to also change the MATL DENSITY and ACOUSTIC IMPEDENCE settings on the thickness monitor when changing metals.

Use the Ocean Optics Spectrometer to analyze the transmission of your three slides and compare them to the theoretical predictions. The thickness of the MgF_2 layer is determined by the condition for constructive interference:

$$d = \frac{\lambda}{4n \cos \beta}$$

Where λ is the wavelength of light passed, β is the angle of incidence, and n is the index of refraction.

PROJECT 3 ANALYSIS

Questions you should be asking yourself and answering in your lab notebook include:

- How close are your results to those predicted?
- What would happen if you vary the angle of incidence?
- What could you do to improve the accuracy of your results?

Include the following in your lab book:

- Exercises 1 through 19
- Pumping Speed and Types of Flow Analysis
- Analysis for Vapor Deposition: Project 1, Project 2, and Project 3
- Chart Printouts for all Vapor Deposition Projects
- Procedure and Conclusion

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