PREPARING A VACUUM CHAMBER TO TRAP ATOMS, AND THE PRINCIPLES OF A MAGNETO-OPTICAL TRAP

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1 Introduction

The goal of our research is to study the properties of a new type of optical trap for eventual use in quantum computers. The term "quantum computer" is a broad term used to describe any computer whose operations are dictated by quantum mechanics. The principles of entanglement and the superposition of quantum states can be used to perform the logic operations necessary to build a quantum computer [1]. Quantum computers will be able to compute many-body systems in quantum chemistry and biochemistry, and the prime factorization of large numbers. These problems would take classical computers the age of the universe to compute. Current RSA encryption relies on the assumption it would take classical computers unreasonably long to find the prime factors of large numbers, so a quantum computer could break this encryption scheme.

Our research is exploring one possible method of making a quantum computer using neutral atoms in an array of optical traps. Atoms will be trapped in the near diffraction pattern of an array of circular apertures [2]. Once trapped, we can study how the atoms can perform the necessary quantum operations for a quantum computer. Think of an optical trap as a point of low potential energy. For atoms to be trapped in this point they must have less energy than the walls of the trap. A magneto-optical trap super-cools and collects the atoms, preparing them to transfer into the optical traps. The atoms need to be cooled to the order of 10^{-4} Kelvin because at higher temperatures the atoms would have too much energy

to be held in the optical trap. It is necessary to trap the atoms in an ultrahigh vacuum because any collision with a stray atom will knock out a trapped atom, and there are very few stray atoms in an ultrahigh vacuum. The quality of the vacuum will largely determine how long atoms will stay trapped and potentially limit the experiments we are able to perform.

2 Theory of a Magneto-Optical Trap

2.1 Basic Setup

A magneto optical trap consists of six laser beams shining into a vacuum chamber clad in two electromagnets [3,4]. The lasers are red detuned so atoms are Doppler cooled [5]. Doppler cooling only slows atoms traveling towards a beam, so six beams are shone into the trap from all x,y,z directions to slow atoms traveling in any direction. Two electromagnets are used to create a magnetic field, which has a zero point in the middle of the trap. The magnetic field induces Zeeman splitting in the rubidium atoms, which allows us to use the laser polarization to collect the atoms at the zero point of the magnetic field. These techniques will be explained in detail in the following sections.

2.2 Doppler Cooling

The principle of Doppler cooling [5] utilizes stimulated absorption and spontaneous emission shown in figure 2.1. An atom can transfer to a higher energy quantum state by absorbing a photon with the same energy as the difference between the quantum states in a process called stimulated absorption. The excited state is unstable so the atom will drop back into the ground state. To release the excess energy the atom fluoresces, and emits a photon in a random direction. This process is called spontaneous emission. When an atom absorbs or releases a photon it also recoils from the photon's momentum.

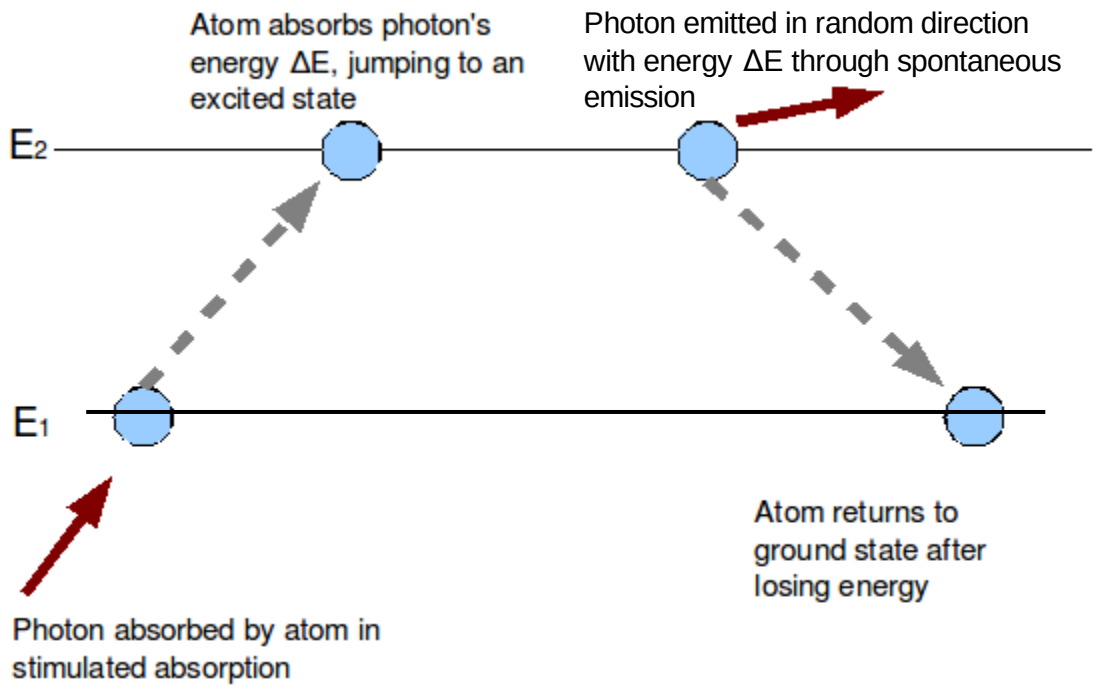

Figure 2.1: Stimulated absorption process on the left and spontaneous emission process on the right, note: $\Delta E=E_2-E1$

Rubidium will only fluoresce when the laser frequency is very close to resonance with the fluorescence frequency. When an atom is traveling towards or away from the laser source it sees the laser frequency as blue or red shifted, respectively due to the Doppler effect. By tuning our lasers to a frequency just below the fluorescence frequency (so it is red shifted), the atom will see the laser frequency blue shifted to the fluorescence frequency when traveling towards the laser beam. When the laser frequency is shifted slightly off the resonant frequency the atoms are less likely to absorb the photons. Consider the configuration in figure 2.2. We tune a laser below the resonant frequency or 'red detune' the laser. When shining a red detuned laser from the left as below, only atoms traveling to the left readily absorb photons.

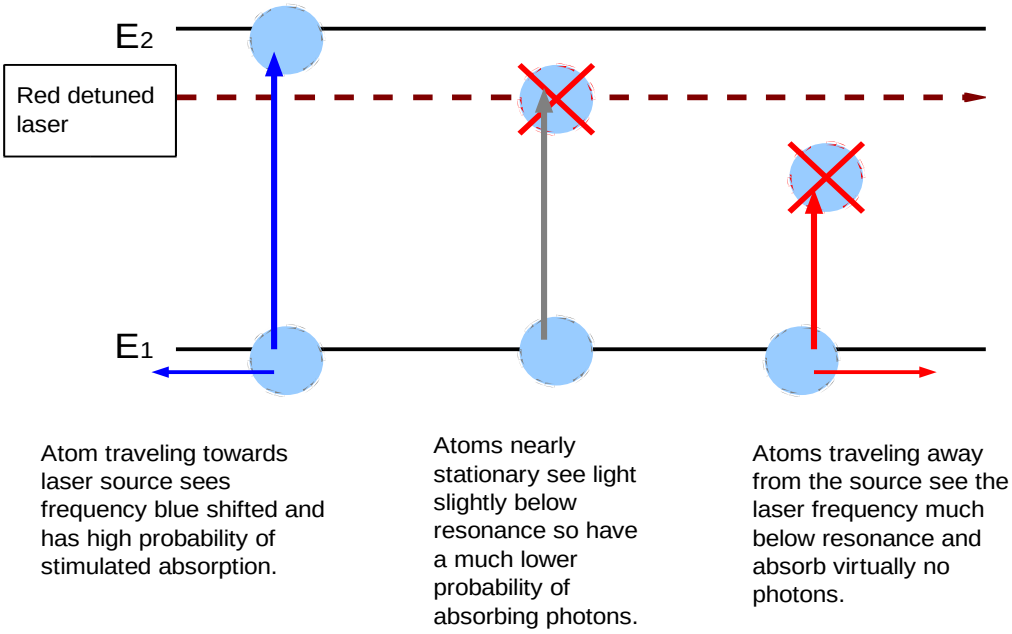

Figure 2.2: Doppler effect on stimulated absorption

When an atom absorbs a photon it absorbs the photon's energy and momentum. The energy from the photon excites the atom into a short-lived excited state. The excited state for rubidium is relatively short lived with a life time of only 26.63ns [3] before undergoing spontaneous emission. The photon emitted carries momentum as well as the excess energy from the transition to the ground state. As an atom undergoes many stimulated absorption and spontaneous emission cycles, photons emitted are in random directions so they exert no net force on the atom. Thus, the overall net force on the atom is only from absorbed photons, as shown in figure 2.3.

We want to slow down and thus cool the Rubidium atoms, thus we only want the rubidium atoms traveling towards the lasers to absorb photons. As the rubidium atoms traveling towards the beam are absorbing the momentum from the photons they are slowing down and losing kinetic energy. In this way the photons absorbed slow down the rubidium. This process is known as Doppler Cooling.

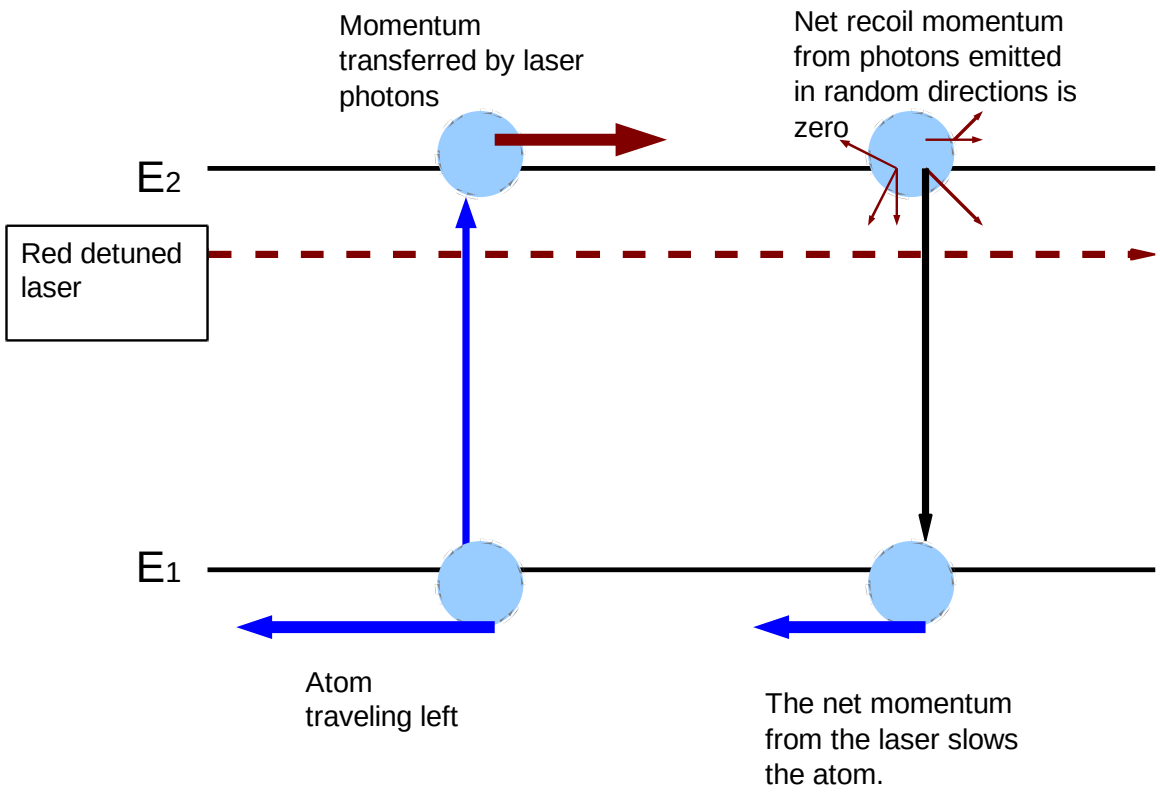

Figure 2.3: Doppler cooling with a single laser.

2.3 Zeeman Effect

In a magnetic field the energy levels of an atom split due to the interaction of the magnetic field with the magnetic dipole moment of the atom, commonly know as the Zeeman Effect. Consider the atomic model in figure 2.4 with two energy levels, ground level E_1 and an excited level E_2, and total angular momentum $J_1=0$ and $J_2=1$, respectively. Both the E_1 and E_2 contain magnetic m_J substates that are normally degenerate. In a magnetic field the m_J states shift energy. The example atom's excited state splits into three levels with $m_J'=0, \pm 1$ and the ground state will have $m_J=0$. The shift in energy of fine structure m_J states by a magnetic field orientated along the z-axis is:

$$E_{magn.dipole} = g_J \mu_B m_J B_z$$

The external magnetic field z-component is denoted B_z, while g_J is the Landé g-factor, and μ_B is the Bohr magneton. The splitting of the m_J states is proportional to the strength of the magnetic field. In a magnetic field gradient the Zeeman splitting increases with a stronger field. Using the same atomic model as above, a stronger magnetic field would bring the $m_J'=-1$ excited energy level closer to the ground $m_J=0$ level, so less energy is needed to make the transition.

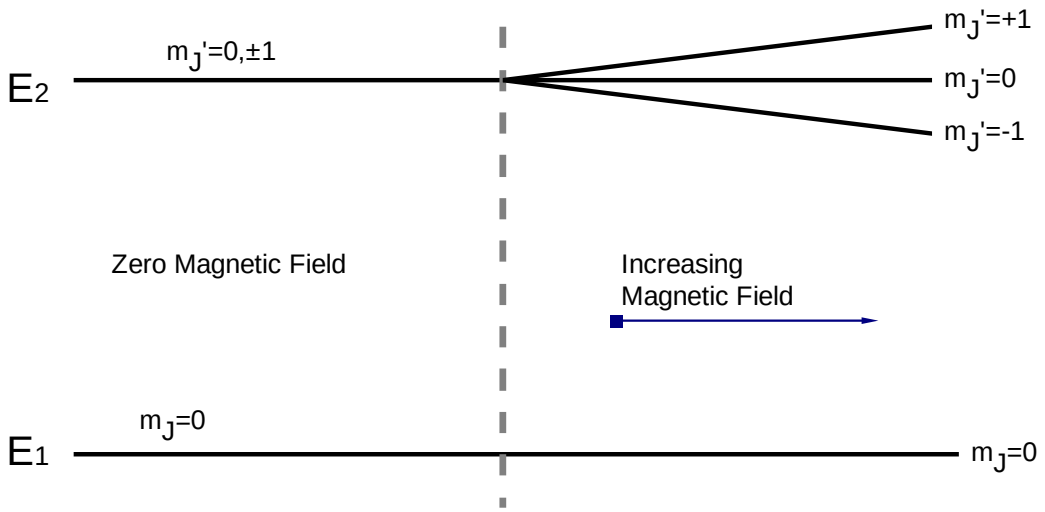

Figure 2.4: Zeeman splitting of E_2 in a magnetic field

The polarization direction of the laser light determines the Zeeman level the rubidium will excite to. Negatively circularly polarized (σ_-) light will only allow the m_J=0 → m_J'=-1 transition along the quantization axis of a magnetic field due to selection rules. By controlling the polarization direction and magnetic field within the chamber we can control the transitions likely for rubidium. Rubidium has a much more complicated atomic structure but the principles are the same.

2.4 Trapping Atoms

Consider the configuration in figure 2.5 with a σ_+ laser beam from the left and a σ_- beam from the right laser shining into a region with a magnetic field increasing to the right with zero field in the center. An atom located to the left of the center of the trap

experiences a negative magnetic field which lowers the $m_J'=1$ energy level. This increases the probability of the atom absorbing σ_+ light over σ_- light, giving the atom net momentum towards the zero point in the magnetic field. If the atom is located to the right of the zero point of the trap center the $m_J'=-1$ energy level is more accessible and the σ_- beam pushes the atom back to the center.

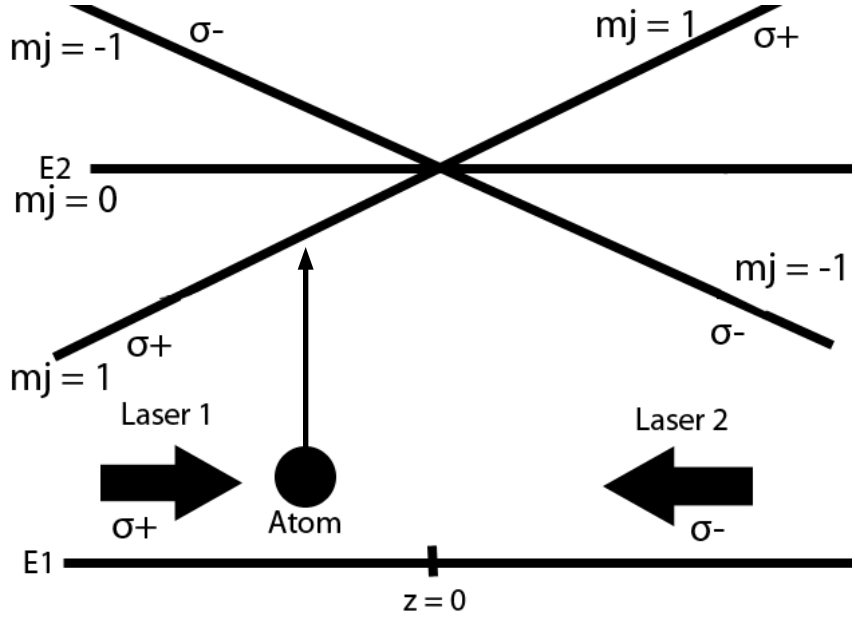

Figure 2.5: Collecting atoms with a magneto-optical trap, adapted from [6]

In our experiment the magnetic field is setup such that it is zero in the center of the chamber and increases in strength linearly in all directions a in figure 2.6. Such a field is

created between two magnets whose poles face each other, and is called a quadrupole magnetic field.

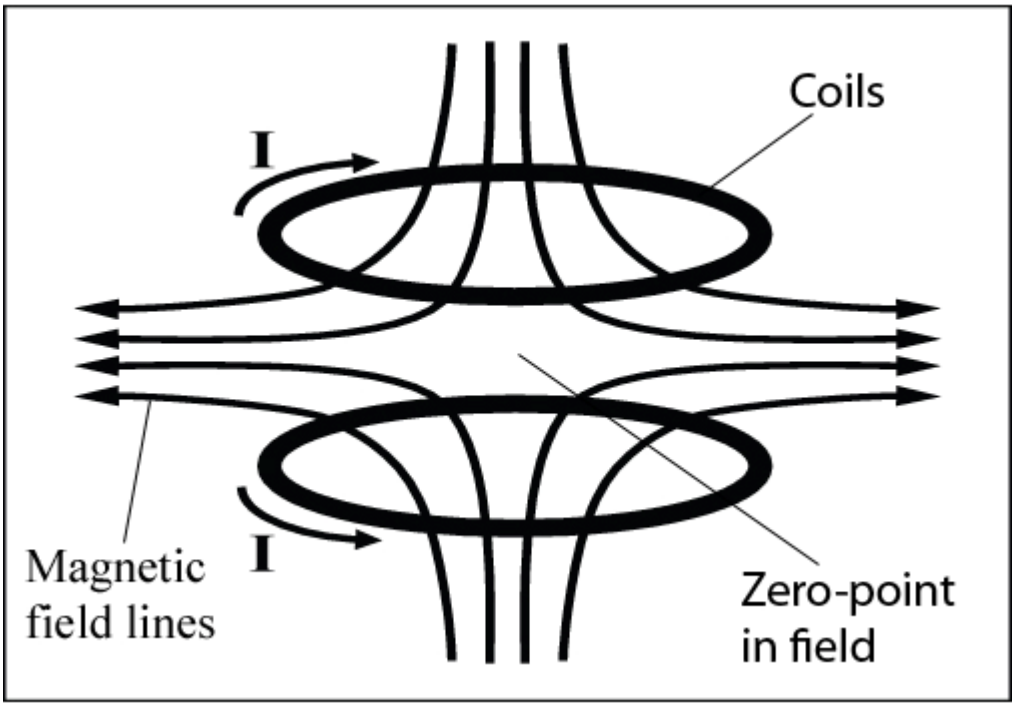

Figure 2.6: Quadrupole magnetic field [6]

We shine in three pairs of opposed σ_+ and σ_- beams from each spatial dimension such that an atom anywhere outside the zero field will be pushed back by a polarized beam.

By shining in lasers from all sides, any moving rubidium is traveling towards a red detuned laser and thus fluorescing and losing kinetic energy due to Doppler cooling. We have now created a magneto-optical trap that cools atoms through Doppler cooling and then collects the atoms in the zero point field of a quadrupole magnetic field. Again, rubidium has a much more complicated atomic structure but the principles are the same.

3 Experiment: Creation of a Magneto-Optical Trap

3.1 Cleaning the Chamber

Most new parts were already “clean” from the factory but we needed a higher degree of cleanliness, any residual oil from manufacturing would be detrimental to our experiment. Every surface was cleaned as thoroughly as possible before assembling the vacuum chamber, see figure 3.1. Parts going inside the vacuum were first cleaned with an ultra sonic cleaner using Contrex AP Powdered Labware Detergent, for one hour to remove any impurities from the surface. After, it is rinsed with distilled water to remove most of the ultra sonic cleaner soap. This is followed by two subsequent methanol rinses to ensure the surface is completely clean. It was common practice to wrap parts in aluminum foil for transport and storage because it can completely protect against dust, and doesn't produce any lint. Methanol is our most common cleaner of choice because it is a strong cleaning solution that evaporates leaving no residue.

Figure 3.1: Grant Rayner assembling the vacuum chamber, after thoroughly cleaning all parts.

The stainless steel metal components of the vacuum chamber were baked to about 400°C in a box furnace for several hours prior to installation. Some parts such as the glass section of the vacuum chamber could not fit in the box furnace and therefore were not baked out. Parts were heated to bake off any residual "dirt" particles, and the heating forms an oxide layer on the metal sealing in molecules trapped within the metal. The inside of the

chamber must be as clean as possible because at ultra low pressures many substances outgas, increasing the pressure in the chamber.

Outgassing is a general term used to describe the releasing of molecules while under vacuum. It can happen from the great increase in the vapor pressure of substances normally liquids or solids at atmospheric pressure so over time they continuously release molecules. Metals also outgas by releasing molecules trapped within the atomic structure.

Components on the exterior of the vacuum chamber were typically cleaned solely with methanol. Every part used on the vacuum chamber and support system had to be thoroughly cleaned. All bolts were cleaned in the ultra sonic cleaner to ensure they had no residual grease from manufacturing or any other impurities what could vaporize during the bake out. Even if a part appeared spotless just a little grease residue left somewhere would smoke during the bake out and potentially stain the glass chamber rendering it useless for our experiments.

3.2 Pumping station

3.2.1 Roughing pump

The pumping station was used to pump out the vacuum chamber during the bake out because we expected a large volume of particles to come off during the bake out. We used two pumps in series, each with a specific role. The roughing pump, see figure 3.2, was

a more traditional pump in its action, and was designed to move a larger volume of air. This pump works in an oil bath, which could potentially get sucked back into the chamber. We replaced the original pump with one equipped with an 'anti-suckback' valve designed to stop the back flow of oil into the chamber. This was very important for us as we would have to meticulously clean the chamber if any oil got in. When the pressure reached the 10^{-3} Torr range the roughing pump was unable to pump any lower.

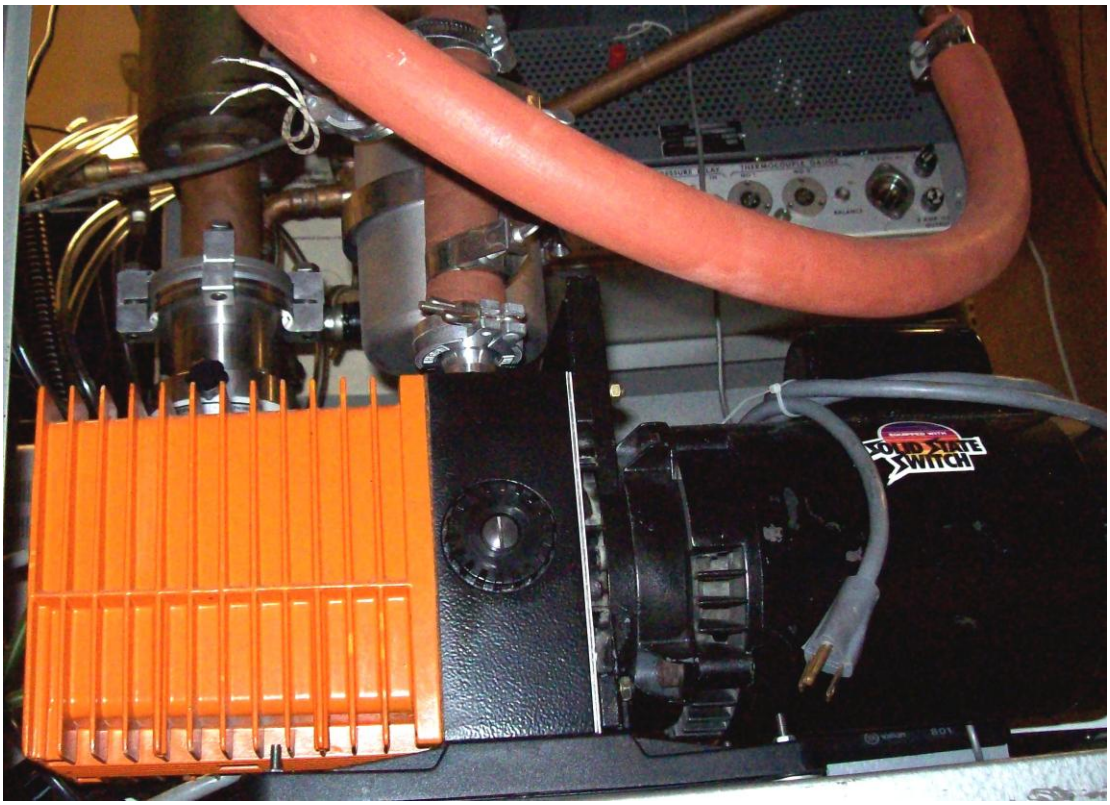

Figure 3.2: Roughing pump, the orange heat sink keeps the oil bath cool.

3.2.2 Turbo pump

To be sure all impurities are pumped from the chamber we need much lower pressures. If any impurity were left it would slowly out-gas over time and raise the pressure we could ultimately reach. A turbo-molecular pump backed by the roughing pump let us reach 10^{-6} Torr pressures.

The turbo pump, see figure 3.3, works by spinning a series of angled blades at 90,000 rpm [7] knocking molecules down towards the roughing pump. The pressures the turbo pump operates at are so low air molecules will not be pulled out merely through airflow; they need to be physically pushed out. It can only be turned on around 10^{-2} Torr pressures because its blades spin so fast the air resistance at higher pressures would damage them. Whenever the turbo pump is on for an hour or more it needs to be cooled with a liquid chiller to keep it from over heating. This is especially crucial during the bake out when the pumps are run for ten days.

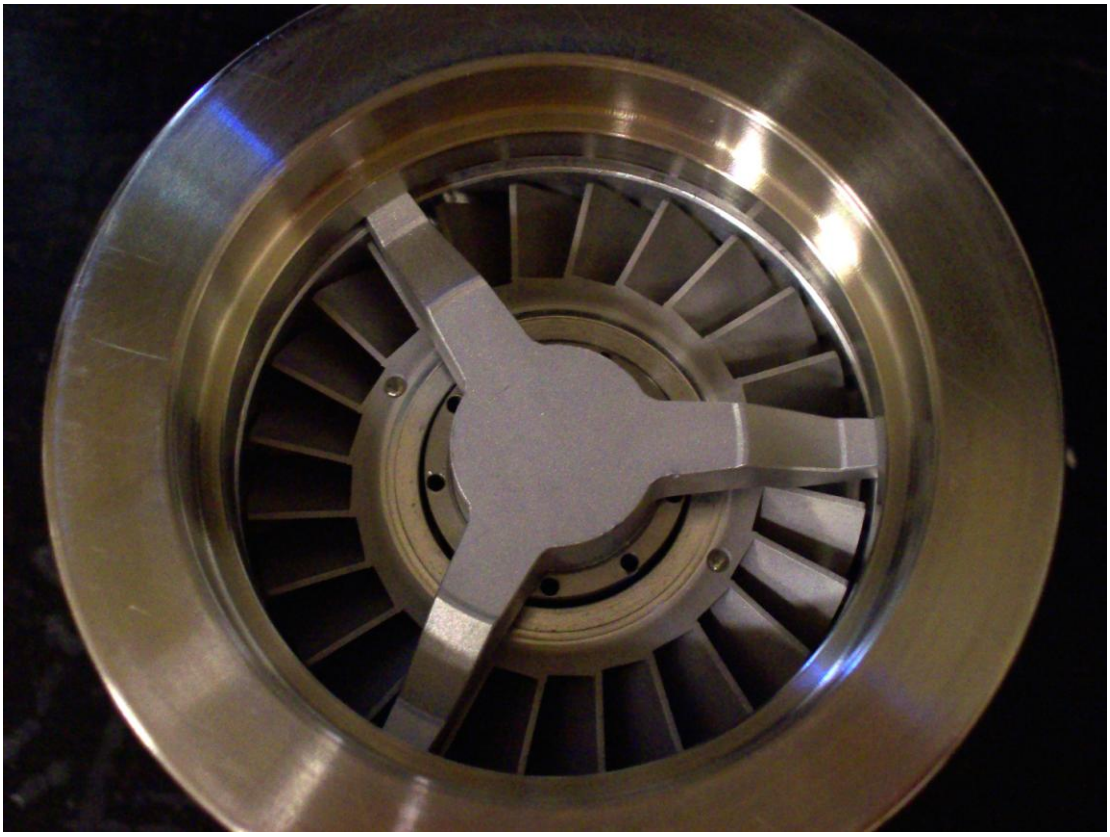

Figure 3.3: Turbo pump inlet showing the angled blades.

3.2.3 Gate Valve

The gate valve, see figure 3.4, allows us to quickly isolate the vacuum chamber from the pumping station. If the roughing pump failed pressure would build behind the turbo pump and eventually leak into the chamber possibly bringing in contaminants. If the turbo pump failed, air would rush in and the high speed of the gate valve would be needed to limit the air and contaminants sucked into the vacuum chamber. If the glass on the vacuum chamber broke the gate valve would protect the pumps from debris.

The valve has a 'gate' that comes down and seals against a wall. It is powered by 80 psi of air pressure (we used nitrogen). The pressure is controlled by an electro-pneumatic solenoid, see figure 3.4. The solenoid is basically a valve controlled by an electromagnet. When there is a current through the electromagnet the gate is open, but when power is cut the gate valve closes. Because the gate valve works on air pressure it can still isolate the chamber in case of a power outage. The solenoid controlling the gate is very sensitive, so we need to take it up to 80 psi in small 5-psi increments while opening and closing the gate valve to relieve the pressure difference. The valve can be kept at operating pressure to ensure readiness, which we did during the bake out.

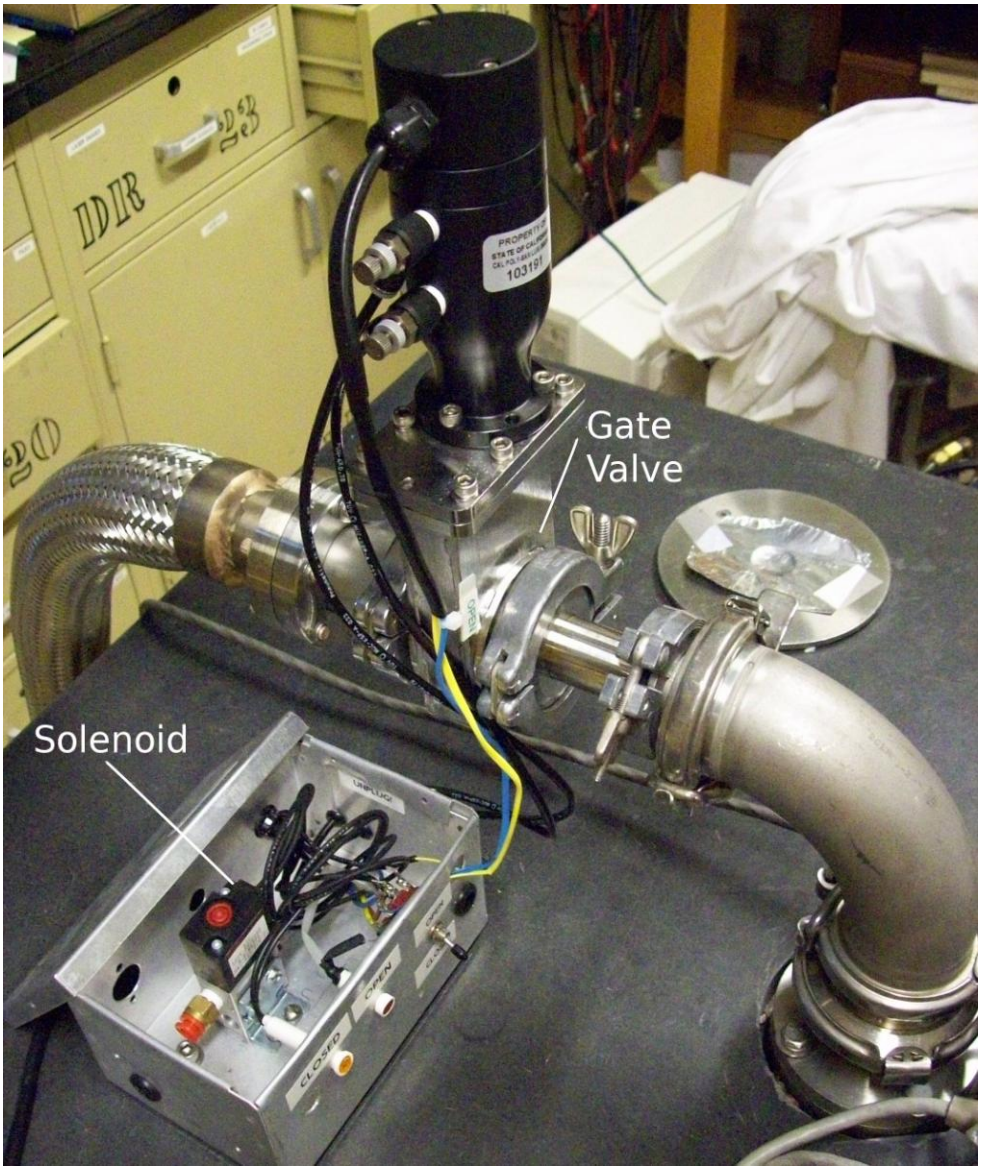

Figure 3.4: Air actuated gate valve and control box with electro-pneumatic solenoid.

Initially we used a soft air hose to connect the nitrogen compressed air supply to the valve, but over time it weakened and expanded. The section of hose just before the solenoid had swollen to three times its normal diameter, as seen in figure 3.5, before we noticed.

After switching to a harder material hose we haven't had any further problems with the air hose.

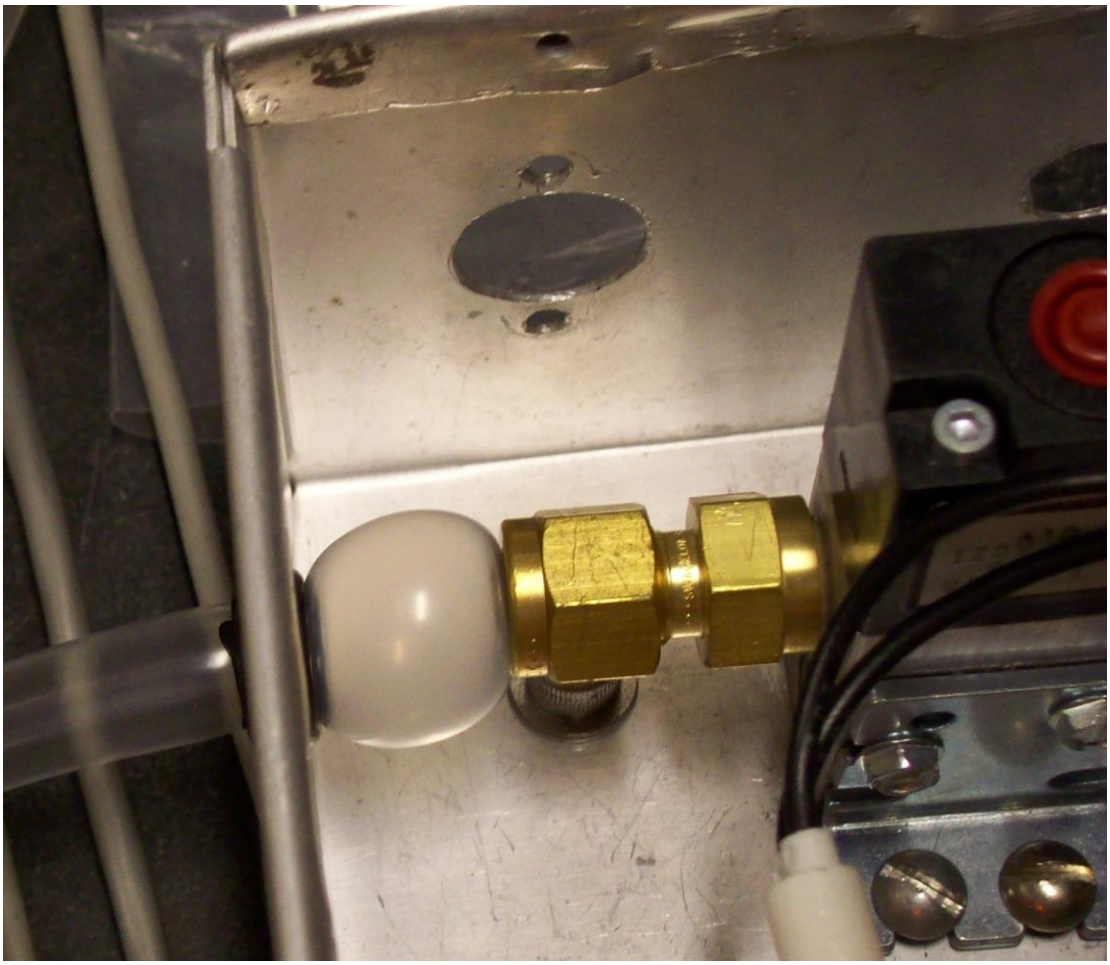

Figure 3.5: Soft solenoid air hose swollen from high pressure.

3.2.4 The Blow Up

During a test, we were pumping down the vacuum chamber prior to the bake out, and nearing the terminal pressure of the turbo pump. Suddenly we heard a very loud grinding noise. Everybody immediately knew it was the turbo pump and jumped into action. Within seconds we closed the gate valve and turned off the turbo pump controller. The turbo pump had destroyed itself and we needed a new one.

We ordered a replacement turbo pump of the same model (Pfeiffer Balzers TPH 060) from Duniway Stockroom, so we could use our same turbo pump controller (Pfeiffer Balzers TCP 121). Using the same model pump also ensures it will bolt up to the plumbing on the pumping station. Duniway cleaned our refurbished pump very thoroughly before sending it to make sure we were not going to introduce new contaminants to the vacuum.

3.2.5 Ion gauge

The Ion gauge works like a vacuum tube. Stray molecules passing through are ionized by the filament and drawn to the cathode. This creates a current that is then read by the control box. Over time the glass actually decomposes and deposits on the filament. This can be expelled by raising the voltage of the filament until the contaminants are vaporized off. This is called degassing. When degassing we change the ion gauge control to 'Degas' to allow us to directly control the voltage to the filament and the glass particles settle on the filament. We slowly increase the voltage until a blue glow is seen around the cathode. The

blue glow is from the ionized glass particles fluorescing. We would only see the blue glow the first time degassing because that is when there are the most contaminants. At other times there wouldn't be enough for us to see any fluorescence.

3.3 Preparation for the Bake Out

3.3.1 Test Bake Out

We ran a test bake out to test multiple parts of the bake out working in conjunction. A thermocouple was placed on the chamber to monitor the temperature over time. We wrapped an unused section of glass and metal just as we would for the bake out. A layer of aluminum foil was first laid down on the glass section before the entire thing was wrapped with a heater tape. After the heater tape the chamber was wrapped many times with new fiberglass insulation.

The test let us know the temperature response to expect from changes made to the heater's variac while heating the chamber. We could see, on a specifically made test bake out Labview program, the temperature of the chamber over time. While heating the test bake out for the first time we noticed a peculiar smell and some smoke coming from the wrapped up chamber piece. We immediately stopped heating, and safely cooled the piece back to room temperature. Upon investigating we found the fiberglass itself had started to change color and was the source of the strange smell. The fiberglass was rated to a much

higher temperature than we had reached in the initial test bake out. The smell and smoke we determined were from impurities in the fiberglass that would bake off the first time it was heated. We couldn't have these impurities bake off of the insulation and stain the glass of the vacuum chamber. Some insulation was therefore baked in a box furnace, and we ran the test bake out again. This time everything worked flawlessly and we baked out the test piece for 5 days.

The rest of the fiberglass was then baked out to assure no impurities would bake onto our chamber. The fiberglass insulation was wrapped in aluminum foil to contain anything that may bake off, and then heated to 400°C for an hour and a half before flipping the insulation and baking for another hour and a half. After leaving the furnace the insulation had a golden tint compared to the ghostly white new insulation.

If we hadn't run the test bake out we wouldn't have known about the insulation reacting when heated and could have stained the glass on the chamber. The test bake out also gave us the opportunity to test the Labview code for the bake out over an extended period of time in practice.

3.3.2 Mounting the Chamber

For the bake out we wanted the vacuum chamber to be mounted as high as possible on the posts for easy access but more importantly to isolate it thermally from the optics

bench. We were worried heat from the vacuum chamber would be transferred through the posts into the table. This would make the entire bench act as a heat sink lowering the maximum bake out temperature as well as making the room warm. The required height of each post was calculated, making sure to leave enough room to mount the ceramic insulating blocks later.

Closer to the bake out, the mounts for the chamber were placed on insulating ceramic blocks to isolate them thermally. Metal screws still connected the mounts to the platforms and posts. The screws could transfer heat to the platform, which would then heat the post and the table. The screws were covered in fiberglass sleeves and ceramic washers were used where the screw would contact the support platform to isolate them thermally. The stands needed to be milled to clear the washers because the ceramic was very brittle and needed to be on a flat surface. The amount milled was fairly small and we determined wouldn't affect the structural integrity to an extent we would need to worry about. The setup is shown in figure 3.6

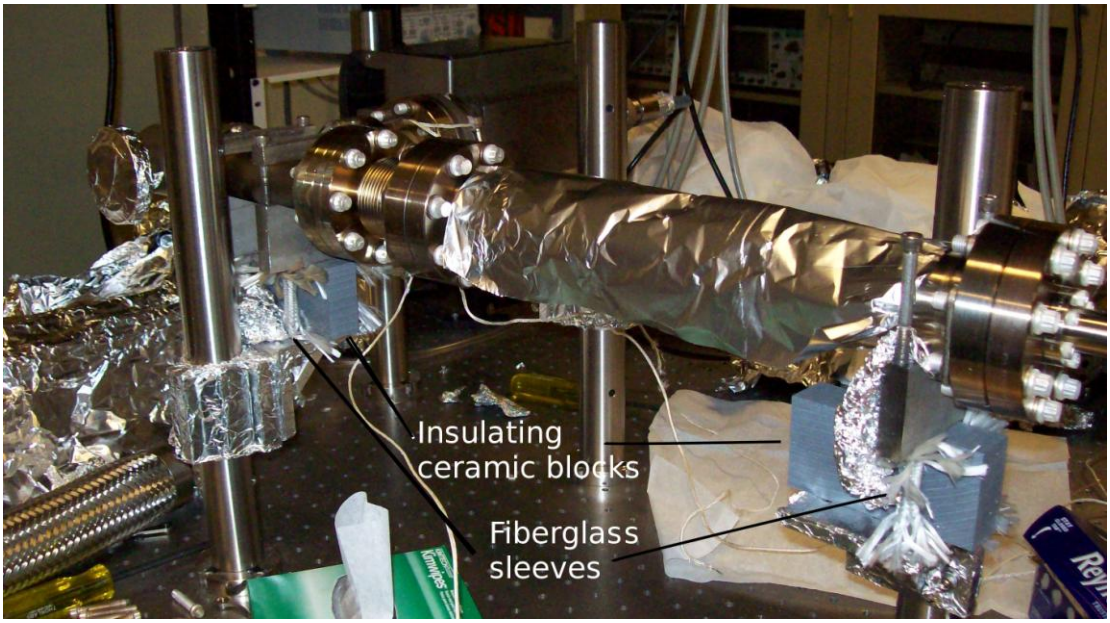

Figure 3.6: Vacuum chamber mounted on ceramic blocks.

During the bake out we were worried about the bolts bonding to the chamber mounts and seizing. The bolts holding the vacuum chamber together are silver plated so they would not seize. Not all bolts were available with silver plating so these needed to be coated in an anti-seize. We needed an anti-seize that could be heated to 300° C without releasing anything that could bake onto the glass of the chamber. We ended up using a graphite powder with acceptable purity. The powder was mixed with methanol and then applied to the screws. The methanol would harmlessly evaporate leaving the threads covered in graphite. After the bake out all bolts unscrewed without a problem.

3.4 Bake Out

3.4.1 Theory Behind the Bake Out

Even though the turbo pump could reach pressures in the 10^{-6} Torr range we need pressures less than 10^{-8} Torr or ideally 10^{-10} Torr for our experiments. To achieve lower pressures we needed to heat the chamber. This had two effects, the pressure inside would rise with the temperature making it easier to pump out more molecules, and molecules would outgas from the chamber walls much more quickly. The metal the chamber is made out of stainless steel, which acts as a sort of sponge and actually has molecules impregnated inside. Over time these will slowly leak out of the metal (outgas) and keep the chamber from reaching the lowest possible pressure. This heating process is also called 'baking out' the vacuum chamber.

3.4.2 Experimental Risks

Uneven heating can cause regions of the chamber to expand at different rates. This is particularly important at the glass-metal junctions. We had separate heater tapes for the glass and metal regions of the chamber, and monitored the temperature at six spots using thermocouples as we heated the chamber see figure 3.7.

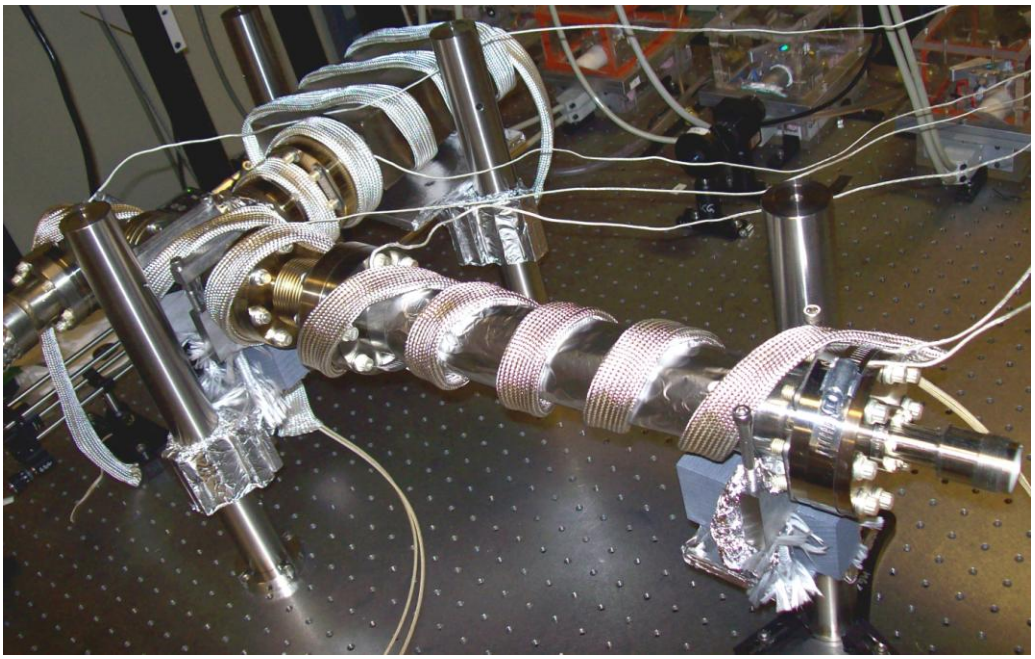

Figure 3.7: Chamber wrapped with heater tapes. The wires leaving the chamber are from the thermocouples.

3.4.3 Heating Up

When heating up the chamber we wanted to take our time so a temperature difference wouldn't develop between the metal and the glass. Every thirty minutes we would check the temperature of all six thermocouples on the chamber. From there we would decide how much to change the voltages of the heater tapes. Because we were raising the temperature over the course of many hours it was easy to make the small adjustments necessary. We ended up taking twenty-four hours to heat up the chamber to a glass temperature of 300° C and a metal temperature of 340° C. We watched the chamber twenty-four hours a day when it was heating. Once we got close to our desired temperature

we slowed down the temperature increase so as not to overshoot our bake out temperature and potentially damage a component. Figure 3.8 shows the chamber during the bake out.

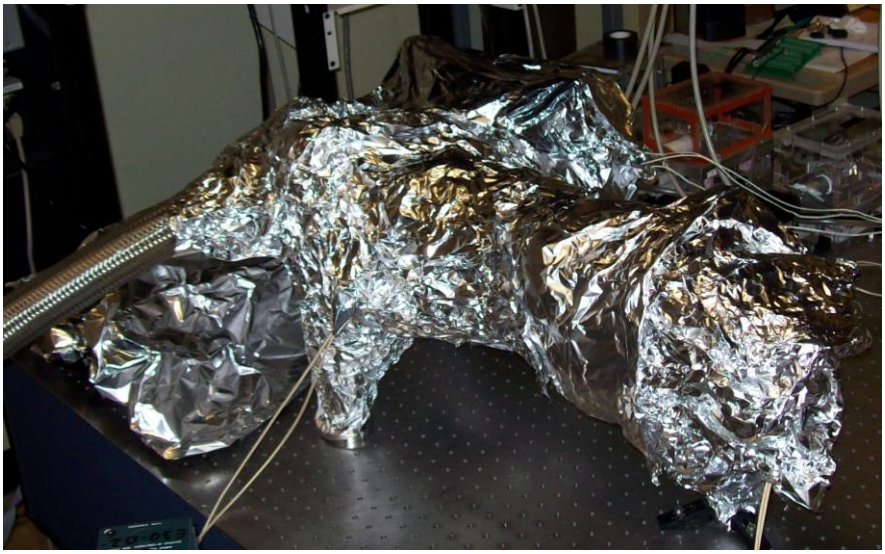

Figure 3.8: Chamber baking out, wrapped with heater tapes, many layers of fiberglass and a final layer of aluminum foil.

3.4.4 Baking out

Once the chamber was up to temperature we watched it as much as possible, but mainly relied on the monitoring program described in section 3.5.1, to catch any problems. Every two hours during the day someone would check on the chamber, but otherwise it was just a matter of waiting for a thorough bake out. We baked the chamber at full temperature for seven days straight before starting to cool it back down.

3.4.5 Cooling down

Cooling down the chamber was pretty straight forward, as we simply had to reverse the process of heating it up. Again we had to watch the chamber continuously while it was cooling off. We were somewhat familiar with the heater tape adjustments necessary for the temperature change we wanted. This let us control the temperature a little more easily and cool down the chamber more efficiently. Because we didn't continue turning down the tapes over night, it took two days to fully cool the chamber. Once the glass was within 25° C of room temperature we had fully turned off the heaters. Within another hour we started unwrapping the chamber to facilitate its further cooling.

3.4.6 Sealing the Chamber and Starting the Ion Pump

With the chamber fully unwrapped and at room temperature we turned on the ion pump. When the ion pump is first turned on some molecules are knocked loose. We watched the pressure on the ion gauge increase from the particles knocked loose. When the pressure reached the base pressure again we closed the gate valve. The pressure inside could be measured from the ion pump as well. Once we ensured the ion pump was working, we sealed off the vacuum chamber with the solid metal valve see figure 3.9.

We knew about how many turns to close the valve so knew where to expect the valve to start to close. We torqued the valve to 14 ft/lb to create a new seal. At this point the chamber is operating completely independent of the pumping station.

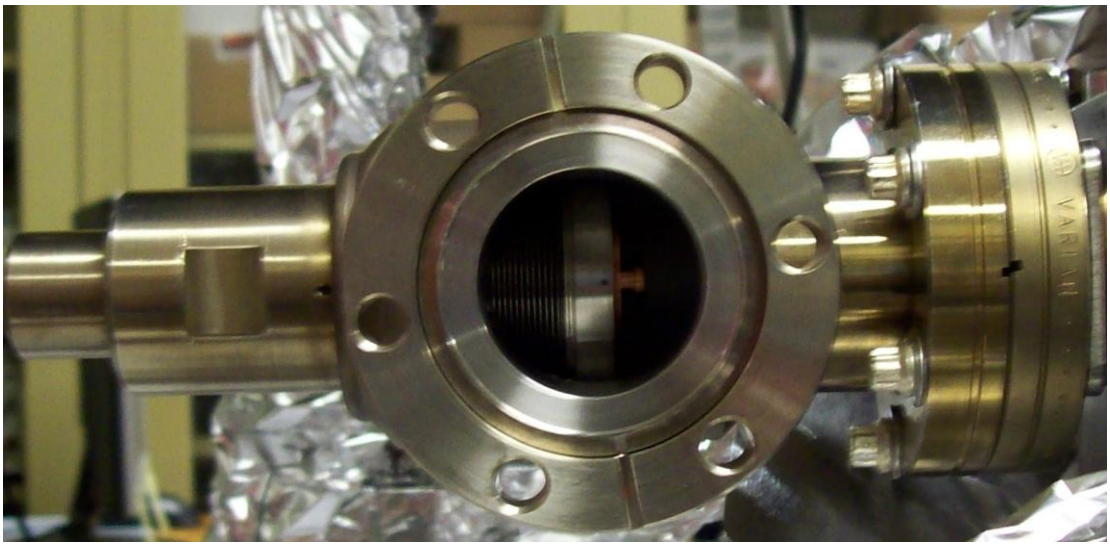

Figure 3.9: Solid metal valve half closed

3.5 Labview

3.5.1 Bake Out Program

Because we could not watch over the chamber at all times we had a program monitor the system as well. The Labview program controlled a relay box it could trip by sending a signal out of the Computer's DAQ (**D**ata **Ac****q**uisition) board. The relay box cuts power to equipment plugged in, so we plugged in the gate valve and turbo pump. When power is cut to the gate valve the solenoid will lose power and the valve will seal off the chamber. Upon losing power the turbo pump controller slows down the turbo pump hopefully saving it in case of a pressure spike.

The program worked by reading a voltage from the ion gauge controller (Granville-Phillips Series 271) through the computer's DAQ board. The ion gauge controller sends out a signal 0-120mV corresponding to 0-12 *10^n where n is the scale the ion gauge is set to. Labview reads the output voltage and multiplies by a user controlled scale to display the pressure. A thermocouple is attached to a high precision multimeter (Agilent 34401A) to measure the voltage created by the thermocouple. The voltage created by a thermocouple is directly related to the temperature using the formula below:

$$T(°C) = 24390(°C/\mathrm{V}) * V(V) + 25°C$$

Where T is the temperature in Celsius, V is the thermocouple voltage in volts. The multimeter is connected to the computer through a GPIB interface. To get readings from the multimeter the computer must send a specific code to the multimeter so it will send back the voltage.

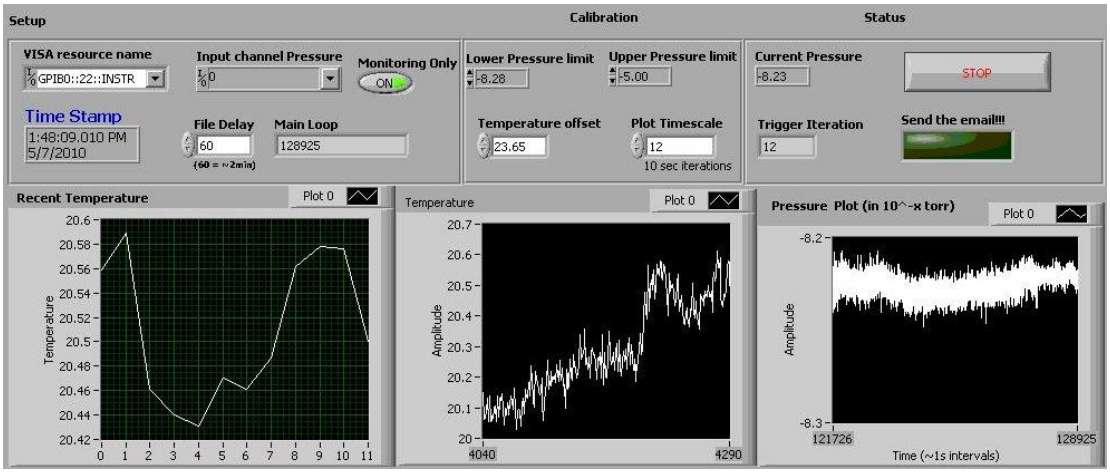

Figure 4.1: Labview bake out monitoring program front panel screen shot from after the bake out.

The Labview bake out program would watch both the pressure from the ion gauge, and the temperature from a thermocouple. Figure 4.1 shows the front panel of the bake out program monitoring the chamber far after the bake out. It saved the data with a time stamp as it was collected, and displayed plots of the recent temperature and pressure. The temperature and pressure of the system was monitored and if the pressure left an acceptable range the program sent a signal to the relay box which controlled the power to the gate valve and turbo pump.

We actually had the chance to test the safety system when a backup power supply failed for the roughing pump during the bake out. The pump stopped, and the anti-suckback valve kept the oil from contaminating the chamber. The program saw a pressure spike and sealed off the chamber. In the end no damage was done, and we were only set back a few hours of pumping. This could have been a devastating accident where we were left with oil coated chamber and a ruined turbo pump, but all of our safety precautions worked as needed.

3.5.2 Laser Program

We need lasers with very stable frequency so the temperature of the laser diode must be closely controlled. Our laser controllers (ThorLabs ITC 502) were not keeping our lasers stable with the built in controls. Using Labview we could record and plot the laser temperature to test different feedback settings to find out why we were having poor laser stability.

The Labview program would take readings from the laser controller as well as control the important functions such as the laser diode current and the laser temperature feedback. The controller interacted with the program through the GPIB interface. The program is designed to send code to the laser to perform various actions such as turning on the laser diode. We can monitor the internal temperature as well as set a desired

temperature. The temperature is calculated from the resistance of a thermistor using the equation below:

$$T = \frac{1162785(°\mathrm{C}\cdot)}{298.15 * \ln\left(R(\Omega)/10000(\Omega)\right) + 3900} + 3626.85(°\mathrm{C})$$

Where T is the temperature in °C and R is the resistance in ohms. This is immensely helpful when tuning the lasers, and investigating laser stability. Now we can change the desired temperature and watch how the thermoelectric coolers change the actual temperature on a plot. All of the data can be saved as well, so we can directly compare different feedback settings.

We found the feedback settings had little effect on the laser temperature stability, and in fact the lasers were more stable with the controls off! This let us thoroughly investigate feedback settings letting us gain insight as to why our controllers and lasers were working improperly. We now have the resources to fully test the feedback settings, so we can determine the source of our laser instability.

4 Future Work

We are reaching the final steps to building a magneto-optical trap. Over the next few months the magnets and optics for the MOT should be setup. Depending on laser stability we could be trapping atoms by the end of Summer 2010. After trapping atoms in the MOT we will transfer them to a pure optical trap. If we can successfully transfer atoms to the optical trap we would be the first to trap atoms in the near diffraction pattern of a circular aperture. From there we will study the optical trap for uses in quantum computers.

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