Outgassing of Materials with respect to XENON

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Abstract

XENON is an international collaboration with goal of directly detecting dark matter, particularly WIMPs. The latest detector constructed by XENON is XENON1T. Detecting WIMPs is a very sensitive procedure and requires a high level of accuracy on the detector. Outgassing of materials inside the detector can cause whole detection events to disappear and is a very important phenomenon to account for. In my time at Nevis Laboratories this summer, I measured the outgassing rates from materials in the XENON1T detector.

1 Introduction

Since Fritz Zwicky’s coining of the phrase in the early 1930s, dark matter has been an astronomical mystery [Zwicky, 1933]. Dark Matter, as we currently understand it, is massive, interacts in the weak force scale and does not interact with light; the latter is one of dark matter’s more elusive properties. Despite the obscurity, astrophysicists have gone undaunted searching for the true nature of dark matter. XENON1T is one of a series of searches to illuminate the true nature of dark matter; it uses a time projection chamber (TPC) filled with liquid and gaseous xenon and is searching for WIMPs, one possible candidate for dark matter. Cross sections of the WIMP, or Weakly Interacting Massive Particle, are in the $10^{-26} \text{cm}^3\text{s}^{-1}$ range [Jungman, 1996]; therefore, very accurate and large detectors must be created to successfully detect these elusive particles. A possible interference to accuracy in many detectors is outgassing of the materials being used. Outgassing is when gas embedded or on the surface of a material is released. From false positives to irreversible contamination, outgassing, both in quantity and composition, can pose huge problems for a system that requires high vacuum and accuracy. The outgassing of detector materials was the focus of my research at Nevis Laboratories this summer. I studied the outgassing of anodized aluminum rings, Teflon rectangular prisms, and the outgassing system itself under vacuum for about a week and recorded the total, partial and specific outgassing rates.
2 What is Dark Matter?

The “universe as we experience it” is much different from the “universe as we know it”. According to the latest measurements by NASA’s Planck Space Mission, dark matter makes up 26.8% of the universe’s mass-energy density while the normal matter we are familiar with makes up a small 4.9% of the universal mass-energy density (dark energy makes up the remaining 68.3% rest of the matter-energy density of the universe) [Nasa, 2013]. This begs the question: how do we even know that dark matter exists?

2.1 Galactic Rotation Curves

Vera Rubin in the 1970s found something peculiar about the relation between the orbital velocity of a star and its distance from the center of a spiral galaxy. Rubin found, contrary to expectation, that stars at large distances all have relatively the same velocity; it is expected in orbiting systems that the larger the radius of the orbit is relative to the central body, the slower the radial velocity.

![Figure 1: A graphic representation of the galactic rotation curve discrepancy. Created by PhillHibbs.](image)

Notice in Figure 1 prediction and observation are exact at low radii, but the two deviate incredibly at large radii. This suggested that there is an invisible entity accelerating stars at the edges of spiral galaxies. Rubin concluded that the only way this anomaly could occur is if there was a large amount of invisible mass accelerating these outer stars; we call the supposed massive matter dark matter [Rubin, 1970].

2.2 Galaxy Cluster Gravitational Lensing

Fortunately, dark matter does interact in a few ways with normal matter; namely gravity. According to general relativity, gravity causes the bending of space-time with the severity of the bending being proportional to the mass exerting the bend. Light travels along space-time on straight paths; if space-time is bent then light’s path will bend along with it. This phenomenon we call gravitational
lensing. It is best shown in observations of galaxy clusters; however, in galaxy clusters such as Abell 1689, shown in Figure 2, the level of distortion observed does not match the amount of normal matter that is seen; therefore, there must be some invisible mass contributing to the bend, which is believed to be dark matter [Taylor, 1998].

Figure 2: Strong gravitational lensing, as seen by the Hubble Space Telescope, of Abell 1689 caused by normal matter and dark matter from hubblesite.org.

2.3 Cosmological Constant Problem

Theory also finds issue with the cosmological distribution of mass and energy. It is best shown with the use of general relativity. One equation of General Relativity can be written as the following:

\[ G_{\mu \nu} = 8\pi G T_{\mu \nu} \]

This equation describes the curvature of space–time \( (G_{\mu \nu}) \) where \( G \) is Newton’s Universal Gravitational Constant and \( T_{\mu \nu} \) is a tensor describing the matter in a system, one system relevant to this discussion being the universe. One can think of the two tensors, \( G_{\mu \nu} \) and \( T_{\mu \nu} \), as describing the nature of gravity and the nature of matter in the universe, respectively. It has been known for some time that the universe is expanding. It is assumed from Quantum Field Theory (QFT) that the vacuum of space-time, in the Planck length, is volatile and constantly creating and destroying particles, thus leaving some residual energy. At first, this energy was used to explain the expanding universe. When the ‘vacuum energy’ according to QFT \( (\Lambda_{QFT}) \) is compared to the "vacuum energy" that is associated with observation \( (\Lambda_{Obs}) \), QFT comes out short. In fact, it was off by a factor of about \( 10^{120} \). This is known as the cosmological constant problem. There are two ways of reconciling this problem and it can be well shown in the above equation: either fix \( G_{\mu \nu} \), which entails creating a whole new theory of how matter interacts with space–time, (ie. gravity), or fix \( T_{\mu \nu} \).
which entails finding matter and energy in the universe that could help explain this $10^{120}$ discrepancy (ie. dark matter and dark energy) [Rosen, 2016] [Rugh, 2001].

2.4 WIMPs

Weakly interacting massive particles are the most likely contender for dark matter. These particles are “weakly interacting” because it is theorized that they interact on the order of the weak force scale. WIMPs, particularly because of their interaction scale and mass, fit very well to the part of dark matter. WIMPs are thought to be supersymmetric (SUSY), beyond the standard model (SM) particles at the $100 \text{GeV}$ mass scale. Despite the lack of SUSY particles found in the last run of the ATLAS experiment, physicists still have confidence in the validity of the WIMP. In fact the ATLAS experiment, as well as other dark matter direct detection experiments, have placed restrictions on the mass of the WIMP making searches for it more focused [Goetzke, 2015].

In short, we do not know what dark matter is; all we know is what it does and what it may be. One such culprit is known as the WIMP and it is what the XENON collaboration is searching for.

3 XENON1T

XENON1T is the latest detection device of the XENON collaboration. Located in the Italian Gran Sasso National Laboratory, XENON1T consists of a cylindrical time projection chamber (TPC) that is filled with mostly liquid Xenon (LXe) and partially gaseous Xenon (GXe) with photomultiplier tubes (PMTs) on the top and bottom of the chamber. Within the chamber there are a set of four grids; from top to bottom there is an anode grid, gate grid, cathode grid, and bottom grid. High voltage is applied to the anode and cathode grid creating a uniform electric field, the gate is set to ground. The gate grid is located just around the change between LXe and GXe. In principle, a WIMP would travel into the detector and interact with the LXe atom, releasing electrons from the atom, the electric field and system is set to prevent recombination. This causes scintillation light which is detected by the PMTs and is marked as S1. The electrons are now accelerated by the electric field upwards towards the GXe. With the stronger electric field and change in phase of the Xenon, there comes about a second, larger scintillation light that is detected by the PMTs, which is referred to as S2. Using the kinematic equation $z = v_e - dt$, where $dt$ is the time between S1 and S2, $z$ is the location of the event in the z-axis and $v_e$ is the velocity of the electrons, the depth of the event can be calculated. The x and y position can be found by the number of photons detected by each PMT. Whether this was an interaction with the electron cloud or with the nucleus is heavily determined by the magnitude of the ratio S2/S1, and from these parameters the energy of the event can be calculated as well [Goetzke, 2015].
4 Outgassing

Many steps must be taken in order to ensure that an event detected by the PMTs is indeed caused by a WIMP-Xenon interaction. Assuming certain parameters at reasonable values, the scattering rate per unit mass is about 0.019 \( \text{events/kg/year} \) and the total annihilation cross section is \( 2 \times 10^{-39} \text{ cm}^2 \) (this is also the reason for the large size of the XENON experiment) [Goetzke, 2015]. Therefore there shouldn’t be too many events occurring in the TPC if indeed the experiment is sufficiently shielded from cosmic rays and other contaminants. In fact, we expect 2 events as a part of background alone. Anything greater than 2 events would be a possible WIMP-Xenon interaction. With this in mind, we must make sure may obstruct a possible third event. One way that this may be jeopardized is the outgassing from the detector materials. The materials I measured, aluminum, teflon and stainless steel walls that contribute to background outgassing, are all incorporated in the detector.

Outgassing, measured in \( \text{Torr} \ast \text{L/s} \) and often referred to as \( Q \), is the measure of volume of gas passing through a plane per unit time; it is often compared to power which is measured in joules per second, or watts. Essentially, all materials have a certain degree of porosity and have the possibility of absorbing and releasing particles, mostly in the form of gas or vapor [O’Hanlon, 1980]. Were this to happen inside the detector it would be good to know what is coming out, how much of it, and how to reduce the outgassing in general. Total outgassing rate is a property that is specific to each measurement and is therefore not useful
outside of the specific conditions. For a more universal measurement we take what is called the specific outgassing rate, which is, just the total outgassing rate divided by the surface area of the material. This gives the outgassing per square meter, which is more useful as a predictor of what comes out of a material of any size.

4.1 Sources of Outgassing

![Diagram of the sources of outgassing from O’Hanlon [1980].](image)

There are quite a few ways that outgassing from materials can occur but the main worries of XENON are desorption, leaks, diffusion and permeation. Desorption is when a previously adsorbed gas is released from the surface as a result of being knocked out by other gas or by change in pressure. Leaks occur when there are scratches on the surface of a material or if there is a penetration in a chamber, both allowing gas to either be embedded in the material or passed through the material. Diffusion is when embedded gas makes it way through a material and then is released from the surface, and permeation is when outside gas embeds itself in to a material and then makes it way through it, releasing via diffusion. All of these forms of outgassing can come from either the material being observed or from the outgassing measuring chamber itself.

4.2 Outgassing System Set Up and Pre-Measurement Procedures

When a material is proposed to go in to XENON1T or into any of XENON’s other equipment, the material must be put in to the outgassing system to observe the nature of it’s outgassing. The system consists of a main chamber (10-in CF nipple with 2.75-in CF T), access port (10-in CF VAT gate valve), bypass pumping port (2.75-in CF) with all–metal angle valve (2.75-in CF), orifice (5mm diameter, 17.8mm long), HiPace 300 turbo pump, MVP 070-3 diaphragm pump,
Figure 5: Diagram (left) and photo (right) of the outgassing system from XENON Columbia Wiki.

PKR 251 full-range pressure gauge, and Extorr 200M Residual Gas Analyzer (RGA). Within the main chamber there is a cooling plate that is made up of two 12-in x 5.46-in x 0.4-in aluminum plates and 6-ft of .25-in diameter copper tubing that is used to study the affects of temperature of outgassing rates by pumping liquid nitrogen through the copper tubing.

4.3 Method of Measurement

The method used to measure the outgassing within the outgassing chamber is the throughput method. The basic idea behind the method is the following: pump the outgassing chamber via an orifice of known conductance, measure the equilibrium pressures on either side of the orifice, plug the pressure and conductance in to the equation $Q = C\Delta P$ where $C$ (measured in $L/s$) is the conductance and $\Delta P$ (measured in Torr) is the pressure difference across the orifice. Fortunately, for the outgassing system being discussed, $\Delta P$ reduces to just $P$; this is because the pressure on the chamber side of the orifice is much greater than the other side of the orifice (about an order of magnitude, actually). As long as the outgassing of the chamber is relatively negligible and a baseline gas composition is known the outgassing (or throughput) of the sample can be easily determined [Yang, 1995].

4.3.1 Gas Flow Regimes and Conductance

Gas flow regimes are determined by what kind of gas and how much of it is flowing in a pipe. The nature of a gas is determined by Knudsen’s Number
(determined by $Kn = \lambda/d$ where $Kn$ is Knudsen’s Number, $\lambda$ is the mean free path, and $d$ is usually the diameter) and its relative flow determined by Reynold’s number (determined by $R = U\rho d/\eta$ where $R$ is Reynold’s Number, $U$ is the stream velocity, $\rho$ is the mass density, $d$ is the diameter of the pipe and $\eta$ is the viscosity). In the case of our system, the gas flow is in the molecular flow region, meaning that the mean free path $\lambda$ is so long compared to the size of the pipe that the flow is determined by gas-wall collisions without gas-gas collisions or viscosity making Reynold’s number useless [O’Hanlon, 1980].

Conductance for molecular flow is defined as the following:

$$C = \frac{Q}{P_1 - P_2} = a \frac{v}{4} A$$

where $C$ is the conductance measured in $L/s$, $a$ is the transmission possibility, a dimensionless scalar that symbolizes the likelihood a gas molecule will go from one end of the orifice to the other. For our system $a = 0.245$, $v$ is the velocity of the gas, measured in $m/s$, and $A$ is the cross sectional area of the orifice, $m^2$.

Conductance is heavily determined by the geometry of the structure that is between the two pressure drops ($P_1, P_2$). The equation above is tailored towards a system under molecular flow with a short round tube between the pressure drops. However, it is not completely useful when we want to see more than just the total or specific outgassing; what if we wanted to see the contribution to the outgassing by water (18 AMU)? To accommodate this we add the following modifications to the equation:

$$C = a \frac{v}{4} A$$

$$v = \sqrt{\frac{k_b T}{2\pi m}}$$

where $k_b$ is the Boltzmann Constant in $m^2 AMU/s^2 K$. Substituting $v$ in the first equation:

$$C = a \frac{A}{4} \sqrt{\frac{k_b T}{2\pi m}}$$

knowing that $a = 0.245$, $A = 3.5 \times 10^{-07} m^2$, $k_b = 8314.66 m^2 AMU/s^2 K$, $T = 293 K$ we can reduce the above equation to:

$$C = \frac{3}{\sqrt{m}}$$

where $m$ is measured in $AMU$.

With this we can find the conductance, and therefore outgassing rate, for any $AMU$ in the composition of what is being outgassed.
5 Measurement and Analysis

5.1 Setting up for Measurement

After the material has been placed inside the outgassing chamber, we wait for the pressure to “taper off” because this signifies an equilibrium between the gas coming out of the material and the speed of the vacuum taking gas out. This takes about 4-8 hours depending on the material being tested. Before taking a scan with the RGA, in accordance with the throughput method, we close the bypass valve.

![Pressure Asymptote With Bypass Closed](image)

Figure 6: Example of fit being used to measure the pressure asymptote.

The reason for this has to do with the part of the Throughput Method that requires an orifice of known conductance: the bypass is another orifice, or long tube, that is not only curved but also corrugated. Along with the complication of how much gas goes through which orifice, there is also the added issue that calculating the likelihood of a gas molecule passing through such geometry is near impossible by hand and would require a Monte Carlo calculation. Therefore, the closing off of the bypass is a simplification that allows the conductance calculation to be done easily. Of course, if the bypass is closed off then the pressure in the chamber will rise to a finite higher amount. Just as we did with in the beginning of analysis, we wait for the pressure to taper off; however, in this case, we can use an asymptotic fit to the data that will give us a suitable estimate to what the pressure will be at the time of a scan by a residual gas analyzer (RGA) as shown in Figure 6. This estimate is off by an error of a little more than 5%, which accounts for errors by the pressure
gauge and the least square method estimation’s covariance matrix used by the asymptote fitting code.

5.2 RGA Scan

Once the pressure has tapered off for 20 to 30 minutes of data has been recorded, an RGA scan is taken; connecting via USB to the RGA with a computer does this and using software provided the supplier of the RGA, Extorr. The RGA takes a scan of a range of 200 AMU for 15 minutes. An RGA, in general, works like a mass spectrometer: it detects different gases by first ionizing them and then separating the gas by mass to charge ratios using a Radio Frequency (RF) Quadrupole with a detector attached to the end of the RF Quadrupole. The ionization occurs using an open ion source as shown in figure number. A filament just above a cathode is heated so that it releases electrons, which are then accelerated towards an anode, creating an electron beam. Gas flowing around this beam will be ionized via electron-electron cloud collisions creating positive ions. Accelerating and focusing electrodes then accelerate the ions and center them, creating an ion beam [O’Hanlon, 1980].

Figure 7: Diagram of RF Quadrupole field and ion path in RF Quadrupole from O’Hanlon [1980]

The RF Quadrupole, a popular mass filter system, uses four rods that are charged to create electric fields as shown in Figure 7. The positive rod pair creates a positive DC potential that creates a potential “valley”; an RF field is added, described by the equation $U + V \cos(\omega t)$ where $U$ is the potential made by the quadrupoles, $V$ is the radio frequency field magnitude, $\omega$ is the frequency of the cycle of the field and $t$ is time. This creates periodic “hills” in the total potential. The combination of the RF and the positive rods acts as a low-mass filter (formally named “high-pass” filter) because lower massed ions become unstable very quickly in this system and are collected by the rods quickly, heavy ions have too much inertia and will not be affected by these small portions of potential instability. The negative rod pair does the opposite of the positive rods and creates a potential “hill”; the RF field creates periodic “valleys” in the total potential. The long periods of “hills” compared to “valleys” destabilizes the heavy ions more than the lighter ions making this part of the RF Quadrupole a high mass filter or “low-pass” filter. It is “by sweeping the RF and DC potentials linearly in time the analyzer can scan a mass range”. During the sweep, the
detector will count the amount of ions that make it across the filters; a proper amount of time to get a reliable scan is about 15 minutes [O’Hanlon, 1980].

After 15 minutes, the scan comes out similar to Figure 8. Each peak is the partial pressure attributed to the AMU. Were we to zoom in, it would be notable that there is a fuzziness around the 0 Torr line; this is just the background of the RGA and must be discriminated during data analysis.

Figure 8: A sample scan made by an RGA from the Extorr Manual

5.3 Data Analysis

After the file has been saved, it must be changed to a more useful form. Though some of the information may be helpful, a list of pressures with no attachment to an AMU is not useful for graphing or gaining outgassing data; this is when we use a code that changes the file from a .xml format to a more useful .txt format. The code also lists the pressures in a way that attributes a set of pressures to a single AMU and at the top lists the total pressure according to the RGA (\(P_{RGA}\)). “Total pressure according to the RGA” is specified because this pressure is wrong, most of the time at least. The RGA is not good at measuring the exact pressure of each AMU; however, it is very good at measuring the relative magnitude of the pressure between AMUs. This is why we take an asymptotic fit to the pressure recorded by the pressure gauge (\(P_G\)), as it is much more accurate. Another issue with the RGA data is the exactness of the mass being taken; in other words, how well can the RGA discriminate between 17AMU and 18 AMU. It turns out in the RGA manual that there is at least a .5 AMU uncertainty which must be taken in to account. To make sure there isn’t anymore ‘spill over’ than the minimum, I fit a Gaussian to the various peaks on the pressure per mass graph that would be made. If the Gaussian curves and the data crossed at more points than just the measurement points, then there would be more of an uncertainty than just the .5 AMU. Luckily, the data and the Gaussian did not exhibit the aforementioned behavior and so the error was at its minimum.

After creating the dat file, I make a 2 by 200 chart that lists the mean partial pressure per AMU to make it easier to find the outgassing of the system and
create a graph. At the same time I create a cut off of 5% of the maximum value in order to remove background. To test if this causes significant difference in the outcome of the data I vary the cut off point from 1% to 10% to see if there are large deviations given from the total pressure with the 5% cutoff. 5% is usually a good cutoff because it’s before any significant change to the total pressure and any change of pressure around it is negligible. Notice the difference in amount of peaks in the new graph and the original RGA graph; the peaks preserved in the code are the main peaks that contribute most to the total pressure. Usually, these preserved peaks will be around 2, 18, 28, and 44 AMU like in Figure 9.

Figure 9: Pressure Composition with 5% cutoff.

As I mentioned before, the total pressure reported by the RGA is wrong while the asymptote fitting method is a good estimation using the pressure gauge data. The only associated errors with the asymptote method are the systematic 5% error and the error from fitting method’s (least square) covariance matrix. To correct the error in the total pressure (and therefore the partial pressure of the various AMUs), we normalize the data by dividing every partial pressure by \( P_{RGA} \), creating proportions, and then multiply these proportions by \( P_G \) to get the correct values. Next, we calculate the outgassing rate of all the masses with a pressure with our useful equations (\( C = \frac{2}{\sqrt{m}}, Q = C \times P \)). To make graphing and further data analysis easier, I create a chart with the following information in the following order: Mass (AMU), Mass Error, Partial Pressure (Torr), Conductance (L/s), Outgassing Rate (Torr * L/s), Outgassing Uncertainty, and Systematic Error.

Following about four days, we have enough data to create a graph and determine a final outgassing rate. The final outgassing rate, the rate at which the outgassing rate stabilizes into a constant rate, is useful to know as a sort of minimum rate of outgassing for materials and would ideally be very small. The graph, as seen in Figure 10, shows the outgassing of the stainless steel chamber as a function of time. An exponential decay fit using the equation
Figure 10: Total outgassing plot of Background from 07/25/2016 - 07/28/2016

$A \exp (t/T) + C$ is shown as the red dashed line going through the points, more or less. We determine that the fit is 'good' as long as the fit was within the error bars, which accounts for systematic error and statistical error. The important parameters that are approximated are $T$ and $C$, the time constant and final outgassing rate, respectively. $T$ tells us how fast the outgassing will fall under vacuum, a very useful factor to know when building detectors and other particle sensitive devices. After plotting the total outgassing rate, we then plot the partial outgassing rate of the main peaks and provide the same information that was in the total outgassing plot (uncertainty, final outgassing rate, time constant, etc.). The decay for each AMU is different for different materials such as in Figure 11.

5.3.1 Measurement Complications

The first problem to be encountered was what was dubbed as “hysteresis”. As shown in figure number, the outgassing of PTFE Teflon, there is a small rise in the outgassing rate. This is caused by too little time being taken between the closing of the bypass valve for two measurements in a day. When the vacuum system is being pumped down using the bypass valve the drop of pressure has a certain “trajectory”, as can be seen in figure number. When we close the bypass valve this trajectory is momentarily interrupted in order to be able to take an RGA scan and to use the Throughput Method. After a measurement is taken we reopen the bypass valve to allow this trajectory to continue and to not significantly affect future outgassing rates. However, the system does not reach this trajectory as fast as others and the time for this trajectory to continue differs between materials. If we prematurely close the bypass valve then the resulting final pressure will be artificially high. If the pressure is artificially high, then the outgassing rate will be as well, which will result in an artificially
Figure 11: Partial outgassing plot of Background from 07/25/2016 - 07/28/2016 raised fit and artificially high parameters. For example, when working with Teflon it is recommended to wait at least 8 hours before closing the valve again. Unfortunately, I am unable to stay that long in the lab and so I have to resort to just one scan a day to keep my data honest.

Figure 12: Total outgassing plot of Background from 07/25/2016 - 07/28/2016

The second complication was jumpiness in the recorded pressure. As shown in Figure 13, the pressure drops out of nowhere to a lower pressure but then continues on its trajectory. At first it wasn’t clear whether this was a problem with the system entirely or when the bypass valve was closed: it was found out, albeit accidentally, that indeed this jumpiness did occur much more when the
bypass was closed; this was discovered by an accidental closing of the bypass valve for the whole weekend. When compared to the other pressure curves it was much more volatile, jumping up and down the pressure axis. It is also possible, based on graphs being made from the asymptote fitting during background measurements, that this phenomenon only occurs when there is a material inside the vacuum chamber. As of now the jury is out as to what is causing this jumpiness; the issue could be a leak, contamination of the valve or perhaps a damaged pressure gauge. The last we would want to do is to take apart the outgassing system or manually fix the pressure gauge, which is a sensitive and risky operation. Nevertheless, jumpiness in the pressure gauge data leads to lower than expected approximated final pressures, which, once again, risks the integrity of the outgassing rate calculations.

![Pressure Asymptote With Bypass Open](image)

Figure 13: Between scan pressure plot of Teflon in time since epoch.

6 Observation

In the ten weeks I was at Nevis, I observed the outgassing rates of Anodized Aluminum, PTFE Teflon, and the background of the outgassing system. Throughout the measurements issues arose such as the AC unit in the room containing the outgassing system breaking causing a leak of water from the ceiling in the room. Along with an increased humidity, the AC leak could have caused greater amounts of outgassing. This being said, nothing too unnatural occurred according to the RGA scans and therefore the following data is worth noting. All materials were prepared for vacuum by cleaning with Isopropyl Alcohol using Kimtech Kimwipes to ensure no oils were introduced to the outgassing system.

6.1 Anodized Aluminum Rings

Measurement of outgassing of the anodized aluminum rings commenced on June 23rd, 2016 and ended on July 12th, 2016. The reason we decided to observe these
rings is because in the atom trap being used by XENON, known as ATTA, was having trouble reaching ultra high vacuum (about $10^{-9}$ Torr). It was heavily suggested that perhaps these rings were outgassing at a higher rate than the rest of the ATTA system. Scans of the anodized aluminum rings were taken from June 24th, 2016 to July 12th, 2016. The total surface area of all the rings was 2064 cm$^2$. The specific outgassing of anodized aluminum is $1.41 \times 10^{-09} +/- 6.78 \times 10^{-11}$ Torr $\ast L/(cm^2 \ast s)$ based on scans.

![Figure 14: Total outgassing rate of Anodized Aluminum](image)

It should be noted that the last data point for all AMUs in the Figures 14 and 15 are very off the fit. This is a problem that has been encountered before and occurs when a long time has been taken between scans, in this case 6 days; this is a phenomenon of the pressure gauge as well as the RGA.

It is very noticeable in Figure 15 that there are two separate groups being outgassed whose final outgassing rates are split in to the $10^{-06}$Torr and $10^{-07}$Torr regions. If we assume that 18 AMU is mostly H$_2$O then this grouping makes a bit more sense. In order of descending magnitude, 2, 1, and 17 AMU could all be thought of as H$_2$, H$^+$, and OH$^-$ which are all parts of the H$_2$O molecule. If we assume that upon ionization by the RGA most of the H$_2$O molecules survived being separated but the molecules that were separated broke apart to the previously mentioned ions and molecule then this spread of AMUs makes more sense. The 28 AMU in the $10^{-06}$ group can be explained with the fact that we purge the chamber with N$_2$ gas and the lower group can be thought of as part of a contribution by exposure to the atmosphere before being placed in the outgassing chamber.
Measurement of the outgassing of the Teflon rectangular prism commenced on July 14th, 2016 and ended on July 25th, 2016.

The reason we decided to observe the outgassing of the Teflon was because it was part of an ongoing measurement of Teflon. Teflon is used in XENON1T as part of the holding structure, so it is very key to know what may outgas from Teflon to make sure none of the outgassing composition may affect the greater experiment. Scans were taken from July 15th, 2016 to July 22nd, 2016. The total surface area of the prism was 612.30 cm$^2$. The specific outgassing of PTFE 17.8x15.4x1.04 Teflon is $4.43 \times 10^{-09} \pm 5.63 \times 10^{-10}$ Torr $\cdot$ L/(s $\cdot$ cm$^2$).

Originally, Figure 16 and Figure 17 both had two more points for each fit: these were removed because they caused a 'hysteresis' effect that was artificially increasing the parameters of the fit. Also notice how the uncertainty in the time constant parameter, $T$, of 44 AMU can cause the value to go negative. This can be caused by errors in assumption being made by the curve fitting code in its calculations. Nevertheless, the other parameters of 44 AMU make sense with their associated uncertainties.

The explanation for 28 AMU (fitted with the top blue line on Figure 17) being significantly higher than all the other masses (about an order of magnitude) is the following. As I mentioned before, to place a new material in the outgassing chamber the system must be purged with $N_2$ gas. This would explain why, at first, there should naturally be a higher concentration of $N_2$ at first. When the RGA attempts to ionize the $N_2$ gas (whose atomic mass is 28 AMU),
Figure 16: Total outgassing rate of PTFE 17.8x15.4x1.04 Teflon

\[ A \times e^{(-t/T)} + C \]

Figure 17: Partial outgassing rate of PTFE 17.8x15.4x1.04 Teflon
the covalent bonds generally survive attempted knock out by the electron beam; however, not all $N_2$ molecules survive this and this contributes to the level of 14 AMU.

Figure 18: Total outgassing rate of Background

6.3 Background

After finding the issue of jumpiness in the pressure gauge data we decided to just take background scans. These also gave us a baseline measurement to compare to the other outgassing rates. Outgassing of the chamber itself was measured from July 25th, 2016 to July 28th, 2016; scans were taken on the same dates. The final total outgassing of the background is $4.93 \times 10^{-07} \pm 1.18 \times 10^{-08}$ Torr $\times L/(cm^2 \times s)$. It would not make sense to take a specific outgassing for background seeing as it would be very unique to this outgassing system.

Note the very fast drop on Figure 19 from the 2 AMU fit; this is a result of the model fitting not working well, as in the case with 44 AMU in the Teflon. However, despite the absurd uncertainties for A and T, C, the final outgassing rate, is reasonable and, according to the fit, is well within data.

6.4 Cross Comparison

What is more revealing about the background measurements is not in its outgassing but in the pressure asymptote measurements. In none of the asymptotes taken before an RGA scan for the background was there an sudden drops in the
Figure 19: Partial outgassing rate of Background

pressure as occurred when there was material in the system. Compare the figures below.

Anodized Aluminum was more obvious in drop than Teflon and background but Teflon would frequently drop with two drops being not too anomalous and four being the maximum, as seen in Figure 21. A good thing to note is how quickly the pressure rises: Teflon is the most drastic in its change from one minute to the next when the bypass valve has been closed. This hints to how much and how long Teflon outgases compared to the other materials.

Teflon, according to the fit parameters, drops its outgassing rate by $1/e$ about every 53.17 hours. This is incredibly slow, as can be seen in Figure 16, where the value the decay is approaching is never seen, unlike anodized aluminum and the background. Background, naturally, was incredibly quick (T = 8.82 hours), because of no material heavily contributing to the outgassing of the chamber itself.

What is fortunate in the case of the materials being used for ATTA and XENONIT is that the most prevalent gases being detected by the RGA are derivatives of water. If this is the case in room temperature measurements it is very likely that at higher temperatures (say at around 373 kelvin) these gases could removed. The high concentration of $N_2$ in all these measurements is an artifact of this outgassing system’s procedures and is not a concern if materials are properly treated after exposure to air.

Another fortunate situation is that for all three measurements of outgassing, elemental oxygen was found to be the lowest of all concentrations in the partial outgassing spectrum. In fact, upon comparison of final total outgassing rates,
all the oxygen seen in the anodized aluminum came from the stainless steel background. This is important because of oxygen’s electronegativity. In the case of XENON1T, this characteristic of oxygen can cause a modification in the scintillation light caused by electrons traveling through the TPC. If the scintillation is modified, any positive detection can be mitigated if even detected at all. If there was a detection there would surely be a misidentification of either the particle that caused the scintillation or even the nature of the interaction (i.e. nuclear or electronic recoil), making the search for dark matter more difficult than it already is.

7 Conclusion

Outgassing is a factor that all groups working with sensitive and costly detectors such as XENON1T should account for. Were any of these materials to put out a high amount of oxygen or any other volatile gas during a run would cause a positive WIMP-Xenon signal to disappear. Taking a scan of materials that are about to be used or being used in a detector is also paramount to the integrity of detection results, especially for a project like XENON1T: if oil was left on one any of the materials in the detector, the whole system would have to be cleaned or replaced. Luckily for XENON1T, the system is at cryogenic temperatures which heavily reduces the outgassing rate and composition of Teflon, stainless steel, and aluminum.

By the measurements made from June 24th to August 2nd of 2016 of Anodized Aluminum and Teflon, it is safe to say that these material do not cause a major compromise to the integrity of XENON1T or ATTA and their respective findings.
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